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Second International Conference on Sustainable Futures: *Environmental, Technological, Social and Economic Matters*

ICSF 2021

May 19-21, 2021
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Date and editor's signature

June 15, 2021

Our sustainable pandemic future

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Abstract. This is an introductory text to a collection of papers from the ICSF 2021: Second International Conference on Sustainable Futures: Environmental, Technological, Social, and Economic Matters, which held at Kryvyi Rih National University, Kryvyi Rih, Ukraine, on May 19-21, 2021. It consists of an introduction, conference topics review, and some observations about the event and its future.

ICSF 2021 at a glance

The International Conference on Sustainable Futures: Environmental, Technological, Social and Economic Matters (ICSF) is a peer-reviewed international conference, which is the premier interdisciplinary forum for social scientists, life scientists, engineers, and practitioners to present their latest research results, ideas, developments, and applications (Fig. 1).

Fig. 1. ICSF 2021 logo (designed by Dr. Andrii Striuk).

The ICSF occupies contributions in all aspects of sustainable development, focused on the intersection of sustainability, environment and technology, and their more significant implications for a corporation, government, education institutions, regions, and society both at present and in the future.

ICSF has two presentation levels, Pre-conference Workshops and Main Conference.

Ecochemistry Education for Sustainable Development Workshop

Ecochemistry Education for Sustainable Development Workshop (EcoChemSD-WS'2021) is a peer-reviewed international workshop that occupies contributions in all aspects of environmental chemistry and ecochemistry, ecochemistry education, and modern educational technologies.

EcoChemSD-WS'2021 main topics of interest are:

- Ecochemistry research for the sustainable development
- Environmental chemistry for the sustainable development
- Ecochemistry education for the sustainable development
- Green Chemistry
- Environmental remediation technologies
- Modern educational technologies in the chemistry education
- Chemistry teacher's training for the sustainable future

EcoChemSD-WS'2021 Program Committee chair is Dr. Pavlo Nechypurenko.

Geography for Sustainable Development Workshop

Geography for Sustainable Development Workshop (GSD-WS'2021) is a peer-reviewed international

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workshop. During the GSD-WS’2021, the researchers who are committed to the problems of geography for sustainable development can present their latest research findings, ideas, developments and programs.

GSD-WS’2021 main topics of interest are:

- Geographical bases of sustainable future: methodological bases
- Problems and prospects for the development of physical and socio-economic geography in the context of sustainable future
- Regional problems of sustainable future and local lore research of territories
- Cartographic research and geoinformatics: theory and practice
- Noosphere nature management is the key to a sustainable future
- The theory of sustainable future in geographical education.

GSD-WS’2021 Program Committee chair is Dr. Olga Bondarenko.

Water Management and Environmental Engineering Workshop

Water Management and Environmental Engineering Workshop (WaterManEnvE-WS’2021) is a peer-reviewed international workshop. WaterManEnvE-WS’2021 occupies contributions in all aspects of water management and environmental engineering, environmental education and modern educational technologies.

WaterManEnvE-WS’2021 main topics of interest are:

- Water Management and water resources use
- Monitoring of water resources
- Irrigation and Drainage
- Water treatment and water supply
- Hydraulic Engineering & Hydraulics
- Hydropower

WaterManEnvE-WS’2021 Program Committee chairs are Dr. Serhii Chukharev and Dr. Serhii Klimov.

Innovative Approaches for Solving Environmental Issues Workshop

Innovative Approaches for Solving Environmental Issues Workshop (IASEI-WS’2021) is a peer-reviewed international Sustainable Computing workshop focusing on advanced research on Sustainable Computing. The workshop occupies contributions in all aspects of sustainable computing, reflecting modern engineering and technological solutions of the information technology era in the sustainable development of society.

IASEI-WS’2021 main topics of interest are:

- Environmental protection.
- Nuclear and radiation safety.
- Complex, economic and technological solutions.
- Problems of training and advanced training.

IASEI-WS’2021 Program Committee chair is Prof. Andrii Iatsyshyn.

Main Conference

Workshop and Conference presentations are grouped into 11 tracks:

1. Geotechnical and Geoenvironmental Engineering [1-8]
2. Measuring, Forecasting and Monitoring Sustainability [9-18]
3. Sustainable Building and Architecture [19-25]
4. Sustainable Cities and Society [26-39]
5. Sustainable Energy [40-55]
6. Sustainable Environment and Environmental Management [56-65]
7. Sustainable Materials and Technologies [66-84]
8. Sustainable Mining [85-105]
9. Innovative Approaches for Solving Environmental Issues [106-129]
10. Water Management and Environmental Engineering [130-140]
11. Ecochemistry and Geography Education for Sustainable Development [141-155]

This volume contains the papers presented at ICSF 2021: Second International Conference on Sustainable Futures: Environmental, Technological, Social, and Economic Matters held on May 19-21, 2021 in Kryvyi Rih, Ukraine.

There were 217 submissions. Each submission was reviewed by at least 3, and on the average 3.2, program committee members. The committee decided to accept 155 papers.

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Conclusion

The vision of the ICSF 2021 is to create a leading interdisciplinary platform for researchers, practitioners and educators, to present and discuss the most recent innovations, trends, and concerns as well as practical challenges encountered and solutions adopted in the fields of sustainability.

The conference is a successfully performing forum for transferring and discussing research results among the academics, students, teachers, government, private sector, or industries. Participants and presenters from Azerbaijan, Belarus, Brazil, Bulgaria, Canada, China, Croatia, Czechia, Finland, France, Georgia, Germany, Hungary, India, Indonesia, Iran, Israel, Jordan, Kazakhstan, Kuwait, Kyrgyzstan, Latvia, Libya, Lithuania, Mauritius, Mongolia, Montenegro, Morocco, Netherlands, Nigeria, Norway, Poland, Romania, Russia, Saudi Arabia, Serbia, Slovakia, Svalbard and Jan Mayen, Tajikistan, Turkey, Ukraine, United Kingdom, United States, and Viet Nam have a conference experience to share their significant contribution in the research of the environmental, technological, social and economic issues of sustainable future.

We are thankful to all the authors who submitted papers and the delegates for their participation and their interest in ICSF as a platform to share their ideas and innovation [156]. Also, we are also thankful to all the program committee members for providing continuous guidance and efforts taken by peer reviewers contributed to improve the quality of papers provided constructive critical comments, improvements and corrections to the authors are gratefully appreciated for their contribution to the success of the conference. Moreover, we would like to thank the developers and other professional staff of Not So Easy Science Education platform (https://notso.easyscience.education), who made it possible for us to use the resources of this excellent and comprehensive conference management system, from the call of papers and inviting reviewers, to handling paper submissions, communicating with the authors etc.

We are looking forward to excellent presentations and fruitful discussions, which will broaden our professional horizons. We hope all participants enjoy this conference and meet again in more friendly, hilarious, and happiness of further ICSF 2022.

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Technological scheme of the combined geothermal-hydrocarbon system for the production and storage of energy resources

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Abstract. The complex researches of schemes of extraction and storage of hydrocarbons and geothermal energy are executed in the work. In particular, according to the location, logistics and nature of the processes of generation, transportation, evacuation, injection and local utilization of hydrocarbon and geothermal energy sources, the scheme is divided into subspecies of consumer regional order of electricity, hydrocarbon and chemical energy and hydrogen. It is shown that the tasks of extraction of natural or synthesized hydrocarbons, geothermal energy and subsequent transformation into the required form of commodity resource can be unified with the organization of circuit-combined technologies. At the same time, the developed technological scheme implements the concept of storage of the required amount of energy resources on the one hand and regulation of production capacity for consumption – on the other. The reduction of current energy costs for the implementation and operation of systems with updated functional systems for a total of 20–45%. It is proved that the selection of the scheme of unified extraction and storage energy systems in accordance with the projected order of energy and energy resources, due to the capabilities of productive reservoirs, leads to minimization of capital costs for their construction on a modular basis. Research of application of combined technologies of dual extraction-storage of heat carriers-hydrocarbons is a perspective direction of researches.

1 Introduction

There is no doubt that there are geothermal resources available in the existing oil and gas sediments of Ukraine and other countries [1–2]. Recently, oil and gas companies, such as Chevron and Shell, have been working to production and exploit geothermal resources using a variety of advanced technologies. In this case, the conceptual and circuit approaches are determined by the choice of coolants and circuit organization of production [2]. The article analyzes the improvement and attempts to unify circuitry to improve the overall logistics of hydrocarbon and geothermal energy resources.

2 Review of the literature

Today, three main types of technological implementation of well geothermal systems (WGTS) and well geoenergy systems (WGS) are used [1–3]:

1. Power plants with a binary (double-loop scheme) cycle, as a working fluid for which not thermal water or steam is used, but another liquid with a low boiling point.

2. Instantaneous or flash steam evaporators, which receive hot water under high pressure and transport it to surface tanks with reduced pressure, where the water is converted into steam to power the turbine.

3) Dry steam power plants that receive steam to rotate turbines directly from a geothermal reservuare.

For oil and gas fields, which after depletion were converted into underground gas storage facilities (UGS), usually implement the first type of technological implementation based on binary schemes (a second circuit with low boiling point of the coolant is added) and thermodynamic Rankine cycle or Kalina cycle [2].

The geothermal system of the first type on the basis of objects of development of oil and gas fields can be realized according to the scheme of open combined WGTS with binary or simpler structure. The diagram in Figure 1 shows the real circuitry of operating systems with heat generation in Germany, Austria, Canada and others. countries where the temperature of geothermal sources reaches 100º C [3–4].

Figure 1 shows that the WGS circuit integrates the units of removal and chemical synthesis of various substances required as inhibitors or catalysts of processes, and additional heating of the working coolant before utilization

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in the consumption units (turbines and heat exchangers) is advantageously realized in parallel hydrocarbon coolant production. The authors of [2–3] did not show the technology unit (technology block) of accumulation and heating in the initial circuit of the formation geothermal fluid (in particular, to simplify understanding), but usually such a unit is used. Therefore, in Fig.1 this block-unit is shown.

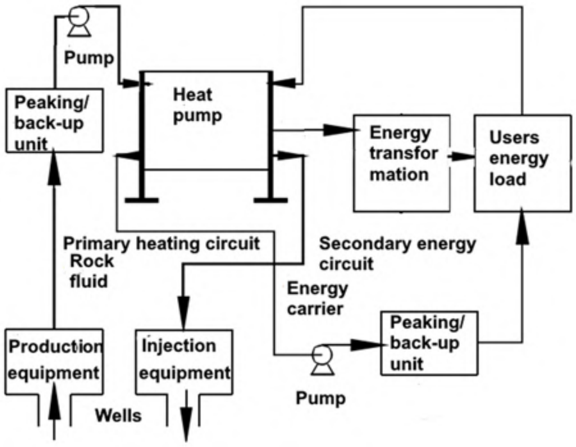

Fig. 1. System of direct use of extracted geothermal energy and formation water / fluid with heating in the peak boiler-accumulator and extraction of useful chemicals (fuel, metals, salt, etc.) near the wellhead.

If it need to generate and local utilize not only heat but also electricity, use combined WGS circuits (Fig. 2), in which the system shown above in Fig. 1 is one of the basic units (is a WGS subsystem). The essence is the multi-stage utilization of extracted geothermal energy in the following stages (as the circuit build-up development, circuit complication) [4]:

– utilization without heat pumps, absorption systems and turbines;

– utilization without turbines and absorption systems;

– utilization without absorption systems;

– complete utilization (using heat pumps, turbines, absorption systems, cogeneration heat exchangers).

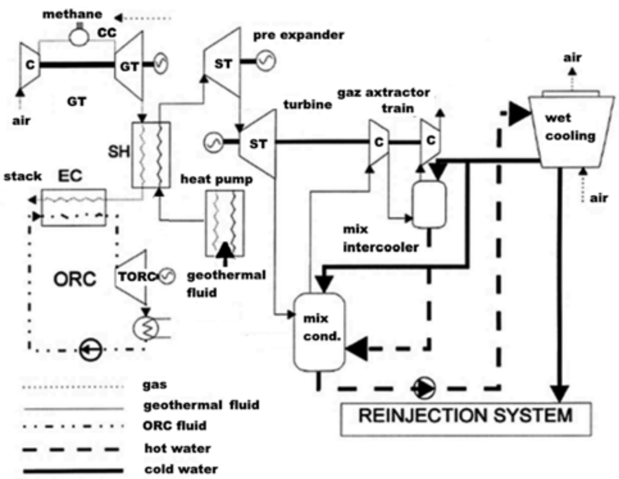

Fig. 2. Technological scheme of GeoPP of open combined type with heat pump and heat utilization of turbines operating on geothermal energy and extracted hydrocarbons (in terms of electricity generation and partial heat utilization) [4].

The scheme shown in Fig. 2 is typical for implemented projects in the USA, Italy, Russia, Iceland and others. countries where the temperature of the local geothermal source significantly exceeds 100 ºC [1–4]. But this scheme actually reveals a typical solution for the generation of power stations of the well-known company ENEL (stage of utilization at the level – without absorption systems), it is only half of the overall scheme in terms of utilization of thermal energy [4]. The turbine circuit often uses prepared water directly from the production well, which is not possible at downhole source temperatures below 100 °C., especially without the use of a methane fuel turbine or boiler. But the scheme is suitable for working with all the above three types of technological implementation, provided the organization of the binary principle. That is, it can be considered universal after some circuit upgrating, in particular the introduction of several circuits with a cycle of Rankine (or Kalina) and cogeneration heat exchangers.

The second half of the general functional scheme is well understood from Figure 3, which is explained in detail in [5] on the cascade principle of thermal energy utilization by a local consumers. Thus, the scheme in Fig. 3 complements the scheme of geothermal power plant (GeoPP) in Fig. 2 and gives a complete stheme picture of the double generation and utilization of electricity and heat in the case when actively extracting both local hydrocarbons and available local geothermal energy. Thermal energy in large quantities can be used as an auxiliary energy of technological processes in the extraction and transportation of natural gas and oil [6–7]. Unquestionably produced electricity can be used for the synthesis of useful fuels (hydrogen, methanol, gasoline) and synthesized methane on site. About the latter problems and the necessary circuit solutions will be discussed below.

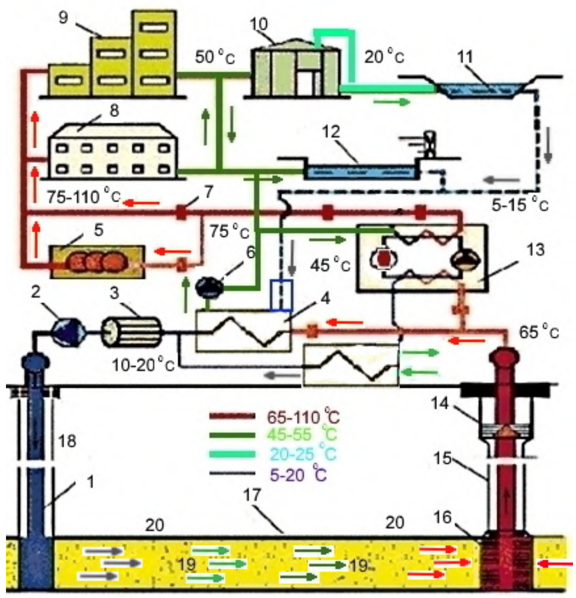

Fig. 3. Technological scheme of WGS of open combined type with heat pump and heat utilization of turbines operating on geothermal energy and extracted hydrocarbons (supplement of the scheme in Fig. 2 in part of full cascade local heat utilization of geothermal sources and emissions of GeoPP) [5].

In Figure 2, which generally repeats the circuit solutions from [4], one heat pump is added, which illustrates the possibility of implementing the operation of turbines on a liquid with a reduced boiling point. The signatures of the individual units have the following abbreviations: C – compressor, CC – hydrocarbon combustion chamber, ST – steam turbine, GT – gas turbine, TORC – turbine in the loop with the Rankine cycle; Cond. – condensing device; SH – superheater; EC – cogeneration heat exchanger.

In Fig. 3 part of the technology of Fig. 2 is shown conditionally in blocks 2–7. Consumers of heat of communaly and industrial-technological type 8–12 receive power both from the heat pump 13 and direct geothermal heat exchangers GeoPP 4, and from boiler rooms and turbines of GeoPP block 5. For mixing (combination) use switching and regulation by valves 7, pumps 2, 6, 14. The diagram also shows the line of the injection well – 1, hydrocarbon separator – 3, production and injection wells – 15 and 18, bottomhole – 16, reservoir – 19 with reservoir fluid – 17, impermeable reservoir roof – 20. The disadvantage of the scheme, which is fully disclosed in Fig. 1 and Fig.2 is the absence of heat accumulators and hydrocarbons in the primary and secondary circuits in the circuit implementation of the binary principle of extraction (the first type of technological implementation of WGS). Figure 1 shows the heat tank, but there are no hydrocarbon acummulation.

To improve the understanding of the consumer part of the modern technological scheme of WGS, we present the result of a simplified circuit design solution [8] in Fig. 4, which details the principle of combined WGS with GeoPP binary type. The diagram shows abbreviated: C – compressor, P – pump, T – turbine, CC – hydrocarbon combustion chamber, G – generator. The work [8] did not focus on the types of local energy consumption, so in Fig. 4 added units of electricity consumption (green) and energy of extracted hydrocarbons (yellow).

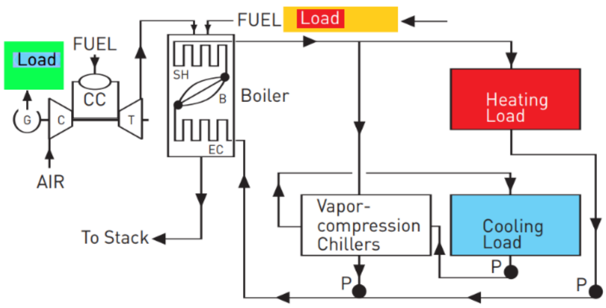

Fig. 4. Simplified technological scheme of GeoPP with shown consumers of energy resources of 4 types: consumers of cold (blue color), heat (red), electricity (green), hydrocarbons (yellow).

It is clear that consumers of cold and heat should be located near the WGS because the accumulation of a large number of such resources is technically difficult and economically unprofitable. It is not economically feasible to accumulate electric energy with the help of batteries at the current level of development of equipment and technologies in large quantities. But to accumulate hydrocarbon-type fuel and hydrogen is possible in large enough volumes and promising with the involvement of underground storage and gas generators. But in the known works the variant of using a combination of GeoPP and UGS from the above point of view is not considered [1–5].

The strategy for the development of geothermal energy in Ukraine states: "Substantiation of the possibility and feasibility of creating systems and installations for the combined use of geothermal heat (from 70 °C) and fossil fuels, as well as construction of special power plants (GeoPP) on promising fields" [5]. The strategy provides for the expansion of the use of such systems, which can be understood as the implementation of a functional chain in the form of: extraction, accumulation, storage, transformation, preparation for marketable quality and consumption or shipment. Earlier in [9–10] the possibility of utilizing electricity produced from subsoil heat for the synthesis of methane and hydrogen for long-term storage of fuel in special storage facilities was considered. In particular, [10] covers P2G (Power-to-gas) technology. In another paper [11], it is recommended to use the heat pump effect more widely for branched and networked pipelines.

In fact, if you install GeoPP and underground storage together, with the most unified scheme for work with extraction and storage of heat and hydrocarbons, and part of the electric generation used for the synthesis of methane and hydrogen (etc. required in current processes), it is possible to regulate basic energy and energy transformation processes to equalize the uneven consumption of both heat / cold and hydrocarbons (in terms of generation and storage capacity), to increase and develope circuit-modular thermo-power grids, which was not previously considered in detailing forms.

3 Research objective and tasks

The aim of the study is to develop a unified technological scheme for extraction and storage of heat and hydrocarbons, which would minimize current energy losses and capital costs for modular organization of production with full-fledged filling at the place of demand for energy resources: extraction, accumulation, storage, transformation, preparation and utilization or shipment.

To achieve this goal the following tasks are set:

1) to compare modern technological schemes of GeoPP and UGS from the point of view of possibility of minimization of quantity of technological units at simultaneous production of hydrocarbons and geothermal energy;

2) to select and add technological units to the scheme that will ensure the functioning of storage facilities and fields-regulators;

3) to estimate the forecast reduction of current energy consumption for operation of combined systems according to the developed scheme of functionally unified combined systems of hydrocarbon-geothermal resources extraction in comparison with similar volumes of individual (non-combined) extraction and consumption of hydrocarbon and geothermal resources.

4 Basic stages and research results

The object of the study is WGS on the basis of an oil and gas field equipped with underground storage facilities for depleted deposits. The comparison of such an improved hybridized system is made with the traditional WGS without underground storage, which schematically includes a binary GeoPP and uses only formation water as a heat carrier.

4.1.1 First stage of research

The developed unified technological scheme of modern WGS of open combined type with binary GeoPP is shown in Fig. 5. The first type of circuit-technological implementation is taken as a basis, with two series-connected turbines and one ORC circuit. For simplicity, the diagram does not show multistage turbines (shown in more detail in Fig. 2), multistage heat pumps (which can operate at the indicated positions of consumer heat exchangers, as shown in Fig. 3), heat recovery units with absorbent heat pump, but clearly three heat exchangers of municipal or technological heat consumers (marked on the diagram – heat exchangers of heat consumers).

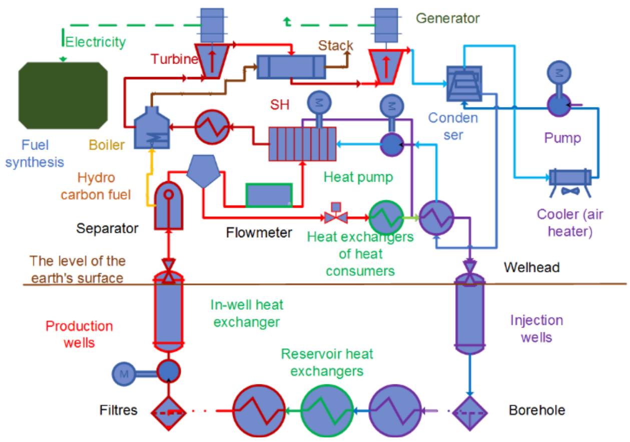

Fig. 5. Unified universal technological scheme of modern WGS of open combined type with binary GeoPP.

The diagram in Fig. 5 does not show (schematically not allocated for simplification) units of heat and electricity storage, as well as chillers – devices for cooling liquid coolant and supplying it by a pumping station through a system of pipelines to end users. In modern UGS and WGS systems, chillers are beginning to be widely used to regulate the main energy production and energy transformation processes and simultaneously equalize the uneven consumption of extracted/stored (taking into account the rate of extraction) heat and hydrocarbons.

Note that Fig. 5 is also, at first glance, not universal in the need to organize the thermodynamic cycle of Kalina in one of the circuits instead of the Rankine cycle. But according to [1], the Kalina cycle begins to be realized when only one gas-liquid separator and cogeneration heat exchanger are added inside the circuit. That is, the developed scheme (Fig. 5) is still unified but with a reduced set of technological components and unit, which in turn are implemented in terms of circuitry according to technical solutions [1, 4, 7, 8, 11, 12].

Scheme at Fig. 5 can be modified to a functional hybrid for simultaneous production and storage of natural gas in the gas cap of the reservoir of a partially depleted oil and gas field and extraction of geothermal energy with conversion into synthesized gas (methane or hydrogen) through the groundwater line (Fig. 6).

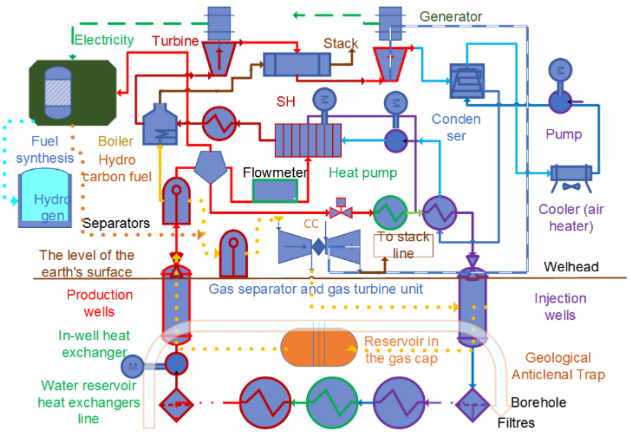

Fig. 6. Unified technological scheme of hybrid WGS of open combined type with binary GeoPP and UGS of water-pressure / gas mode of cyclic operation.

4.1.2 Second stage of research

The developed combined technological scheme of hybrid WGS can be realized under the condition of the available water pressure mode of development of oil and gas field or at artificial flooding and maintenance of pressure of a gas cap of an oil and gas deposit at technologically necessary level.

It is envisaged that wells, separators, as well as a line with a pump for the preparation and injection of separated formation water are used in combination. Electric generators and turbines, as well as other WGS units, also work to synthesize additional volumes of methane and fuel, which may be in high demand during the UGS filling season and peak consumption periods. Thus, for the use of a unified scheme for simultaneous storage of natural gas (methane), extraction of oil residues from the reservoir (flooding technology) and gas condensate (cycling process) added only two technological units: finishing preparation by gas separator and gas compressor with gas turbine drive (gas turbine unit – GTU).

The aircooling device (ACD) present in the classic UGS schemes does not make sense (absent) in the developed scheme because all excess heat is removed by the scheme for electricity generation and synthesis of artificial gases. In addition, when implementing the circuit-technological solution shown in Fig. 6, the geothermal field with UGS acquires a new economic meaning – it can add volumes of synthesized methane (other fuels by gas–to–liquids (GTL) and mini-refineries) or hydrogen. The scheme works smoothly during the gas injection season for storage or in the mode of regulating consumer demand for energy types at the place of their using.

At the end of the second stage of the study, one feature of the case was found – to obtain synthetic oil or LNG, you need to change the average carbon / hydrogen ratio in the hydrocarbon feedstock (mini–refinery by hydrocarbon-hydrogen conversion), and the necessary hydrogen is easiest to take from reservoir water. In this case, the combination of "water" geothermal energy and "hydrocarbon" energy production / storage according to the hybrid scheme (Fig. 6) becomes even more profitable on a regional scale. To do this, the scheme (Fig. 6) shows the supply of prepared water to the methane (and others. fuel) synthesis unit .

According to the obtained circuit technical results, for the developed hybrid scheme the number of modules of the whole WGS decreased by four units: 1) separation module for mechanical impurities, water and oil; 2) GTU; 3) gas heating unit during reduction in the sampling/production mode: 4) ACD. To implement the storage of gas / energy resources and control the production of hydrocarbons / energy resources, we add only one gas separator. Minimization of modular units in capital construction and a corresponding reduction in the cost of the entire technical complex of WGS and increase its manufacturability are obvious.

4.1.3 Third stage of research

When using cogeneration units that produce both electricity and heat, the efficiency can reach 60–80% (achievable efficiency at both ends “power–power”). This became possible with the implementation of reversible solid oxide fuel cells under pressure [13]. When converting in the scheme of Fig. 6 electricity–gas–heat / electricity (with a pressure of up to 50–80 atm. Under the standard main natural gas pipeline) work [14–17] more pragmatically announce the average efficiency of 43–68%. In the diagram in Fig. 6, one power energy unit is added – a turbine for pumping gas for its storage and maintaining the required level of pressure in the reservoir. The efficiency of gas–tube compressors averages 23–28% [19]. But important for the future of combined hydrocarbon–geothermal energy system may be the fact that turbines in GeoPP schemes are enough, they are also multi–stage. That is, in the technological scheme of the hybrid type the compressor is added only schematically, and mechanically it will rotate on the existing shafts. Let's analyze this circuit solution in more detail. The diagram in Fig. 2 separately shows a gas turbine unit running on methane (top left in the diagram), which is used to increase the efficiency of GeoPP in normal mode. Undoubtedly, in general, the WGS will have additional losses on the compression of hydrocarbons for injection to well (2–3% – fuel gas) of the GTU [19], but this is incomparably less than acquired. That is, for traditional incompatible operation in the GeoPP + UGS pair, the turbines will operate with double energy loss according to the efficiency, and during the operation of the unified developed scheme, the efficiency losses in the WGS will be reduced by an average of 23%. This ratio of energy losses is performed as accurately as possible in the conditions of the Proletarsky UGS (Dnipropetrovsk region, Ukraine), where the potential power of geothermal energy is close to the power in the hybrid circuitry involved GTU. Therefore, the current energy consumption of combined systems of extraction / storage of hydrocarbon–geothermal resources according to the developed hybrid scheme in comparison with similar volumes of individual (non–combined) extraction / storage of hydrocarbon and geothermal resources will be reduced by 20–45%. Since the ranges of energy consumption by technological units individually have significant differences according to data from different sources, it is not possible to estimate the energy positive more accurately.

5 Conclusions

1. The developed unified scheme of combination of GeoPP and UGS on the basis of oil and gas partially-depleted deposit with residual water characteristics is characterized by the minimum number of additional technological units to GeoPP for realization of simultaneous extraction and storage of hydrocarbons and evacuation / transformation of geothermal energy.
2. For maximum efficiency of hybrid WGS of open combined type with binary GeoPP and UGS of water-pressure / gas mode of cyclic operation in the circuit solution it is important to use the synthesis gas unit and the compressor of gas injection into the gas cap of the oil and gas development object. Production of synthetic gasoline and LPG, and not only compressed natural gas (CNG) for local internal combustion engines is realized by schemes of mini–refineries and GTL–technology.
3. The forecast of reduction of current energy costs of combined systems of extraction / storage of hydrocarbon-geothermal resources in comparison with similar volumes of individual (not combined) extraction / storage of hydrocarbon and geothermal resources showed 20–45%.

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Deposits of the hydrocarbon raw materials of the Republic of Kazakhstan, where it is possible to introduce a microbiological method for stimulating the formation

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Abstract. The article is devoted to the analysis and systematization of data on hydrocarbon deposits in the Republic of Kazakhstan, highlighting those aspects that will allow the use of this method. The microbiological method of exposure refers to the chemical methods of the tertiary stage of development of oil reservoirs. It has already proven its effectiveness in highly depleted, waterflooded formations with irregular, diffuse oil saturation. Its main advantages are its relative cheapness, it does not require additional equipment during injecting of the microorganisms into the reservoir, and for their nutrition, as a rule, food industry waste is used, and its implementation cannot cause harmful effects on the environment. Also, a fairly extensive database was compiled, according to which various classifications of the republic's deposits were created.

1 Introduction

The purpose of the study was to identify the parameters needed for the introduction of the method of microbiological influence on oil reservoirs, justification of the need for its use, as well as collection, analysis and systematization of data on all known this type deposits of the republic.

Nowadays, when the reserves-to-production ratio is declining in all countries, which are advanced in oil production, the introduction of methods of improving oil recovery is more urgent than ever before.

Well-known are thermal (steam, hot water, formation combustion are used), gas (carbon dioxide, air, natural gas, nitrogen, flue gases, etc. are injected directly into the formation), chemical (oil is displaced by using surfactants, polymers, alkalis, acids and other reagents), hydrodynamic (water is injected), physical (using wave and electromagnetic radiation, hydraulic fracturing, drilling horizontal wells) and, naturally, combined methods.

Due to extensive application experience, their disadvantages are also known: when pumping steam and hot water, chemical reagents of various types, gases, equipment quickly wears out; and the use of physical methods initially requires the installation of expensive additional equipment.

In addition, when igniting the formation and using chemicals, it is impossible to avoid harmful effects on the environment. In the first case, combustion is difficult to control and as a result, instead of liquefied heavy hydrocarbons, only a dry residue, consisting only of low fractions can be obtained, which will no longer be removed, plus gases that can be extremely hazardous to health will be released. And chemical solutions can permanently poison underground waters, which will entail the death of all flora on the surface.

2 About the method of the microbiological enhancement oil recovery (MEOR)

This method of exposure is of two types:

1. Method of the biostimulation – injecttion of nutrients for the development of populations of microorganisms already existed in the oil reservoir.
2. Method of the bioaugmentation – injecti on of both microorganisms, and nutrients.

These bacteria are aerobic and anaerobic, in the process of their development and life, they liquefy hydrocarbons, absorbing some of them and emitting gases.

Also, their colonies, growing, form biofilms, reducing the possibility of water crossflows, therefore this method is effective when applied in heavily flooded fields.

In comparison with the methods mentioned earlier, it is environmentally friendly, and this is one of the most important advantages today.

To implement it, there is no need to purchase additional equipment, you can simply use the existing one.

Bacterial nutrients can be food waste such as milk serum and molasses.

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3 Data about the characteristics of deposits, where the microbiological method was implemented

In order to derive general characteristics for the use of the above-mentioned method, articles about deposits were studied, where it had already been tested.

These are the projects of San Andres, Queen Sand, Tupunyato Refugio, Huabey, Xinjian [1], Norne [2], Romashkinskoe [3], Pirallahi [4, 5], Lisbon, Novo-Elkhovskoe, Pervomayskoe, Ersubaikinskoe, Berezovskoe, Sterrap [6] , White Tiger [7], Bokor [8].

San Andres Project (U.S.A.): it was discovered in 1945, was produced by solution gas drive until the waterflood was started in 1967.

The Microbial EOR started in October 1994 oil in place was 239 bbls/ac-ft with an oil saturation of 41%. Current formation pressure is estimated at 1,000 psi. Rock properties are relatively inhospitable to microbes. The low 1.7 md average horizontal permeability would normally be indicative of pore throat sizes well below what microbes could enter. Reservoir temperature at 115°F is ideal for microbe growth. Average production per well is 14 barrels of oil per day at a 91% water cut.

After 19 months of microbe treating by 10% or 40 barrels per day are received.

Queen Sand Project (U.S.A.): it was discovered in 1984, this reservoir was quickly waterflooded due its very low solution gas content. Injection was begun in 1990 and oil production increased quickly from 200 to 2,500 barrels per day. This rate continued until late 1991 when a rapid decline began.

The Microbial EOR started in August 1992, oil in place was 758 bbls/ac-ft with an oil saturation of 56%. Rock properties are generally favorable for microbe colonization. Average permeability is 13 md with an upper limit of 300 md and provides adequate pore throat size for microbes to colonize. Additional permeability developed by fracture treatments with 60,000 gallons and 135,000 pounds of sand on initial completion provide excellent porous media for microbe colonization. Reservoir temperature at 110°F is ideal for microbe growth. Average production per well is 42 BOPD at 75% water cut.

After 24 months of treating by 43% or 300 barrels per day are received.

Tupungato-Refúgio Project (Argentina): it was discovered in 1930. The field was produced by a combination of solution gas drive, water drive and waterflood.

Microbial EOR was started on one well in June 1994 and on the other two wells in March 1995. At the start of the project oil in place was 625 bbls/ac-ft with an oil saturation of 47% and a gas saturation of 10%. The wells are on approximately 42 acre spacing. Rock and fluid properties are all favorable for microbe colonization.

After 14 months of treating by 29% or 60 BOPD are received.

Huabei Project (P. R. China): it contains seven wells located in the Huabei Petroleum Administration Bureau. The wells, in the later stage of being waterflooded, are scattered and not in the same reservoir. Therefore, while production data can be analyzed, reservoir performance cannot be determined for this grouping.

Microbial EOR started September 1994. The wells are rod pumped, with pumps set an average of 2,500 feet above the perforations. Reservoir and fluid parameters are all favorable for microbe growth.

Twelve months after the first treatment by 552% or 127 BOPD are received.

Xinjiang Project (P. R. China): it contains ten wells located in the Xinjiang Petroleum Administration Bureau. The wells, most in the later stage of being waterflooded, are scattered and not in the same reservoir. Therefore, while production data can be analyzed, reservoir performance cannot be determined for this grouping.

Microbial EOR started January 1995. The wells are rod pumped, with pumps set from 200 to as high as 6,000 feet above the perforations on one well. Reservoir and fluid parameters are all favorable for microbe growth.

Six months after the first treatment by 36% or 80 barrels per day are received.

Norne Project (Norway): was discovered in 1992, developing started in 1997. Oil density is 862 kg/m^3, Sulphur cintent is 0,21%, oil viscosity – 3 mPa·s.

The incremental oil recovery due to biofilm formation can be around 2 % OOIP.

In conclusion, an incremental oil recovery of almost 15 % OOIP can be achieved by the combined effect of surfactant, biofilm formation and the resulting microscopic fluid diversion. Each mechanism contributes to the overall effect, where the main contribution comes from production of surfactant.

Romashkinskoye Project (Russian Federation): production started in 1975, carbonate collector, depth 493–515 m, porosity – 9,8%; pressure – 6–7 MPa, temperature of stratum – 17–23 °C, oil density 903 kg/m^3, oil viscosity – 50–80 mPa·s, stratal water mineralization – 40–60 g/l.

The studying of the implementation of the Microbial EOR started in 1997. As the result 27% of residual oil can be recovered against 13% in the beginning.

Pirallahi Project (Republic of Azermaijan): the productiona started in 1902. Before Microbial implementation oil production in the 3-d quarter of 2009 comparing with the 1-st decreased on 30%, production rate was 0,39.

Microbial EOR started in August 2009. For the well number 931 production increased from 0,7 tons per day up to 1,8 tons per day.

Lisbon Project (U.S.A.): North Carolina state. It was the first implementation of the Microbial EOR in 1954, which also was successful.

Novo-Yelkhovskoye, Pervomayskoye, Yersubakiy-skoye, Berezovskoye Projects (Russian federation): they are operated by OJSC "TatNeft", water cut 90%, sandstone collectors.

After Microbial EOR implementation the produation increased on 59,8; 44,5; 9,3; 7,4 thousand tons.

Sterrap Project (U.S.A.): Kansas State, depth of occurrence – 1600 m, water cut – 95%.

After Microbial EOR implementation, the production increased on 50-55 thousand barrels.

White Tiger Project (Socialist republic of Vietnam): it is located in the shelf, it's flooded by sea water, salinity 35-37 g/l, reservoir temperature 120°C, pressure 4 MPa.

After Microbial EOR implementation, the oil displacement efficiency amounted to 57.4%. Using a combined physico-chemical and microbiological method increased oil displacement efficiency by 14.2%.

Bokor Project (Malaysia): high viscosity crude (4 to 10 cp) and low oil specific gravity of 20°API, low recovery factor in major reservoirs ranges from 19% to 25% of its original oil in place. Water depth of near 220 feet below msl; porosity – 15-32%; permeability – 50-4000 mD; oil gravity – 19-22°API in the shallower reservoirs (1500 – 3000 Ft. ss) to 37°API in the deep reservoirs (6300 Ft. ss).

After Microbial EOR implementation over 5 months period significant increase of the oil production rate and reduction of water cut were observed. The average oil production rate for the period increases by 270 b/d, which is equivalent to 47% oil incremental.

Summarizing the data of these articles, we can draw the following conclusions:

Table 1. Range of characteristics for the application of the microbiological method of impact on oil deposits.

Options	Range
Depth of occurrence, m	180 – 2500
Total thickness, m	3,88 – 18,2
Collector types	terrigenous, carbonate
Open porosity, %	7,9 – 24
Permeability, mcm^2	0,03 – 300
Temperature, °C	17 – 120
Pressure, MPa	0,344 – 7
Density, kg/m^3	830 – 914
Water type	calcium chloride
Mineralization of groundwater, g/l	8 – 235

Taking into account everything, mentioned before, it is obvious, that MEOR is applicable for most of the existing fields.

4 Low-profit deposits in Kazakhstan in accordance with the official data

Naturally, in order to offer this method, first you need to find potential customers, collect information about fields, where it is already required, to implement methods for improving the oil recovery.

Although it is known, that most of the republic's oil reservoirs have been in operation for a long time, and, as written in the many articles, they are at a last stage of operation. The search on state sites gave the following results: relating to the Resolution of the Government of the Republic of Kazakhstan No. 449 dated June 27, 2019, and also the estimates of the independent experts we receive the following table.

Table 2. List of low-profit fields.

Field	Location	Geological reserves, mln tons
1. Containing high viscosity oils		
Temir district, Aktobe region	Temir district, Aktobe region	Temir district, Aktobe region
Tupkaragan district, Mangistau region	Tupkaragan district, Mangistau region	Tupkaragan district, Mangistau region
Temir district, Aktobe region	Temir district, Aktobe region	Temir district, Aktobe region
Isatai district, Atyrau region	Isatai district, Atyrau region	Isatai district, Atyrau region
2. Low-income		
East Akshabulak	Syrdarya district, Kyzylorda region	n/d.
North Akshabulak	Syrdarya district, Kyzylorda region	n/d.
Yeszhan	Syrdarya district, Kyzylorda region	n/d.
Zhylankabak	Zhylyoi district, Atyrau region	n/d.
Zholdybay	Makat district, Atyrau region	1,5 recov. - 297 thousand tons
Kalzhan	Syrdarya district, Kyzylorda region	n/d.
South Kamyskol	Zhylyoi district, Atyrau region	n/d.
Kokzhide post-salt	Temir district, Aktobe region	50,9 on the 1st Jan. 2008 res.rec.res. – 12,5
Krykmyltyk	Zhylyoi district, Atyrau region	n/d.
Tobearal	Kurmangazy district, Atyrau region	n/d.
3. Waterflooded		
Uzen	Karakiya district, Mangistau region	1100
Kumkol	Ulytau district, Karaganda region	90 280 - geol., 130 – recov., 15 bln m^3 gas
East Kumkol	Ulytau district, Karaganda region	n/d.
Arman	Mangistau district, Mangystau region	30
Karaarna	Zhylyoi district, Atyrau region	27,6 25,4 - recov.
East Kokarna	Zhylyoi district, Atyrau region	6,8 4 – recov.
Matin	Makat district, Atyrau region	30
North Pridorozhnoe	Beineu district, Mangystau region	30
4. Irreplaceable (worked out)		
Zhaksymay	Temir district, Aktobe region	25
Shubarkuduk	Temir district, Aktobe region	n/d.

It turns out there are only 24 fields, at the same time there is an article by NOC Kazakhoil, which states that out of 45 fields they operate, at least two, Dossor and

Makat, are among the oldest in terms of exploitation time [9].

In this paragraph, the abbreviation "n/d." appears for the first time, meaning "no data", i.e., unfortunately, this information is closed for public use. It will often meet further.

5 Classification of the hydrocarbon deposits of the Republic of Kazakhstan

Further searches for the necessary information led to even more interesting discoveries – the number of deposits, published on the Wikipedia site is 216 deposits, and those found by mentions in media publications for five months – 269.

The database in Excel format was compiled, which includes information on 289 fields, of which 269 are Kazakhstani and 20 foreign, where the microbiological method of stimulating the formation has already been introduced. As a result, we've got the following table:

Table 3. Comparison results.

Deposit volume	Known number of deposits (site Wiki2.org)	Number of deposits mentioned on the Internet
Supergiant (more than 5 bln tons)	1	2
Giant (more than 1 bln tons)	3	3
Large (from 100 mln tons)	11	29
Medium (from 10 mln tons)	26	42
Others	more than 1000	40
No data	-	153

The difference is quite tangible. Especially considering that the second supergiant, the Kurmangazy field, discovered in Soviet times with reserves of 6,200 million tons of raw materials and then called Kulalinskaya, for some reason is only mentioned in Russian sources, although its estimated reserves are only slightly inferior to Kashagan, which is the largest in the world offshore field with reserves of 6,400 million tons.

It's needed to pay attention to the fact that there are no data on the geological reserves of 153 fields out of 269, i.e. more than half of the known deposits are in operation without disclosing their characteristics.

Another classification was drawn up in accordance with a slightly different division by geological reserves [10].

Table 4. Second classification.

Options	Q-ty	Deposits' names
Unique deposits (more than 300 mln tons of oil &/ or more than 300 bln m^3 of gas)	13	Bekturly, Darkhan, Kalamkas, Karachaganak, Kashagan, Khvalynskoye, Kurmangazy, Nursultan, Rakushechnoye-sea, Tengiz, Uzen, Zhanazhol, Zhetybai
Large deposits (deposits 30 – 300 mln tons of oil &/ or 30 – 300 mln m^3 of gas)	42	Akshabulak, Aktoty, Arman, Asar, Atash, Bobek, Bozoba, Chinarevskoe, Dosmukhambetovskoe, Dunga, East and Central Prorva, East Tegen, Imashevskoye, Isatayskoye, Kairan, Kalamkas-sea, Karakuduk, Karaton-Koshkimbet, Karazhanbas, Karpovsky Northern block, Kenbai, Kenkiyak post-salt, Khasar, Kokzhide post-salt, Korolevskoye, Kultuk Mertvyi, Kumkol, Makhambet, Morskoye, Mortuk, North Buzachi, North Pridorozhnoye, North Truva, Prigranichnoye, Rakushechnoye, Shagyrly-Shomyshty, Tub-Karagan, Turkmenoy, West Prorva, West Terenozek, Zhambyl, Zhemchuzhina
Medium deposits (deposits 5 – 30 300 mln tons of oil &/ or 5 – 30 mln m^3 of gas)	32	Amangeldy, Ashhisay, Auezov, Bolganmola, Borankol, East Kokarna, East Zhagabulak, Kamenistoye, Kamenskoye, Kansu, Karaarna, Karataikyz, Karatube, Kemerkol, Komsomolskoye, Kozhasay, Kulzhan, Kumsay suprasaline, Maibulak, Masabay, North Akkar, North Karagie, North Karamandybas, Nuraly, Oymasha, Rozhkovskoye, Rozhkovskoye-Fedorovsky block, South Gremyachinskoe, Tyubedzhik, Zhaksymai, Zhambay South Sea, Zhangurshi
Small deposits (deposits 1 – 5 mln tons of oil &/ or 1 – 5 mln m^3 of gas)	17	Airakty, Akingen, Aksai, Anabai, Doschan, East Karaturun, Karabulak, Kopa, Kyzyloyskoye, North Nuraly, North Usharal, North-West Konys, Rostoshinskoye, West Karabulak, West Tuzkol, Zholdybai, Zhylandy
Very small deposits (less than 1 mln tons of oil &/ or less than 1 blm m^3 of gas)	12	Akkuduk, Arysskoe, Asanketen, Ayrantakyr, Borkyldakty, East Kyzylzhar, Koschagyl, Kulsary, Sagiz, Tuilis, Uytas, West Sagiz
No data	153	Abay, Abylaikhan, Aiyrtau, Aksu-Kenderly, Aktas, Aktobe, Akzhar, Alatyube (East block), Alatyube, Alibekmola, Alimbay, Altykol, Aryskum, Arystan, Ashchiagar, Atambay-Sartube, Auketayshagyl, Ayrankol, Baishonas, Balgimbaev, Bazayskoye, Bekbike, Bektas, Besbolek, Botakhan, Burmasha, Daraimola, Daryinskoe, Dauletaly, Dossor, East Akshabulak, East Akzhar, East Gremyachinskoe, East Kumkol, East Moldabek, East Normaul, East Ongar, East Saztobe, East Uzen, East Zhetybay, Eskene, Espelisay, Eszhan, Gran, Gremyachinskoe, Gryadovoe, Kalzhan, Karagan, Karagay, Karakuduk, Karatal, Karaturun Marine, Kisimbai, Konys, Korsak, Kenlyk, Kumisbek, Kyrykmyltyk, Kyzylkiya, Laktybay, Makat, Makhat, Maldybai, Matin, Munaily, Munaily-Mola, Narmundanak, Naryn, North Akshabulak, North Baklaniy, North Karazhanbas, North

Options	Q-ty	Deposits' names
		Kotyrtas, North Zholdybai, North-East Karaturun, North-East Saztobe, North-West Zhetybai, Nsanovskoe, Oktyabrskoe, Okzhetpes, Ortalyk, Oryskazgan, Pionerskoye, Port-Arthur, Pribrezhnoe, Pridorozhnoe 1, Pridorozhnoe 2, Pustynnoe, Ravninnoe, Rovnoe, Sarsenbay, Satbayev site, Sazankurak, Shagala, Shattyk, Shingiz, Shinzhir, Shubarkuduk, Sinelnikovskoye, South Alamuryn, South Kamyskol, South Karatube, South Karaturun, South Koshkar, South Kozha, South Narmundanak, South Tagan, South Tanatar, South Zhetybai, South-East Bekturly, South-East Kamyshitovoye, South-East Novobogatinskoe, South-East Saztobe, South-West Dossor, South-West Kamyshitovoye, South-West Tazhigali, Tamdy, Tanatar, Tasbulat, Tastobe site, Tasym, Tazhigali, Tenge, Tenteksor, Teplovskoe, Tobearal, Tokarevskoe, Tolegen, Tolkyn, Tortay, Tsentralnoye, Tsyganovskoe, Tulpar, Ulyanovskoe, Urikhtau, Usharal, Ushkultas, West Aktas, West Novobogatinskoe, West Opak, West Tenge, West Teplovskoe, Yuzhnaya Rovnaya, Zaburunye, Zhanatalap, Zhanatan, Zhanazhol, Zhangeldy, Zharty, Zhenis site, Zhilankabak, Zhilankyr, Zhubantam

Table 5. Classification of the deposits by location.

Names of regions (districts)	Quantity
1. Aktobe region	**25**
Baigany district	7
Mugalzhar district	6
Temir district	10
Shalkar district	2
2. Atyrau region	**88**
Zhylyoi district	39
Isatay district	13
Kyzylkogy district	10
Kurmangazy district	3
Makat district	22
Makhambet district	1
3. Zhambyl region	**5**
Moyinkum district	3
Talas district	2
4. West Kazakhstan region	**19**
Baiterek district	14
Burlinsky district	1
Zhangalinsky district	1
Kaztalovsky district	1
Taskaly district	2
5. Karaganda region	**5**
Ulytau district	5
6. Kyzylorda region	**18**
Zhalagash district	4
Syrdarya district	13
Shiely district	1
7. Mangystau region	**65**
Beyneu district	12
Karakiya district	36
Mangystau district	11
Munaylinsky district	1
Tupkaragan district	5
8. Turkestan region	**3**
No data about the exact regional location at the district level	3
9. Kazakhstani part of the Caspian Sea shelf	**29**
10. No data on the exact geographic location	**12**

Over the period of independence of the Republic of Kazakhstan, i.e. since 1991, only 42 fields have been discovered: Kashagan, Aktoty, Kalamkas-sea, Kairan, Aiyrtau, Asanketen, Auezov, Ashisay, Borkyldakty, Gremyachinskoye Yuzhnoye, Doschan, Vostochny Zhagabulak, Zhambyl, Zhanatan, Zhemchuzhina, Karabulakulak, Zapadny Karaturun North-East, Kemerkol, Kokzhide post-salt, Kyzylzhar East, Laktybay, Narmundanak South, Novobogatinskoe West, Nuraly North, Border, Pridorozhnoe (Mangistau region), Rakushechnoye, Rakushechnoye-sea, Severnaya, Rozhkovskoe, Rostoshinskoye, Western Tuzkol, Tulpar, Uytas, Isataisskoye, Khazar, Khvalynskoye, Centralnoye, Chinarevskoye.

During its time in the USSR – 158 deposits.

Could not find data on the year of discovery of 69 deposits.

In addition, the data on licensed field operators are often hidden, for example, the owners of 85 fields are unknown.

For a more complete picture, the phase states of the collectors have been added to the resulting database, since we are primarily interested in oil deposits.

Table 6. Classification of the deposits by phase state.

Phase state	Quantity
Gas (g)	24
Gas, condensate (gc)	15
Gas, condensate, oil (gco)	2
Gas and oil (go)	16
Oil bituminous (ob)	3
Oil and gas (og)	34
Oil, gas, condensate (ogc)	32
Oil (o)	103
No data	40
TOTAL	269

6 Additional information

Already after writing the chapter of the dissertation, and this article, an additional source of information was found. It is published in Moscow in 2010 the report “Current state and development trends of the oil and gas complex of Turkmenistan and other Central Asian countries of the Near Abroad” [11], which is known only in the circles of oil specialists, but also not in the public domain.

It says, that there are 304 hydrocarbon deposits in Kazakhstan, i.e. even more than was found by me, and this, of course, also expanded the already existing picture of the data.

In it deposits are listed and described by basins.

Table 7. Classification of the deposits by basins.

Basin name	Fields	Q-ty
Volgo-Uralsky	1 oil field, 1 oilgascondensate field	2
Zaisansky	1 gas field	1
Caspian	11 – gas fields, 6 – gascondensate fields, 98 – oil fields, 49 – oilgas fields, 15 – oilgascondensate fields	179
North Caucasian-Mangyshlak	10 – gas fields, 5 – gascondensate fields, 10 – oil fields, 19 – oilgas fields, 12 – oilgascondensate fields	56
North Ustyurt	12 – gas fields,, 4 – gascondensate fields, 3 – oil fields, 13 – oilgas fields	32
Turgay	2 – gas fields, 2 – gascondensate fields, 7 – oil fields, 11 – oilgas fields, 1 – gascondensate fields	23
Chu-Sarysu	9 – gas fields, 2 – gascondensate fields	11

7 Conclusions

After carrying out of this work, the following conclusions are suggested:

1. Based on the data in the Table 1, it can be concluded that the microbiological impact method is applicable to the most hydrocarbon deposits of the republic, namely, referring to the Table 6, at least 103, if not 172.

2. Table 5 shows that Atyrau and Mangistau regions of Kazakhstan are leaders in terms of the number of deposits and the volume of hydrocarbons contained in them, but at the same time, it can also possible to see that 8 other Kazakhstan regions out of all 14 also have their own hydrocarbon raw materials. For example, we, the residents of the Karaganda region, did not know that we also have deposits of this type. Moreover, one of them, Kumkol, with initial reserves of 280 million tons of oil and 15 billion cubic meters of gas, in accordance with prepared classification belongs to the large one.

3. The oil and gas industry of our republic is one of the most closed to the public. But the disclosure and publication of these data, perhaps, will help to improve this situation.

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Research of the properties of quarry tuff-stone for complex processing

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Abstract. This article focuses on the complex processing of quarry tuffs-stone to extract metals (iron, titanium, copper, silver, etc.) and obtain raw materials for construction and agriculture. The issue of tuff-stone softening was investigated and the analytical dependence of the regularity of tuff-stone softening at water saturation was established, which indicates that the saturation increases with increasing mass of the sample according to the logarithmic law, and the dehydration process occurs according to the parabolic law. Also in the course of researches the magnetic susceptibility of tuff-stone was defined, which depends on size of induction of a magnetic field. The magnetically sensitive part is up to 50% by weight of the sample, and the remaining silicate part at a magnetic field strength of 1.3 Tesla. Spectral analysis showed a high content of metals in the magnetically sensitive part of tuff-stone, which consists of iron (35-40%), titanium (2.5-4.0%) and copper in the silicate part (0.4-0.7%). It was found that the percentage of content representing commercial interest, and therefore it is appropriate complex processing.

1 Introduction

The unique basalt deposit in the Rivne region is usually accompanied by rich deposits of tuff-stone, which are the products of volcanic eruptions. Geologists' forecasts for tuff-stone raw material reserves are hundreds of millions of tons. As a mineral, they have already been widely used in agriculture to increase soil fertility and to decontaminate their radioactive contamination, as a feed additive for livestock and poultry, as well as a building material.

The growing interest in tuff-stone mining requires improving its processing and bringing to the finished product. The rich mineralogical composition of tuffs, the presence of trace elements of rare metals, high content of iron, titanium, native copper in the tuffs of Rivne-Volyn region of Ukraine necessitated their comprehensive processing, the initial stage of which is ore preparation of rock mass to extract useful components [1].

In the process of ore preparation and selection of tuffs from the dumps of the basalt quarry there is a need to study its particle size distribution for the selection of equipment for further processing. The established effect of softening of tuff-stone at repeated irrigation with water demands specification of its granulometric structure both in a dump massif, and as a result of the subsequent crushing and crushing [2-4].

The aim of the research was to establish the regularities of softening of zeolite-smectite tuffs of the quarry mining method and their magnetic susceptibility [5-9].

2 Methods

According to the results of previous studies, it was found [10] that the softening of quarry tuff-stone as a result of water saturation leads to its involuntary destruction, which contributes to its separation from the total dump rock mass by screening. In turn, the time of water saturation depends on the mass of the sample, so to control the process of destruction and preparation for the screening operation, it is necessary to establish such a relationship. Based on the data of the study of tuff-stone saturation with water, the saturation time was determined for samples of different masses. [11-14]. These data are presented in Table 1.

Analyzing the data shown in table 1, it was found that the saturation time increases with increasing mass. Analysis of the data suggests that the dependence can be described by logarithmic-linear regression of the form:

$$t_H = a + b \cdot ln(m), \tag{1}$$

where m – sample weight, t_H – saturation time.

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Table 1. Saturation time for samples of different masses.

Sample weight, kg	0,052	0,106	0,348	0,681	1,025	2,18	3,347
Saturation time, h	1	23	96	68	96	96	96

As a result of the received data the corresponding calculations are carried out and the following model is received:

$$t_H = 23{,}34 + 23{,}2 \cdot ln(m). \qquad (2)$$

The coefficient of determination of this model is indicative of its acceptable adequacy. Graphically, the dependence was obtained (Fig. 1), which confirms that theoretically the saturation time should continue to increase with increasing mass according to the logarithmic law.

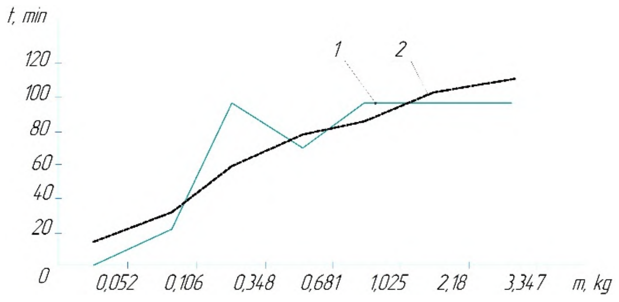

Fig. 1. The dependence of the time of saturation of tuff with water: 1 – according to the experiment; 2 – according to the calculation.

To model the process of softening of tuff-stone, it is of considerable interest to determine the analytical type of dependence on which the dehydration process takes place. Sample № 7 was taken for the study as the most characteristic for dump tuff-stone [15-17]. The analytical dependence of the species was established, and it is assumed that this dependence reduces the mass of the sample over time during dehydration.

As a result of the calculation, the following regression equation was obtained

$$m(+) = 3{,}54 - 0{,}00152t \ \text{ at } r^2 = 0{,}88. \qquad (3)$$

The obtained model has a fairly high level of adequacy, but the consistency of experimental and theoretical values $m(t)$n graphical form is not satisfactory (Fig. 2).

In this regard, a parabolic regression model of the species was calculated $m(t) = a + bt + ct^2$. This model, unlike the previous one, takes into account the nonlinear nature of the process. The result is obtained

$$m(t) = 3{,}569 - 0{,}00327t + 0{,}0000124t^2 \ \text{ at } r^2 = 0{,}98, \qquad (4)$$

which is significantly higher than for the linear model.

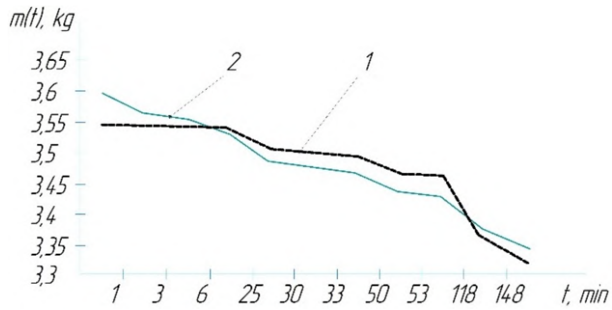

Fig. 2. Linear model of tuff-stone dehydration process: 1 – experimental; 2 – estimated.

The graph of actual and analytical parabolic dependences is given in Fig. 3, which shows their consistency. Thus, it can be argued that the process of dehydration is subject to the parabolic model, which is shown in Fig. 3.

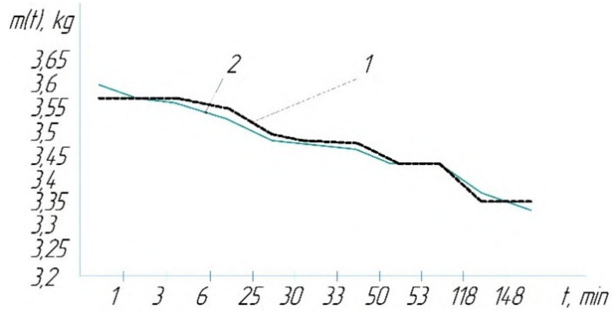

Fig. 3. Parabolic model of the process of dehydration of tuff-stone: 1 – experimental; 2 – calculated.

As a rule, in practice one cycle of saturation and dehydration is not enough for destruction of tuff-stone in a dump to the conditional sizes. Therefore, it is recommended to use a repeated cycle of saturation and subsequent dehydration naturally – drying [18-23].

Analysis of data on the re-saturation of tuff-stone with water and testing on these data of different regression models allowed to choose the most adequate of them:

$$m(t) = a + b_1 t + b_2 m_0 + b_3 m_0 t, \qquad (5)$$

where m_0 – the initial mass of the sample, before saturation; t – saturation time.

As a result of the calculations, the following model was obtained

$$m(t) = 0{,}0075 - 0{,}00004t + 1{,}0285m_0 + 0{,}00016m_0 t. \qquad (6)$$

Coefficient of determination $r^2 = 0{,}99$ and indicates an acceptable functional dependence $m(t)$. Given the rather large sample size (n = 56), this model can be adopted for further practical use. It takes into account not only the influence of time and mass of the sample separately, but also the combined influence of these factors. To illustrate the results in Fig. 4 shows the dependences of the mass of tuff-stone on time for three samples: $m_{01} = 1{,}025$ kg; $m_{02} = 2{,}18$ kg and $m_{03} = 3{,}347$ kg.

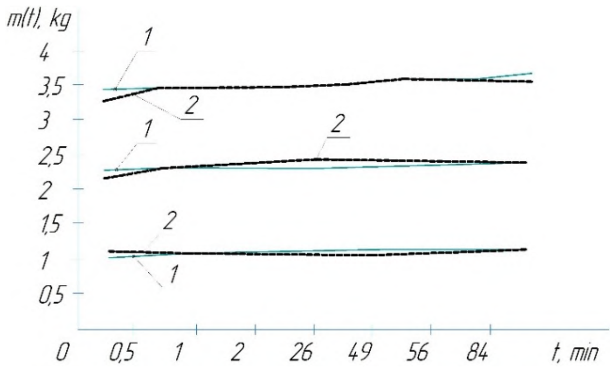

Fig. 4. The dependence of the mass of the tuff-stone sample on the re-saturation of three samples with water: 1 – according to the experiment; 2 – by calculation.

According to experimental studies, a regression model was obtained for the process of re-dehydration

$$m(t) = 0{,}00137 - 0{,}000045t + 1{,}0697m_0 - 0{,}000063m_0t \ . \tag{7}$$

Coefficient of determination is $r^2 = 0{,}99$.

Model m_0 – the mass of the sample after dehydration.

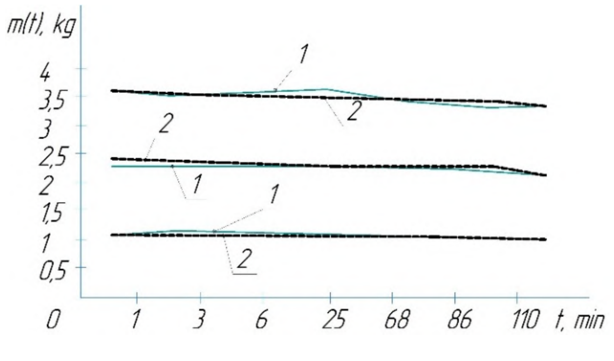

Fig. 5. The dependence of the mass of the tuff-stone sample during repeated dehydration for three samples: 1 – according to the experiment; 2 – by calculation.

In Fig. 5 shows the experimental data and the results of analytical calculations according to the above model. The high level of coincidence of graphs indicates the reliability of the chosen model and the possibility of its application in practice.

Thus, as a result of research the analytical dependence of the regularity of softening at water saturation was established, which shows that the saturation increases with increasing mass of the sample according to the logarithmic law, and the dehydration process occurs according to the parabolic law. tuff processing.

3 Investigation of the magnetic susceptibility of zeolite-smectite tuff-stone

In recent years, researchers' interest in tuffs in order to use them in industry has grown significantly. Therefore, there is a need for a detailed study of their properties, methods of extraction, processing and integrated use. In the process of research of zeolite-smectite tuffs, which occur in large quantities in Rivne-Volyn, their magnetic susceptibility was established, which is explained by the presence of iron and titanium. Quantitative and qualitative analysis of the content of these elements was performed experimentally using magnetic and spectral analyzes of crushed tuff-stone samples of different sizes at variable magnetic field strength to determine the level of its sufficiency in the ore preparation of raw materials for complex processing [24-27].

Studies have shown that tuff-stone contains native copper in the form of thin films or point inclusions, the extraction of which is possible only with fine grinding of tuff-stone for maximum separation of the silicate part from native inclusions. Since iron and titanium are also in the joints in the form of compounds, by fine grinding followed by screening to achieve maximum disclosure of minerals. Obtaining the maximum allowable degree of grinding of tuff-stone for reasons of the possibility of a hardware method of extracting metal compounds (magnetic and electric separators) allows to determine the content of silicate and metal parts in the composition of tuff-stone [28-30].

The purpose of studies of the composition of tuff-stone by magnetic and spectral analysis was to determine the particles of silicate and metal parts, as well as the influence of magnetic field strength on the extraction of the magnetically sensitive part and its composition.

Because zeolite-smectite tuffs are associated rocks in basalt mining and are not widely used, they are a waste rock in basalt quarries. From the point of view of complex extraction and processing of basalts with division into three components in the deposit (basalt, lavobrekcia and tuff), the Rafalivka deposit is perspective, therefore researches of zeolite-smectite tuff-stone of this deposit are executed in work. In the process of ore preparation for this method of tuff-stone processing it is important for rationalization to determine the basic particle size and chemical composition and reaction of rock mass to different types of influences [31-32].

For research, the tuff of the Rafalivka basalt quarry was crushed into three groups of size: (-2.5+0.63 mm); (-0.63+0.1 mm); and (-0.1 mm). Next, the weight fraction of each size class in the sample and the percentage of magnetically sensitive part in it was determined (Table 2). The magnitude of the magnetic field for each sample varied stepwise from 0.08 Tesla to 1.3 Tesla in five stages of exposure. The experimental technique involved increasing the induction of the magnetic field to determine the part of the tuff-stone separated from the total mass of the part that was attracted at a given intensity, and then, by spectral analysis, the content of the elements of each part was determined. This is due to the fact that the degree of susceptibility of tuff increases with increasing magnetic field strength. Factors influencing the process of magnetic separation are particle size distribution and chemical composition of tuff-stone [33].

Table 2. The distribution of the mass of tuff-stone in the sample depending on the induction.

№ research	Class +0,63 –2,5			№ research	Class +0,1 –0,63		
	Induction, B, Tesla	Susceptible mass, *m*, g	Percentage, γ,%		Induction, B, Tesla	Susceptible mass, *m*, g	Percentage, γ,%
1	0,08	63,2	19,1	8	0,08	30,5	14,6
2	0,16	59,5	18,0	9	0,16	37,0	17,7
3	0,3	51,7	15,6	10	0,3	37,7	18,1
4	0,44	49,7	15,0	11	0,44	31,9	15,3
5	0,58	44,8	13,5	12	0,58	32,5	15,6
6	1,3	6,1	1,8	13	1,3	5,8	2,8
7	nonmagnetic	56,4	17,0	14	nonmagnetic	33,4	15,9
	Total (sum)	331,4	100		Total (sum)	208,9	100
The total mass of the sample	331,4 + 208,9 + 104,5 = 644,8 g						

Since the third group of size (-100 microns) showed complete magnetic immunity, it is attributed to the non-magnetic part of the sample.

Based on the obtained results, the magnetically impermeable part of the sample is 49.1 % or 194.3 g. The different susceptibility of the metallized part of the crushed tuff-stone in relation to the magnitude of the magnetic field induction and size indicates product.

The nature of the heterogeneity of the composition was established by spectral analysis of all obtained fission products. The analysis was performed by spilling on the device STE-1 with a prefix USI-10. The results of the analysis are presented in Table 3 and Table 4. It should be noted the lack of accuracy in the percentage of some elements, in particular titanium (> 1.0 %), iron (> 15 %), and the lack of data on the presence of silicates and carbonates (SiO_2 and CaO) in samples. Their content was determined by chemical analysis. It was precisely established that the iron content in the samples of the first group is 36.2 %, and in the second - 39.6 %, respectively, titanium - 1.3 % and 4.1 %. The increase in the average percentage of native copper in the sample of the second group of size is explained by the fineness of its inclusions, but this indicator requires additional separate studies [34-37].

Table 3. The results of the analysis of the content of elements in the tuff-stone for the sample 1.

№	Induction, Tesla	The weight of the sample in the first group, g	The mass content in the sample, %	Content of elements, %							
				Fe	Ti	Cu	Mn	Ba	SiO_2	CaO	Ag, g/t
1	0,08	63,2	19,1	> 15	> 1,0	0,1	0,07	0,07	43,8	3,44	15
2	0,16	59,5	18,0	> 15	> 1,0	0,4	0,07	0,05	43,8	3,44	10
3	0,3	51,7	15,6	> 15	> 1,0	0,2	0,05	0,07	43,8	3,44	7
4	0,44	49,7	15,0	> 15	> 1,0	0,3	0,07	0,05	43,1	3,04	10
5	0,58	44,8	13,5	> 15	> 1,0	0,5	0,07	0,07	43,1	3,04	10
6	1,3	6,1	1,8	> 15	0,7	0,5	0,05	0,07	43,1	3,04	15
7	nonmagnetic	56,4	17,0	> 15		0,4	0,05	0,065	43,8	51,6	50
Σ		331,4	100	> 15	> 1,0	0,45	0,06	0,06	43,5	52,0	17

Table 4. The results of the analysis of the content of elements in the tuff-stone for the sample 2.

№	Induction, Tesla	The weight of the sample in the first group, g	The mass content in the sample, %	Content of elements, %							
				Fe	Ti	Cu	Mn	Ba	SiO_2	CaO	Ag, g/t
8	0,08	30,5	14,6	> 15	> 1,0	0,1	0,07	0,07	42,1	51,8	7
9	0,16	37,0	17,7	> 15	> 1,0	0,4	0,07	0,06	43,1	51,9	10
10	0,3	37,7	18,1	> 15	> 1,0	.0,5	0,05	0,07	43,1	52,3	10.
11	0,44	31,9	15,3	> 15	> 1,0	0,7	0,07	0,07	42,8	51,2	15
12	0,58	32,5	15,6	> 15	> 1,0	0,5	0,07	0,07	41,7	52,1	15
13	1,3	5,8	2,8	1,0	0,5	0,5	0,15	0,05	44,6	53,2	50
14	nonmagnetic	33,4	15,9			0,6	0,1	0,04	43,5	53,1	50
Σ		208,9	100			0,5	0,08	0,05	43,6	52,6	23

As the experiment showed, the discrepancy in the mass of the magnetically sensitive part (49%), which is due to the presence of titan magnetite and iron content in the samples obtained by chemical analysis (36.2-39.6%), is due to the presence of splices with hollow rock. The presence of copper in the magnetically sensitive part indicates the need to choose a rational degree of grinding of tuff-stone for a more complete separation of copper from the silicate part. At the same time the particles of titan magnetite are more fully revealed. Since magnetic separation allows to separate even finely divided iron particles (up to 44 microns) from crushed tuff-stone to a size of less than 100 microns, the electric separation of the silicate part of the product in copper extraction is most effective up to a size of 100 microns. This indicates that the re-grinding of tuffs in the ore preparation process leads to losses in the extraction of metals [38-40].

Thus, the performed researches established that the degree of grinding of tuff-stone in the process of ore preparation should be not less than 0.05-0.1 mm. The magnetically sensitive part reaches 49 % by weight of the sample, respectively; the silicate part is 50-51 %. During the extraction of the magnetically sensitive part is significantly affected by the magnetic field strength, which reaches 1.3 Tesla. The performed studies indicate the expediency of complex processing of not only basalts but also tuffs, as the percentage of basic elements is of industrial interest. Such elements are iron, titanium, copper, silver. The remaining silicate part is disposed of for construction and agriculture. This recycling technology is waste-free and resource-saving.

Conclusions

Analysis of experimental studies suggests that tuff-stone is a valuable raw material of interest to industry, as it contains valuable elements in the form of native copper, iron, titanium. Removal of these components is technologically possible and economically feasible.

For dump tuff-stone, an analytical dependence of the regularity of softening at water saturation is established, which indicates that the saturation increases with increasing mass of the sample according to the logarithmic law, and the dehydration process occurs according to the parabolic law.

As a result of the conducted researches the magnetic susceptibility of tuff-stone which depends on size of induction of a magnetic field was established. The magnetically sensitive part of tuff-stone, at a magnetic field strength of 1.3, Tesla is up to 50% by weight of the sample, and the rest is the silicate part. The spectral analysis showed a high content of metals in the magnetically sensitive part of tuff-stone, which consists of iron (35-40%), titanium (2.5-4.0%) and copper in the silicate part (0.4-0.7%). The percentage of these elements is of industrial interest, so it is advisable to comprehensively process dump tuffs in the Rivne-Volyn region of Ukraine.

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Modeling the distribution of rock mass and native copper output by size classes during crushing

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Abstract. The article considers the features of the distribution of technological indicators (product output, content and extraction of copper) by size classes, the main factors influencing the crushing process are identified and regression dependences of productivity on influencing factors are received. The parabolic nature of the dependences of the output of crushed rock on the size class is established. The high adequacy of the obtained models was confirmed and the most promising classes of rock size for copper extraction were determined. The obtained results and models will allow to develop a generalized model of the process of native copper mining and to implement this process with rational and optimal parameters. Also, the received models will allow to carry out an estimation of productivity of a research site of processing of raw materials of basalt quarries.

1 Introduction

Historical and archeological data indicate that Volyn native copper was well known to the ancient Slavs. This is evidenced by the names of places (Midsk, Medishche, etc.) of Old Slavic origin (mid - copper), tools from ancient settlements and ancient basalt mines in the basin of the Goryn River. The first thorough written data on Volyn native copper appeared in the Polish geological literature in the late 1920s, although some publications as early as 1887 already mention Volyn native copper.

In addition to Volyn copper, several other rich manifestations of native copper have been discovered in Ukraine relatively recently. All these previously unknown ore occurrences were found on the Ukrainian Shield. In the early 1990s, native copper was found among polymetallic ores in the Precambrian carbonate rocks of the Volyn mega block (Kurchytsia ore occurrence), and at the beginning of the new millennium in the weathering crust of the Zhdaniv ultrabasic intrusion in the 2003 Berdychiv uplift and uplift. Chemerpil structure of the Podolsk block. Rare finds of native copper are known in the Carpathians, Azov, Donbass and Kryvyi Rih.

Xenomorphic native copper predominates in the ore manifestations of Ukraine due to a significant influence on the shape of its allocations in the crystallization medium. There is a significant variety of xenomorphic forms of native copper - lamellar, membranous, druse-, vein-, dendritic-, lump-, droplet-, wire-, sponge-, needle- and hair-like. Among the small allocations of copper are often perfect and imperfect polyhedra, their regular and irregular growths, dendrites and dendritoids.

The dominant method of growth of polyhedra of native copper of Ukraine is free crystallization, the tangential mechanism of growth of crystals prevailed. Crystals of hydrothermal copper from volcanic of Volyn grew in cubic layers, as well as crystals of hyper genic copper from the Zhdanovka ore occurrence, while crystals of hypergenic copper from the Chemerpil ore occurrence grew in octahedral layers.

In terms of chemical composition, copper from ore occurrences in Ukraine is a relatively pure mineral, especially in the case of hydrothermal native copper from volcanic of the Volyn copper ore district. Magmatic copper from volcanic of Volyn has a high content of impurities Ni, Co, Cr and Fe [1].

Important minerals-indicators of native copper mineralization in the volcanic of Volyn are native iron and silver, which have characteristic features of chemical composition: iron enriched with impurities Mn and Cr, silver – Hg. In terms of crystal morphological features, hydrothermal native copper from Volyn volcanic is most similar to native copper from Michigan deposits (USA), which indicates the close conditions of their crystallization [2].

Native copper of Ukraine belongs to several genetic types: a) hypo genic (magmatic and post-magmatic hydro-thermal) in the Vendian volcanic of the Volyn copper ore district; b) hyper genic in the oxidation zones of the Precambrian ultrabasites of the Zhdanovka and Chemerpil ore occurrences of the Podil block of the

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Ukrainian Shield; c) metamorphogenic in Precambrian metamorphic rocks ore occurrence of Kurchytsia of the Volyn megablock of the Ukrainian Shield [3-7].

2 Methods

As you know, the average copper content in the main geological and industrial types of copper deposits is from 0.2 to 6.0 % (for example, for cuprous sandstones and shale 1.0-6.0 %, for deposits of native copper 1.0-2.5 %) [8]. The lower limit of the conditions for copper ore is the copper content in the ore 0.35-0.50 %, for oxidized ores, according to world practice, this limit is higher - from 0.7-1.0 % at which its industrial use is technically possible and economically expediently [9].

Sulfide copper ores make up 90 % of all industrially processed copper ores. They are finely crushed and enriched by flotation, for oxidized ores the most common and cheapest method is hydrometallurgy (leaching and extraction of copper from solution), ore preparation of oxidized and native ores, as a rule, includes gravity methods [10].

Studies of rocks from basalt quarries in Volyn (Rafalovsky, Berestovetsky and some others) did not reveal the presence of sulfide copper ores in an amount sufficient for industrial processing, mainly copper is contained in the form of native mineralization and accompanying oxidized varieties [11]. Considering this, when extracting copper from basalt quarry rocks, the main thing is to create a strong, developed ore preparation scheme. Further, copper can be obtained from the concentrate of ore preparation, either by modifying it by hydrometallurgy or roasting-flotation concentration, or directly by smelting (pyro metallurgy).

Due to the fact that all three main rocks of the open pit are copper-bearing - tuff, basalt, lavobrekcia, it is necessary to clarify in advance, at least in general terms, whether the ore preparation scheme will be the same for all three rocks or will it be necessary to create separate processing lines. For this, the prepared representative rock samples were uniformly detailed (on a roller crusher) and dispersed into three narrow particle size classes.

To determine the nature of the distribution of native copper in different grades of the size of the crushed rock, studies of technological samples of lumpy lava breccia with pronounced numerous inclusions of copper were carried out [12]. Sampling was carried out on the blasted rock mass at different points along the face of the Rafalovsky basalt quarry. A total of 10 samples were taken, each weighing 10 kg in the form of a single piece or a set of separate pieces.

Crushing was carried out on a vibration-type jaw crusher with an adjustable slit for unloading the crushed mass. After crushing each sample, the resulting mass was vibrated and divided into six control size classes. The weight of the sample as a whole, the weight of each screening class and the weight content of copper in each of the classes and in the sample as a whole were measured [13-16].

3 Results and discussion

Experimental studies have shown that in all classes the copper content is not more than 4.1 %, that is, not excluding the presence of nuggets and pure grains of copper minerals in the classes, there is a lot of waste rock in all classes and, most importantly, there are many intergrowths of copper minerals with the rock. To destroy the aggregates, these classes will have to be crushed, otherwise the aggregates will be extracted during enrichment and the quality of the concentrate will be insufficient [17].

Based on the experiments carried out, for 10 samples of lavobrekcia, the cumulative (cumulative) characteristics of copper extraction into classes were constructed (Table 1).

Table 1. Cumulative characteristics of copper recovery in size classes of crushed mass of lavobrekcia.

Classes, mm / Sample No.	**Total copper recovery, %**										**Average**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
+10	21.4	14.7	17.2	15.7	20.0	26.0	29.0	24.3	22.0	22.2	21.3
-10 +5	44.7	42.3	46.8	36.2	35.6	58.5	60.3	53.5	50.9	48.3	47.7
-5 +1.0	70.7	64.6	71.9	64.4	55.6	70.0	85.8	73.5	74.1	72.4	70.3
-1.0+0.5	85.4	78.8	84.9	81.1	76.8	86.2	92.2	88.0	90.5	84.8	84.9
-0.5+0.1	94.1	89.8	93.3	90.4	89.0	100	96.5	95.5	97.6	93.5	94.0
-0.1 +0.05	100.0	100.0	100.0	100.0	100.0	-	100.0	100.0	100.0	100.0	100.0

Table 1 shows that, on average, the total extraction of copper in the top three classes -10 + 1 mm is 70.3 %, in classes -10 + 0.5 about 85 %, and in classes -10 + 0.1 mm – 94 %. This concentration of copper in relatively large grades is typical for native deposits.

Using the obtained data on extraction, two conclusions can be drawn, firstly, regarding the structural diagram of the developed ore preparation technology, and secondly, about the expected performance of copper concentrate.

The nature of the extraction (Table 1) suggests the possibility of using a variant of the technology for separate enrichment of lavobrekcia, when the raw material is divided into two streams - large and small classes, each of which is enriched separately. The decision on which size to accept as the boundary will depend on the chosen method of enrichment, since the enrichment equipment operates at a certain lower limit of the feed size. For example, grades +0.5 mm, where copper recovery is 85%, are easily enriched by gravity methods, for example, jigging [18-23]. Classes +0.1 mm, the recovery in which is higher than 94 %, are well enriched on concentration tables and corona electrostatic separators [24].

The second possible variant of the technology is simpler - it is possible, without dividing the raw material into two streams, in the head of the diagram from large classes to isolate native formations by gravity methods. This approach is often used for gold-bearing ores - native mineralization is extracted by gravity, or, as they say in the practice of beneficiation, the valuable component is removed, that is, a rich gravity concentrate is obtained, and the remaining product is enriched in the usual way.

Extraction, as a technological indicator, characterizes not so much the raw material as the method or equipment for enrichment. In the practice of beneficiation, the concept of extraction is rarely used, since it is a complex indicator that does not provide information either on the yield of the concentrate or on its quality - the copper content in it. In practice, they strive to achieve a maximum of both yield and quality, and they do not operate on extraction. However, extraction, as a complex indicator, is indispensable for making forecasts and estimates.

So, using the recovery rate, it is possible to predict the possibility of obtaining standard copper concentrate with a content of 15 % from lavobrekcia Cu (according to GOST 52998-2008, copper concentrate must contain at least 15 % copper (sometimes 12 %)). To determine the yield (amount) of concentrate, let us set the copper content in the feedstock and the extraction.

As the copper content in the original product (α), we take from table 2 the highest copper content in the samples is 1.5 %. Let's set the final recovery of 85%. Let us make a preliminary remark regarding this extraction figure.

According to the practice of enrichment of copper ores, recovery of 85 % is a very high indicator. Thus, the most efficient flotation method today provides recovery of 70-80 %. For example, ε = 70 % for the main copper flotation at the Krasnouralsk plant, ε = 75 % for the collective flotation of the Udokan mixed oxidized and sulfide copper ores. In about 10% of cases, flotation yields 82 % recovery and very rarely 85 %. The same applies to the gravitational enrichment of non-ferrous metals, where the typical recovery is 60-70 %, not higher than 80 % [25-28].

Thus, in the best case, with $\alpha = 1.7\%$, $\varepsilon = 85\%$, the yield of concentrate from lavobrekcia will be $\gamma = \frac{\alpha \cdot \varepsilon}{\beta} = \frac{1.7 \cdot 85}{15} = 9.6\%$.

It follows that the original sample must be reduced by at least 10 times to obtain a concentrate with a quality of 15%. If the recovery is less, then the yield of the concentrate will be less.

For example, for the same high-grade ore, with $\varepsilon = 70\%$, $\gamma = \frac{\alpha \cdot \varepsilon}{\beta} = \frac{1.7 \cdot 70}{15} = 7.9\%$.

Also, the poorer the feedstock, the lower the concentrate yield will be, since the more waste rock must be discarded to obtain a concentrate of a given quality. For example, with a copper content of 0.5 % in the original and a high $\varepsilon = 85\%$, the yield of a concentrate with a quality of 15% will be only $\gamma = 2.8\%$.

The average technological characteristics of raw materials were calculated - for all 10 samples of crushed lava breccia (Table 2).

Table 2 shows that all size classes contain a lot of copper (more than 0.35 % - the industrially necessary minimum), that is, none of the classes can be removed from the redistribution of copper concentration.

Also, the data in Table 2 show the highest absolute copper recovery of 21 – 26 % for the three upper classes -10 + 1 mm. The same classes have the highest copper content of 1.1 - 1.5 %. According to the norms, it is required to obtain a standard concentrate with a copper content of at least 10-12 times more (the quality of standard copper concentrates is from 15 to 28 % Cu). In principle, it is possible to divide raw materials according to the 1 mm class, and everything that is finer can be subjected, for example, to direct enrichment by hydrometallurgy (leaching), but everything that is larger will first have to be crushed and only then enriched. When grinding large grades, copper will not disappear, it will go into smaller grades, which can already be effectively enriched.

Table 2. Average values for 10 samples of lavobrekcia.

Classes, mm	**Output, γ, %**	**Copper content, β, %**	**Extraction of copper, ε, %**	**Total extraction**	
				Output, %	**Cu, %**
+10	18.0	1.3	21.3	18.0	21.3
-10+5	19.0	1.5	26.5	37.0	47.7
-5+1.0	21.5	1.1	22.6	58.5	70.3
-1.0+0.5	16.0	1.0	14.6	74.5	84.9
-0.5+0.1	14.0	0.7	9.1	88.5	94.0
-0.1+0.05	11.5	0.6	6.0	100.0	100.0
Total	100.0	1.06	100.0		

Let us carry out an estimated calculation of the amount (yield) of standard copper concentrate from lavobrekcia. As you can see from the table. 2, the average copper content for 10 tests was 1.06%. To obtain a standard concentrate with a lower quality limit of 15% at a recovery of, for example, 70%, the initial quantity of raw materials must be reduced to $\gamma = \frac{\alpha \cdot \varepsilon}{\beta} = \frac{1.06 \cdot 70}{15} = 5.0\%$

Even with ε = 90% (not achievable in practice), the yield of the standard concentrate will be small, only 6.4%. The estimated yield values obtained show that during ore preparation it is necessary to strive to reduce the mass of raw materials as much as possible, but without losing the valuable component. So, with a copper content of 0.5–1.7% in lavobrekcia, to obtain a concentrate with a quality of 15 %, the mass of raw materials must be reduced to 5–10% of the original amount [29].

Thus, 10 representative samples of lavobrekcia from the Rafalovsky basalt quarry with a copper content of 0.5 to 1.7 % were experimentally studied, which were separately subjected to crushing on a vibration-type jaw crusher with an adjustable discharge slot and vibrating screening with division into six control size classes. As a result, the main technological indicators were established – the yield, content and extraction of copper in narrow grain size classes of crushing products and the dependences of the distribution of these indicators by size classes were obtained [30].

The cumulative sieve characteristics showed that the crushing size was 20% cell -0.1 mm, on average 11.5% cell -0.1 mm.

The dependences of the distribution of copper by size classes showed that the content of copper in small classes -1 mm is less than in large ones +1 mm (8 samples out of

10). In large grades of -10 + 1 mm, the distribution of copper content is almost uniform. In general, the distribution of copper by size class, with sufficient accuracy for practice, is described by a logarithmic relationship, which is pronounced for rich samples ($\beta \geq 1\%$) (6 samples). For poorer samples ($\beta \approx 0.5\%$), the logarithmic dependence flattens out and, with an accuracy sufficient for practice, can be considered linear (4 samples). More precise mathematical approximations of the distribution of the mass of raw materials and the amount of copper by size will be considered below. All grades of lavobrekcia size, including the thinnest -0.1 + 0.05 mm, have a standard copper content and cannot be removed from the copper concentration redistribution.

The dependences of copper recovery on the particle size showed that with an increase in the size, the recovery monotonically increases up to a certain limit and, starting with a particle size of about 1-2 mm, the nature of the dependences flattens out. The total extraction of copper in the upper size classes -10 + 1 mm is 70.3%, in the wider class -10 + 0.1 mm – 94%.

When the copper content in the lavobrekcia samples is 0.5-1.7 % to obtain a concentrate with a lower quality limit of 15 % (GOST 52998-2008), the mass of the rock must be reduced to 5-10 % of the initial amount of raw materials. Two variants of the technological scheme can be considered as promising - with the separation of a rich gravity concentrate in the head of the process and with separate enrichment of large and small classes according to the main and sludge scheme.

For the development of ore preparation technology, it is important to determine the calculation formulas that provide, in particular, the forecast of the copper yield depending on the crushing size. Previous studies have established experimental dependences of the yield, grade and recovery of copper on the size for 10 samples of crushed lavobrekcia. In this case, the grain size distribution of each initial sample was arbitrary and the samples were subjected to crushing. Since after crushing the output of the rock mass into each of the 6 classes of sieving (vibrating screening was used) was different for each of the 10 samples, then to obtain a generalized characteristic, it is necessary to establish the regularities of the distribution of the rock mass output and the output of native copper from the size. The initial experimental data for determining these patterns are given in Tables 3-7.

For such studies, first of all, the assumption about the subordination of the yield of the breed to the class to the normal distribution law is checked. To check compliance with the theoretical distribution law, the criteria of agreement of Pearson, Kolmogorov, Shapiro-Wilk, and others are applicable. However, most of these criteria are suitable only for medium to large samples. In our case, the sample is small (*n* =10), these criteria are not applicable.

The studies carried out were based on the well-known method of analysis of small samples [31], according to which selective without bias and kurtosis can be used for an approximate test of the hypothesis of the normal distribution.

Table 3. Initial experimental data for determining the amount of copper in the class.

Size classes, mm	Try №1			Try №2		
	Hitch weight in the class, x, kg	Copper weight in class, X_m		Hitch weight in the class, x, kg	Copper weight in class, X_m	
		g	%		g	%
+10	1.5	33.5	19.7	1.5	20.1	14.7
-10+5	1.0	40.5	23.8	1.5	37.9	27.7
-5+1.0	2.5	45.1	26.5	1.5	30.5	22.3
-1.0+0.5	1.0	25.6	15.1	2.0	19.5	14.2
-0.5+0.1	2.5	15.1	8.9	1.5	15.0	10.9
-0.1+0.05	1.5	10.2	6.0	2.0	14.0	10.2
Total	10.0	170.0	100.0	10.0	137.0	100.0

Table 4. Initial experimental data for determining the amount of copper in the class.

Size classes, mm	Try №3			Try №4		
	Hitch weight in the class, x, kg	Copper weight in class, X_m		Hitch weight in the class, x, kg	Copper weight in class, X_m	
		g	%		g	%
+10	2.0	16.5	17.2	1.5	12.4	15.7
-10+5	2..0	28.4	29.6	2.0	16.2	20.5
-5+1.0	1.5	24.1	25.1	2.5	22.3	28.2
-1.0+0.5	1.0	12.4	12.9	2.0	13.2	16.7
-0.5+0.1	1.5	8.1	8.4	1.0	7.3	9.2
-0.1+0.05	2.0	6.4	6.7	1.0	7.6	9.6
Total	10.0	95.9	100.0	10.0	79.0	100.0

Table 5. Initial experimental data for determining the amount of copper in the class.

Size classes, mm	Try №5			Try №6		
	Hitch weight in the class, x, kg	Copper weight in class, X_m		Hitch weight in the class, x, kg	Copper weight in class, X_m	
		g	%		g	%
+10	2.0	10.5	20.0	2.0	12.2	26.0
-10+5	1.0	8.2	15.6	3.0	15.3	32.6
-5+1.0	2.0	10.5	20.0	2.0	5.4	11.5
-1.0+0.5	3.0	11.1	21.1	3.0	7.6	16.2
-0.5+0.1	1.5	6.4	12.2	-	6.5	13.8
-0.1+0.05	1.5	5.8	11.0	-	-	
Total	11.0	52.5	100.0	10.0	47.0	100.0

Table 6. Initial experimental data for determining the amount of copper in the class.

Size classes, mm	Try №7			Try №8		
	Hitch weight in the class, x, kg	Copper weight in class, X_m		Hitch weight in the class, x, kg	Copper weight in class, X_m	
		g	%		g	%
+10	2.0	41.8	29.0	2.0	27.1	24.3
-10+5	2.0	45.1	31.3	2.0	32.4	29.1
-5+1.0	2.0	36.7	25.5	2.5	22.3	20.0
-1.0+0.5	1.0	9.1	6.3	1.5	16.1	14.5
-0.5+0.1	1.5	6.2	4.3	1.0	8.4	7.5
-0.1+0.05	1.5	5.1	3.5	1.0	5.0	4.5
Total	10.0	144.0	100.0	10.0	111.3	100.0

 https://doi.org/10.1051/e3sconf/202128001004

Table 7. Initial experimental data for determining the amount of copper in the class.

Size classes, mm	Try №9			Try №10		
	Hitch weight in the class, x, kg	Copper weight in class, X_m		Hitch weight in the class, x, kg	Copper weight in class, X_m	
		g	%		g	%
+10	1.0	38.1	22.0	2.5	10.2	22.2
-10+5	1.5	50.0	28.9	3.0	12.0	26.1
-5+1.0	2.0	40.1	23.2	3.0	11.1	24.1
-1.0+0.5	3.0	28.4	16.4	0.5	5.7	12.4
-0.5+0.1	2.5	12.3	7.1	0.5	4.0	8.7
-0.1+0.05	0.5	4.1	2.4	0.5	3.0	6.5
Total	10.5	173.0	100.0	10.0	46.0	100,0

Sample values of without bias and kurtosis are compared with the standard deviations of asymmetry and kurtosis, and the results of the comparison are used to judge the agreement with the normal distribution law [32-36].

The yield of classes is not given (%), but the yield of copper per class of the total amount of copper in the sample (%). The yield of the size class and the yield of copper in the class are different indicators. The calculation of the extraction for the specified yield of copper in the class is incorrect (the balance is not observed).

The calculation procedure in this case is as follows.

A sample is given (testing results):

$$x_1, x_2 ..., x_n, \qquad (1)$$

where n – sample size.

We calculate the following indicators:

- average value:

$$\ddot{x} = \frac{\Sigma x_i}{n}; \qquad (2)$$

- variance:

$$S^2 = \frac{\Sigma x_i^2}{n} - \ddot{x}^2; \qquad (3)$$

- standard deviation:

$$S = \sqrt{S^2}; \qquad (4)$$

- asymmetry:

$$A_S = \frac{\Sigma\left(x_i - \ddot{x}\right)^3}{n \cdot S^3}; \qquad (5)$$

- excess:

$$E = \frac{\Sigma\left(x_i - \ddot{x}\right)^4}{n \cdot S^4} - 3; \qquad (6)$$

- standard deviation for asymmetry:

$$S_{AS} = \sqrt{\frac{6 \cdot (n-1)}{(n+1)(n+3)}}; \qquad (7)$$

- standard deviation for kurtosis:

$$S_{AS} = \sqrt{\frac{24 \cdot (n-2)(n-3)n}{(n-1)^2 (n+3)(n+5)}}. \qquad (8)$$

If the absolute values of without bias and kurtosis do not exceed their standard deviations, then the hypothesis about the agreement of the sample with the normal distribution law is confirmed.

Calculation results for the rate of rock mass (rock) yield into classes γ_{ni}, 1, 2,…, 6 (Table 8).

Table 8. Dependence of rock yield on controlled size classes.

Class number, *N*	Size limits in class, mm	Average breed yield in the class, X_m, kg	Average sample weight in a class of 10 samples, X_m, kg	Standard deviation, S	Asym-metry, A_S	Excess, *E*
1	0.1-0.05	0.115	1.15	0.634	–0.280	–1.200
2	0.5-0.1	0.135	1.35	0.743	–0.025	–0.584
3	1.0-0.5	0.175	1.75	0.844	0.187	–1.300
4	5.0-1.0	0.205	2.05	0.567	–0.196	–0.753
5	5.0-10.0	0.190	1.90	0.663	0.370	–0.780
6	+10	0.180	1.80	0.400	–0.328	–0.336

We have for the sample size n = 10:

$$S_{AS} = 0.615; \; S_E = 0.922. \qquad (9)$$

Comparing without bias and kurtosis with these critical values, we note that in the overwhelming majority of cases, the condition of agreement of the sample with the specified distribution law is satisfied. Only in two cases does excess exceed the critical value (for classes 1 ... 0.5 mm and 0.1 ... 0.05 mm), but this excess can be considered insignificant [37].

Thus, it can be argued that the rock yield is consistent with the normal distribution law.

This distribution law is symmetric with respect to the mathematical expectation; therefore, the generalizing characteristic of the yield of rock mass in a class is its average value.

Figure 1 shows the dependence of the rock mass yield on the size class.

This dependence is parabolic:

$$\gamma_n(i) = 0.053 + 0.0611 \cdot i - 0.0066 \cdot i^2, \; i = 1, 2, ..., 6. \qquad (10)$$

The coefficient of determination R^2 = 0.926, which indicates a high level of adequacy of this model.

Similar studies were carried out for the yield of copper in a single sample of each size class. First of all, the agreement with the normal distribution law was checked. The calculation results are shown in table 9.

Table 3-7 shows that, with the exception of class 1-0.5 mm, agreement with the normal distribution law can be considered satisfactory.

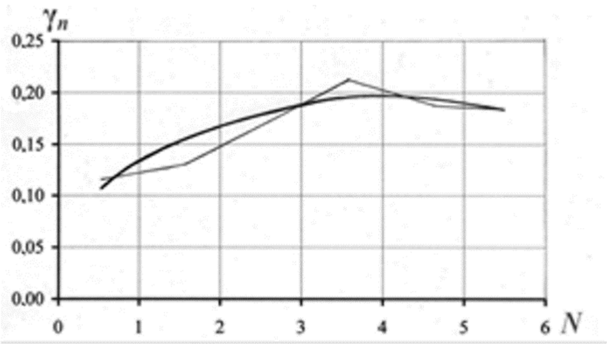

Fig. 1. The nature of the dependence of the yield of crushed rock on the size class.

Table 9. Dependence of the copper yield on the controlled size classes.

Class number, N	Size limits in class, mm	Class output	Copper output in class	Copper yield over the entire sample, kg	Copper output based on accumulated results, kg	Cumulative copper output, %
1	0.1-0.05	0.1075	0.0052	0.00056	0.00056	0.05
2	0.5-0.1	0.1488	0.0058	0.00086	0.0014	0.14
3	1-0.5	0.1769	0.00966	0.0017	0.0031	0.31
4	5.0-1.0	0.1918	0.0142	0.0027	0.0058	0.58
5	10.0-5.0	0.1935	0.0166	0.0032	0.009	0.91
6	+10	0.1820	0.0143	0.0026	0.012	0.17

Dependences of rock mass yield γ_p and yield copper γ_m on the size class are shown in Fig. 1 and Fig. 2, respectively. From both graphs it can be seen that the main copper content corresponds to classes 4 and 5, that is, classes 5-1 and 10-5 (mm).

Table 10. Dependence of the output of copper by size class cumulative.

Class number, N	**Size limits in class, mm**	**Average copper yield per class, X_m, kg**	**Root mean square deviation,** S	**Asym-metry,** A_S	**Excess, E**
1	0.1-0.05	0.0051	0.00239	–0.654	–0.3840
2	0.5-0.1	0.0058	0.00266	–0.569	0.0547
3	1-0.5	0.0100	0.00600	1.278	1.6400
4	5.0-1.0	0.0127	0.00630	–0.280	–1.3900
5	10.0-5.0	0.0177	0.01170	0.590	–0.8760
6	+10	0.0140	0.01000	1.228	0.6300

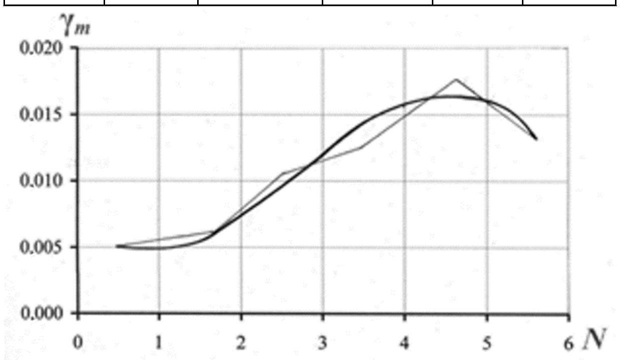

Fig. 2. Dependence of the copper yield on the size class.

It was found that the dependence of the copper yield $\gamma_м(i)$ from class *i* with a high level of adequacy obey the cubic parabola law:

$$\gamma_m(i) = 0.01063 - 0.009334 \cdot i + 0.004351 \cdot i^2 - \\ -0.000449 \cdot i^3, R^2 = 0.9682. \quad (11)$$

For the sake of completeness, let us consider the indicator “copper yield in the class by the cumulative total in relation to the entire sample”, which was defined as

$$\gamma(i) = \gamma_n(i) \cdot \gamma_m(i) \quad (12)$$

The calculation results for the output of copper in the size classes by the cumulative total in fractions and percentages are given in Table 10 and Fig. 3.

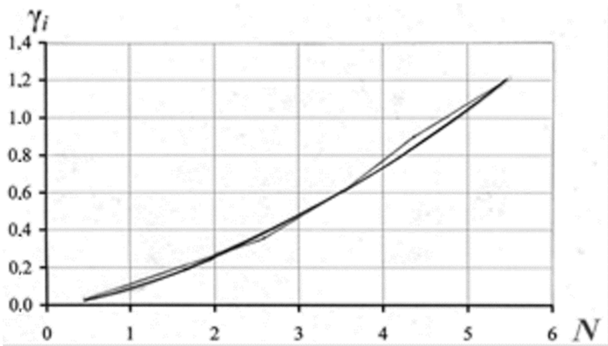

Fig. 3. Dependence of the distribution of the yield of copper by size classes by the cumulative total.

As can be seen from Fig. 3, the dependence of the cumulative copper yield on the size class with a high level of adequacy is described by a quadratic parabola:

$$\gamma(i) = -0.0384 + 0.0479 \cdot i + 0.0263 \cdot i^2, \ i = 1, 2, ...6; \\ R^2 = 0.994 \quad (13)$$

The resulting graph in Fig. 3, as well as the dependences in Fig. 1, 2, confirms the highest efficiency in terms of copper yield in classes 1-5 and 5-10 mm [38, 39].

Thus, the performed studies made it possible to establish that for lavobrekcia, the regularity of the yield of crushed mass from the size class is parabolic (R^2 = 0.926), and the distribution of the copper yield from the size class obeys the cubic parabola law (R^2 = 0.9682). The indicated high values of the coefficients of determination R^2 indicate a high degree of adequacy of these models [40].

The obtained regularities of the distribution of rock mass and copper yield by size class are relevant and can be used for predictive calculations in the development of an integrated technology for ore preparation [41, 42].

Conclusions

The considered features of distribution of technological indicators (output, copper content and production) on size classes allow defining the basic factors influencing process of crushing. The regression dependences of copper yield on the influencing factors are obtained.

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The high adequacy of the obtained models was confirmed and the most promising size classes of rocks for copper mining were identified.

The regression dependences of copper yield on the influencing factors are obtained. The obtained results and models will allow to develop a generalized model of the copper mining process and to implement this process with rational and optimal parameters. Also, the received models will allow carrying out an estimation of productivity of a research site of processing of raw materials of basalt quarries.

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Improving the methods for determining the promising boundaries of iron ore open pits

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Abstract. The article considers the determination of the final contours of the open pits. One of the problems of development of iron ore deposits at the present stage of development of opencast mining is described, which consists in the fact that in most open pits their working contours on the surface have reached final position. In these conditions, it is necessary to reevaluate the capabilities of the raw material base for further operation of mining enterprises. The analysis of scientific achievements in the decision of the final definition of the open pits` contours is executed. The well-known principle of determining the boundaries of opencast mining, the principle of which is to determine the boundaries based on a comparison of the allowable cost of ore production with the expected for the designed open pit. On the example of the open pits, which reflect the characteristic features of the development of steep-dipping deposits of Ukraine, the influence of current overburden ratio of the existing open pits on the economic overburden ratio, which serves as the main criterion in determining the boundaries of opencast mining for the designed open pits. A method for determining the boundaries of the open pits has been developed, which provides for the use of the economic overburden ratio of opening as a value not constant but variable over time, and one that depends on the change of current coefficients of opening in open pits-competitors. As a result, the theory in the field of determining the final contours of the open pits is improved. The new method differs from the known ones by taking into account the change in the economic overburden ratio over time, as well as determining the impact of technological indicators of open pits - competitors on the final depth of the designed open pit.

1 Introduction

One of the main parameters in the design of opencast mining is the boundaries of the open pit.

At present, the upper horizons of most iron ore open pits are approaching their design boundaries. Therefore, the work of open pits will be characterized by the achievement of the highest operating overburden ratios.

This will lead to the fact that the cost of ore and in general the cost of production of concentrate will reach the acceptable values. Based on this, the value of the operating overburden ratio, which determines the final boundaries of the open pits, can be reduced by choosing the direction of development of mining operations and determining the rational contours of the open pits on the surface. Reducing the operating factor will expand the final boundaries of the open pits, thereby increasing the ore reserves in the contours of the open pits and the industrial potential of mining and processing plants [1].

It should be noted that timely determination of the final contours of the open pits allows you to plan the need for land for surface buildings and technological structures that ensure the normal operation of mining and processing plants for a long time [2]. At the same time, the social factor is also important.

The need to determine the promising final boundaries of the open pit is due to the fact that after the upper horizons to the final contour of the open pit will work in the mode of annual reduction (disposal) of production capacity, and to prepare the overlap of such disposal it will take 5-7 years at any method of development. It will increase the depth of development of the deposit, and most of the upper horizons of the working area will be repaid, which will require attracting much more investment in the development of reserves in the approved by the designed contour of the open pit.

With the definition of promising final contours of the open pit there will be a change in the volume of overburden, ore and its quality, at which it is necessary to establish its production capacity and the period of the plant operation.

2 Object and methods of research

Significant achievements [3-16] in the theory of designing the boundaries of opencast mining belong to M.I. Goberman, W.W. Rzhevsky, V.S. Khokhryakov, O.I. Arsentiev, M.S. Chetverik, V.G. Blizniukov. Of course, the determination of the boundaries of open pit mining should be carried out taking into account the conditions of stability of the massif of boundary rocks, which are performed by modern remote methods [17, 18]. When determining the boundaries of the open pits according to known calculation principles, the economic calculating ratio is calculated according to technical and economic indicators, which are achieved at the time of design and its value is constant [19-21].

In study [22], a method was proposed to determine the economic overburden ratio, which allows avoiding of the influence of unnatural and non-technological factors on the price of concentrate. The developed method allows to bring prices at the cost of one percent of iron in 1 ton of concentrate and to avoid the influence of subjective factors while the determining the boundaries of opencast mining.

Analysis of the work of mining and processing plants showed that their economic indicators and overburden ratios change over time [23]. It was found that the existing methods of determining the boundaries of the open pits do not take into account the possibility of changing the economic overburden ratio due to the inconsistency of technical and economic indicators, in particular, the cost of ore production in a competitive environment [24].

The enterprises develop minerals in an open way there is a constant change in the volume of overburden per ton of the extracted ore, which entails significant changes in the cost of marketable products [25, 26]. Ignoring the change in the economic overburden ratio over time can lead not only to exceed, but also to the reduction of economic sense depth of the designed and existing open pits.

Therefore, the idea was put forward to take into account the dynamics of the external competitive environment of the mining company and determine the boundaries of opencast mining, based on the fact that the cost of ore mining in the designed open pit in every operation period should be no more than on other enterprises of the same industry, that conduct mining operations both open and underground methods.

Therefore, the goal was to prove that economic overburden ratio is not constant, but changes over time and will significantly depend on the final depth of the open pit.

3 Results

Many calculation principles for determining the boundaries of the open pits are based on the condition - the allowable cost of ore mining (c_m) should be more or equal to the cost of ore mining in the designed open pit:

$$c_m \geq c_a,\ \text{UAH/t}. \qquad (1)$$

It should be noted that the allowable cost is the cost of ore of one of the basic mining companies-competitors with an open method of deposit development. Moreover, the allowable cost of ore is taken as it is at the time of designing a new open pit or reconstruction of an existing one.

The expected cost of ore for the designed open pit is calculated depending on the value of the overburden ratio (n_d) by the formula:

$$c_a = a + b \cdot n_d,\ \text{UAH/t}, \qquad (2)$$

where a – the cost of ore production without the overburden cost, UAH/t; b – overburden cost, UAH/m^3; n_d – overburden ration in the designed open pit, m^3/t.

After substituting the expected value of the cost of ore mining and transformation the inequality (1), formula (2) will take the following form:

$$\frac{c_a - a}{b} = n_d,\ \text{m}^3/\text{t}. \qquad (3)$$

The left part of expression (3) determines the value of the economic overburden ratio (n_e) and then, taking into account expressions (1, 2 and 3), we obtain the inequality

$$n_e \geq n_d,\ \text{m}^3/\text{t}. \qquad (4)$$

Based on the above mentioned, the condition of competitiveness of the designed open pit can be formulated as follows: the overburden ratio in the designed open pit should not exceed the economic overburden ratio, which takes into account the economic performance of the existing (base) company.

It should be noted that in the regulations providing the work of mining companies with an open method of development [27], the calculated economic overburden ratio to determine the final depth of the open pit is taken as a constant value. However, the basic enterprise-competitor continues its work, and its economic performance will change over time [28], in our case - the cost of ore. The reason for this is the change in the current overburden ratios upward or downward.

Consider the example of two conditional basic open-pits-competitors possible changes in current overburden ratios (Fig. 1 and 2).

Conditional basic open pit-competitor №1 develops ore deposit, in which: the incidence angle is 80°; horizontal width – 350 m; length – 2700 m. Open pit parameters: angle of inclination of the working side – 16°; the angle of inclination of the designed side – 45°; the final depth of the open pit is 630 m. It should be noted that in this open pit the surface boundaries have already approached the design position and further development of the open pit is carried out with the development of mining only in depth.

Conditional basic open pit-competitor № 2 (Fig. 2) develops an ore deposit in which: the incidence angle is 80°; horizontal width – 120 m; length – 4500 m. Parameters of this open pit: angle of inclination of the working side – 16°; the angle of inclination of the designed side – 45°; the final depth of the open pit is 345 m.

In the conditional base open pit-competitor № 2, in contrast to the considered conditional base open pit-competitor № 1, the boundaries on the surface have not yet approached the design position and further development of the open pit is carried out with the mining works development, both in the horizontal direction, and in depth.

In the figures 1 and 2, the numbers 0, 30, 60, 90, 120 indicate the steps of reduction of mining works in conventional base open pit-competitors every 30 m. The position of the working side of the open pit at step "0" characterizes the current state of mining works in the open pit and serves as a starting point for further research of their development.

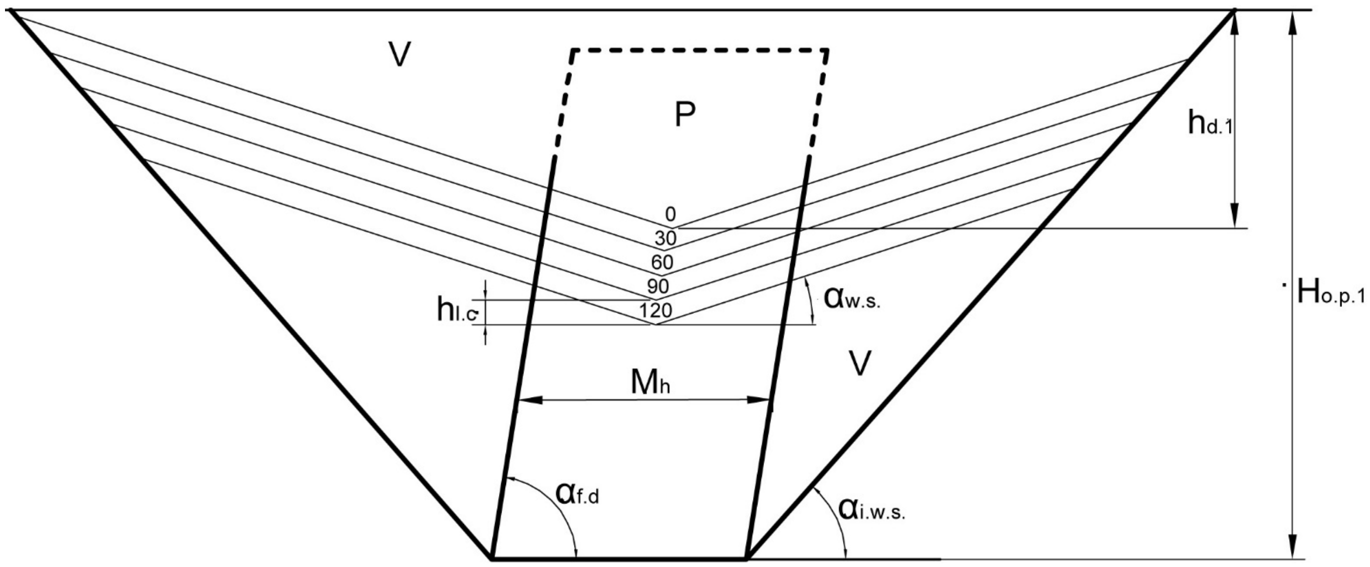

Fig. 1. Open pit-competitor № 1: V – overburden rocks; P – ore; $h_{d.1}$ – current depth of mining works; $h_{l.c.}$ – step of reduction of mining works; $\alpha_{w.s.}$ – angle of inclination of the working side of the open pit; $\alpha_{i.w.s}$ – angle of inclination of the designed side of the open pit; $\alpha_{f.d.}$ – incidence angle of ore deposit; M_{h1} – horizontal width of the deposit; $H_{o.p.1}$ – final depth of the open pit; 0, 30, 60, 90, 120 – step of reduction of mining works in the open pit.

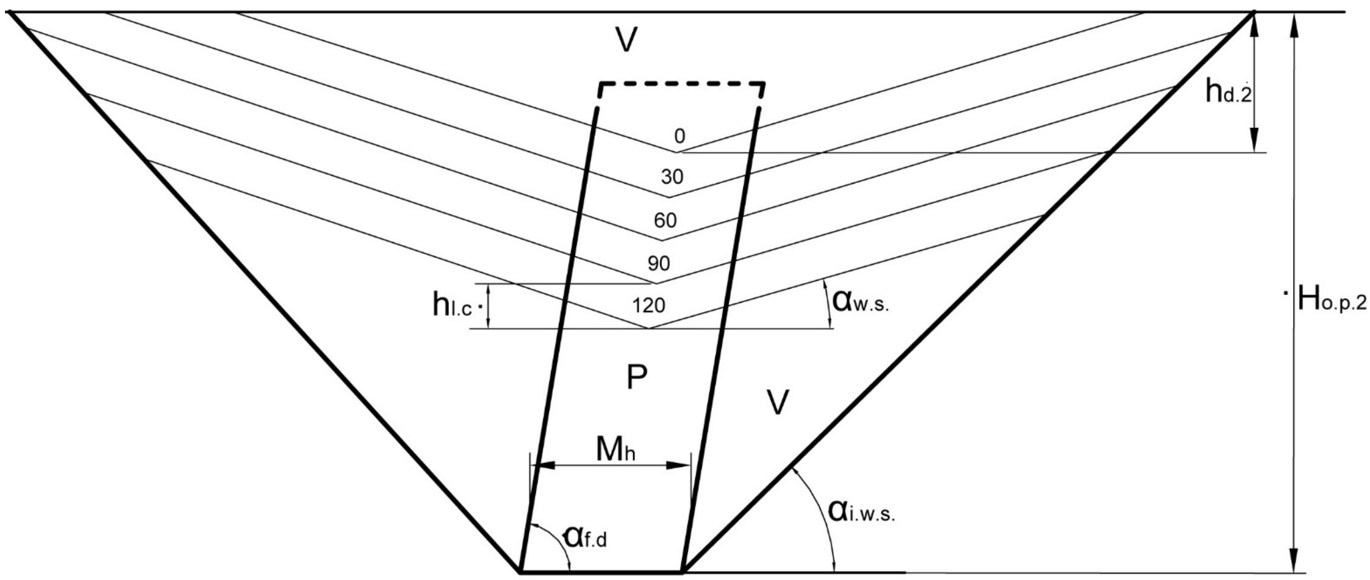

Fig. 2. Open pit-competitor № 2: V – overburden rocks; P – ore; $h_{d.2}$ – current depth of mining works; M_{h2} – horizontal width of the deposit; $H_{o.p.2}$ – final depth of the open pit.

The positions of the working sides of conventional base open pits-competitors at the zero step are selected so that the ore bodies were cut to full horizontal width, and the value of the current coefficients was the same as the value of the calculated economic overburden ratio.

When designing a new open pit, it is necessary to determine the prospective depth of opencast mining first: it will determine the boundaries of the open pit on the surface and the possible productivity of the open pit for minerals. The condition for determining the prospective boundaries of the designed open pit is to obtain economic indicators of the designed open pit not worse than the economic indicators of the existing open pits. This condition is written by inequality (4).

To determine the final depth of the future conditional (designed) open pit, a typical section of the deposit is selected in which: the incidence angle is 80°; horizontal width – 230 m; length – 3200 m. All open pits exploit the reserves of the same type of mineral with the same quality, and the existing technology allows them to work with relatively equal costs for extraction of one ton of overburden and mining of one ton of ore.

As on the conditional base open pits-competitors №1 and №2, and for the conditional open pit that is designed, from the position of the working sides at the zero step we rebuild their further position at the steps of mining development every 30 m in depth. At each step we determine the volumes of ore and overburden with the definition of the current overburden ratio, the results of the calculations are entered in Table 2.

Table 1. Volumes of ore and overburden, as well as current overburden ratio according to research options.

Deepening of the open pit, m	Conditional basic open pit № 1			Conditional basic open pit № 2			Conditional designed open pit		
	Ore, m^3	Overburden, m^3	Overburden ratio, m^3/m^3	Ore, m^3	Overburden, m^3	Overburden ratio, m^3/m^3	Ore, m^3	Overburden, m^3	Overburden ratio, m^3/m^3
0	28080000	101250000	3,6	16425000	59400000	3,6	21920000	47680000	2,2
30	28080000	95445000	3,4	16425000	80325000	4,9	21920000	68800000	3,1
60	28080000	89775000	3,2	16425000	88650000	5,4	21920000	87520000	4,0
90	28080000	84240000	3,0	16425000	92025000	5,6	21920000	109760000	5,0
120	28080000	78435000	2,8	16425000	90000000	5,5	21920000	126880000	5,8

Table 2. Current overburden ratio on open pits of Kryvbas in 2010-2020 yy.

Open pit	Years of exploitation										
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
InMPP	0,40	0,40	0,45	0,56	0,60	0,42	0,3	0,71	0,74	0,85	0,92
AMKR	0,31	0,29	0,29	0,28	0,26	0,24	0,20	0,39	0,27	0,25	0,25
AMKR № 2-bis	0,18	0,22	0,22	0,22	0,22	0,19	0,17	0,23	0,20	0,17	0,16
AMKR №3	0,39	0,33	0,33	0,32	0,28	0,28	0,22	0,49	0,31	0,31	0,31
SouthMPP	0,37	0,30	0,26	0,22	0,22	0,19	0,19	0,16	0,16	0,13	0,13
CenMPP	1,51	1,63	1,63	1,49	1,65	1,38	1,64	1,65	1,85	1,85	1,85
CenMPP №1	1,58	1,43	1,56	1,32	1,40	1,20	1,35	1,40	1,65	1,65	1,65
CenMPP №3	1,07	1,43	1,35	1,29	1,34	1,08	1,50	1,40	1,6	1,6	1,6
CenMPP №4	3,33	3,51	3,28	3,16	388	3,09	3,1	3,2	3,2	3,2	3,2
NorthMPP	1,07	1,01	1,03	1,01	0.9	0.8	0.85	0.91	0,94	0,95	1.01
Gannivskyi	1,68	1,50	1,57	1,55	1,4	1,38	1,3	1,4	1,47	1,5	1,56
Pershotravnevyi	0,78	0,77	0,77	0,76	0,67	0,54	0,64	0,68	0,7	0,7	0,76

For the designed open pit and basic operating open pits, we build a schedule of changes in the current overburden ratio according to the stages of reduction of mining works of conventional basic and conditional designed open pits (Fig. 3). Also we reconstruct on the graph the line of the calculated economic overburden ratio (line 1).

Based on the accepted mining and geological conditions of development of conditional deposits, the current overburden ratio in the further operation of the conditional base open pit №1 will decrease. In the further operation of the conditional base open pit №2, the current overburden ratio will increase until the design boundaries of the open pit on the surface are reached, and then gradually decrease. This change in the current overburden ratio is shown in Fig. 3 lines 2 and 3.

In these cases, the current overburden ratio of conditional base open pits №1 and №2 will be the cutoff ratio for the conditional (designed) open pit. If we calculate economic overburden ratio for the newly designed open pit without taking into account the time-varying current overburden ratio of the base open pits №1 and №2, as accepted for the present research, it will be constant, line 1 in Figure 3. Intersection of these lines (lines 1, 2, 3 in Fig. 3) with a line of current overburden ratio of the conditional open pit (designed) (line 4 in Fig. 3) gives the decision of definition of final depth of the given open pit mining.

As we can see from the presented graph (Fig. 3) for the conditional open pit (designed), there are three values of the final depth of its development:

– $H_{1d.o.p}$ – the final depth of the open pit, which is determined by a constant economic overburden ratio and is 560 m;

– $H_{2d.o.p.}$ – the final depth of the open pit, which is determined by the current overburden of the conditional base open pit №1 and is 485 m;

– $H_{3d.o.p}$ – the final depth of the open pit, which is determined by the current overburden ratio of the conditional base open pit №2 and is 800 m.

The graphical solution for determining the final depth of the conditional open pit (designed) is presented in Fig. 4.

From Fig. 3 and 4 we can see that the deviation of the final mining depth of the designed conditional open pit, which is determined on the basis of comparing its current overburden ratio with the current overburden ratio of conventional basic open pit-competitors, from the final mining depth determined by constant overburden ratio from 14 to 45%.

It follows from the above that to determine the boundaries of the designed open pit, the designed economic overburden ratio must be determined taking into account the possible change in the volume of overburden extraction and ore mining at basic enterprises-competitors, that means to take into account changes in their current overburden ratio.

To confirm this, the design data of the open pits of Kryvbas were analyzed, which are presented in Table 2. The clarity of the dynamics of the current overburden ratio reflects the presented graph in Figure 5.

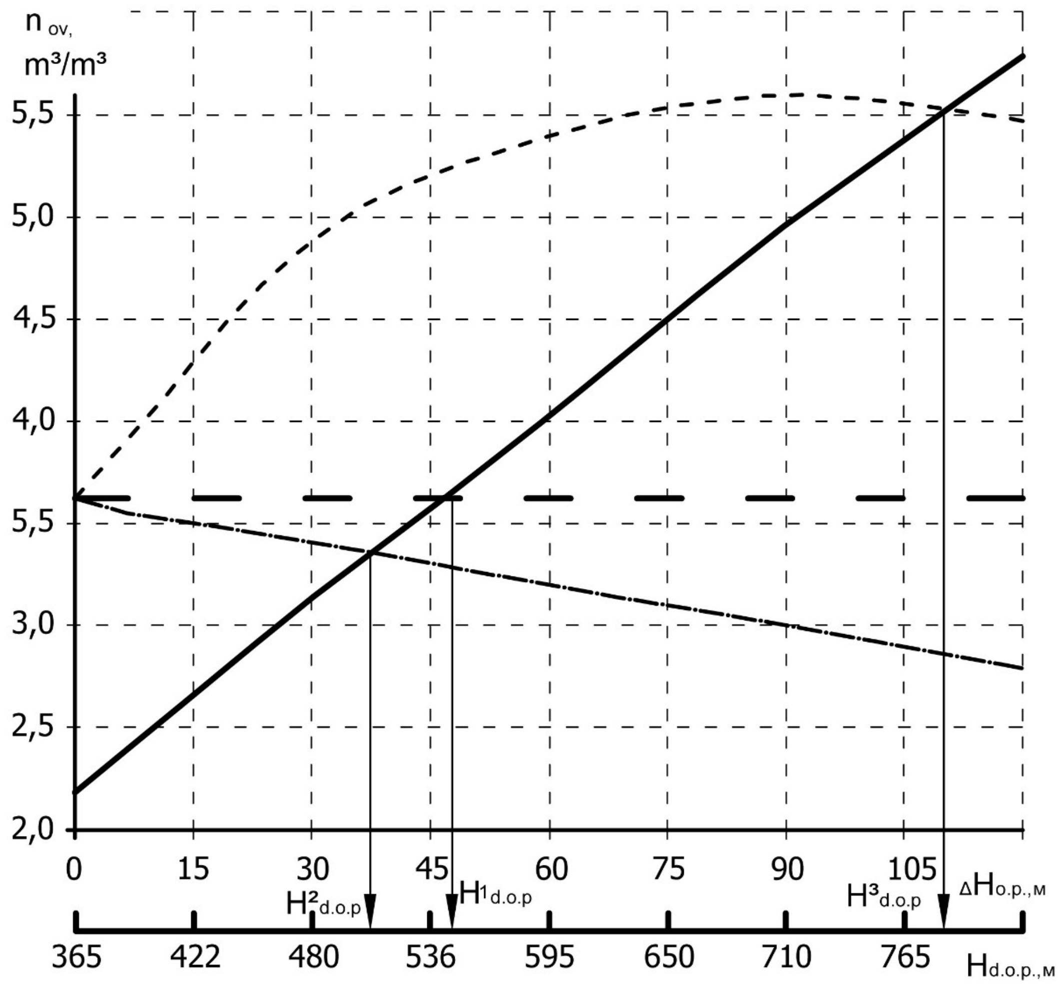

Fig. 3. Determination of the final depth mining of conditional open pit (designed): 1 – constant economic overburden ratio; 2 – current overburden ratio according to the conditional base open pit № 1; 3 – current overburden ratio according to the conditional base open pit № 2; 4 – current overburden ratio according to the conditional open pit (designed).

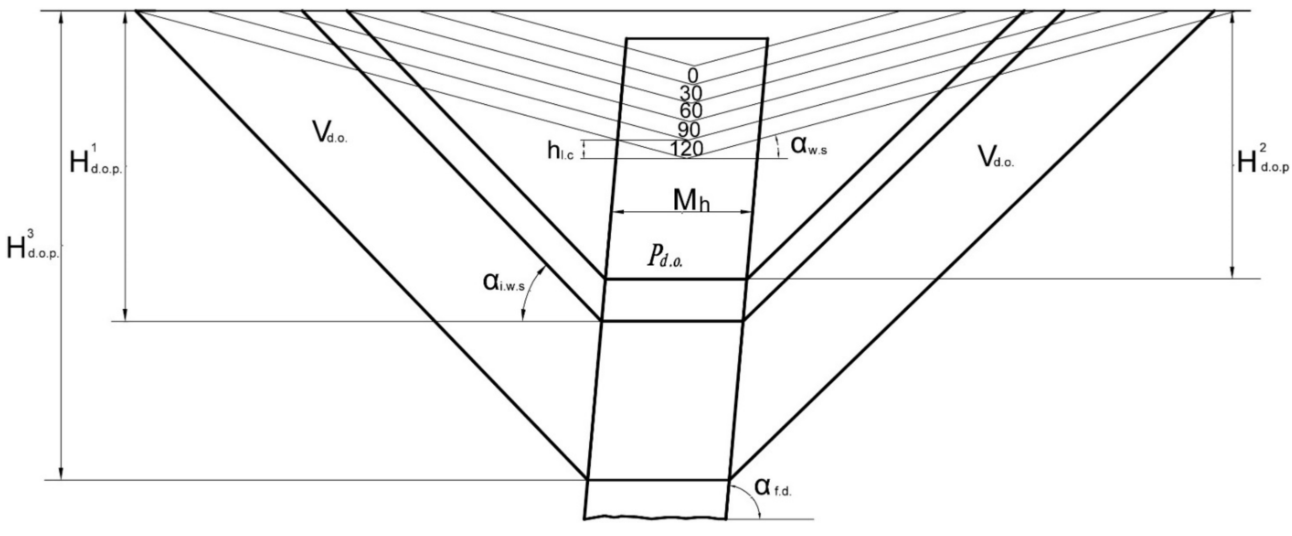

Fig. 4. Cross section of the deposit, that will be developed by the designed conditional open pit: $V_{d.o.}$ – overburden in the design contours of the open pit; $P_{d.o.}$ – ore in the design contours of the open pit; $H_{1d.o.p.}$ – the final depth of the open pit mining, which is determined by a constant economic overburden ratio; $H_{2d.o.p.}$ – the final depth of the open pit, which is determined by the current overburden ratio of the conditional basic open pit-competitor №1; $H_{3d.o.p.}$ – the final depth of the open pit, which is determined by the current overburden ratio of the conditional basic open pit-competitor №2.

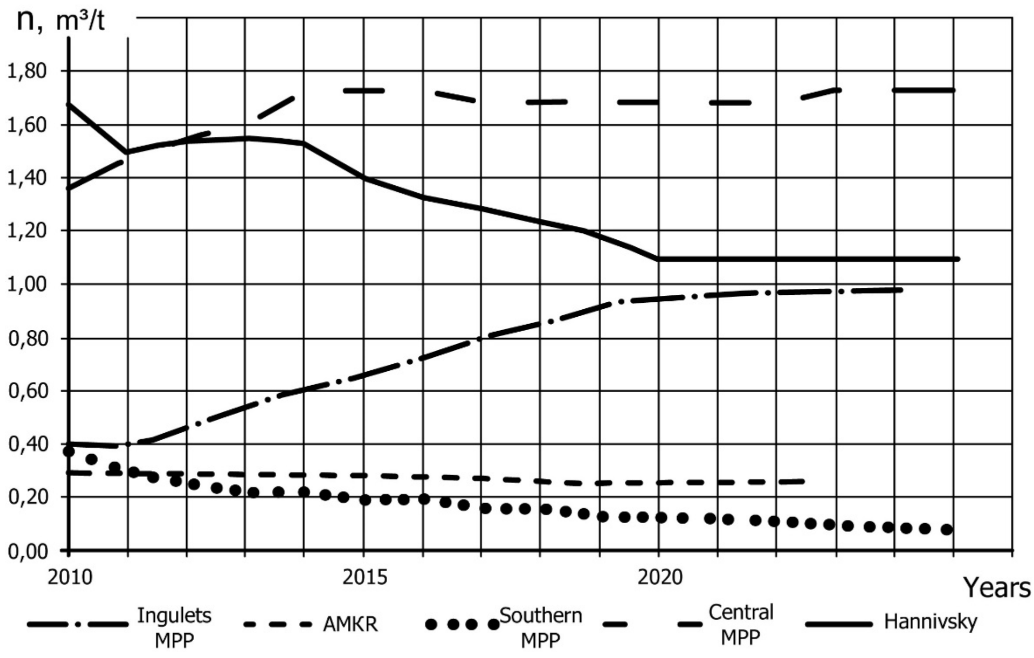

Fig. 5. Dynamics of the current overburden ratio on the open pits of Kryvbas on years of exploitation.

As we can see from the table, the current overburden ratios at the basic enterprises are changing over time. In addition, the indexes of every enterprise are open to different trends: they can grow, decrease or be relatively constant. It depends on whether the open pits have reached their contours on the surface, and whether the reconstruction or reactivation of the sides of open pits was carried on.

5 Conclusions

A new method for determining the final contours of mining the open pit has been developed, which differs from the known ones by taking into account the change in the economic overburden ratio in time, as well as determining the impact of technological indicators of open pits-competitors on the final depth of the designed open pit. It is proved that the deviation of the final depth of working of the designed conditional open pit, which is determined on the basis of comparing its current overburden ratio with the current overburden ratio of conventional basic open pits-competitors, from the final

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Application of roof bolting to reduce water inflow into mine workings during the crossing of tectonic faults

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Abstract. In this work, the problem of water inflow reduction in Ukrainian coal mines, which are distinguished by difficult hydrogeological conditions, was considered. A numerical study of the change in water inflow into a mine working when it crosses a tectonic fault was carried out. The cases when the permanent working was supported by frame supports and roof bolts were considered. The calculation of stress fields, zones with inelastic deformations and coefficients of permeability, which depend on the stress state and takes into account tectonic and natural permeability of the rocks, was performed. The results of calculating the water pressure and water inflow into the mine working in all considered cases are presented in the article. Analysis of the calculated data showed that a disturbed area, which covered water-bearing ricks, was formed in the roof of the mine working with the frame support. Within this area, water can move towards the contour of the mine working. The filtration permeability of the host rocks increases significantly when the mine face approaches the tectonic disturbance. The flow rate of water reaches critical values. The use of roof bolting restrains the unloading of the boundary rocks from the rock pressure and keeps them in a triaxially compressed stress state. The permeability value decreases by the value of its technological component. In different areas of the intersection of tectonic disturbance, the water inflow into the mine working with roof bolting is 3-8 times less than in the working, supported by frame supports. Therefore, the use of roof bolting allows not only to keep the mine working in a stable state, but also to significantly reduce water inflows at complicated hydrogeological conditions.

1 Introduction

Ukrainian coal mines are notable for complicated geological conditions due to the great number of tectonic disturbances and flooded rocks. Different forms of geological structures, both plicate and disjunctive, characterize Donbas. Most of the Donbas coal mines are concentrated in large synclinal folds [1]. There is a failure of rocks integrity and an increase in their permeability in zones of local folding [2]. Permeability of rocks reaches its maximum in areas with the highest concentration of tectonic stresses [3]. Type and forming conditions of the faults determine their influence on the filtration properties of rocks. If joint fissures are formed under conditions of stretching of the earth's crust (mainly faults), then they increase permeability of the coal-bearing deposits in the zone adjacent to the fault [4].

The hydrogeological structure of the Western Donbas is a system of aquifers and complexes that cover the entire sedimentary layer and the upper part of the fractured zone of crystalline rocks. The total thickness of the flooded rocks ranges from 20 m to 1660 m and more, and it increases in the direction of rocks deepening to the axis of the Dnipro-Donetsk trough [5]. Water inflow into the mine workings mainly depends on the features of the geological structure of the mine fields and particularly on the tectonic disturbance of rocks, the number of aquifers, their thickness, pressure and filtration permeability [5-7]. For example, water production in the N.I. Stashkov Mine (the most water-flooded one in the Western Donbas) is 1640 m^3/h. When the edge rocks are flooded, they become soaked and their strength decreases. This leads to a loss of workings stability and requires additional finance for water extraction and supporting of mine workings [8-9].

In recent years, the researchers of the Institute of Geotechnical Mechanics named by N. Poljakov have done a lot of work to improve the roof bolting technology [10, 11]. The modified technology makes it possible to preserve the enclosing rocks in their natural, monolithic state and ensure reliable and safe functioning of mine workings throughout their operation [12]. The experience of coal production shows that technological operations can influence on filtration processes in the disturbed zone of the rock mass [13]. So, the use of roof bolting allows to prevent the process of crack formation in zone of the mine working influence and to reduce intensity of filtration flow [14-16].

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In this article, the authors consider a possibility to use roof bolting in the mine workings in order to reduce water inflows from the undermined water-bearing rocks when crossing tectonic faults.

2 Methods and problem definition

Deformation of the coal-rock massif can be described by the equation:

$$c_g \frac{\partial u_i}{\partial t} = \sigma_{ij,j} + X_i(t) + P_i(t)\,, \tag{1}$$

where u_i is displacements, m; c_g is the damping coefficient, kg/(m^3·s); $\sigma_{ij,j}$ are the derivatives of the stress tensor components along x, y, Pa/m; t is time, s; $X_i(t)$ is projections of the external forces acting on the volume unit of solid body, N/m^3; $P_i(t)$ is projections of forces caused by gas pressure in the porous fractured space, N/m^3.

Deformation of rocks during mining operations leads to a change in their filtration permeability [17-20]. The change in the values of the permeability coefficients depending on the components of the principal stress tensor can be described as follows:

$$k_{tech} = f(\sigma_{ij}), \tag{2}$$

where k_{tech} is coefficient of permeability, which depends on the mine working driving, D; $f(\sigma_{ij})$ is a function which the authors defined in the work [19].

The process of water filtration in disturbed rocks is described by the following equation:

$$\frac{\partial p}{\partial t} = \frac{K}{\mu \cdot \beta \cdot m_p}\left(\frac{\partial^2 p}{\partial x^2} + \frac{\partial^2 p}{\partial y^2}\right) + q(t)\,, \tag{3}$$

where p is the water pressure, Pa; K is the permeability coefficient, D; μ is water viscosity, Pa·s; β is water-compressibility factor, 1/Pa; $q(t)$ is the water release function.

The coal and rocks are ground and have an initial tectonic permeability on 10-20 m from both sides of the fault. Some rock layers are also initially permeable and they have permeability k_{nat}. Technological permeability k_{tech}, which is formed during the mine working driving and depends on the stress tensor components, is superimposed on the tectonic k_{tect} and natural k_{nat} permeability fields:

$$K = k_{tech} + k_{tect} + k_{nat}. \tag{4}$$

As an example, let's consider a longitudinal section of a permanent working of 4 m high, which is driven at complicated conditions, similar to the conditions of the eastern main entry of the N.I. Stashkov Mine. There is a watered fractured coal band with a thickness of 0.4 m and watered sandstone with a thickness of 2.2 m in the mine roof. There is watered sandstone with a thickness of 0.8 m in the mine face. The permanent working intersects a disjunctive tectonic fault with displacement amplitude of 1 m.

The central fragment of the finite element mesh for this problem is shown in Figure 1.

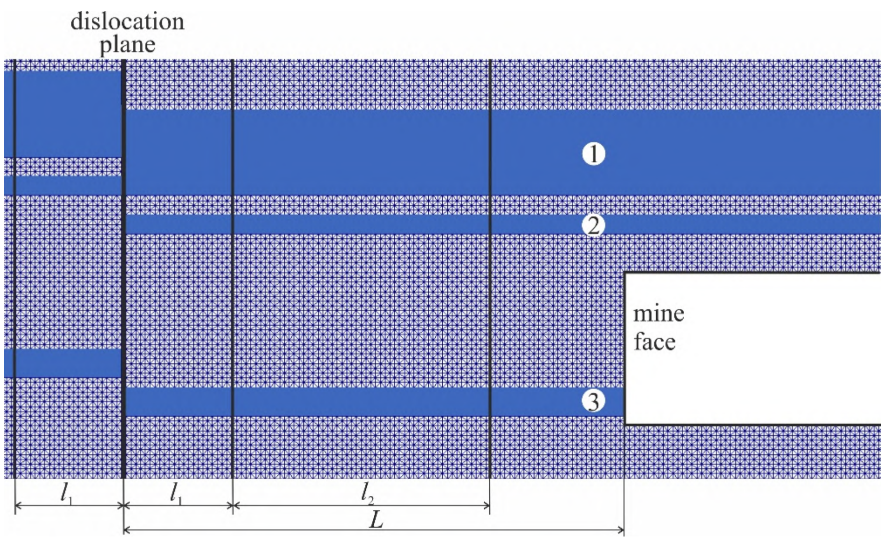

Fig. 1. The central fragment of the finite element mesh: 1, 3 – the watered sandstones; 2 – the watered fractured coal band.

The initial and boundary conditions for the task set:

$$\begin{gathered} \sigma_{yy}\big|_{t=0} = \gamma H; \quad \sigma_{xx}\big|_{t=0} = \lambda\gamma H; \\ u_x\big|_{\Omega_1} = 0; \quad u_y\big|_{\Omega_2} = 0; \\ p\big|_{\Omega_3} = 0.1\ \text{MPa}\,; \quad p\big|_{\Omega_3, t=0} = p_0\,, \end{gathered} \tag{5}$$

where σ_{xx}, σ_{yy} are components of the stress tensor, Pa; γ is the average weight of the overlying mine rocks, N/m^3; H is the mining depth, m; λ is the side thrust coefficient; u_x, u_y are components of the displacement vector, m; Ω_1 is vertical boundaries of the outer contour; Ω_2 is horizontal boundaries of the outer contour; Ω_3 is the contour of the permanent working; Ω_4 are the watered sandstones and coal seam; p_0 is the water pressure in the virgin massif, Pa.

The finite element method is widely used to solve geomechanics problems [21-23]. It is a powerful tool for simulating the coupled processes in rocks during mining operations. We solve the problems (1)-(4) with initial and boundary conditions (5) by the finite element method in the elastoplastic formulation by using the Coulomb-Mohr strength condition. To analyze the stress state of the rock massif, we use parameter $Q^* = (\sigma_1 - \sigma_3) / \gamma H$. This parameter characterizes diversity of the stresses field components.

We assumed that initial permeability of the watered sandstones is 0.002 mDa, initial permeability of the watered coal band is 0.005 mDa; permeability in the area l_1 = 3 m from displacement plane is 0.5 mDa; in the area l_2 = 7 m is 0.1 mDa; p_0 =3.5 MPa. Let's consider the cases when permanent working is supported by the frame support and roof bolting, and its face is located at different distance L (Figure 1) from the tectonic fault:

a) L = 12 m, $L > l_1 + l_2$, the permanent working is outside the influence of tectonic fault;

b) L = 7 m, $l_1 < L < l_1 + l_2$, the permanent working is in the slightly disturbed area;

c) L = 1 m, $L < l_1$, the permanent working is located in the most disturbed zone of tectonic fault.

3 Results and discussion

3.1 The stress state of the host rocks

As a result of the modeling, fields of stresses and zones of inelastic deformations were obtained, Figure 2.

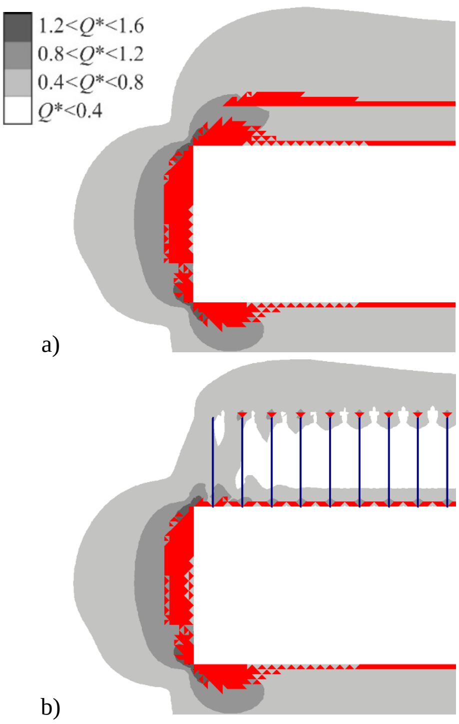

Fig. 2. The distribution of parameter Q^* values and inelastic deformation zones: a – the permanent working with frames; b – with roof bolting.

Hereinafter, the calculation results are given for t = 1 day after the mine face movement.

The Figure 2 shows that area of increased diversity of the stress field components is formed around the mine working. Single defects, not interacting between each other, are accumulated in zone where $0.4 < Q^* < 0.8$. In areas where $0.8 < Q^* < 1.2$, the process of intense cracking develops. Here, uncontrolled growth of cracks takes place, and deformations rapidly increase due to the propagation of cracks and loosening of the rock [24]. Zone of inelastic deformation (is shown in red) surrounds the permanent working contour, hence, indicating the destruction of rocks.

In the mine roof with frame support (Figure 2 a), the disturbed zone includes both coal band and sandstone. Here, weak coal band is completely destroyed.

When using roof bolting (Figure 2 b), zone of inelastic deformations is significantly reduced in boundary rocks of the roof and completely disappears in the coal band. In the anchored area, rocks and bolts form a slab, where $Q^* < 0.4$. Here, both the rocks and the weak coal band are in a triaxially compressed state that keeps them from destruction.

3.2. Filtration permeability of the host rocks

The results of the permeability coefficient calculation are shown in Figures 3 and 4. In these figures, we can see dark zones of tectonic permeability and lighter zones of natural permeability in water-flooded sandstones and coal band.

A filtration area up to 2.4 m deep is formed in the mine roof with frame support (Figure 3) to where the watered coal band enters completely and sandstone enters partially. Inside this filtration area, water can move towards the contour of the mine. When the working face approaches the disjunctive disturbance, Figures 3 b and 3 c, it moves into the zone of disturbed rocks, which stratify easily and are destructed during undermining. The bearer support is not able to suppress this process, and filtration permeability is significantly increases in this zone.

Contours of the filtration area are changed when bolts are installed in the mine roof, Figure 4. The use of roof bolting restrains the unloading of the boundary rocks from the rock pressure and keeps them in a triaxially compressed stress state. Therefore, in all cases of the mine face location relative to the tectonic fault plane, the resulting permeability K decreases by the value of its technological component.

Outside of the influence of the tectonic fault (Figure 4 a), depth of permeable zone in the mine roof is reduced by 7-8 times in comparison with the same zone in Figure 3 a. The impermeable rock-bolt slab is preserved between the watered layers and the roof of the permanent working. As a result, the process of water filtration from aquifers into the mine working is inhibited.

In disturbed zone near the fault, action of the steel-polymer bolts only is not sufficient to form an impermeable slab. For this purpose, injection anchors, for example, could be used here. However, in the roof of the permanent working with roof bolting (Figures 4 b and

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4 c), the permeability is significantly lower than in zone with the frame support (Figures 3 b and 3 c), which should reduce water inflow into the mine working in the hazardous zone.

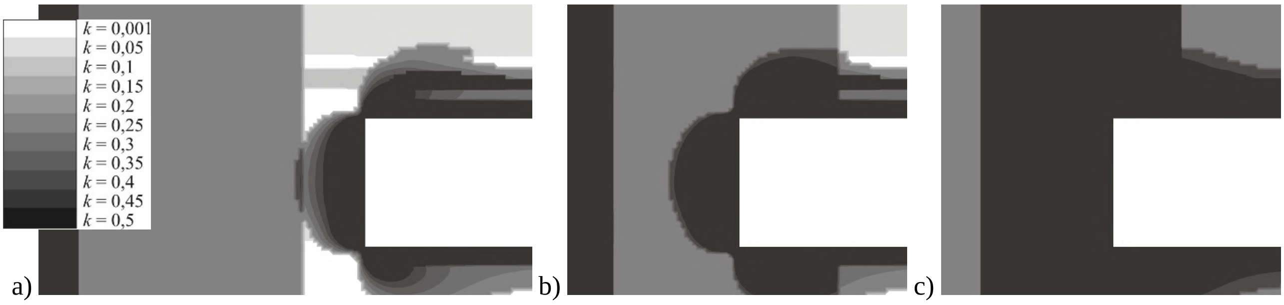

Fig. 3. The distribution of permeability coefficients around the permanent working with frame support: a) L = 12 m, permanent working is outside of the fault influence; b) L = 7 m; c) L = 1 m.

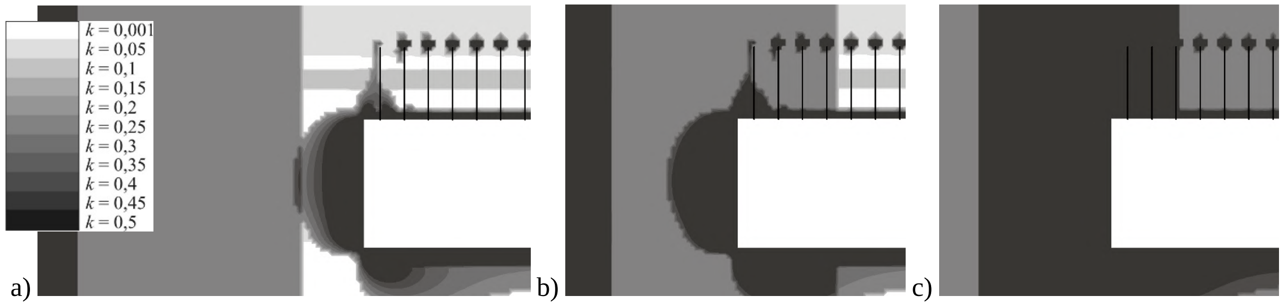

Fig. 4. The distribution of permeability coefficients around the permanent working with roof bolting: a) L = 12 m, permanent working is outside of the fault influence; b) L = 7 m; c) L = 1 m.

3.3 Analysis of changes in filtration parameters

The distribution of water pressure values are shown in Figures 5 and 6. It can be seen that water pressure in the watered beds near the fault is significantly reduced as compared with formation pressure, Figures 5 b and 6 b. As practical experience shows, the increased permeability of rocks in zones of tectonic faults causes the movement of deep pressured water along the plane of displacement in the vertical direction.

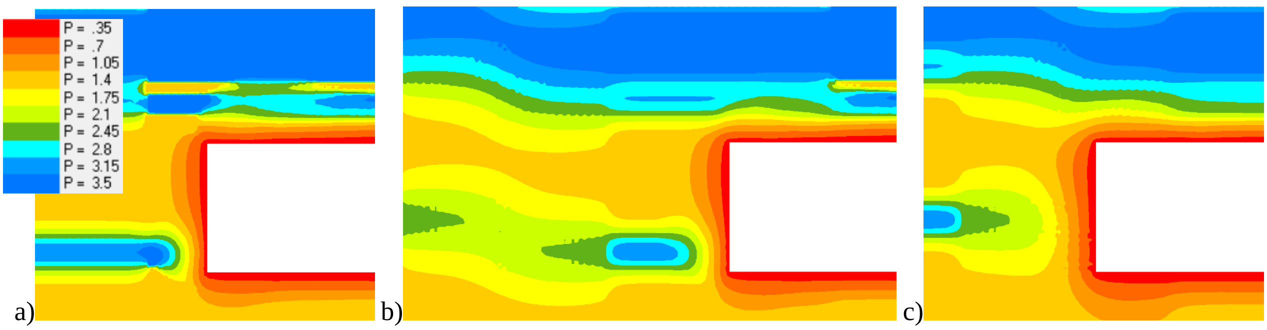

Fig. 5. Water pressure; permanent working with frame support: a) L = 12 m; b) L = 7 m; c) L = 1 m.

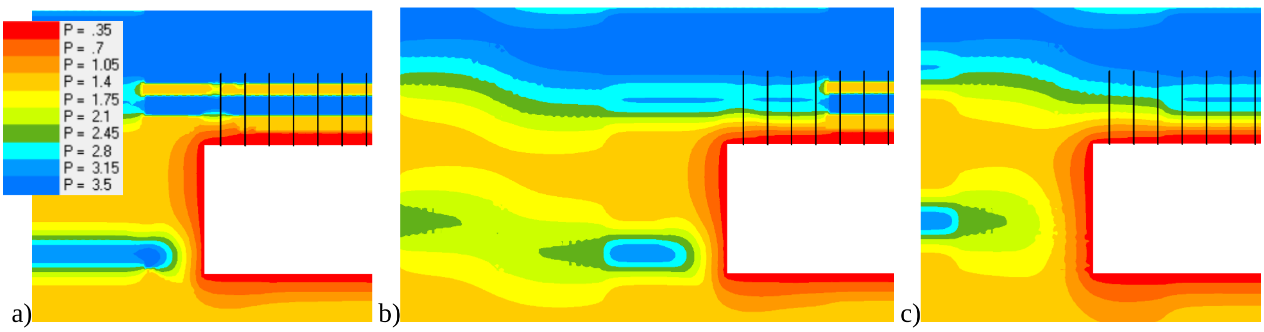

Fig. 6. Water pressure; permanent working with roof bolting: a) L = 12 m; b) L = 7 m; c) L = 1 m.

In the mine roof with frame support, the process of water filtration is actively taking place both outside the disturbed zone and near the tectonic fault. Water pressure in the undermined watered coal band and in part of sandstone decreases, Figure 5. Water moves from areas with higher pressure to the mine working where the pressure is minimal. When the mine face approaches the fault and enters the disturbed zone, the intensity of the filtration process increases, Figures 5 b and 5 c. The water inflow into the permanent working from the roof is doubled, Figure 7, and from the watered sandstone in the mine face increases by 1.5 times, Figure 8.

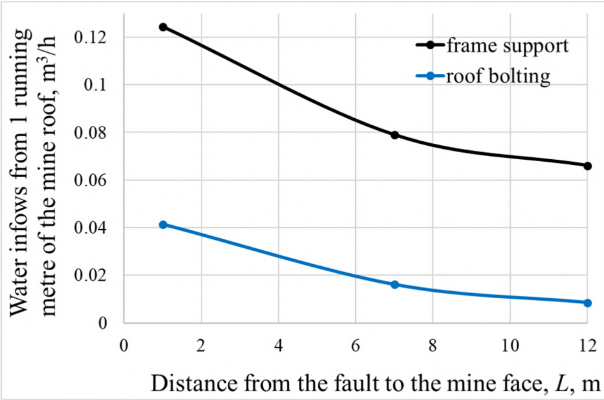

Fig. 7. Water inflow from the undermined roof rocks (per 1 running meter of permanent working).

If the roof bolting is used, the coal band pressure and sandstone pressure practically do not change in the mine roof, in the area outside the zone of influence of tectonic disturbance, Figure 6 a. This indicates a significant decrease in the intensity of the filtration process. The water inflow from the roof into the anchored mine working is almost 8 times less than into the mine working with frame supports, Figure 7. We can assert that outside the zone of fault influence, the impermeable rock-bolt slab in the roof reduces water inflow into the mine working to a minimum.

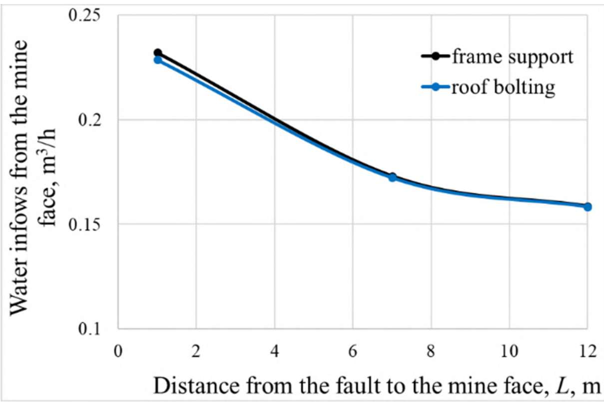

Fig. 8. Water inflow from the mine face.

When the mine face approaches the tectonic fault, where the roof rocks have already been disturbed as a result of tectonic impact, the roof bolts can only reduce the value of the filtration permeability by the value of k_{tech}. However, this is sufficient to reduce the water inflow by 5 times at L = 7 m and by 3 times at L = 1 m, Figure 7.

The water flow rate from the watered sandstone in the mine working face increases by 1.5 times when it approaches the fault and does not depend on the kind of roof supporting, Figure 8.

Roof bolting in mine workings at difficult hydrogeological conditions, when they cross tectonic faults, allows to reduce permeability of tectonically disturbed host rocks, slow down the water filtration process and reduce water inflow from the undermined watered rocks into the mine workings by 3-5 times. Outside the zone of disturbance influence, an impermeable rock-bolt slab in the mine roof stops water inflow into the mine working almost completely.

4 Conclusions

The problem of water inflow reduction in Ukrainian coal mines, which are distinguished by difficult hydrogeological conditions, was considered. A numerical study of the change in water inflow into the mine working when it crosses a tectonic fault was carried out. The cases when permanent working was supported with frame supports and roof bolts were considered.

Stress fields, zones of inelastic deformations and permeability coefficients, which depended on the stress state and took into account tectonic and natural permeability of rocks, were calculated. The results of calculation of water pressure and water inflow into the mine working in all considered cases are presented.

Analysis of the calculated data shows that filtration area, which covers water-bearing rocks, is formed in the roof of the mine working with frame support. Within this area, water can move towards the contour of the mine working. Filtration permeability of the host rocks increases significantly when the mine face approaches the tectonic disturbance. The flow rate of water reaches critical values.

The use of roof bolting restrains the unloading of the boundary rocks from the rock pressure and keeps them in triaxially compressed stress state. Permeability value decreases by the value of its technological component. In different areas of the intersection of tectonic disturbance, water inflow into the mine working with roof bolting is 3-8 times less than in the working with the frame supports. Therefore, the use of roof bolting allows not only to keep the mine working in a stable state, but also to significantly reduce water inflows at complicated hydrogeological conditions.

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Principles for certain geomechanics problems solution during overworking of mine workings

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Abstract. This paper deals with two relevant and interrelated directions of coal mining development. Firstly, the resource-saving complete extraction of reserves, and secondly, the intensification of mining activity through mining operations conducted on several seams. The objective of overworking of mine workings with a real representation of mining-and-geological and mining-engineering conditions has been formulated. Five peculiarities of the geomechanical models construction for overworking of mine works have been revealed and substantiated. The technology for performing a series of computational experiments is proposed. The task of the protecting pillar influence, which is located in overlying coal seam, on the state of mine working placed in the underlying coal seam has been solved. An optimal scheme for its maintenance is proposed.

1 Introduction

The research purpose relevance is conditioned by the necessity for geomechanical substantiation of various engineering decisions in mining the series of strata based on two main directions of coal mining development: resource-saving complete extraction of reserves due to their partial preparation in favourable mining-geological and mining-engineering conditions; intensification of mining activity through mining operations conducted simultaneously on several seams.

The term “complete extraction of reserves” means the extraction of various types of protecting pillars on the overlying horizons remaining after the transition of mining operations to the underlying horizons. These protecting pillars are to some extent delineated by mine workings, in which, from one side, a mined-out space (after the stope works of previous periods) with a consolidated massif of previously collapsed rocks is located. The mechanical properties of such rocks are essentially different from the holistic massif, which, according to studies [1-5], leads to the “smoothing” of stresses, their more uniform distribution, which increases the stability of the noted delineating mine workings. Moreover, when mining protecting pillars, new anomalies of rock pressure will have a reduced intensity of action due to the damping properties of previously collapsed and consolidated rocks. The above trends as a whole contribute to lowering the costs for maintaining the mine workings delineating the pillar, if there is a necessity for their further use according to the mining plan. This is confirmed by a number of studies [6-9].

The technology of two or three coal seams joint mining has more widespread experience in practical implementation, for example, in the Western Donbas. This is conditioned by a motivation to radically increase the stope works intensity with the corresponding technical-and-economic benefits [10-16].

2 Problem statement and solution

Both resource-saving coal mining trends in terms of the parameters substantiation suggest the development of geomechanical models that differ by sufficient complexity and multifactority. Most mining-engineering situations under study require the spatial models construction in order to reflect mine workings network which includes, as a rule, stope and preparatory mine workings, having a mutually perpendicular direction. This is the first peculiarity of this class of problems.

The second peculiarity is the significant dimensions of geomechanical models, in which to achieve the required level of their adequacy and reliability of the results obtained, the following should be reflected:

– in a direction perpendicular to the longwall face length (it is denoted by the coordinate X), the frontal bearing pressure zone ahead of the stope face and the unloading zone behind it at distances that provide attenuation (or stabilization) of the stress-strain state components (SSS) to the level of the permissible error of their deviations; according to this condition, the considered direction should be not less than $X = 120 – 150$ m;

– in a direction parallel to the longwall face length

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(coordinate Z), at least half of its length should be placed, extraction mine working and part of the massif in the side opposite to the stope face to a width, which ensures the SSS components stabilization in the area of the model vertical bound; the massif texture is not essential here – holistic or collapsed and consolidated rocks; the fulfilment of such a condition implies a model size not less than 150 – 180 m, taking into account sufficiently symmetrical initial and borderline conditions relative to the axis X located in the centre of the longwall face length, since with significant asymmetry the size Z will have to be doubled;

– the model height (coordinate Y) should be chosen according to the reflection condition (with a certain margin) of all characteristic zones of rock pressure anomalies and the related texture transformations of the surrounding rock massif; in the coal seam roof, the model height should corresponds to the height of the frontal bearing pressure zone ahead of the longwall face with at least one-and-a-half margin for various SSS distortions types, conditioned by the vertical geostatic load application; behind the longwall face, in the mined-out space, three characteristic zones should be placed [2, 7, 18]: uncontrolled collapse, hinged-block displacement and smooth deflection of layers without discontinuity; in the seam bottom, also with a one-and-a-half fold margin, the zones of frontal bearing pressure and unloading are provided; meeting these conditions usually requires a model height of at least 60 – 80 m; when modelling the joint mining of several coal seams, the height Y should include all of the above elements for the upper seam in the roof and the lower seam in the bottom, plus the thickness of partings; here it is necessary to choose a height Y for each specific case, but it definitely increases by 2 times or more.

The third peculiarity of the considered group of geomechanics tasks is the necessity to represent the mining operations consequences for the previous periods – it mainly relates to the development of previously left protecting pillars. Here it is necessary to take into account the parameters of residual rock pressure anomalies acting in the borders of the protecting pillars and the areas of the mined-out space contacting with them together with the delineating mine workings.

Existing studies [1, 2, 19-23], note a tendency toward a decrease in the activity of the rock pressure anomalies action over time t that has passed since the end of the stope works. The parameters of anomalies in the borders of the protecting pillars substantially depend on the rheological phenomena of creep deformations and stresses relaxation; but there is one more important factor here – the process of shrinkage (consolidation) of previously collapsed rocks in the mined-out space under the geostatic pressure action. Experimental research on the process of rocks shrinkage in the uncontrolled collapse zone in the Western Donbas [19] show the development of this process to 45 – 55% of the initial height; at the same time, the resistance of consolidated rocks can increase to 10 – 15 MPa, which approximately corresponds to 40 – 60% of the compressive resistance of argillite and siltstones of the Western Donbas in the holistic state. Relative to the deformation modulus of collapsed and consolidated rocks, then (in accordance with experimental data) it increases from 5 – 10 MPa in the initial stage of consolidation to 100 – 300 MPa in the final stage of shrinkage development.

Thus, massif of collapsed and consolidated rocks over time t becomes more rigid and more actively resists to the geostatic load. In qualitative terms, the tendencies in the influence of rheology and consolidation factors of collapsed rocks are shown in the scheme of Figure 1. Thus, at the end of the previous period of coal extraction (formation of a protecting pillar $t = t_1$), the vertical geostatic pressure σ_y distribution corresponds to traditional concepts: from the side of the pillar, there is a lateral bearing pressure zone with concentration σ_y of at least several units from the initial state $\sigma_y = \gamma H$ of virgin massif (where γ – weight-average unit specific gravity of rocks to depth H of the pillar location). Above the mine working and from the side of the mined-out space, the component σ_y sharply decreases with its gradual growth in the depth of the uncontrolled collapse zone. Then, over time ($t = t_2 > t_1$), the concentrations σ_y in the border of the protecting pillar decrease, and from the side of the mined-out space σ_y grows near mine working due to the collapsed rocks consolidation and an increase in their resistance to the vertical rock pressure. After a long period of time ($t = t_3 > t_2$), usually calculated in years, the process of the so-called collapsed rocks consolidation is stabilized repulsing the rock pressure at the level of about half of the holistic rocks compressive resistance in the coal seam roof. This is usually quite enough to reach the initial state of virgin massif $\sigma_y = \gamma H$: from the side of a pillar, the concentrations σ_y in the larger zone of the lateral bearing pressure are maximally reduced, and from the side of the mined-out space, small concentrations σ_y are formed near mine working (a kind of lateral bearing pressure zone). In general, rock pressure anomalies are “smoothed”, which contributes to the increase in stability of delineating mine workings.

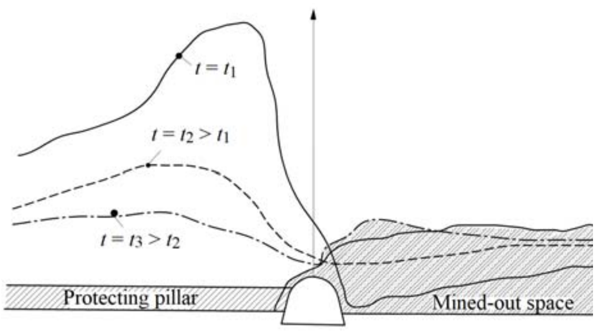

Fig. 1. Change in time t of the vertical stresses σ_y distribution near the border of the protecting pillar.

Such a mechanism for converting rock pressure anomalies after previous periods of stope works is expedient to be reflected in the geomechanical model at the last stage, that is, after a long period of time when the protecting pillar mining is planned. This process is taken into account by changing the mechanical characteristics of collapsed and consolidated rocks in accordance with their behaviour over a long period of time after disintegration. In the first approximation, for the Western

Donbas conditions, it is recommended to accept the following mechanical characteristics of collapsed and consolidated rocks:

– compressive resistance σ_{compr} in the range of 40 – 60% of that for the holistic lithotype state;

– tensile strength σ_{str} is practically absent; for unambiguous calculation procedure, $\sigma_{str} \leq 0.1$ MPa can be accepted;

– deformation modulus E_d is accepted in the range of 5 – 10% of the value for the holistic lithotype.

The fourth peculiarity of the studied geomechanical problems class is the necessity to take into account the texture transformations of the adjacent rocks of the main roof (the so-called hinged-block displacement zone) that have occurred above the uncontrolled collapse zone in previous periods of stope works. Texture transformations in the hinged-block displacement zone signify the development (in the process of roof rock layers bending) of a system of predominantly vertically directed fractures that divide the lithotype into a series of rock blocks, from which a kind of thrust system is formed. It can lose stability at a certain value of the rock layer deflection, and, when the flexure strains are restricted (by means of a bearing from the side of underlying massif), this thrust-block system has a significant load-bearing capacity and actively resists to geostatic vertical rock pressure. The formation mechanism of thrust systems constituting the hinged-block displacement zone is described in sufficient detail in the works [19, 24-28], and the adequate reflection of this zone in models of this class of geomechanics problems is of great interest for us.

The importance of adequate hinged-block displacement zone modelling is determined by its significant influence on the displacement processes in the coal-overlaying formation both in the course of stope works and when maintaining the extraction mine workings (in case of the operational necessity) behind the stope face. The texture transformations in the studied zone lead to a sharp increase in the flexure strains of the thrust system as a whole without a significant change in the mechanical properties of the lithotype within the rock block itself; this is the fundamental difference of changes in the behaviour and properties of rocks and, for example, the zone of uncontrolled collapse.

Techniques for modelling the hinged-block displacement zone are as follows. Within the zone thickness, there is a differentiated division of each rock layer into blocks. The most reliable prediction of the zone thickness is expedient on the basis of stability analysis of the main roof rock layers with the use of mining-and-geological sections in the area of location, for example, of protecting pillars, as well as a gained experience in the stope works operations on this coal seam or series of strata. As a rule, the hinged-block displacement zone is propagated (in the Western Donbas conditions) to a height of 10 – 15 m and most often its top border is a very thin coal seam or interlayer, which has virtually no adhesion to either the overlying or underlying lithotypes. Thus, the thickness of the hinged-block displacement zone is assessed in each specific mining-engineering situation, but with the obligatory consideration of the weakening factors, such as water cut and fracturing which actively influence on the lithotypes stability.

On the practical level, each rock layer is being broken up into a number of blocks by tension cracks simulators, on the surfaces of which adhesion is completely absent, and the interaction of the blocks with each other is performed due to normal forces and shearing friction stresses. By means of this geometric construction, the adequacy is ensured of the process of thrusting the rock blocks due to the possibility of their repetition relative to each other: when maintaining the previous mechanical characteristics within the rock block, an increased deformability of the thrust system is realized at a level ten times higher than the flexure strain (without destruction) of the holistic rock layer.

The question remains relative to the geometrical parameters of the hinged-block displacement zone, which are recommended on the basis of existing concepts on the mechanism of the rocks displacement in the coal-overlaying formation with specification for the Western Donbas conditions in accordance with studies [19, 24-28]. To clarify the geometric parameters substantiation, the schemes are presented in Figure 2 of the hinged-block displacement zone propagation in two mutually perpendicular directions, for example, along the strike and to the dip (rise) of a coal seam. In the coal pillar cross section (along the strike of the seam), the hinged-block displacement zone is propagated to its depth by 12 – 20 m and blocks in each rock layer should be modelled over this distance. From the side of the mined-out space (previous periods of stope works operation), the hinged-block displacement zone is constantly present, but stabilization of the SSS components distribution occurs, as a rule, at a distance of 15 – 20 m due to the significant deformability of the thrust-block systems; therefore, with some margin, it is recommended to accept $Z = 25 – 30$ m.

The blocks dimensions along the strike in each layer are different, and their value is partially chosen arbitrarily, based on the tendency: the greater the lithotype thickness, the more it is resistant to bending loads and is able to form rock cantilevers with an increased length. Moreover, the blocks length can be substantiated using a two-staged modelling technology [29, 30]: at the first stage, the SSS of holistic layers is studied and the areas of destructive stresses concentrations impact are determined, where the layer is most likely to be divided into blocks; at the second stage, the SSS of an already block system of all layers is calculated according to the thickness of the hinged-block displacement zone. However, this approach also has some uncertainty, since the curves of the SSS components distribution are changed quite smoothly. Hence, it is difficult to set (according to various criteria of discontinuity) the exact coordinate of the main crack location, which separates one or another lithotype.

At the same time, the studied ambiguity in the rock blocks dimensions has an insignificant influence on the rocks SSS of the hinged-block displacement zone. Such a conclusion has been made on the basis of multivariate SSS calculations of this zone, for example, [19], where its essence is revealed: the main peculiarity of the thrust systems is their yielding property – the layer rigidity is reduced tenfold, and the value of this decrease is relatively independent on the blocks dimensions, since the length of the thrust systems is at least an order of magnitude greater.

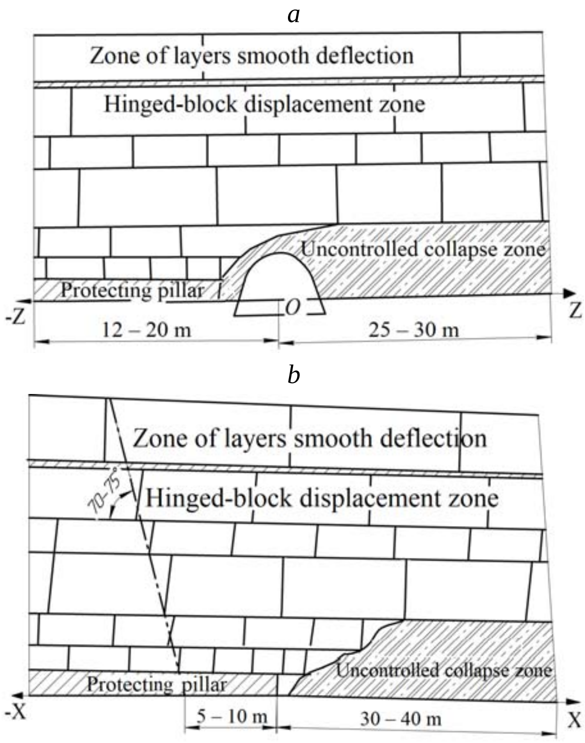

Fig. 2. Schemes for texture transformation of the coal-overlaying formation in a cross (*a*) and longitudinal (*b*) protecting pillar sections.

In the protecting pillar longitudinal section (for example, to the rise of the seam), the same principles to substantiate the block dimensions (usually from 2 m to 8 m) are recommended with a different general tendency of the block length increase when removing from the coal seam. Here, according to [24-26], the maximum stresses concentrations in the former frontal bearing pressure zone are propagated to depth of a pillar by 5 – 10 m. Over time, the line (by the coal-overlaying formation thickness) of their maxima is located at an angle of 70 – 75º to the horizontal, which will be the boundary of the hinged-block displacement zone from the side of the seam rise. From the opposite side, the vast dimensions of the mined-out space with a sufficiently constant texture of the hinged-block displacement zone make it possible to restrict the dimensions of its reflection to 30 – 40 m.

Based on these parameters, it is recommended to construct geomechanical models of the massif initial state before mining the protecting pillars; in the process of their stope extraction, the dimensions should be increased to the peculiarities of modelling, previously indicated in the second paragraph. However, when calculating such models with vast sizes, provided that it is necessary to consider the structural transformations of adjacent roof rocks, one usually has to deal with a lack of computational resources and, for this reason, stop the calculation procedure.

The accumulated experience of modelling such geomechanical situation has led to two ways of its solution without significant damage to the calculation accuracy. The first way is to restrict the extension (in coordinates *X* and *Z*) of the rock layers of the hinged-block displacement zone, where they are broken up into rock blocks; the sizes of these restrictions are shown in Figure 2. The second way is to break up into blocks only the lower layers of the zone, the number of which is determined experimentally by the criterion of the possibility to perform the calculation procedure. As for the remaining upper layers of the zone, the deformation modulus should be reduced by an order of magnitude for cumulative account of this technogenic fracturing in accordance with studies [31-33].

In general, modelling of the second, third, and fourth peculiarities of the protecting pillars extraction process will allow for acceptable (for mining-engineering calculations) adequacy of the real research object reflection and the reliability of the SSS calculation results of the coal-bearing massif.

Another group of geomechanics tasks related to the joint mining of two or three coal seams, quite reasonably uses (for constructing the models) the principles studied above, but taking into account the specifics of mining operations. Thus, in the works [17, 19], the following algorithm for performing a computational experiment:

– a coal-bearing stratum composed of holistic rock layers is modelled with a reflection of the uncontrolled collapse zone during extraction of an overlying coal seam; based on the results of the SSS calculation, the parameters of the hinged-block displacement zone of the main roof rocks and the block texture in the soil rocks of the overlying coal seam are substantiated;

– a geomechanical model is being constructed with a reflection of the roof and bottom rocks continuity of the overlying seam; the SSS of the entire coal-bearing stratum is calculated with the definition of the influence areas boundaries (on the underlying coal seam) of the rock pressure anomalies caused by the overlying seam extraction;

– the underlying coal seam extraction is modelled with the reflection of the uncontrolled collapse zone behind the longwall face, as well as all discontinuities caused by mining the overlying coal seam;

– according to the SSS calculation results from the previous stage, the parameters of massif discontinuities related to the underlying seam extraction are introduced. Then, the SSS of the coal-bearing stratum is calculated and analysed with an assessment of the degree of parting rocks stability;

– the final conclusion is made on the extent of the overwork influence on the state of the massif around mine workings of the lower horizon; the most dangerous areas along their length are determined and initial data are generated for constructing the geomechanical models of maintaining mine workings in the conditions of their overworking.

Thus, despite the significant differences in the tasks being solved in the two directions under study (extraction of protecting pillars and joint mining of coal seams in the suite), the principles for approaching their solution have a common implementation algorithm in terms of reflecting similar peculiarities of the coal-bearing massif discontinuities. The same common peculiarities exist for the final stage of research, which is formulated as the fifth peculiarity of the computational experiment – constructing a model, calculating the SSS and its analysis for the adjacent massif and the support of the overworked mine working. The peculiarity consists in the multi-scale modelling of the geomechanical "massif – support" system, because adequate reflection of the support elements (special interchangeable SCP profile of the frame support, roof-bolts, means for strengthening the fastening structures, etc.) requires finite elements mesh that differ by two – three orders from those for the adjacent massif.

The noted reason is decisive (in the conditions of a limited computational resource) for finding a compromise solution to the problem of failure-free computational experiment. The essence of the compromise is as follows. It is necessary to adequately reflect the real design of the fastening system of the overworked mine working for subsequent assessment of its elements state with a sufficient for practice reliability degree. A small-scale mesh of volume finite elements is required here. On the other hand, the loading of the fastening structure is conditioned by the surrounding rock massif deformation, where a larger-scale finite element mesh can be used, but with differentiation in reflection of different-sized texture peculiarities, including areas of discontinuity.

The model adequacy and the reliability of the SSS calculation results of the "massif-support" system will depend on the dimensions of the modelled massif surrounding mine working and the conditions of its loading at the borders. The general tendency is that, the larger the model dimensions, the less distortion in the fields of the SSS components distribution. Therefore, as a rule, it is necessary to perform several stages of calculating the SSS with a gradual decrease in the model dimensions (or, on the contrary, their increase) in order to search for such maximum permissible values, at which the calculation procedure stability within the available computational resource is still ensured.

When the maximum permissible model dimensions are determined, the borderline conditions of its loading are specified in the form of functions of vertical $\sigma_y(x, z)$, horizontal $\sigma_x(y, z)$ and $\sigma_z(y, x)$ stresses distribution along the model boundaries. These functions are determined from the calculation of the initial (general) model, which includes all the previously described peculiarities of mining-engineering situations of the protecting pillars mining or joint mining of coal seams in the suite.

Thus, the final peculiarity of modelling the fastening structure of overworked mine workings provides for the general two-staged performance of calculations:

– the first stage is a reflection of the mining-engineering situation as a whole using a geomechanical model with the required dimensions (it is sometimes called a "macro model") in a coal-bearing massif, but without reflection of mine workings fastening structure; insignificant error from such an assumption is substantiated, for example, in the works [34-36];

– the second stage – constructing of the so-called subordinate model with a detailed reflection of the fastening structure of the overworked mine working with the search for its maximum permissible dimensions; on the model bounds, the load functions are specified, determined when calculating macro model.

The calculation schemes and certain results of solution in one of the studied directions of the protecting pillars mining are given as examples of the proposed principles implementation for solving the geomechanics problems class on overworking of mine workings.

Figure 3 presents the macro model of mining the protecting pillar left in the previous periods of stope works along the seam C_6 in order to protect the underlying steep-dipping ventilation crosscut No. 1 (SVC No. 1) located in the bottom of the seam $C_5 + C_5^{top}$ (MM "Dniprovske", PJSC "Pavlohradvuhillia", Ukraine). Such a mining-engineering decision is conditioned by two reasons: moderate thickness of a parting and low strength characteristics of the constituent lithotypes, some of which are exposed to the active influence of weakening factors, namely, moisture saturation and fracturing. Now the task set is to assess the degree of the stope works influence in case of the protecting pillar extraction on the state of the SVC No. 1, the further maintenance of which ensures reliable functioning of ventilation systems in this area of the mine field.

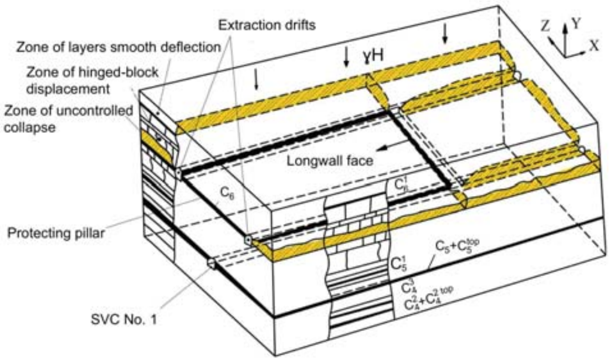

Fig. 3. Macro model of the protecting pillar extraction above the SVC No. 1.

The macro model (Figure 3) is being constructed with the maximum size along the strike (coordinate *Z*), although a sufficiently symmetric SSS components distribution is assumed here with respect to the axis *X* drawn along the centre of the pillar width. Therefore, it is entirely permissible to consider only half of the macro model by the coordinate *Z*, which will significantly save the computational resource. It is appropriate to recall that when calculating the macro model, the fastening structure of the SVC No. 1 is not modelled, and the main task is to determine the fields of σ_y, σ_x and σ_z distribution around the SVC No. 1 at a distance of up to several tens of meters from it. These fields of the SSS components distribution serve as borderline conditions when constructing the subordinate model.

The subordinate model (Figure 4) has been constructed with account of a stage-by-stage search for its maximum permissible dimensions by the factor of failure-free computational experiment. As a result, its dimensions have been determined by the coordinates: $z = 25$ m, $x = 4.5$ m, $y = 29.8$ m. The lower horizontal bound is modelled as a rigid base; on all other bounds, the loads are specified in the form of distribution curves $\sigma_y(x, z)$, $\sigma_x(y, z)$ and $\sigma_z(y, x)$ at the corresponding distances of the subordinate model boundaries from the contour of the

SVC No. 1. In the mine working itself, the frame support is modelled (10 sets with a step of setting 0.5 m) in full compliance with the technical documentation.

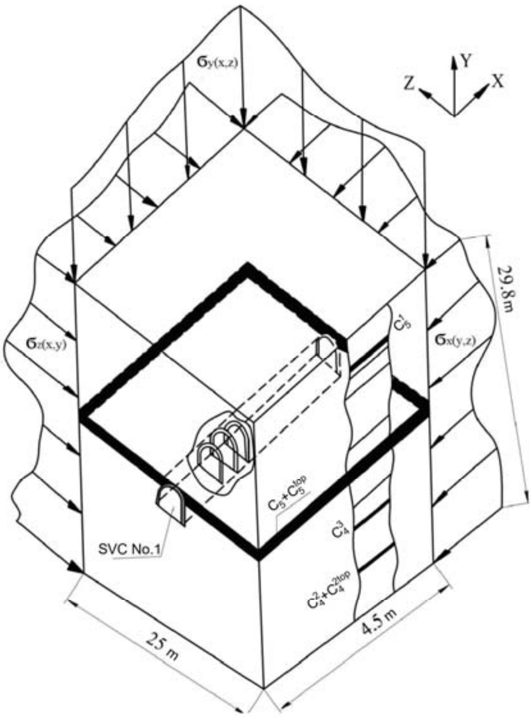

Fig. 4. Subordinate model for maintenance of the SVC No. 1.

The results of calculating the SSS of subordinate model can be illustrated by several options, for example, in the form of curves of the stresses components σ_y, σ_x, σ_z distribution, as well as an integral indicator – stresses intensity σ. But, the distribution of the relative indicator σ/σ_{yield} along the frame support contour is a more evident final result of the analysis performed. This indicator (σ_{yield} – the estimated yield limit of the SCP steel of the frame support) most informatively assesses the frame support state in terms of approaching the maximum permissible value σ_{yield} or even exceeding this value.

On the practical level, according to the curve of the indicator σ/σ_{yield} distribution, it is possible to judge about the areas of the frame contour that are in a stable state and, on the contrary, about the areas requiring the frame support strengthening. For example, Figure 5 shows that in the cap board of the frame, in the central part of the arch of 1.5 – 1.6 m long, the indicator σ/σ_{yield} varies in the range of 64 – 85%. This indicates a stable state in the central area of a cap board. At the same time, when approaching the peripheral areas of the cap board, the indicator σ/σ_{yield} increases to 87 – 98%, and in separate local intervals of length to 100 – 106%. Consequently, the occurrence of the limiting state of SCP steel with the exhaustion of load-bearing capacity of the cap board is predicted here. Obviously, it is necessary to strengthen the peripheral areas in the cap board, for example, by setting a pair of oblique roof bolts in each side of mine working.

An even more dangerous state is along the length of the rectilinear part of the frame prop stays: the indicator σ/σ_{yield} reaches 113 – 137% and characterizes the widespread occurrence of the limiting and superlimiting state of SCP steel (Figure 6).

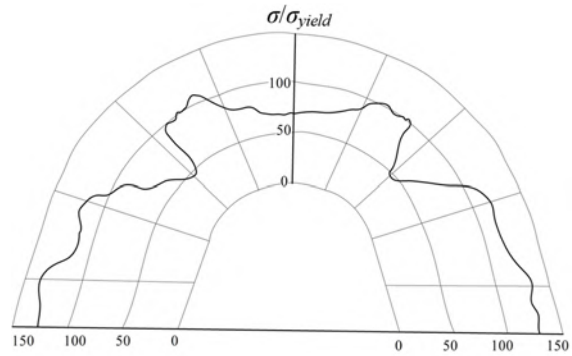

Fig. 5. Relative stresses intensity σ/σ_{yield} distribution in the frame support of the SVC No. 1.

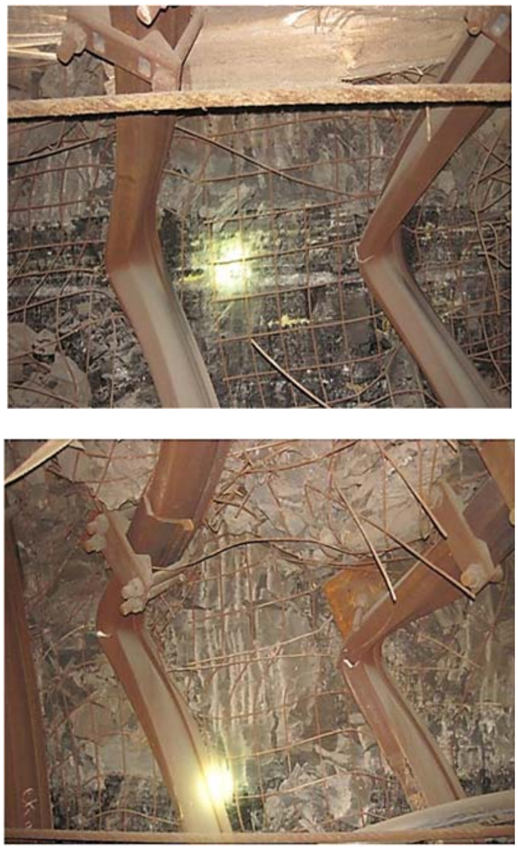

Fig. 6. Deformation of the frame stays.

This contributes to the loss of a stable form by the prop stays and the activation of their convergence with a significant reduction in the residual cross-sectional area [37]. It is also recommended to set predominantly horizontally directed roof bolts, strengthening the border lateral rocks; in addition, it is expedient to tie the tail joints of the roof bolts with the frame prop stays, which will effectively restrict their convergence (Figure 7).

Thus, using a specific example of the protecting pillar extraction, a structure has been developed for conducting a computational experiment from a macro model with vast sizes to the substantiation of practical recommendations for ensuring the overworked mine working stability.

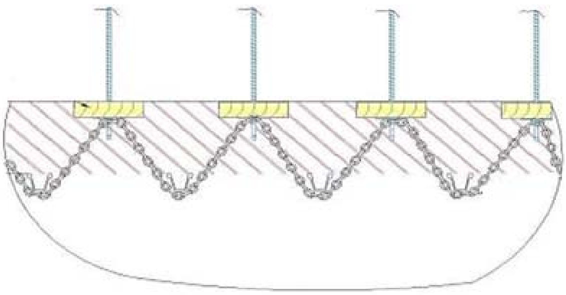

Fig. 7. Improvement of fastening technology.

3 Conclusions

1. The tasks of geomechanics on overworking of mine workings are distinguished by the sufficient complexity of reflecting the mining-and-geological and mining-engineering situation adequately for three main reasons:

– the necessity of modelling a network of underground mine workings at different horizons of mining operations;

– it is required to consider the parameters of rock pressure anomalies (zones of bearing pressure and unloading) when mining an overlying coal seam. This determines not only the spatial problem setting, but also the significant model dimensions by all three its coordinates;

– the stope works, conducted at different periods on overlying coal seams, have led to radical transformations of some lithotypes texture of the coal-bearing stratum, which has a significant effect on its SSS as a whole and, therefore, requires adequate reflection in geomechanical models.

2. Five peculiarities of the geomechanical models construction on overworking of mine workings have been substantiated and revealed, the implementation of which predicts obtaining the reliable results for determining SSS within the accuracy sufficient for mining-engineering calculations.

3. A stage-by-stage algorithm is proposed for solving this class of problems, which differ in the scale of the modelled objects (the dimensions of volume finite elements vary by two or three orders of magnitude). The technology of sequential performance of a series of computational experiments to operate the parameters of the so-called macro model (reflects the studied object as a whole) has been substantiated, followed by obtaining the results for constructing and calculating a subordinate model. Here, the parameters of the overworked mine working and its fastening structure are reflected in full compliance with the technical documentation on conducting and exploitation of mine working.

4. An example is presented of the task solution of the protecting pillar influence of the overlying coal seam on the state of a mine working located in the underlying coal seam. The state of the overworked mine working support has been assessed and recommendations are formulated for its maintenance in operational condition.

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Simulation of the influence of dynamic loading on the stress-strain state of the natural and geoengineering environment

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Abstract. The paper provides numerical simulation of the influence of dynamic loading on the stress-strain state of the natural and geoengineering technogenic environment taking into account the soil basis for forecasting its use as the basis of the structure. Paper demonstrates the impact of static and dynamic loading on the subsidence of the landfill. To take into account the liquid phase of the waste and the visco-plastic medium, Darcy's law is used as an equation of balance of forces. The body of the landfill is modeled by weak soil taking into account the creep, using the Soft Soil Creep model. The covering and underlying soil layers are described by the Coulomb – Mohr model. An effective method for calculating the sedimentation of natural and geoengineering environment on the example of a solid waste landfill, based on numerical modeling of the stress-strain state of the landfill and underlying soil using finite elements is developed. It is demonstrated that the largest subsidence is experienced by the landfill with sand, as the base soil, but in percentage terms the amount of subsidence with the maximum load relative to the initial subsidence without loading is the largest in clay (33.7%). The obtained results must be taken into account when using landfills as a basis for buildings, structures, routes, recreational areas, etc.

1 Introduction

Due to the continuous growth of industry and, as a result, the increase in industrial and household waste, dumps and tailings of the mining industry, the area allocated for them is growing accordingly. For example, currently in Ukraine only landfills for solid waste occupy 160 thousand hectares of land.

Therefore, the question of the sustainability of such *natural-technogenic* geoengineering areas for their possible use in the future as a basis for engineering buildings and structures. As a result, scientists are faced with the task of assessing and predicting stability under static and dynamic loads [1].

Analysis of the literature demonstrated that experimental methods for assessing the resilience of *natural-technogenic* environments are costly and are not always effective. It is most expedient to apply mathematical modeling to take into account the stress-strain state of such medium, taking into account the underlying soil arrays and dynamic loads.

Mathematical models used to predict subsidence can be divided into rheological models, empirical models, models based on soil mechanics and models that take into account biodegradation.

Although properties of hard domestic wastes differ from properties of traditional soils, Kockel and Jessberger set that the landfills can be modelled by weak soil [2, 3]. Sowers and Edil were the first, who applied principles of ordinary mechanics of soils for the estimation of sinking as a result of primary compression [4].

Marquez developed a composite rheological model to take into account the primary and secondary mechanisms of compression [6].

Park and Lee proposed a sedimentation model that takes into account time-dependent biodegradation of waste [7].

A common feature of mathematical models [8, 9] is that they take into account only waste, their behavior and properties, neglecting such an important component of the landfill as the soil underlying it. Type, strength, deformability, geotechnical properties of the underlying soil determine the stability of the natural and geoengineering environment, because it feels the greatest load. Currently, this issue is not studied.

The aim of the research is to substantiate theoretically the stability of the natural and geoengineering environment as the basis of structures, taking into account the stress-strain state of the underlying soils and dynamic loads to predict the stability of the landfill as the basis of structures.

To achieve this goal, the following research objectives are formulated:

– to research the impact of static and dynamic loading on the subsidence of the landfill using the developed methodology for selecting and predicting the

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possible use of the landfill as a basis for construction after its closure;

– to study the influence of the underlying soil and its stratification on the deformation of the landfill body using the developed mathematical model and methods of calculating the stress-strain state.

Sediment simulation taking into account the dynamic load predicts the suitability of a particular closed landfill for use as a road, highway, expressway, etc.

2 Materials and methods

Numerical modeling of the stress-strain state of the solid waste landfill and the soil base is carried out to predict the possibility of its use as the basis of a building or structure. To take into account the liquid phase of the waste and the visco-plastic medium, Darcy's law is used as an equation of balance of forces:

$$-\nabla P - \frac{\eta}{K}\vec{u} + \rho\vec{f} = 0, \tag{1}$$

where P – external pressure; ρ – density; η – dynamic viscosity; g – acceleration of free fall; $\vec{u}$ – filtration rate; $\vec{f}$ – field of external forces; $K = \eta k/\rho g$ – the permeability coefficient, which characterizes the ability of a porous medium to pass fluid.

The complete system of equations of filtration of incompressible liquid includes the equation of incompressibility:

$$div\,\vec{u} = 0, \tag{2}$$

and the continuity equation:

$$div\,\rho\vec{u} = -\rho m, \tag{3}$$

where m – the porosity of the soil.

It is assumed that the compressibility of the skeleton and pore fluid is small, which leads to a linear dependence of soil porosity on pressure.

The covering and underlying soil layers are described by the Coulomb – Mohr model, in which the complete yield condition consists of six flow surfaces and six plastic potential functions [10]:

$$\begin{aligned}
f_{1a} &= \frac{1}{2}(\sigma'_2 - \sigma'_3) + \frac{1}{2}(\sigma'_2 + \sigma'_3)\sin\varphi - c\cos\varphi \le 0;\\
f_{1b} &= \frac{1}{2}(\sigma'_3 - \sigma'_2) + \frac{1}{2}(\sigma'_3 + \sigma'_2)\sin\varphi - c\cos\varphi \le 0;\\
f_{2a} &= \frac{1}{2}(\sigma'_3 - \sigma'_1) + \frac{1}{2}(\sigma'_3 + \sigma'_1)\sin\varphi - c\cos\varphi \le 0;\\
f_{2b} &= \frac{1}{2}(\sigma'_1 - \sigma'_3) + \frac{1}{2}(\sigma'_1 + \sigma'_3)\sin\varphi - c\cos\varphi \le 0;\\
f_{3a} &= \frac{1}{2}(\sigma'_1 - \sigma'_2) + \frac{1}{2}(\sigma'_1 + \sigma'_2)\sin\varphi - c\cos\varphi \le 0;\\
f_{3b} &= \frac{1}{2}(\sigma'_2 - \sigma'_1) + \frac{1}{2}(\sigma'_2 + \sigma'_1)\sin\varphi - c\cos\varphi \le 0,
\end{aligned} \tag{4}$$

where $\sigma'_1, \sigma'_2, \sigma'_3$ – normal stresses.

The condition f_j=0 for all surfaces of fluidity together shows a hexagonal cone in space of main tensions.

In addition to the surfaces of fluidity, the model of Coulomb – Mohr is presented by six plastic potential functions g:

$$\begin{aligned}
g_{1a} &= \frac{1}{2}(\sigma'_2 - \sigma'_3) + \frac{1}{2}(\sigma'_2 + \sigma'_3)\sin\psi;\\
g_{1b} &= \frac{1}{2}(\sigma'_3 - \sigma'_2) + \frac{1}{2}(\sigma'_3 + \sigma'_2)\sin\psi;\\
g_{2a} &= \frac{1}{2}(\sigma'_3 - \sigma'_1) + \frac{1}{2}(\sigma'_3 + \sigma'_1)\sin\psi;\\
g_{2b} &= \frac{1}{2}(\sigma'_1 - \sigma'_3) + \frac{1}{2}(\sigma'_1 + \sigma'_3)\sin\psi;\\
g_{3a} &= \frac{1}{2}(\sigma'_1 - \sigma'_2) + \frac{1}{2}(\sigma'_1 + \sigma'_2)\sin\psi;\\
g_{3b} &= \frac{1}{2}(\sigma'_2 - \sigma'_1) + \frac{1}{2}(\sigma'_2 + \sigma'_1)\sin\psi.
\end{aligned} \tag{5}$$

The corner of dilatancy ψ is needed for the design of positive plastic volume to deformations, that are in dense soils. The corner of internal friction φ is used for the design of effective friction in soil in combination with the effective coupling of *c*.

The body of the landfill is modeled by weak soil taking into account the creep, using the model Soft Soil Creep (SSC) [11-12].

Advantage of this model before other is that she takes into account not only a primary compression but also creep and secondary compression, that is especially important for the grounds of hard domestic wastes, in that a secondary compression plays a major role. Its duration can present 10-30 years. It must be taken into account on the stage of planning of building of construction on the basis of ground. The feature of body of ground is him high compressibility. The large primary sinking of foundations and embankments, as a rule, is accompanied by the substantial sinking as a result of creep in later years. In such cases it is desirable to estimate a creep by means of eventual elements method.

Basic descriptions of model of SSC are: dependency inflexibility; a difference is between the primary loading and unloading-overload; secondary, dependency upon time compression; taking into account of pre-consolidation tension; criteria of destruction of Coulomb – Mohr. The feature of design of ground is linear dependence of his tension on odometric inflexibility.

The total volume deformation ε_v, caused by the increase of effective stresses from the initial value p_0' to p' for the period of time t_c+t', consists of elastic ε_v^e and viscoplastic ε_v^{vp} components. The viscoplastic component is the sum of the deformation during the consolidation $\varepsilon_v^{vp}{}_c$ and after the consolidation $\varepsilon_v^{vp}{}_{ac}$. The relationship between deformations is expressed as follows:

$$\varepsilon_v = \varepsilon_v^e + \varepsilon_v^{vp}{}_c + \varepsilon_v^{vp}{}_{ac}; \tag{6}$$

$$\varepsilon_v^e = \kappa^* \ln\left(\frac{p'}{p'_0}\right); \tag{7}$$

$$\varepsilon_v^{vp}{}_c = (\lambda^* - \kappa^*) \ln\left(\frac{p'_{pc}}{p'_0}\right); \tag{8}$$

$$\varepsilon_v^{vp}{}_{ac} = \mu^* \ln\left(\frac{\tau_c + t'}{\tau_c}\right), \tag{9}$$

where μ^* – modified creep coefficient; τ_c – consolidation time, which depends on the geometry of the sample under study; t' – elapsed time since the start of landfill loading; κ^* – modified swelling coefficient; λ^* – modified compression ratio (compression); t_c – time of completion of the initial consolidation; p' – initial effective voltage; p' – effective voltage; p'_{pc} – effective pre-consolidation voltage.

Izotropic effective tension of p' is determined after a formula:

$$p' = \frac{1}{3}\left(\sigma'_{xx} + \sigma'_{yy} + \sigma'_{zz}\right). \tag{10}$$

Attitude of model parameters following toward the internationally rationed parameters

$$\mu^* = \frac{C_\alpha}{2{,}3(1+e_0)}; \quad \lambda^* = \frac{C_c}{2{,}3(1+e_0)}; \quad \kappa^* = \frac{2C_s}{2{,}3(1+e_0)}, \tag{11}$$

where C_c – coefficient of compression, C_s – swelling coefficient, C_α – coefficient of creep, e_0 – initial coefficient of porosity.

The equations for determining the free surface of the filtration flow when calculating the unstable filtration in the body of the landfill, taking into account the infiltration, must satisfy the following boundary conditions: 1) the pressure is equal to atmospheric; 2) the normal velocity component on the surface is missing. At the boundaries between the landfill layers and the soil base, the conditions of equality of normal stress components and filtration rate occur.

The initial conditions are: the filtration rate in the layers of the landfill and the underlying soil is zero; atmospheric pressure acts on the surface, each layer of waste and soil has its own initial physical and mechanical properties, the initial geometric parameters of the landfill are set.

3 The results of studies of the stress-strain state of the natural-technogenic environment under dynamic loads

The finite element method is used to solve the problem numerically. The calculation area is divided into 5200 triangular elements.

The landfill for which the simulation is performed consists of ten layers of waste, the thickness of each layer is 3 m. Sedimentation is determined taking into account the step-by-step load of the landfill for 30 years after its closure.

Sand, loam and clay are considered as underlying soils, the physical and mechanical parameters of which are given in table 1.

The physical and mechanical parameters of wastes are given in table 2.

Table 1. Physical-mechanical parameters of soils.

Parameter	Soil		
	Sand	**Loam**	**Clay**
Deformation module, E_{ref}	18000	10000	9000
Poisson's ratio, ν	0,34	0,34	0,34
Specific gravity of soil, γ_{unsat}	18,0	13	19,0
The proportion of water-saturated soil, γ_{sat}	20,7	14,6	21,8
The filtration coefficient in the horizontal direction, k_x	0,5	0,006	0,004
The filtration coefficient in the vertical direction, k_y	0,5	0,006	0,004
Coupling, c	2	13	17
The angle of internal friction, φ	31	14	13

Table 2. Physical-mechanical parameters of wastes.

Parameter	Size
Specific gravity γ_{unsat}, (kN/m^3)	7,504
Specific gravity of water saturated soil γ_{sat}, (kN/m^3)	10,0
Specific coupling c, (kPa)	25
Corner of internal friction φ, (degree)	20
Initial coefficient of porosity, e_0, (unit)	0,4268
Coefficient of compression, C_c, (unit)	0,3987
Coefficient of swelling, C_s, (unit)	0,0394

In [9], the sedimentation of the landfill without load is calculated. For the landfill with clay base, it is 3.83 m, with loam – 4.47 m, with sand – 4.95 m. These data are used to determine the stress-strain state of the landfill 30 years after its closure and predict the possibility of its use as the basis of the road surface.

As a result of numerical calculation it is established that if the value of the vertical load is 50 kPa, it can be observed that deformations are achieved equal to 4.19 m for clay (Fig. 1) and 5.06 for sand (Fig. 2).

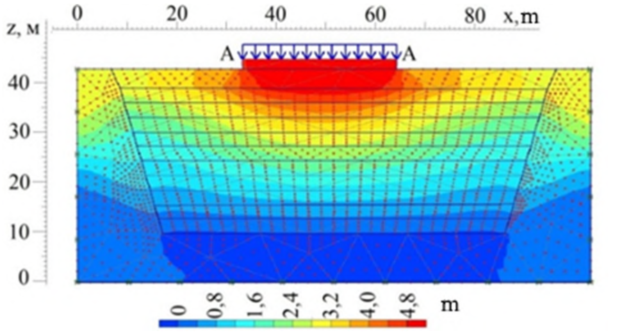

Fig. 1. Vertical deformations of the landfill with a vertical distributed dynamic load of 50 kPa (clay at the base).

With an increase in the load up to 100 kPa, the sediment of the landfill with a sand base increases by 4.2% (5.27 m) (Fig. 3), with clay – by 4.8% (4.39 m) (Fig. 4).

It is established that at dynamic loads the underlying soils have a similar effect on the subsidence of the landfill, but the amount of subsidence is less than 0.5-4% depending on the underlying soil.

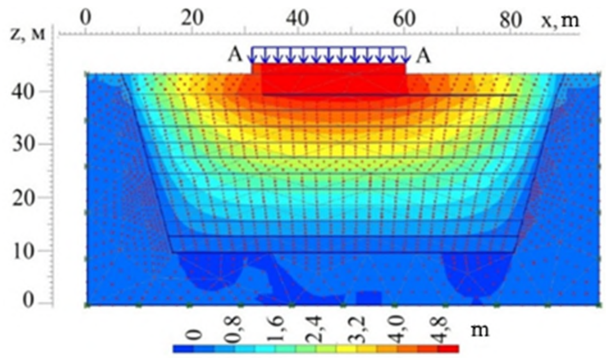

Fig. 2. Vertical deformations of the landfill with a vertical distributed dynamic load of 50 kPa (sand at the base).

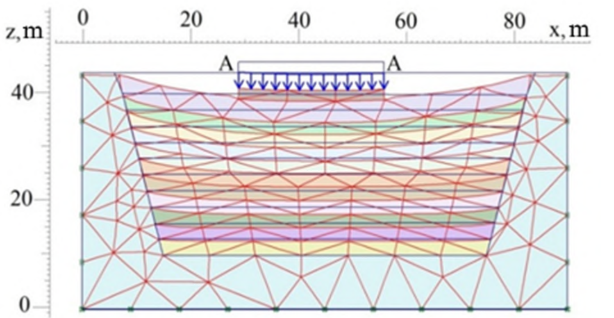

Fig. 3. Deformed calculation area of the landfill with a vertical distributed dynamic load of 100 kPa (sand at the base).

The landfill with sand as the base soil undergoes the greatest vertical deformations. The amount of sedimentation with the maximum load in relation to the subsidence without load is the largest in clay (28.7%), the minimum – in sand (18.6%). It is established that with increasing load from 5 to 180 kPa, the sedimentation increases by 1.2-17.4% for sand and by 2.5 - 21% for clay.

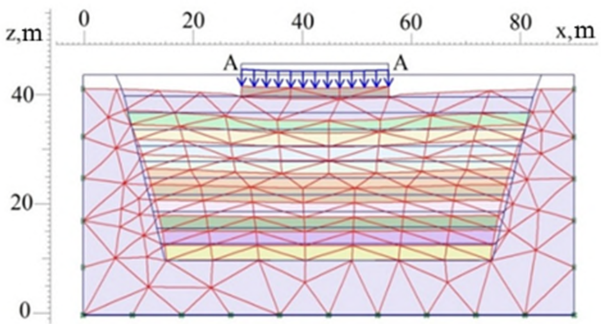

Fig. 4. Deformed calculation area of the landfill with a vertical distributed dynamic load of 100 kPa (clay in the base).

Analytical dependences of subsidence of the landfill with different underlying soils on the value of static loads (Fig. 5) are obtained:

for sand

$$y = 0{,}0243x^2 + 0{,}0686x + 3{,}79,$$

for loam

$$y = 0{,}0043x^2 + 0{,}2129x + 4{,}29\ ,$$

for clay

$$y = 0{,}0277x^2 - 0{,}008x + 4{,}945 \qquad (12).$$

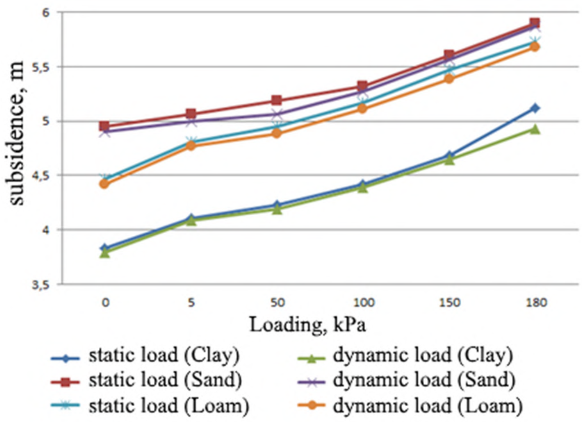

Fig. 5. Dependence of landfill subsidence with clay and sandy base soil on vertically distributed static [10] and dynamic loads.

Analytical dependences of subsidence of the landfill with different underlying soils on the value of dynamic loads (Fig. 5) are obtained:

for sand

$$y = 0{,}035x^2 - 0{,}0516x + 4{,}928;$$

for loam

$$y = 0{,}0068x^2 + 0{,}1922x + 4{,}266;$$

for clay

$$y = 0{,}0096x^2 + 0{,}1491x + 3{,}672. \qquad (13)$$

These dependences make it possible to predict the subsidence of landfills in order to assess their stability under static and dynamic loads of different nature: roads, highways and more.

For practical application of the worked out methodology the calculation of sinking was implemented on the example of landfill, located in Boryspil, Kyiv region.

A landfill was put into an operation in 2003 in accordance with a project in place of exhaust sand-pit, its area folds 6,5 hectare. The landfill's capacity of solid household waste was about 85 thousand tons per year. The total amount of waste is estimated in 0.723 million tons, the average depth is 18-20 m.

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Sediment is determined in landfill site (50x50 m), taking into account the step-by-step loading of the landfill with waste during 30 years after its closure, as approximately 90% of sediment occurs within the first five years and may continue for 25-30 years at a slower rate.

Clay and sand are in different parts of the landfill at its base. Modeling is performed for two options: with intermediate sand pouring every 3 m of waste and without it.

The calculated deformed area of the landfill with a clay underlying layer is presented in Fig. 6 and vertical deformations of the landfill with a sandy underlying layer is presented in Fig. 7.

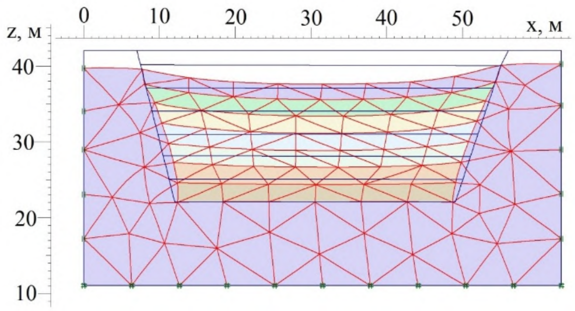

Fig. 6. Deformed calculation area of the landfill with a clay underlying layer.

From the analysis of numerical calculations it follows that the maximum vertical deformation at the clay base of the landfill is 2.27 m. In case of sand as the underlying layer, the deformation increases significantly up to 2.61 m.

It is found that at the landfill with overflow there are much smaller deformations compared to the landfill without overflow: 32% less at the landfill with a clay base, 30% less at the landfill with sand. Thus, if the underlying layer is clay (Fig. 8), then vertical deformations in 1.55 m are achieved, and in case of sand as the base (Fig. 9), – it is 1.82 m. The percentage of sediment to the height of the landfill is 14.2% and 15.26% respectively.

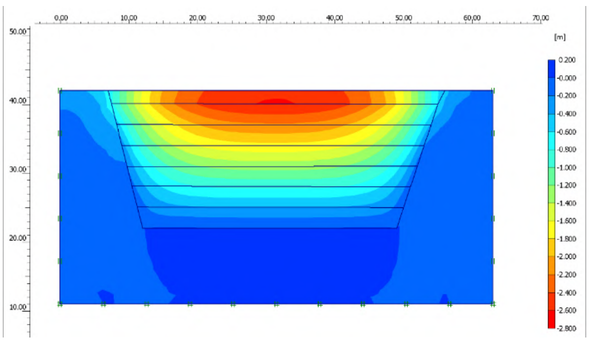

Fig. 7. Vertical deformations of the landfill with a sandy underlying layer.

It is established that at the same parameters of the landfill body during pouring, the landfill with a sand base is subject to greater sediment than the landfill with a clay base (13%). There is a significant effect of overflow on the amount of deformation. Thus, for the clay base the sediment increases by 32%, for the sand base – by 30%.

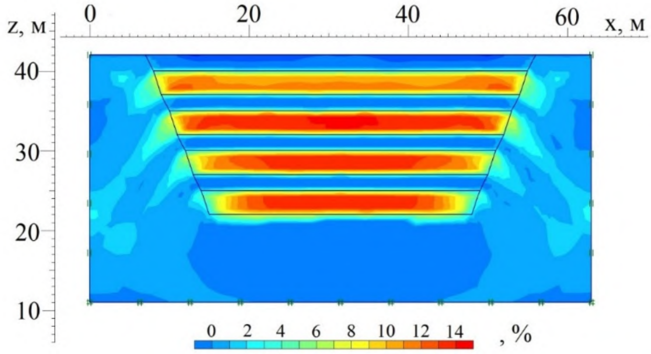

Fig. 8. Vertical displacements of the landfill with overflow and with a clay underlying layer (in percents).

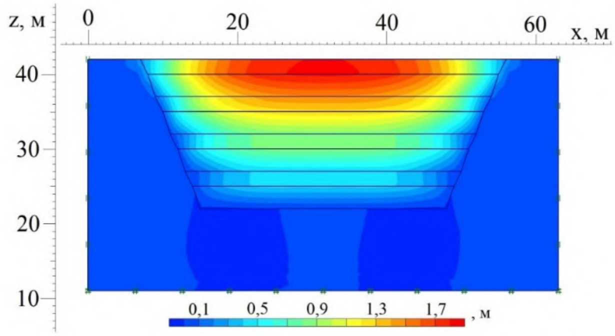

Fig. 9. Vertical deformations of the landfill with overflow and with a sandy underlying layer.

4 Discussion of the results of the research

As a result of numerical calculation, it is established that if the value of the vertical load is 50 kPa, it can be observed that deformations are achieved equal to 4.19 m for clay (Fig. 1) and 5.06 for sand (Fig. 2).

With an increase in the load up from 50 to 100 kPa, the sediment of the landfill with a sand base increases by 4.2% (5.27 m) (Fig. 3), with clay – by 4.8% (4.39 m) (Fig. 4).

It is established that at dynamic loads the underlying soils have a similar effect on the subsidence of the landfill, but the amount of subsidence is less than 0.5-4% depending on the underlying soil.

As it follows from Figure 5 the landfill with sand as the base soil is subjected to the greatest vertical deformations. However, in percentage, the amount of sedimentation with the maximum load in relation to the initial subsidence without load is the largest in clay and is 33.7%, the same figure in the sand – 19.2%.

It is established that in the landfill with overflow there are much smaller deformations compared to the landfill without overflow: 32% less in the landfill with a clay base, 30% less in the landfill with sand. Thus, if the underlying layer is clay (Fig. 8), then vertical deformations of 1.55 m are achieved, and if the base is sand (Fig. 9) – 1.82 m. The percentage of sediment to the height of the landfill is 14.2% and 15.26% respectively.

This is due to the fact that the more porous unstable soil of the sand base has reached the maximum subsidence in 30 years and is subsequently deformed to a lesser extent than the clay, which has not yet reached the final deformation. This established fact must be taken into account when designing and operating buildings for various purposes, built on closed landfills.

5 Conclusions

An effective method for calculating the sedimentation of natural and geoengineering environment on the example of a solid waste landfill, based on numerical modeling of the stress-strain state of the landfill and underlying soil using SSC models for the landfill and Coulomb-Mora for the soil base using finite elements is developed.

For the first time it is proposed to take into account the underlying soil when calculating the stability of the landfill, as it is one of the main factors in the formation of subsidence.

It is demonstrated that the largest subsidence is experienced by the landfill with sand, as the base soil, but in percentage terms the amount of subsidence with the maximum load relative to the initial subsidence without loading is the largest in clay (33.7%).

It is established that in the landfill with overflow there are much smaller deformations compared to the landfill without overflow: 32% less at the landfill with a clay base, 30% less at the landfill with sand.

The obtained results must be taken into account when using landfills as a basis for buildings, structures, routes, recreational areas, etc.

As a result of the research it can be concluded that in the preliminary planning of the landfill it is necessary to provide for the overlapping of landfill layers with soils to choose areas with denser underlying soil to be able to use it after closure as a foundation. If there has been no prior planning and / or the basis is weak soil, it is necessary to use different methods of compaction or use it with less load (parks, recreational areas, golf courses).

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Shifting consumers' sustainable behavior in the hospitality industry

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Abstract. Although research on hotel booking intention has been carried out in the last decade, the research that reveals the role of hotel reservation information through online consumer reviews in the millennial generation is still very rare. This study aims to determine the factors of online consumer reviews that affect hotel booking intentions for the millennial generation in Bali, Indonesia. This study uses a quantitative approach by distributing questionnaires to 385 respondents through a non-probability sampling technique, namely purposive sampling. The data analysis technique of this research is a multiple linear regression analysis processed using the SPSS 25.0 program. The results reveal that usefulness, timeline, and comprehensiveness have a significant effect on hotel booking intentions. Meanwhile, the volume of online reviews, the positive valence of online reviews, and the negative valence of online reviews are not significant for hotel booking intentions. The research findings reveal the characteristics of the millennial generation which are in line with the theory of reason action that they have their views in making decisions. The research implications are discussed in the paper.

1 Problem statement

Tourists traveling to Indonesia during 2019 were mostly young tourists aged 15-24 (24.2%), 25-34 years (15.3), and 35-44 years (18.8) (Central Bureau of Statistics) 2018) [1]. The increasing number of young tourists from year to year is the largest market segmentation for the hotel and tourism industry so it is important to understand the character and needs of these millennial travelers.

In making buying and selling transactions, the millennial generation has an interesting pattern. Where to purchase after reading reviews by searching for information through social media, e-commerce sites, or online travel agents. Due to the nature of product experience, online reviews have become an increasingly popular source of information in travel planning and have a major influence on consumer purchasing decisions, especially in hotel bookings [2].

Online reviews provide information about goods or services that are different geographically and have experience with the goods or services in question [3]. Consumers prefer to read reviews and recommendations from experienced customers before buying a product or service that significantly influences consumer buying decisions [4].

Online surveys are central in tourism, tourism sustainability in turn affects the environment and economies of countries, taking into account the needs of consumers and sustainable changes in consumer behaviour. Environmental factors in choosing a hotel do not play a key role in contrast to basic factors (such as location, price, etc.), but the development of green tourism over time should change this situation.

Due to the intangible nature of tourism products, prospective tourists buy hotel rooms that have a high level of risk and uncertainty [5-6]. Although the information guidance provided on the website is very limited, the role of information in decision making has not been studied much. Thus, hotels are expected to show uniqueness that is characteristic of increasing competitive advantage [7].

Before deciding to book a hotel room, consumers first seek information about the desired hotel either through family, friends, travel agents, or the Internet to help make decisions [8]. In the tourism industry, tourists rely on information whether it is obtained online or offline.

This study will try to close the existing research gap, namely, first, although several studies have identified the individual role of information cues, such as scarcity, popularity, and consumer ratings [9], research investigating the effect of different information is still scarce. Therefore, it is important to check which information clues (i.e. usefulness, timeline, volume, positive valence, negative valence, and comprehensiveness) have a significant influence on potential traveler booking intentions.

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The second gap is for tourists, searching for information via the Internet both from the official hotel website and online consumer review (OCRs) provides a lot of information. However, the online reviews that are presented have various characteristics, how online reviews are measured, both in quality and quantity, and how detailed and specific the information is uploaded on the website. This leaves tourists with many confusing perspectives [10]. As a result, hoteliers and travel agents are challenged to provide comprehensive facilities on online consumer reviews (OCRs), such as categorizing relevant OCRs to help consumers get the right information to make decisions.

The third gap is in the field of study relating to Indonesian millennial consumers, which is currently the largest target hotel market. Millennial consumer hotel reservation intentions have not been well researched, especially those influenced by online consumer reviews factors. Although millennial consumers are a very attractive consumer segment, not much research has been conducted on millennial consumer hotel booking behavior caused by online consumer reviews.

Based on this, it is important to conduct this research, which is to find out more details about which factors or attributes of OCRs can affect booking interest [11], especially consumers from the millennial generation, get a better experience when they look for relevant information about hotels that want to be visited and make it easier for them to make decisions. The effect is that the hotel manager or travel agent can implement a better marketing strategy, especially related to OCRs.

Online consumer review as a form of e-WOM have become an important factor in shaping consumer behavior. Through online reviews from other consumers, sharing review platforms can influence consumer buying interest [12, 13]. Online reviews have a positive and significant impact on hotel booking intentions so online reviews must be managed as a strategic communication channel [14].

2 Research methods

This research was conducted in Bali Province, Indonesia with respondents are the millennial generation, the generation aged 20 to 39 years, or those born in 1980-2000 [1]. The sample was determined using non-probability sampling, namely purposive sampling, that is the millennial generation, having or planning to book hotels, have read online reviews.

The reason for choosing the millennial generation is because it has a strong potential to read online consumer reviews first before booking a hotel according to the theory of experts, is a productive age group (15 - 64 years) to book high hotels, read online hotel reviews and conduct hotel booking. The data collection technique of this research is through distributing questionnaires with a Likert scale of 1-5, which were analyzed by multiple linear regression analysis.

The methods of questionnaires of hotel services customers and analysis are used in the research and they show that consumer resilience don not reflect the primary importance for OCRs, since most online reviews do not contain information stability and do not influence hotel booking, unlike other factors that are detailed in the article.

3 Literature review

The usefulness of an online review refers to the quality or level of usefulness of an online review. Park and Lee [15] suggested that usefulness is how far consumers believe online reviews will facilitate their purchasing decision-making process. An online review will have a useful value for consumers if it contains additional information that contains information that is relevant, useful, neutral in nature, and comes from the perspective of consumers Abdullah et al. [16]. One of the reasons travelers look for information about hotels online is to plan their trip, so they need precise information that can describe hotel conditions based on previous consumer experiences. This is an organizational competitive advantage through the dissemination of appropriate information [7].

H1 = Usefulness of online review has a significant positive effect on hotel booking intention

Timeline refers to "whether the message is current, timely and up to date" Cheung et al. [17]. During the process of searching for information, consumers may be faced with relevant information but in large quantities and originate from different times. Thus, the website must be updated on an ongoing basis to provide useful information for consumers/users. The results also reveal that in the current e-commerce era, the most recent product reviews will get more attention from users [18]. Consumers will follow the latest news developments from hotels of interest through OCR or hotel social media. , the latest information will describe the current condition of a hotel which can affect the purchase decision [19].

H2 = Timeline of online review has a significant positive effect on hotel booking intentions

Review volume refers to the number of reviews that a product or service gets from reviewers of Davis and Khazanci [20]. The number of reviews given by reviewers is another attribute of the word of mouth because it displays reviews from different reviewers. The higher the volume of reviews, both positive and negative reviews, in the context of online communication, this will attract the attention of information seekers which can then increase product awareness [21].

H3 = Volume of online reviews has a significant positive effect on hotel booking intentions

Online positive reviews are a form of response that usually can be in the form of recommendations from consumers for their satisfaction with the services they received previously. Previous research has highlighted the importance of customer recommendations in the context of service delivery, as it has been illustrated empirically that one recommendation can be sufficient to convince someone to try a recommended service provider [22]. Reviews with a very positive rating will lead to significant growth in product sales (Clemons et al. (2006) [23]. Consumer purchase intentions increase if the quality of reviews is maintained. The more quantity of positive reviews, the more likely it is to influence consumers to book hotels [24].

H4 = Positive valence of online review has a significant positive effect on hotel booking intentions

Several researchers have analyzed the negative impact of online reviews on hotel bookings and found that a large number of negative reviews on a hotel lead to negative attitudes towards hotel bookings [25]. Negative reviews are generally written in response to consumer dissatisfaction which can harm business [26] because it is considered to be more dangerous than complaints and complaints, which are largely invisible. goods [15]. The results of other studies reveal that negative online reviews can reduce consumer attitudes towards hotels that are in demand, although online negative reviews will be able to increase their consumers' awareness of that hotel [25].

H5 = Negative valence of online review has a significant negative effect on hotel booking intentions

The completeness features in the online review have a relationship with the online review recommendation itself and are an advantage in being able to measure how detailed and complete a review is [17]. For consumers, especially the first When going to make a purchase, it certainly requires complete information about the product or service to be used and as a basis for deciding whether to purchase or not, which means that the detailed and comprehensive features of online reviews have a significant contribution to consumer hotel booking intention [27] Another study stated that online review completeness is one of the most effective elements of online posting in terms of the extent to which people are willing to accept and adopt online reviews, as well as the factors that drive adoption [17].

H6 = Comprehensiveness of online review has a significant positive effect on hotel booking intentions.

4 Results of research

Before distributing the questionnaires, the first 30 respondents tested the validity and reliability. After that, the questionnaire was distributed via google forms, and distributed via email, social media by including a cover letter about this research. From 385 data obtained for approximately 9 months (September 2019- May 2020), information was obtained that as many as 63% of respondents were women and 37% of respondents were men. The age category ranges from 20-24 years (43.4%), 25-29 (36.4%), 30-34 years (16.9%) and 35-39 (3.4%). Besides, 3-star hotels dominate the respondents' choices for the category of hotels that are preferred and often chosen when traveling with a percentage of 43.6%, 4-star hotels (29.8) and 5-star hotels (26.6) (see Table 1).

Table 1. Demographic of respondents (*n*=385)

Criteria	Amount	Percentage
Gender		
Male	143	37
Female	242	63
Ages		
20-24	167	43,4
25-29	140	36,4
30-34	65	16,9
35-39	13	3,4
Hotel Classification		
3*	168	43,6
4*	115	29,8
5*	102	26,6

4.1 Classic assumption test

The normality test is carried out to find out whether the data to be used is normally distributed or not. The results of the normality test are seen from the Asymp value. Sig. (2-tailed) of 0.761, which exceeds the value of the level of significance of 0.05, so it can be concluded that the data in this study were normally distributed.

Tabel 2. Heteroscedasticity and multicollinearity test.

Model	Sig.	Tolerance	VIF	Remarks
(Constant)				
Usefulness of online review (X_1)	0,138	0,877	1,140	Free
Timeline of online review (X_2)	0,965	0,930	1,075	Free
Volume of online review (X_3)	0,862	0,920	1,087	Free
Positive valence of online review (X_4)	0,773	0,942	1,062	Free
Negative valence of online review (X_5)	0,142	0,907	1,102	Free
Comprehensiveness of online review (X_6)	0,074	0,942	1,061	Free

A heteroscedasticity test is performed to test whether the regression model has inequality of variants from the residuals of one observation to another (see Table 2). The heteroscedasticity test was tested using the Glejser test, namely by regressing the absolute residual value on the independent variable. The significance value of the variable usefulness (0,138), timeline (0,965), volume (0,862), positive valence (0,773), negative valence (0,142), and comprehensiveness (0,074) is greater than 0.05. This means that there is no influence between the independent variables on absolute residuals so that the model made does not contain symptoms of heteroscedasticity.

Multicollinearity (see Table 2) between independent variables does not occur if they have a VIF of less than 10 and a Tolerance number of more than 0.1. The results show that the tolerance values for the usefulness variables (1.140/0.877), timeline (1.075/0.930), volume (1.087/0.920), positive valence (1.062/0.942), negative valence (1.102/0.907), and comprehensiveness (1.061/0.942) are greater than 0.1 and have a VIF value that is smaller than 10, so it can be said that there are no multicollinearity symptoms in this study.

4.2 Multiple regression analysis

Multiple regression analysis is used to examine the effect of two or more independent variables on the dependent variable. The independent variables in this study are the variable usefulness (X_1), timeline (X_2), volume (X_3), positive valence (X_4), negative valence (X_5), and comprehensiveness (X_6). Meanwhile, the dependent variable is hotel booking intentions. Based on the results of the multiple regression test in Table 1, the multiple linear regression equation in this study is as follows.

$$Y = 0{,}796 + 0{,}272\ X_1 + 0{,}183\ X_2 - 0{,}068\ X_3 + 0{,}096\ X_4 - 0{,}055\ X_5 + 0{,}189\ X_6 + e \quad (1)$$

Table 3. Multiple regression analysis.

	Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	0,796	0,439		1,820	0,072
	Usefulness[X_1]	0,272	0,057	0,246	4,904	0,000
	Timeline[X_2]	0,183	0,055	0,166	3,402	0,001
	Volume[X_3]	-0,068	0,062	-0,058	-1,128	0,261
	Positive Valence [X_4]	0,096	0,048	0,097	1,955	0,054
	Negative Valence [X_5]	-0,055	0,046	-0,062	-1,209	0,229
	Comprehensiveness [X_6]	0,189	0,053	0,178	3,719	0,000
R Square		0,158				
Adjusted R Square		0,145				
F value		11,688				
Sig. F		0,000				

In Table 3 information is presented that the adjusted R Square value is 0.145 which means that 14.5% of hotel booking intentions variations can be explained by the variables usefulness, timeline, volume, positive valence, negative valence, and comprehensiveness, while the remaining 85.5% is explained by other factors beyond this research model. The significance value of F is 0.000. The significance value is lower than the value of $\alpha = 0.05$. This means that the research model involving usefulness, timeline, volume, positive valence, negative valence, and comprehensiveness variables is feasible to estimate hotel booking intentions variables.

4.3 Hypotheses testing

Hypothesis testing as presented in Table 3 explains that the usefulness variable of the Sig. 0.000 is smaller than $\alpha = 0.05$ with a positive regression coefficient of 0.272. This shows that the usefulness variable has a significant positive effect on hotel booking intentions so that H_1 is accepted. This shows that the higher the usefulness of online reviews, the more interest in hotel bookings will be. The usefulness of online review will be considered important and useful if the information submitted in the OCR is related to the hotel, the content is reliable, neutral and reflects the reviewer's heart, according to experience, presents useful information, is related to the hotel, is not confusing and impartial. The results of this study are in line with the research [27, 28] that the usefulness of online reviews has a positive effect on hotel booking intentions.

The timeline variable is Sig. 0.001 is smaller than $\alpha = 0.05$ with a positive coefficient of 0.183. This shows that the timeline variable has a significant positive effect on hotel booking intentions so that H_2 is accepted. This shows that the more up to date an OCRs will increase interest in hotel bookings. This condition illustrates that consumers are very concerned about uploading reviews, loading the latest information, following the latest news developments that affect purchasing decisions [19]. This is in line with what was stated by Jindal and Liu [18] who found that in the current e-commerce era, the latest online reviews will get more attention from other consumers. Consumers will get information about the development of hotel services through OCRs, which has been around for a long time. As for the company, this will help build the company's reputation in terms of responsiveness when answering consumer reviews. The results of this study support the research of Zhao et al. [27] that the timeline has a significant effect on consumer interest in hotel booking intentions.

The volume variable (X_3) is the Sig. 0.261 is greater than $\alpha = 0.05$ but the negative coefficient value is -0.068. This shows that the volume variable has a negative and insignificant effect on hotel booking intentions, so H_3 is rejected. This means that the number of online consumer reviews (OCRs) cannot increase interest in hotel bookings. Respondents assumed that the amount of OCRs does not guarantee the information that is informative, original, and following consumer expectations. On the other hand, consumers often only read a portion of reviews before deciding to purchase because they are more focused on new reviews [30]. Another factor is opinion leadership where consumers do not care or pay much attention to volume but rather trust the opinions of influential people [20]. The findings of this study confirm the characteristics of the millennial generation who are more easily influenced by the opinions of influential people such as the public figure.

The positive valence variable is Sig. 0.054 is greater than $\alpha = 0.05$ and the regression coefficient is positive at 0.096. This shows that the positive variable has a positive but insignificant effect on hotel booking intentions, so H_4 is rejected. Positive comments written by reviewers are a response to the satisfaction of the service received but unable to attract online bookings. The results of the study contradict the results of the research of Tsao et al. [3] who found that reading positive comments has a strong influence on booking intentions.

This condition can occur because positive valence expresses subjective opinions so that consumers do not pay attention to the number of positive reviews. Besides that, the number of positive online consumer reviews that is too much can also cause doubts to consumers about the credibility of the online consumer reviews. This may be caused by companies that pay reviewers to write reviews according to the company's wishes to help their sales [30], where the valence of these reviews can be adjusted according to the seller's needs. The results of this study refute the results of the study by Tsao et al. [3] that positive reviews are the most influential in determining interests and attitudes to decide [34].

The negative valence variable is Sig. 0.229 is greater than $\alpha = 0.05$ and the negative regression coefficient value is -0.055. This shows that the negative valence variable has no significant effect on hotel booking intention, so H_5 is rejected. This shows that negative valence does not affect hotel booking intentions. Negative reviews are a response to dissatisfaction with the service perceived by consumers and have a negative impact on business interests [26] so that these negative comments can be handled properly, it will increase room bookings/hotel room sales [32-35].

The variable comprehensiveness value is Sig. 0.000 is smaller than $\alpha = 0.05$ and the regression coefficient value is positive 0.189 so that H6 is accepted. This shows that the more complete and detailed the contents of an online consumer review (OCR) will increase interest in hotel bookings. When consumers are unfamiliar with a product/service, consumers will need more detailed and specific information to help them make decisions [32].

Consumers are more interested in a complete and detailed OCR which contains information such as the experience of staying, reviews of the hotel's superior facilities, information about the location, prices, and services provided by the hotel based on the customer's perspective. Consumer behavior should be aimed at achieving more sustainable results and achieving sustainable consumer behavior, which includes simplification of consumption [31-33]. This means that the assessment from the reader side is an important indicator in decision making [2] because it is proven that comprehensiveness of online reviews is an important attribute among the attributes of OCR that can influence consumer purchase interest [17, 27].

5 Conclusion

Theoretically, the results of this study add to the body of knowledge in the hotel booking intentions literature while closing the research gap. First, that the model formed from the variable usefulness, timeline, volume, positive valence, negative valence, and comprehensiveness contributed significantly to online booking intention in industrial hotels.

The results of this study also succeeded in closing the second gap in how hotel websites and online travel agents paid high attention to the quantity, quality and detail of information so as to present comprehensive and not confusing information. This information provides an important impact on how consumers take attitudes and determine decisions for hotel bookings. Last, to closing the third gap, the results of the present study also provide insight that the behavior of the millennial generation is unique, a characteristic that is aware of technology and tends to follow leadership opinions from influential figures. The results of the study illustrate that OCR has a significant effect on the online booking intentions of hotels. Overall, our findings show that the perspective of the millennial generation is important in considering hotel booking intentions.

Given the complexity of the online environment, several variables may influence the intentions to purchase online. The theory of reason action (TRA) provides a structure for the model adopted in this study and helps to focus on the main antecedents of online ordering intentions. TRA is one of the most widely used theories for predicting attitude-behavior relationships and has been widely adopted in tourism studies. The concept underlying TRA is that individuals evaluate the implications of their reasoned actions before they decide to engage in certain behaviors. In particular, this theory proposes that behavioral intentions is the main element responsible for consumer behavior.

Managerially, managers can carry out strategies at two levels, namely, at the individual level, by increasing knowledge sharing between units that manage the website so that it becomes more innovative, creative, up to date and interesting. managerial is by implementing:

1) adding the usefulness voting feature of existing online reviews, so that readers can judge which reviews they think to help their information search process;

2) use review categories by entering the time sequence category to display the latest reviews from reviewers;

3) hotel managers or travel agents are advised not only to focus on a large number of reviews but also pay attention to the quality and valence (positive or negative) of online reviews;

4) pay more attention to negative reviews or complaints from consumers;

5) provide information in the form of a summary from written reviews, such as graphic information that shows the percentage of reviewers who said they were satisfied with hotel services and other information.

Because millennial consumers tend to rely on categorical information because it is simple and easy to understand, the effect is that organizations have a culture of innovation to be able to maintain competitive advantage through the continuous system and website updates.

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Ensuring sustainable development of enterprises in the conditions of digital transformations

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Abstract. Modern enterprises are dynamically developing due to the fourth industrial revolution, contributing to the introduction of innovative infocommunication technologies in most business processes, thereby shaping and developing the digital economy. The aim of the article is to substantiate the concept of sustainable development of enterprises in the context of digital transformations. The theoretical and methodological foundations of sustainable development at different levels of the hierarchy have been determined. The concept of sustainable development of enterprises has been developed, the implementation of which is aimed at harmonizing the economic, environmental and social activities of the enterprise. The stages of the process of implementing the concept of sustainable development of enterprises are highlighted, providing for the justification of an inert, neutral, progressive or forced vector. Ensuring the implementation of the concept of sustainable development is expected through the use of applied models, in particular, the implementation of a parametric model of joint deployment of enterprise infrastructure with other infrastructure facilities in economic activity, taking into account technical, geographical, organizational and socio-economic factors to strengthen financial stability; building a model for ensuring a balanced balance between economic efficiency and environmental and social responsibility of an enterprise using a mechanism for managing transformation processes in the process of transition to sustainable development in the context of digitalization.

1 Introduction

Modern enterprises are dynamically developing due to the fourth industrial revolution, contributing to the introduction of innovative infocommunication technologies in most business processes. Given the conditions for the transition of the Ukrainian economy to a digital development strategy, where the main driving force is digital trends, smart products and services, the issues of sustainable development of enterprises are being actualized. The implementation of the concept of sustainable development of enterprises is due to the constantly growing needs of consumers of telecommunications services in the global digital revolution, the need to comply with the goals of sustainable development of Ukraine, modification of the economic, social and environmental activities of enterprises.

Therefore, there is a scientific and applied problem of theoretical substantiation, methodological support and practical implementation of the process of sustainable development of enterprises for their harmonized evolution, reducing the existing digital divide and the qualitative development of the economy in the context of digital transformations.

2 Analysis recent research and publications

The possibility of enterprises' transition to sustainable development is associated with the solution or mitigation of a number of fundamental contradictions between the interests of the world community, the interests of individual countries and regions, national-state interests and the interests of enterprises in various spheres of economic activity. Therefore, such a transition requires the formation of effective models or mechanisms for ensuring sustainable development of enterprises [1-3].

The theoretical aspects and practical approaches to the essence of the balanced development of enterprises, the prerequisites for the transition to sustainable development, the problems of ensuring the social and environmental responsibility of enterprises, the directions for ensuring the sustainable development of economic systems are devoted to scientific works: K. Andriushchenko, A. Buriachenko, O. Rozhko et al. [1],

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R. Sharma, A.-R. Fantin, N. Prabhu, C. Guan, and A. Dattakumar [2], J. Mao, C. Li, Y. Pei, L. Xu [3], Y. Zaloznova, N. Trushkina [4], T. Osburg, C Lohrmann [5], I.W.E. Arsawan et al. [6] and others. Paying tribute to the importance of scientific achievements of foreign and domestic scientists, it should be noted that the issues concerning the features of ensuring sustainable development of enterprises in the context of digital transformations remain insufficiently studied. The complex and multifaceted issue of ensuring sustainable development of enterprises should be investigated on the basis of economic efficiency and environmental and social responsibility.

3 Methods

The conceptual and methodological basis of the work is formed by the fundamental provisions of foreign and domestic scientists on the theory and practice of the concepts of sustainable development of enterprises. The study is based on a set of general scientific and special methods of cognition of the theoretical, methodological and conceptual foundations of sustainable development of enterprises: The article uses methods of dialectical cognition, generalization, scientific abstraction, formalization of structures and a system-situational approach in substantiating the concept of sustainable development of enterprises in the context of digital transformations through the definition of a set of prerequisites, motives and goals for the transition to this concept.

The aim of the article is to substantiate the concept of sustainable development of enterprises in the context of digital transformations.

4 Results

The globalization ecological transformations of the last century made it possible to understand that society has overcome the permissible ecological boundaries and, over time, human dependence on the laws of the biosphere is increasing, which affect the use of natural resources, the course of the ecological and social crisis [7-8].

With the beginning of the development of digital technologies and the formation of the digital economy, a new round of globalization transformations began, based on electronic products, the sale of which is carried out by a network of business entities through the flow and process of "digitizing" objects and the creation and exchange of digital assets (virtual assets) using electronic means, which are the backbone of the digital economy. The activities of business entities are subject to significant perturbations of the rapidly changing states of international markets, since the impact of globalization and digital transformations is directed not only to the microeconomic systems themselves, but also to the existing and emerging interconnections between them, leading to their unpredictable behavior [9].

The ICT development index (IDI) [10] has been used to measure the information society in the world for over 10 years 66; it is intended to be global and reflect changes in countries with different levels of development (Table 1, Table 2) and is a composite an index that combines 14 indicators (covers 81 indicators for telecommunication / ICT services).

Table 1. Dynamics of the ICT Development Index according to ITU regions and countries with different levels of development (based on data from [10]).

Regions	Years				
	2013	**2014**	**2015**	**2016**	**2017**
IDI by ITU Region					
Africa	2,31	2,31	2,30	2,48	2,64
South and North America	4,86	4,88	4,89	5,13	5,21
Arab countries	4,55	4,59	4,63	4,81	4,84
Asia and the Pacific	4,57	4,46	4,35	4,58	4,83
CIS	5,33	5,45	5,56	5,74	6,05
Europe	7,14	7,17	7,19	7,35	7,50
IDI by countries with different levels of development					
World	4,77	4,76	4,74	4,94	5,11
Developed countries	7,20	7,23	7,25	7,40	7,52
Developing countries	3,84	3,85	3,85	4,04	4,26
Least developed countries	–	–	–	2,07	2,2

Table 2. ICT development index of some countries of the world (based on data from [10]).

Countries	Years			
	2014	**2015**	**2016**	**2017**
Iceland	8,74	4,86	8,78	8,98
Hong Kong, China	8,50	8,52	5,47	8,61
Korea	8,90	8,93	8,80	8,85
Netherlands	8,47	8,53	8,40	8,49
Switzerland	8,32	8,56	8,66	8,74
Norway	8,44	8,49	8,45	8,47
Denmark	8,87	8,88	8,68	8,71
Luxembourg	8,44	8,59	8,40	8,47
Great Britain	8,60	8,75	8,53	8,65
Japan	8,38	8,47	8,32	8,43
France	8,01	8,12	8,05	8,24
Belarus	7,03	7,18	7,29	7,55
Russian Federation	6,82	6,91	6,91	7,07
Georgia	5,02	5,25	5,59	5,79
Ukraine	5,18	5,23	5,31	5,62

IDI as a comprehensive indicator measures the level and evolution of ICT development in countries to build a ranking of countries and is used as a tool for comparative analysis of progress in ICT development, digital divide etc. [10]. That is, IDI can be used as an indicator for determining the information technology support of business entities.

The IDI is on the rise in many countries, but the constraints are the link between levels of ICT development and income levels, which requires better government policies and legislation for developing countries to stimulate competition and promote foreign direct investment.

Considering the convergence of communications and informatics, which led to progressive changes both in the production and consumption of goods and services, it provided a new stage in the development of not only all sectors of the national economy and relevant economic entities, but also social life in various directions.

Infocommunications have a system-forming role in the formation of a single digital economy and ensuring sustainable development of enterprises in various spheres of economic activity. At the same time, considerable attention should be paid to the issues of ensuring the sustainable development of these enterprises from the standpoint of their compliance with the global and national strategic goals for sustainable development.

For the first time, the UN was engaged in the search for ways out of the crisis and determination of the further movement of civilization, created the International Commission on Environment and Development in order to develop a “global program of changes”, which pointed out the connection between economic and social development problems with environmental problems.

At the same time, an important contribution was made by the scientific reports of the Club of Rome, which formulated the ideas of the transition of civilization from exponential economic growth to a state of “global dynamic equilibrium”, from quantitative to qualitative growth and a “new world economic order.”

All this served to form a new the institutional component – the ministries and departments responsible for environmental policy and the environment. As a result, there was a large-scale spread of “sustainable development” in order to long-term satisfaction of basic needs with the rational use of natural resources and formations go down to 2030, within which 17 Sustainable Development Goals Based on the principles of sustainable development defined by these documents, the world has begun the process of approving its own program initiatives to ensure it, taking into account national characteristics.

In Ukraine, the processes of forming a regulatory framework on environmental policy and ensuring sustainable growth began with the adoption of certain legislative initiatives in the field of environmental protection. Important legal documents in this direction are the Concept of Sustainable Development of Human Settlements, according to which socially, economically and environmentally balanced development of urban and rural settlements is assumed, and the Comprehensive Program for the Implementation of Decisions at the National Level was adopted directly. It should also be noted the approval of the National Action Plan for Environmental Health for 2000-2005, the Program for the Use of Production and Consumption Wastes for the Period until 2005, the Ukraine-EU Action Plan, which contains important initiatives to harmonize Ukrainian legislation with norms and standards. EU, ensuring the country's economic, social and environmental growth, and then the National Environmental Action Plan for 2011-2015. and a range of other fragmented initiatives towards environmental and social sustainability.

In addition, several legislative attempts were made to approve the concept of sustainable growth in Ukraine, in particular in 2001, 2004 and 2012. Now the achievement of balanced sustainable growth is identified as a strategic development priority both at the level of the national economy and regional and business ecosystems. Therefore, at the state level, the strategic guidelines for the balanced development of the country are outlined in the Sustainable Development Strategy “Ukraine 2020”, which defines the implementation of 62 reforms and development programs of the state within four vectors of movement: development, security, responsibility and pride. It should also be noted on the Concept of Ukraine’s transition to sustainable development, the purpose of which is to ensure a high quality of life for current and future generations based on a balanced solution to the problems of socio-economic development, preservation of the natural environment, rational use and reproduction of the state's natural resource potential. The modern transformation of the Ukrainian economy in the process of integration into the world society and the country's active participation in globalization processes necessitate a balanced development of domestic enterprises based on the preservation of their structural features, potential and capacity. This requires the participation of various stakeholders and stakeholders in order to develop balanced consumption in view of the principles of consistency and the like.

4.1. Justification of the concept of sustainable development of enterprises in the context of digital transformations

The content of the concept of sustainable development of an enterprise should be formed on the basis of a system-process approach. It should be based on the synthesis of three basic components: economic, social and environmental, and represent a model of economic growth of an enterprise, in which the use of resources is aimed at meeting the needs of the enterprise while ensuring a stable balance of the socio-ecological-economic system (Fig. 1).

The general idea of the concept is the sustainable development of the enterprise (SDE), the object is the economic, environmental and social activities of the enterprise, and the subject is the management system for the economic, environmental and social development of the enterprise under the influence of external and internal factors. At the same time, the paradigm is the provision of sustainable development of the internal and external environment through the harmonization of economic, environmental and social activities through the phased implementation of the concept in order to substantiate the development vector and its most overwhelming trajectory.

Since the concept is a systematization of all generated ideas for understanding the development and has to answer the question of how to achieve the general idea, it is advisable to present the process of its implementation, consisting of the following stages [11-13]:

1. Determination of the regulatory and information base regarding the legal framework and strategy of the country for the transition to sustainable development, the main trends in the world of enterprise development in the use of digital technologies.

2. Identification of factors of positive and negative influence on the activities of the enterprise of the processes of globalization and identification of existing problems in ensuring sustainable development.

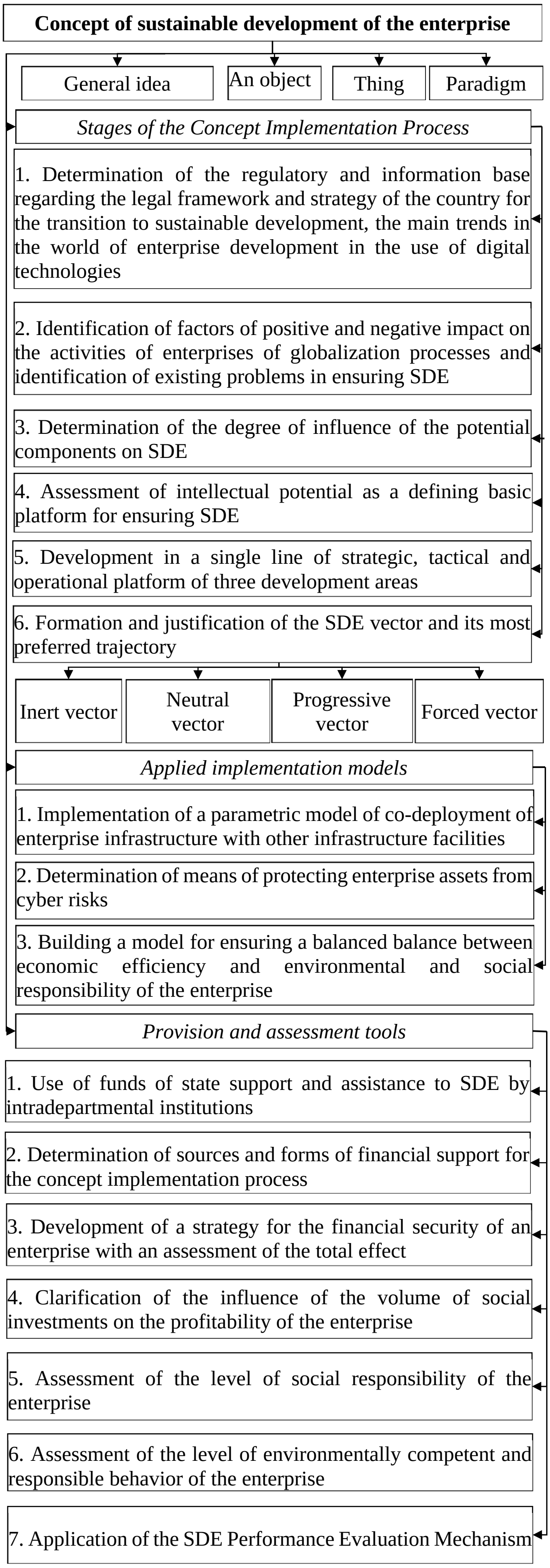

Fig. 1. Concept of sustainable development of the enterprise.

3. Determination of the degree of influence of the components of the potential on the sustainable development of the enterprise to determine the synergistic effect of sustainable development, taking into account digital transformations and the uniqueness of the communication and informatization sphere, taking into account the degree of economic, environmental, social, technological and intellectual potential. This analysis provides background information for identifying the benefits of the current state of the enterprise and modeling future states in a space-time aspect.

4. Assessment of intellectual potential as a determining base platform for ensuring sustainable development of the enterprise.

5. Development in a single channel of a strategic, tactical and operational platform of three directions of development – economic, environmental and social with modeling of possible states: the potential for survival, the potential for sustainability and development. They should provide for a set of strategic and tactical measures to implement the transition from an initial level to a new quality one in accordance with the chosen vector along a certain trajectory.

6. Formation and substantiation of the vector of sustainable development and its most overwhelming trajectory, that is, the direction of the enterprise. Sustainable development of an enterprise as a projection of its goals and capabilities in the context of the need to adapt to transformational changes can occur by:

– the inert vector, which is characterized by the situation of resistance to the process of sustainable development of the enterprise from the stakeholders of the near and far circle, consists in reducing the performance indicators of the enterprise, weakening the internal and external positions, the significant influence of unfavorable factors requiring immediate elimination of threats and restoration of the dynamic consistency of business processes

– a neutral vector, which can be considered as a transitional / waiting state in the short term for the formation of the necessary basis for further development, which is characterized by a controlled delay in development and a local concentration of the enterprise's activities aimed at forming sufficient financial support for the implementation of appropriate social and environmental investments;

– a progressive vector, is determined by the transition to frontal development, which provides for both economic development and fundamental socio-ecological development and covers various functional subsystems of the enterprise, based on the intensification of the use of the development basis, maximum use of existing opportunities in order to gradually achieve hierarchical strategic goals and the formation qualitative potential state;

– a forced vector, which provides for the transition to a comprehensive sustainable development of the enterprise, aimed at ensuring, maintaining and maintaining the balance of qualitative development in order to repel negative and absorb positive impulses from the external environment with the aim of further sustainable functioning and performance of economic, social and environmental functions within the formed harmonious space by focusing the enterprise not only on internal business processes and building internal potential, but also on ensuring the development of society.

Determining the trajectory of the enterprise's development allows us to find out how realistic it is to approach the upper limit of dynamic equilibrium in the process of enterprise development, for which it is necessary to establish a list of economic, social and environmental measures that contribute to this, without losing stability and reducing the level of security of the enterprise (staffing, information protection). The plane of socio-ecological and economic sustainability changes in the process of enterprise development, providing the necessary level of flexibility and adaptability, which is due to the variability of external and internal conditions of functioning. The concept of sustainable development of the enterprise provides for the implementation of applied models in the activities of the enterprise, in particular [14-16]:

1. Implementation of a parametric model of joint deployment of enterprise infrastructure with other infrastructure facilities into economic activity, taking into account technical, geographical, organizational and socio-economic factors to strengthen financial stability and security.

2. Determination of means of protecting enterprise assets from cyber-attacks (based on the identification of the most vulnerable assets and the formation of a matrix for systematizing cyber threats by determining the degree of cyber-attacks.

3. Building a model for ensuring economic efficiency and environmental and social responsibility of an enterprise using a mechanism for managing transformation processes in the process of transition to sustainable development in the context of digitalization of activities.

4.2 Implementation and assessment tools

The tools for ensuring the implementation of the concept and assessing its effectiveness are:

1. Use of funds of state support and assistance to sustainable development of enterprises by intradepartmental institutions. Support and promotion of sustainable development by enterprises should take place on the principles of public-private partnerships to form social dialogue, the widespread introduction of corporate social responsibility, which, in turn, will facilitate effective cooperation and fulfillment of obligations to ensure sustainable consumption and production. That is, government regulation should stimulate the activation and actualization of the use of all types of available resources, revealing modern potential market and social opportunities, organizing stimulating conditions for intensification, maintaining a favorable environment for increasing the efficiency of business and improving the quality of services provided [17].

2. Determination of sources and forms of financial support for sustainable development of enterprises. The sources for the implementation of the concept can be as own financial resources: profit, income, depreciation charges, insurance funds; and attracted financial resources on various terms of return: credit funds of financial institutions and other organizations, issue of shares, investments, sponsorship; while the forms of financial support can be external financing and self-financing. Financial support for the sustainable development of enterprises should occur through constant analysis of the compliance of the financial condition of the enterprise with a certain plane of sustainable space. The choice of each source and form of financial security must be justified in accordance with its characteristics, taking into account the disadvantages and advantages that can significantly affect the functioning of the enterprise. Depending on the vector of development and its trajectory, the volume of each source of financing will change in the total volume of financial resources of the enterprise.

3. Development of a strategy for the financial security of an enterprise with an assessment of the total effect of its implementation. Financial resources are one of the basic conditions for ensuring sustainable development of the enterprise and the formation of positive results of its functioning. Therefore, the existence of an effective financial security strategy that will protect the enterprise from threats requires careful consideration by the enterprise. The strategy of the economic security of the enterprise is an integral part of the formation and implementation of the general strategy of the enterprise development, since it is responsible for the goals, directions, sources and objects of financing. It provides all the main directions of the development of financial activities and financial relations of the enterprise.

4. Clarification of the influence of the volume of social investments on the profitability of an enterprise in order to form more perfect and effective ways to increase the competitiveness of enterprises and their value.

5. Assessment of the level of social responsibility of an enterprise involves taking into account the basic, corporate and higher levels of social responsibility in order to determine the effectiveness of the path of social investment.

6. Assessment of the level of environmentally competent and responsible behavior of the enterprise, taking into account the management's policy in helping to maintain the desired state of the environment by: implementing measures aimed at motivating changes in the behavior of its stakeholders, aimed at reducing the negative impact on the environment and human health; search for solutions that do not contradict the goals of sustainable development of the country.

7. Application of a mechanism for assessing the effectiveness of sustainable development of an enterprise in the context of digital transformations, based on the principles of building neural networks and aimed at determining the generalized multiplier of the effectiveness of sustainable development of an enterprise.

Thus, the scientific and practical meaning of the concept of sustainable development based on the system-process approach is substantiated, it is contained in the triad “existing initial state – development potential – change in the qualitative state” and makes the management of individual subsystems of enterprise development, constitute a single integral socio-ecological economic system of sustainable development [18-19]. This approach will optimize the methods and tools used, increase adaptability to fluctuating conditions, and will also serve as a guarantee of responsibility to the owners of the enterprise (receipt of dividend income), employees (a decent level and timeliness of remuneration, career growth, socio-cultural development), partners (successful and effective long-term cooperation), local and state authorities (ensuring long-term development and participation in charitable events in the regions of presence, replenishing the budget with tax revenues), as well as consumers (ensuring and raising people's awareness of the possibilities of using IT services, promoting the popularization of services, training citizens, environmental and socially responsible business) [20].

5 Conclusions

Using the system-process approach as a scientific basis, the content of the concept of balanced development, taking into account the peculiarities of the activities of a telecommunications enterprise, is generalized, based on the synthesis of three basic components: economic, social and environmental, and is aimed at ensuring their harmonization. The process of implementing the concept is aimed at choosing the most optimal (in existing conditions) trajectory of balanced development, is selected from inert, neutral, progressive, forced vectors. The concept of balanced development of enterprise is implemented through the use of applied models and tools to ensure and assess the effectiveness of sustainable development. Ensuring the implementation of the concept of sustainable development is expected through the use of applied models, in particular, the implementation of a parametric model of joint deployment of enterprise infrastructure with other infrastructure facilities in economic activity, taking into account technical, geographical, organizational and socio-economic factors to strengthen financial stability; building a model for ensuring a balanced balance between economic efficiency and environmental and social responsibility of an enterprise using a mechanism for managing transformation processes in the process of transition to sustainable development in the context of digitalization.

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Ecological and economic aspects of sustainable development of Ukrainian regions

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Abstract. The need for sustainable development of Ukrainian regions is due to the global threat of environmental degradation, the unstable situation in the world economy, low socio-economic indicators of the country and weak innovation activity. An important factor that has an influence on the economic development of regions is the ecological state of the environment. It plays one of the most important roles in the conducting of economic activities that require the use of natural resources. According to the results of the investigation, four clusters were formed. Cluster analysis made it possible to conduct a general assessment of the state of the regions of Ukraine, to form groups by similarity and to draw sound conclusions about the existence of similarities in the economy. The formation of clusters and the development of sustainable development policies for individual clusters, which should have significant differences, taking into account their specifics, will contribute to the more effective achievement of sustainable development goals.

1 Introduction

Currently, sustainable development is becoming an important component of the development of Ukraine and its regions. However, the unstable economic situation in the country, raw materials, and export-oriented nature of the country's economy do not allow it to effectively use the mechanisms of sustainable development policy developed for developed countries.

Ecological and economic aspects of sustainable development are in fact the separation of production processes and environmental protection. When developing a policy for the sustainable development of regions, it is important to take into account both the socio-economic and environmental interests of the local population. Underestimation of the environmental factor and environmental constraints in the development of sustainable development documents leads not only to numerous negative consequences in nature management, but also deep long-term disparities between economic, social, and environmental development of different levels, affects the quality and efficiency of environmental regulation. In this regard, taking into account the environmental factor in the management of sustainable development of the region becomes especially important.

In crisis and an unstable external environment, the regions of Ukraine are faced with the problem of sustainable and stable socio-economic development. Sustainable regional development in a crisis is of particular importance and significance, since without clear goals and guidelines for movement, the achieved results can be negative. The cluster approach, which allows government bodies to achieve a long-term competitive advantage, can become the basis for sustainable development of the region. The idea of the investigation is to substantiate a theoretical and practical approach to assessing the need to form the regional potential of cluster formation for sustainable regional development. The purpose of the study is to use data mining tools to identify patterns and relationships based on data on air pollution in the regions of Ukraine. Spatial data mining involves identifying interesting and potentially useful templates from databases by grouping objects into clusters.

2 Sustainable development of Ukrainian regions

The need for sustainable development of Ukrainian regions is due to the global threat of environmental degradation, the unstable situation in the world economy, low socio-economic indicators of the country and weak innovation activity. The basic aspects of sustainable development policy, goal setting and interaction between them, as well as the experience of developed countries are presented in studies [1-7].

Competitive regions of Ukraine are a source of growth for the whole country, a pillar of national policy to reduce regional disparities, promote more balanced development and promote sustainable development of the country. In general, ensuring sustainable development of the country is possible only when sustainable development of all regions is achieved. The policy of sustainable development of the regions provides for the formation of such conditions and the use of such mechanisms under which the natural basis of this development is not

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destroyed, the preservation and reproduction of the environment is ensured.

Sustainable development of the region is an activity of planning, organization, coordination of economic, social, technical-technological, ecological, and other processes, aimed at effective use of its economic potential in order to improve the quality of life and working conditions of economic entities. not only present but also future generations. Moreover, this activity is carried out both within the region and abroad. Analysis of sustainable development of regions, their features and prospects for implementation are presented in [8-17]. Measurement of various aspects (ecological, financial, technical etc.) of regional development and analysis of their impact on sustainable development presented in the papers [18-23].

Sustainable development policy at the regional level should be aimed at achieving the following goals:

– greening of the economy;
– improving the quality of the environment;
– improving the quality of life of the population;
– restoration of natural resources.

The main tools for developing sustainable development policy are:

– at the state level – coordination of infrastructure development, granting special status to certain territories, direct financial support (subsidies, transfers);

– at the regional level – strategic planning of regions in order to balance socio-ecological and economic development, limiting the creation of environmentally harmful enterprises in densely populated areas;

– at the community level – cooperation between communities to join forces to accelerate development.

3 Cluster analysis as method of organizing groups of objects

Cluster analysis is used in various fields and industries. It works even when there is little data and the requirements for the normality of the distribution of random variables and other requirements of classical methods of statistical analysis are not met. It is useful when you need to classify a large amount of information.

Cluster analysis has a number of advantages over other methods of data classification. First, it allows to break down objects by a single feature or by a whole set of features. Moreover, the influence of each of the parameters can be quite simply enhanced or weakened by making the appropriate coefficients in the mathematical formulas. Second, cluster analysis does not restrict the type of grouping objects and allows to consider many data source of almost arbitrary nature. Third, the peculiarity of clustering is that most algorithms are able to independently determine the number of clusters into which you want to break down the data, as well as to identify the characteristics of these clusters without human intervention, only using the algorithm used. The essence of the cluster analysis procedure is that the objects are represented by a vector (set) of individual features of these objects in the form of a table “object-property”, on the basis of which the matrix of distances (similarity, proximity) is calculated, which is carried out by clustering. This solves the problem of classifying data using a well-formed mathematical apparatus.

Cluster analysis of the spatial distribution of objects allows to reduce the dimensionality of data, to make it clear. Thus, whenever a large amount of information needs to be classified into groups suitable for further processing, cluster analysis is very useful and effective. The main task of cluster analysis is the formation of homogeneous groups in multidimensional space.

Clustering algorithms are usually built as a certain way to search the number of clusters and determine its optimal value in the search process and include 5 basic steps:

1. Sampling for clustering.
2. Determining the criteria by which objects will be evaluated in the sample.
3. Calculation of values of one or another degree of similarity between objects.
4. Application of cluster analysis to create groups of similar objects.
5. Verification of the results of the cluster solution.

Today, there are many methods of dividing groups of objects into clusters. There are several dozen algorithms and even more modifications. But most often the methods of cluster analysis are divided into two large groups: hierarchical and non-hierarchical.

When choosing between hierarchical and non-hierarchical methods, it is necessary to take into account their features. Non-hierarchical methods show higher resistance to noise and emissions, incorrect choice of metrics, the introduction of insignificant variables in the set involved in clustering. The price to pay for these benefits of the method is the word "a priori". The analyst must determine in advance the number of clusters, the number of iterations or the stop rule, as well as some other clustering parameters. This is especially difficult for novice professionals. If there are no assumptions about the number of clusters, it is recommended to use hierarchical algorithms. However, if the sample size does not allow this, a possible way is to conduct a series of experiments with different numbers of clusters, for example, to start breaking down the data set from two groups and, gradually increasing their number, to compare the results. Due to this "variation" of the results, a fairly high flexibility of clustering is achieved. Hierarchical methods, in contrast to non-hierarchical ones, refuse to determine the number of clusters, and build a complete tree of nested clusters. Complexities of hierarchical clustering methods: limiting the scope of the data set, choosing the degree of proximity, inflexibility of the obtained classifications. The advantage of this group of methods compared to non-hierarchical methods is their clarity and the ability to obtain a detailed representation of the data structure.

Thus, the following conclusions can be drawn: cluster analysis is a universal tool that can be used in regional modelling. With its help, you can analyse data on the similarity of objects. The results of the analysis are presented in a convenient visual form, which facilitates decision-making to determine the optimal number of factors and the relationship of various clusters.

4 Regions of Ukraine clustering by ecological and economic indicators

4.1 Regions of Ukraine clusterization by the level of air pollution

An important factor that has an influence on the economic development of regions is the ecological state of the environment. It plays one of the most important roles in the conducting of economic activities that require the use of natural resources. Personnel potential often depends on the ecological condition of the region, people have a desire to live and work in cities with good environmental performance, access to drinking water, and clean air.

For investigating the economic potential of the regions, it is advisable to form a comprehensive assessment of the regional environmental conditions according to several indicators that are most important. To characterize the quality of the ecological state, the regions should be classified according to several diverse quantitative characteristics in order to identify homogeneous and unique objects by the obtained values. The most effective method for such a multicriteria classification is cluster analysis.

The subject of this investigation is the application of clustering methods for the formation of cluster groups from the regions of Ukraine. The comprehensive assessment will be based on the comparison of all regions, the formation of groups on the similarity of their characteristics with each other, using the techniques of multidimensional classification of economic objects to combine them into homogeneous classification groups on selected characteristics.

The aim of the investigation is a clustering of regions of Ukraine by air pollution. Statistical data from the Statistical Yearbook Environment of Ukraine 2018 (published by the State Statistics Service of Ukraine) on air pollution in the regions of Ukraine by emissions of nitrogen dioxide (thousands of tons) and emissions of sulfur dioxide (thousands of tons) are used [24].

Unlike controlled learning, where there is a base of values to assess the effectiveness of the model, the cluster method k-means does not have a solid evaluation metric that we can use to evaluate the results of different clustering algorithms. Moreover, the k-mean method requires an input number k, and this value is not calculated from the values that need to be evaluated. As a result, there is no right answer to what number of clusters we need to build. Sometimes subject knowledge or intuition can help you choose the number k, but this is not always true. According to the methodology of cluster forecasting, we can assess how well the models work based on different numbers of clusters. In this paper, we will consider 2 indicators that can help us estimate how many clusters we need to use in the k-mean method: elbow method and Silhouette analysis.

The Elbow method will help calculate the optimal number of clusters based on the sum of the squares of the distances between the data points and the centroids. When visualizing this method, the optimal value is where the curve is the first bent, and then gradually aligned.

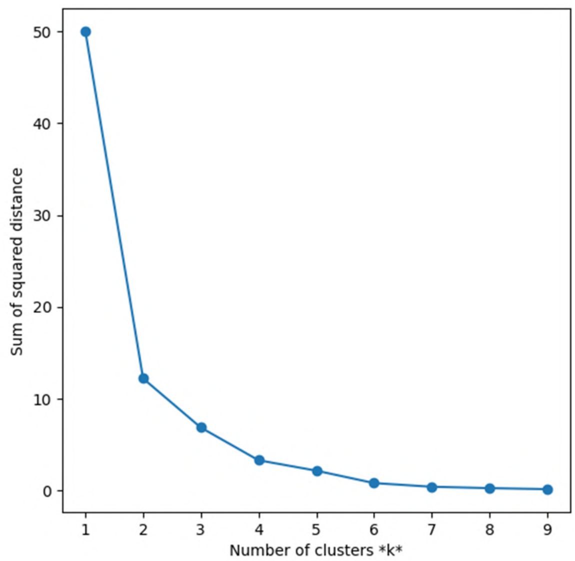


Fig. 1. Calculation of the number of clusters with the Elbow method.

As we can see, the graph from Fig. 1 indicates that the number of clusters should be 2. However, sometimes it is difficult to determine the exact number of clusters, because the curve may fall monotonically and will not be visually visible moment of its “fracture” or “elbow”.

Silhouette analysis can be used to determine the degree of division between clusters. For each example you need:

1. Calculate the average distance from all data points in one cluster (a^i).
2. Calculate the average distance from all data points in the nearest cluster (b^i).
3. Calculate the coefficient:

$$\frac{b^i - a^i}{\max(a^i, b^i)}.$$

The coefficient can take values in the range [-1; 1]:

– If it is equal to 0 – then the element is very close to neighboring clusters.

– If it is equal to 1 – then the element is far from neighboring clusters.

– If it is equal to -1 – then the element is improperly classified, belongs to the wrong cluster.

As we see from Fig. 2 – 4, the coefficient from the Silhouette analysis method is closest to 1 when constructing two clusters and is equal to 0.8 (Fig. 2). We obtained good results, which confirm the result of the previous method Elbow method, that the optimal number of clusters for clustering our data by the k-mean method is the number 2. So, both Silhouette analysis method and Elbow method has given the same result for the number of the clusters, that’s why regions of Ukraine were grouped in two clusters.

Clustering results:

1. The first cluster includes Donetsk, Dnipropetrovsk and Ivano-Frankivsk regions.
2. The second cluster includes Vinnytsia, Volyn, Zhytomyr, Zakarpattia, Zaporizhia, Kyiv, Kirovohrad, Luhansk, Lviv, Mykolaiv, Odesa, Poltava, Rivne, Sumy,

Ternopil, Kharkiv, Kherson, Khmelnytsky, Cherkasy, Chernihiv and Chernivtsi, Kyiv.

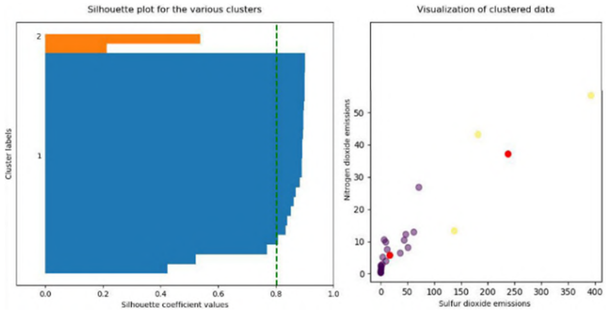


Fig. 2. Silhouette analysis for two clusters.

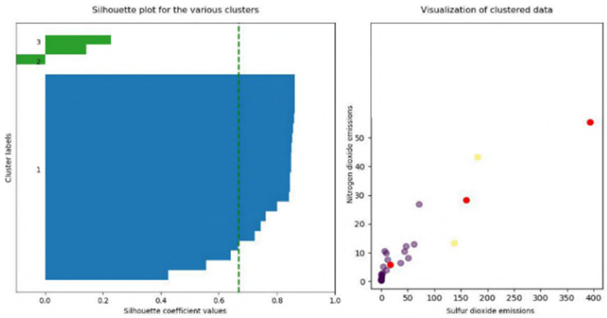


Fig. 3. Silhouette analysis for three clusters.

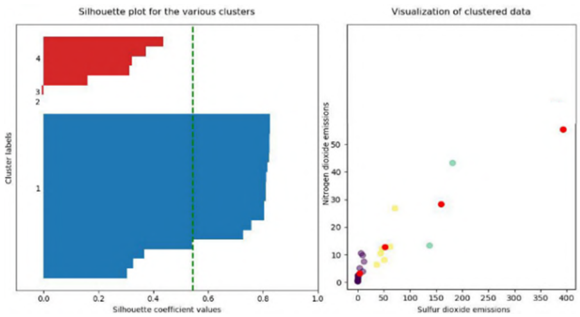


Fig. 4. Silhouette analysis for four clusters.

The centroid for the first cluster contains a pollution value of 237.5 thousand tons of sulfur dioxide emissions and 37.2 thousand tons of nitrogen dioxide emissions into the atmosphere; for the second cluster 16.54 thousand tons and 5.83 thousand tons, respectively.

4.2 Clustering of Ukraine regions by environmental factors

It is obvious that the ecological condition of the regions of Ukraine depends not only on the state of air pollution. Therefore, in addition to the characteristics of air purity, the study includes the number of green areas, the degree of environmental pollution and the capacity of treatment plants.

The criterias that will characterize the state of the environment in all areas and prospects for its improvement:

– emissions of pollutants into the atmosphere from stationary sources of pollution by region (t / km^2);

– area of forests reproduction by regions (ha);

– waste incineration by regions (thousand tons);

– capacity of treatment plants by regions (million m^3).

All statistical indicators are taken from Statistical Yearbook Environment of Ukraine 2018 (by the State Statistics Service of Ukraine) [24].

Four clusters were obtained by the hierarchical clustering method:

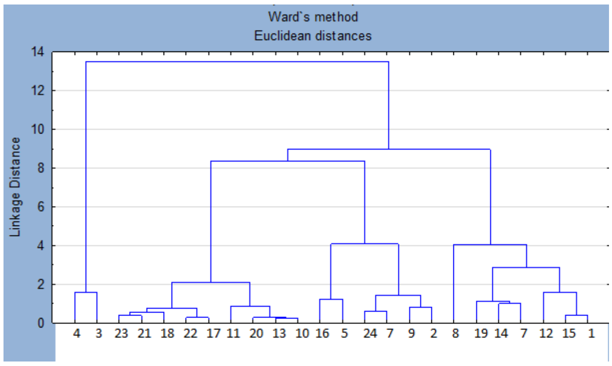
– The first cluster. Donetsk and Dnipropetrovsk regions;

– The second cluster. Chernivtsi, Khmelnytsky, Ternopil, Cherkasy, Sumy, Luhansk, Kherson, Mykolaiv, Kirovohrad regions;

– The third cluster. Rivne, Zhytomyr, Chernihiv, Zakarpattia, Kyiv, Volyn;

– The fourth cluster. Ivano-Frankivsk, Kharkiv, Odesa, Zaporizhia, Lviv, Poltava and Vinnytsia regions.

The dendrogram is shown in the figure 5.



1 – Vinnytsya, 2 – Volyn, 3 – Dnipropetrovsk,4 – Donetsk, 5 – Zhytomyr, 6 – Zakarpattya, 7 – Zaporizhzhya, 8 – Ivano-Frankivsk, 9 – Kyiv, 10 – Kropyvnyckyi, 11 – Luhansk, 12 – Lviv, 13 – Mykolayiv, 14 – Odesa, 15 – Poltava, 16 – Rivne, 17 – Sumy, 18 – Ternopil, 19 – Kharkiv, 20 – Kherson, 21 – Khmelnytskiy, 22 – Cherkasy, 23 – Chernivtsi, 24 – Chernihiv.

Fig. 5. Diagram of hierarchical cluster of regions of Ukraine by environmental conditions.

For the accuracy of the study, we form four clusters using another method – k-means.

We get the result, where for each cluster there is the region and the distance from the cluster center:

– the first cluster: Dnipropetrovsk 0.393, Donetsk 0.393;

– the second cluster: Zakarpattia 0.377, Kropyvnyckyi 0.268, Luhansk 0.344, Mykolayiv 0.378, Sumy 0.103 Ternopil 0.293, Kherson 0.310 Khmelnytsky 0.194, Cherkasy 0.1, Chernivtsi 0.186, Chernihiv 0.544;

– the third cluster: Volyn 0.332, Zhytomyr 0.548, Kyiv 0.544, Rivne 0.462;

– the fourth cluster: Vinnytsia 0.376, Zaporszhzhya 0.538; Ivano-Frankivsk 1,202; Lviv 0,527, Odessa 0.416, Poltava 0.529, Kharkiv 0.653.

The means of the emissions of pollutants into the atmosphere from stationary sources of pollution by cluster for the first cluster is 702,25 for the second cluster is 21,07$ for the third cluster is 21,13 and for the fourth cluster is 104,9 t / km^2.

The means of the area of forests reproduction by regions for each cluster respectively are 245,5; 1389,9; 6185,25 and 1537 ha.

The waste incineration by clusters are 15; 17,25; 37,1 and 65,35 (thousand tons);

The capacity of treatment plants by clusters are 792,5; 85,63; 110.2; 250,56 (million m^3).

As we can see, the two regions with the largest number of industrial facilities in Donetsk and Dnepropetrovsk, are immediately combined into one group, which can be explained by voluminous emissions of pollutants into the atmosphere from production, a large amount of incinerated waste, and a small area of the forest reproduction, given the location in the steppe zone.

In the second cluster, there are the objects that have the closest connection with each other – these are the regions of the central and partly western part of the country. They have a similar relief, the average man-made load on the environment. They can be described as areas with an ecological situation that needs improvement, due to the planting of forests and increasing the number of treatment facilities. It should be noted that this includes the Zakarpattia region, which does not have a large number of industrial facilities, but there is a problem of mass deforestation, which has grown into a real environmental disaster.

The third group is formed in regions that have a medium close connection with each other. These are the regions of Ukraine where the ecological situation is considered the best. Volyn, Zhytomyr, Rivne regions have the best indicators of air purity, there are no heavy industry enterprises that carry out large-scale emissions of waste. The areas are located in a forest area, which only benefits the ecology of the areas.

The fourth cluster regions, as well as the previous one of medium-density connections between objects. These are the regions of the southern and western parts of Ukraine, without a large number of industrial facilities with emissions of harmful substances. Areas of forest and steppe zones, with treatment facilities of medium capacity.

4.3 Regions cluster analysis taking into account the gross regional product

For investigation the relationship between environmental indicators and economic potential, we will carry out clustering of regions based on gross regional product (figure 6).

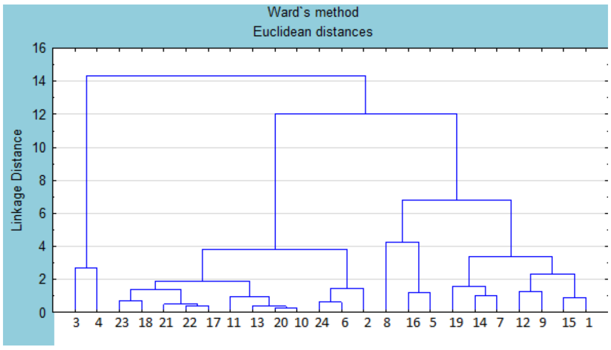
Three groups of objects are now clearly distinguished by similarity. The first cluster remained unchanged: Donetsk and Dnipropetrovsk oblasts, while the second was supplemented by Chernihiv, Zakarpattia, and Volyn oblasts as a result of the reduction of distances to the cluster center. The other three areas in the third group became similar to the objects in the next cluster.

For a more detailed distribution we use the method of k-means:

– the first cluster: Volyn 0.822, Transcarpathian 0.822, Kropyvnyckyi 0.288, Luhansk 0,358, Mykolayiv 0.414, Sumy 0.08, Ternopil 0.314, Kherson 0.345, Khmelnytsky 0.203, Cherkasy 0.219, Chernivtsi 0.352, Chernihiv 0.42;

– the second cluster: Dnipropetrovsk 0.608, Donetsk 0.608;

– the third cluster: Vinnytsia 0.382, Zhytomyr 1.257, Zaporizhya 0.696, Ivano-Frankivsk 1.189, Kyiv 0.764, Lviv 0.324, Odessa 0.633, Poltava 0.516, Rivne 0.462, Kharkiv 0.959.



1 – Vinnytsya, 2 – Volyn, 3 – Dnipropetrovsk,4 – Donetsk, 5 – Zhytomyr, 6 – Zakarpattya, 7 – Zaporizhzhya, 8 – Ivano-Frankivsk, 9 – Kyiv, 10 – Kropyvnyckyi, 11 – Luhansk, 12 – Lviv, 13 – Mykolayiv, 14 – Odesa, 15 – Poltava, 16 – Rivne, 17 – Sumy, 18 – Ternopil, 19 – Kharkiv, 20 – Kherson, 21 – Khmelnytskiy, 22 – Cherkasy, 23 – Chernivtsi, 24 – Chernihiv.

Fig. 6. Diagram of the results of cluster analysis taking into account the gross regional product.

The distance to the centers of clusters has increased for all regions, which is due to the addition of another characteristic of the studied objects. The number of groups also changed, with an increase in the similarity between the objects of each group. This indicates that we have been able to explore in more detail the relationship between environmental performance and economic development. The greater the similarity of the regions with each other in terms of the environment, the greater the similarity between them in economic characteristics.

Cluster analysis of the data made it possible to conduct a general assessment of the state of the regions of Ukraine, to form similarity groups, and to make reasonable conclusions about the existence of similarities in economic development and shortcomings that should be addressed.

5 Conclusions

According to the results of the investigation, four clusters were formed, the first of which included regions with developed heavy industry: Donetsk and Dnipropetrovsk, which characterizes them as regions with the worst environmental status. The second cluster – 12 regions of central and eastern Ukraine with a lower level of pollution than in the previous group, but still not with the best performance. This group includes the objects with the closest connection. The other two clusters have a medium-tight relationship, and are characterized by some of the best environmental performance. Cluster analysis made it possible to conduct a general assessment of the state of the regions of Ukraine, to form groups by similarity and to draw sound conclusions about the existence of similarities in the economy.

The sustainable development policy design should be implemented taking into account the specifics of the regions. In some regions, the pace and timing of changes and development may be different. The features of sustainable development are due to the fact that the goals and conditions of socio-economic development, the use of natural resources, and environmental protection are inextricably linked with a certain territory, which is characterized by specific geographic, demographic, and economic conditions. The regions of Ukraine differ significantly from each other in the area of territories, population size, volumes of industrial and agricultural production, the average per capita real incomes, which predetermines the differentiation of regions in terms of the available economic potential, level, and populations life quality.

This explains the fact that a universal sustainable development policy for all regions cannot be developed. Therefore, each region needs to design its own sustainable development policy as part of the country's overall sustainable development policy. The formation of clusters and the development of sustainable development policies for individual clusters, which should have significant differences, taking into account their specifics, will contribute to the more effective achievement of sustainable development goals.

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Global benchmarking for monitoring environmental, economic, and social performance for metallurgical production enterprises

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Abstract. The development of the ideology of sustainable development stimulated the emergence of companies' Performance Management Systems with an emphasis on the environmental aspects of their activities. Benchmarking, as a modern management tool, is often used for competitive analysis and setting development goals. This study's scientific problem is to assess the feasibility of applying benchmarking studies to assess the global industry's environmental aspects. The purpose of the study is to identify the prerequisites for using benchmarking to improve environmental performance, as well as to identify best practices among world-leading companies. For benchmarking, a logical information model is proposed in the study. On its basis, eight world leaders were selected, trends in the industry's development were analysed, and reference values of environmental indicators were established. For environmental performance assessment, it is proposed to use such indicators as greenhouse gas emissions, energy consumption, material efficiency, environmental management systems. Comparative benchmarking analysis of world leaders and 16 largest Ukrainian companies allowed determining the reserves for increasing environmental performance. The directions for increasing environmental performance are Investment in resource-saving technologies, production of higher value-added products, investments in energy-saving and new technologies, improvement of management systems, and certification. These ideas are complemented by recommendations for improving environmental performance, based on the Circular Economy Concept's philosophy and Industry 4.0. The study's practical significance is that Ukrainian companies can use their results to achieve higher environmental and economic outcomes.

1 Introduction

1.1 Research question

Metallurgy is a factor in the success of national economies and the basis of global sustainable development, as well as a driver of related industries – shipbuilding, aviation, transport and heavy engineering, defence industry, energy, construction. In addition, the metallurgical industry is a source of environmental problems, as it produces harmful emissions into the atmosphere, wastewater and generates waste that pollutes the soil in the surrounding areas. Due to the extraction of ferrous and non-ferrous metals, there is a subsequent degradation and land quality change. The metallurgical industry is also responsible for thermal pollution.

The scale of world trade, the transnational nature of leading manufacturers, and their predominant export orientation confirms the industry's global nature.

According to the results of 2019, Ukraine is one of the leading producers of metallurgical products in the world. It ranks 13th (in 2016 – 7th) among the top exporters of metal products in terms of total exports (13.5 million tons) and fourth after China (60.9), Japan (31.2), and Russia (24.9) in terms of net exports (the difference between the number of exported and imported products of the industry). In 2019, the products of the metallurgical industry amounted to 20.5% (2nd place) in the total structure of exports from Ukraine.

The peculiarities of the development of the metallurgical industry in Ukraine are excessive capacities and technological backwardness, dependence on foreign trade, as well as a high level of openness of the industry (the coefficient of openness of foreign trade in Ukraine is 5.2 versus 0.7 in China, 1.8 – in the Russian Federation and 2.8 – in the USA). In addition, Ukrainian metallurgy produces a relatively small share of finished products with a large production of semi-finished products. As a result, Ukrainian products are not competitive enough. The industry is also characterized by low use of secondary raw materials and high capital and energy consumption. The industry is highly monopolized, led by vertically integrated holdings. Six manufacturers account for 84% of the industry's sales. Significant differences in productivity levels are observed between the largest holdings and other domestic producers.

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The last decade has been characterized by the spread of the ideology of sustainable development with the simultaneous digitalization of the economy. This has led to the emergence of new models and indicators for companies' Performance Management Systems (PMS) and has identified critical areas for improving their business models. As part of sustainable development, PMS has been dubbed “Sustainable and Resource Efficient Business Performance Measurement Systems” (SuRE BPMS). Enterprise performance and the methods used to measure and manage it are studied in theories of management, organization, and information systems (in particular, in business process management or BPM) [1]. Performance management is a multidisciplinary topic and assumes the existence of differentiated approaches to implementing tools to ensure it. One such tool, which is not widespread enough to solve environmental problems, is benchmarking.

The research question in this paper is to analyze the possibilities of improving performance based on global benchmarking and attention to issues of sustainable development. The use of benchmarking for sustainable development will allow metallurgical companies to calculate the quantitative parameters of the changes needed to increase competitiveness, including the environmental vector.

1.2 Previous researches

The basis of modern Sure BPMS systems is the concept of global effectiveness of sustainable development “Triple Bottom Line” [2], which is used to assess sustainable development strategies based on a set of economic, social, and environmental indicators (Figure 1). This concept maintains a balance between the three goals.

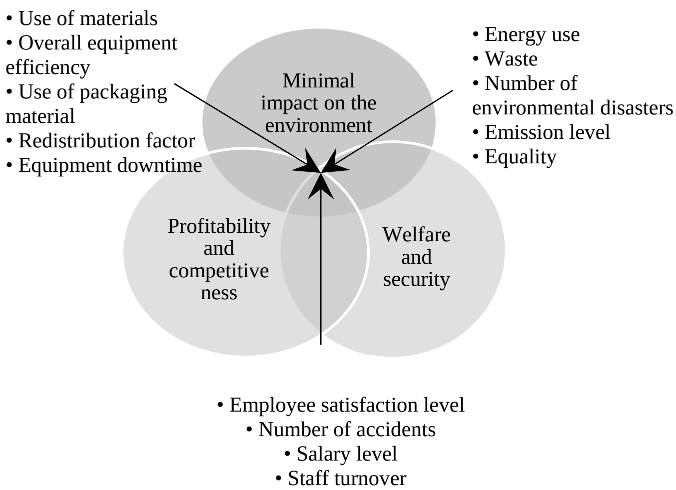

Fig. 1. The concept of the global performance of sustainable development “Triple Bottom Line” [2].

First, maximizing economic performance. This goal can be measured by traditional financial criteria (revenue, profitability, cash flow, economic value-added, market value-added, etc.).

Second, maximizing social performance, which requires taking into account the interests of all stakeholders. Third, the increase in environmental performance involves activities that do not create harmful effects on the environment [3].

According to the concept, a sustainable corporation strives for low environmental impact, cares about staff and society as a whole while remaining competitive. The basis for sustainable production is to create more value while using fewer resources. Resource efficiency is a consequence of every production operation. The resources spent do not add value to the client and represent costs for the enterprise and society. The critical challenge is to link improvements in resilience at the operational level to financial performance and stability at the corporate strategic level.

Central to today's process-oriented models developed in the BPM concept is the Measurement and Performance Management Lifecycle Model proposed by Bourne & Bourne in 2011, which consisted of four phases: design, implementation, use, and revision. This model was supplemented by Landström et al. [4] in 2018, the fifth stage – the cycle of double learning. Central to the model is the choice of adequate performance indicators for specific prospects for implementing the corporate strategy.

The development of the ideas of the “Triple Bottom Line” and the Bourne & Bourne Life Cycle Model is manifested in the System of Measuring Enterprise Performance Based on Sustainable Development by Almström et al. [5]. The authors note that performance measurement systems' use and improvement are closely linked to management systems, such as environmental protection, quality, occupational health and safety, and operational development programs. The integration of management systems and operational development programs involves the development and maintenance of appropriate PMS. In practice, management systems and operational development programs are not fully integrated and contain different key performance indicators. Success factors for operational development from the authors of the model's point of view can be the participation of management, training, education, empowerment of workers, and coordination of long-term strategy.

Thus, modern SURE models reflect PMS development's last stage, forming a modern philosophy of integrated performance measurement concept, which combines BSC elements, process-oriented life cycle models, and business excellence models, and subordinating PMS to a single system of strategic management. According to the authors, performance indicators should provide the right feedback for strategic decisions. At the heart of the benchmarking methodology, as you know, is the process of comparing the potential of a particular object of analysis (enterprise, industry, etc.) with the potential of competitors. Therefore, the use of benchmarking, in our opinion, can be considered an instrumental implementation of modern models of performance management.

1.3 The scientific problem

The scientific problem is the possibility of using benchmarking studies of the global industry to improve the performance of national manufacturers based on the philosophy of sustainable development and the use of relevant models of Sustainable and Resource Efficient Business Performance Measurement Systems. The article's *hypothesis* has both a theoretical and an applied basis concerning the practicality of using benchmarking results and the technology of using its consequences in the global market. *The purpose* of this study is to identify the prerequisites for using benchmarking to influence the environmental performance of market participants, identify best practices and their carriers among world-leading companies and test the proposed toolkit for Ukrainian companies. *The research object* is the environmental, social, and economic performance of companies in the metallurgical sector in the world and Ukraine.

1.4 The research methodology

The research is based on the data on metallurgy from global and national statistics of Ukraine, as well as data from top global and Ukrainian producers of metallurgical products, collected directly from companies and processed by statistical methods.

The analysis of global trends covers 1980-2019, with details for the period 2007-2017.

To monitor environmental, economic, and social performance for benchmarking the metallurgical industry, we have selected eight largest world companies representing the TOP countries of the industry sample of comparisons and key areas: 1) Production of iron, steel, and ferroalloys: ArcelorMittal (Luxembourg), Nucor (USA), POSCO (South Korea), China Baowu Grou (China), Nippon Steel & Sumitomo Metal Corporation (NSSMC) (Japan), OJSC Novolipetsk Metallurgical Plant (NLMK) (RF) 2) Production of light metal packaging: Crown Holdings, Inc. (USA) 3) Manufacturing of metal structures and products: Lindab group., Inc. (EU).

To test the use of benchmarking for national manufacturers' performance, we formed a sample of 16 largest Ukrainian companies, which provided 88% of the total sales of the metallurgical industry of Ukraine. The first six (Metinvest Holding, ArcelorMittal Ukraine, Privat Group, EastOne Group (Interpipe), Donbass Industrial Union (ISD), and DCH-Evraz) accounted for 84% of industry-wide sales. The 16 largest companies accumulate 80% of assets and 56.6% of employees in the industry.

The sample proportion fully corresponds to the scale of enterprises' activities, both globally and nationally.

The methodology's scientific novelty is as follows: Authors propose identifying three groups of benchmarking parameters, which reflect environmental, social, and economic performance. To assess the environmental performance, the authors of this article proposed to use such indicators as Greenhouse gas emissions, Energy consumption, Material efficiency, Environmental management systems.

An analysis of the environmental aspects of the metallurgical sector showed that Environmental requirements should be viewed as an incentive for innovation and as a source of competitive advantage. Environmental requirements are also a push to eliminate structural crisis phenomena.

For benchmarking, the article proposes a logical information model, the main elements of which are the selection of a narrow range of players in the metallurgical market as carriers of “best practices”, analysis of trends in the global development of the industry, setting benchmark targets, and their comparison with the indicators of Ukrainian companies.

1.5 The current research structure

This study consists of the following parts:

– first of all, a theoretical basis is presented, based on the study of modern models of performance management in the context of sustainable development; on this basis, a logical-informational model of benchmarking and a group of indicators for assessing environmental, economic, and social performance are proposed;

– secondly, the prerequisites for the use of benchmarking for the analysis of the metallurgical industry were investigated; trends in the development of metallurgy at the global and national levels were revealed;

– thirdly, the results of the analysis of performance indicators for two groups of companies – global leaders and Ukrainian manufacturers are presented, and recommendations for improving environmental performance based on the results of global benchmarking are proposed;

– further, the ideas of improving environmental performance are considered through the prism of the Concepts of the circular economy and Industry 4.0.

The study's practical significance lies in the fact that its results can be used to achieve higher environmental and economic results by Ukrainian companies and, as a result, to create and maintain competitive advantages in the world market through the use of benchmarking in management practice.

2 Main theoretical assumptions of the research

2.1 Environmental, economic, and social performance under the ideology of sustainable development

Following the doctrine of sustainable development, we propose identifying three groups of parameters for benchmarking, which reflect the environmental, social, and economic performance, and determine the socially-oriented strategic management on the corporate social responsibility principles. According to the authors' approach, this approach to community-based management is an extended modification of the “Eight

Global Economic, Social and Environmental Indicators" of WSA Sustainability [6].

Indicators of environmental performance are given in table 1.

Table 1. Indicators for assessing environmental performance (based on the benchmarking of global industry leaders).

Indicator	Calculation
Greenhouse gas emissions	tons of CO_2 per ton of steel
Energy consumption	GJ per ton of steel
Material efficiency	The ratio of the mass of the obtained scrap to the mass of residues and production waste, %
Environmental management systems	Share of personnel and contractors working at certified production facilities, %

The greenhouse gas emissions (CO_2 / t) show tons of CO_2 emissions normalized against production (tons of manufactured metallurgical products in crude steel equivalent). The calculation is based on the specific energy trajectory and intensity of CO_2 emissions for the main production routes. Reducing greenhouse gas emissions in steel production needs to be addressed globally. Reducing CO_2 emissions requires breakthrough technologies. Metal products play an essential role in a low-carbon economy due to their long life cycle, 100% recycling, and innovative qualities.

Energy intensity, GJ per ton of steel, shows the energy consumed, normalized to production (equivalent to a ton of crude steel), and reflects energy-saving policies' effectiveness.

Material efficiency reflects the share of recycled (primary and secondary by-products) residues of production, and therefore the company's commitment to the circular economy's values.

Environmental management systems are estimated as the share of personnel and contractors working at production facilities certified according to international EMS standards such as ISO 14001 or EMAS. The indicator characterizes the degree of responsibility and compliance of the production process with modern requirements.

Among the indicators of social performance, we propose to include the coefficient of the frequency of injuries with a temporary disability, staff training, and wages (Table 2).

Table 2. Indicators of social performance (based on the benchmarking of global industry leaders).

Indicator	Calculation
The coefficient of the frequency of injuries with a temporary disability	Injuries/ million hours of work
Employee training	Training days/employee
The average salary	The ratio of labor costs to the number of staff, thousand dollars

Trauma with loss of working time is an incident that prevents a person from returning to work. The rate of injuries with a temporary disability, including deaths, reflects the number of incidents per million person-hours. With the help of the indicator, it is possible to determine the state of working conditions.

Employee training indicator measures the total average number of training days per employee and does not focus on safety and health, but should include it. Training can consist of different development programs: seminars, computer training, self-study, or on-the-job training. Training programs should aim to expand employees' knowledge and skills and help them make the most of their talents.

The average level of wages is calculated by the ratio of labor costs to the number of staff. Characterizes the level of well-being and is a motivating factor for achieving better results.

The proposed indicators of economic performance are (Table 3):

Table 3. Indicators of economic performance (based on the benchmarking of global industry leaders).

Indicator	Calculation
Investments in new processes and products	Cost of investment in capital expenditures and R&D, % of revenue
Creating added value	The ratio of gross value added to revenue, %
Distributed economic value	value distributed to society (direct and indirect), % of revenue

Investments in new processes and products are the amount of investment in technical and technological innovations and research and development, % of revenue; reflect the company's commitment to continuous improvement.

The value-added indicator is defined as the ratio of gross value added to revenue, %, and reflects the level of the economic value of the company for the country's economy

Distributed economic value is an indicator of the quantitative assessment of the value sent to society by industry. It includes direct and indirect contributions (taxes, dividends to shareholders, employee salaries, direct payments, etc.)

All these indicators should be evaluated in the process of comparison with the reference global average.

The proposed indicators cover the critical prospects for achieving the best results in the metallurgical industry. Further research aims to model the field of optimal outcomes for domestic enterprises based on benchmarking of global industry leaders and analyze their actual performance, focusing on world leaders' performance.

2.2 Global benchmarking for monitoring environmental, economic, and social performance

The study and identification of factors influencing the performance of metallurgical enterprises, in our opinion,

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should be based on empirical global experience of best practices in the industry.

To create an adequate scale and perception of data in the global situation, we have developed a conceptual logic and information model of benchmarking (Fig. 2). According to this model, the basis of comparison is a narrow range of players in the metallurgical market as carriers of "best practices."

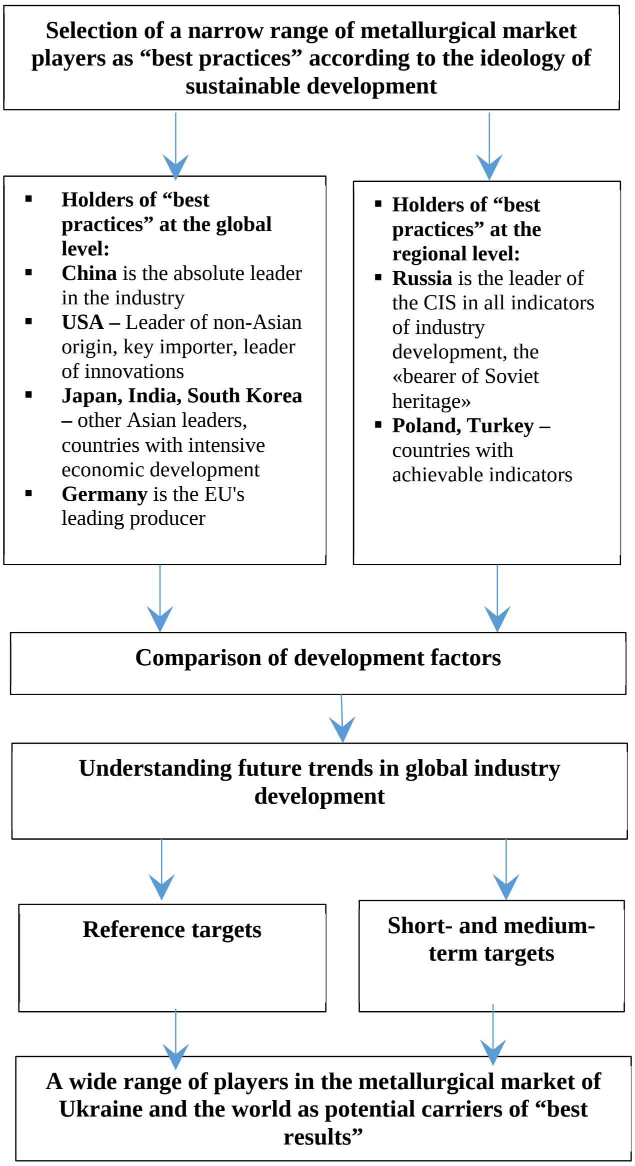


Fig. 2. Logical-information model of benchmarking.

These companies represent China as the most powerful country in the global metallurgical sector, the United States as a leading country of non-Asian origin, and the Russian Federation as a country with identical historical foundations for the industry and the CIS leader.

Also, to understand future trends in global development and Ukraine's place in it, it is necessary to consider a wider range of players.

For this purpose, other Asian leading manufacturers from Japan, India, South Korea, as well as companies from Germany – as a European regional leader, Poland, and Turkey – as countries close to Ukraine's level of economic development.

3 Research results

3.1 Global benchmarking of the steel industry on the ideology of sustainable development and environmental performance

According to the WSA, the top ten places in the world ranking of steel producers in 2013-2017 are stably occupied by the same companies. The first place is occupied by the multinational corporation "ArcelorMittal SA", whose production facilities are located, including in Ukraine, producing in 2017 97 million tons of steel (5.86% of world production), the second – the Chinese China Baowu Group (3.9 %), the third – the Japanese "Nippon Steel & Sumitomo Metal Corp" (2.8%). The twenty largest steel companies (their share in world steel production is 38%) include 10 Chinese companies, two metallurgical companies in Japan, India, South Korea, and companies in the United States, Russia, and Brazil. Thus, the development of Chinese metallurgy has a significant impact on the balance of power in metallurgical products' world market. If in the period 1980-2017. world steel production increased 2.4 times – from 716 to 1690 million tons, then in China over the same period, production increased more than 22 times: in 1980, China smelted 37 million tons of steel (5% of world volume), and in 017 – 831 million tons (50% of world volume). The growth of world steel production in the amount of 974 million tons during this period by 85% is due to China's formation as the largest player in the world steel market.

The significant acceleration in steel production growth in the last decade has led to a sharp increase in demand for raw materials, particularly iron ore, coal, coke, scrap ferrous metals, and various alloying elements. *In our opinion, this, in turn, is a factor in the development of the circular economy*.

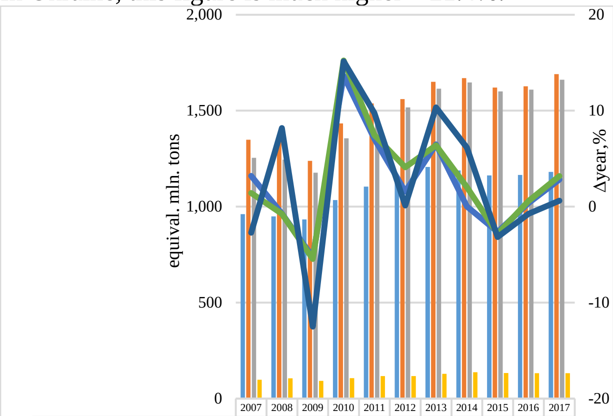
Environmental requirements as an incentive for innovation

According to the WSA and the International Energy Agency (IEA), ferrous metallurgy accounts for 6.7% of the world's total carbon dioxide (CO2) emissions, averaging 1.8 tons of CO2 per tonne of molten steel. WSA experts note that the reduction of emissions of CO2 and other harmful substances in the future is possible only through the development and implementation of radically new steelmaking technologies (electric arc furnaces recycling) [7]. Strengthening environmental requirements provokes the introduction of environmental innovations. This is manifested in the use of continuous metal production processes and other innovations in line with the circular economy.

Global trends in the metallurgical industry are the growth of metal production (Fig. 3) against qualitative technological transformations.

An essential ecological innovation of global metallurgical production is the refusal to use the open-hearth method of steel production (Fig. 4), which has long occupied a production monopoly, giving way to a more productive oxygen-converter process in the late 1960s.

The transition from the open-hearth process to the oxygen-converter process saves a significant amount of energy and dramatically reduces the environment's burden. According to the results of 2017, the oxygen-converter method in the world produced 71.4% of steel, 27.9% – electric arc, 0.4% – open-hearth (and this method is used only in the former CIS – up to 6.7% of production In Ukraine, this figure is much higher – 21.4%.



	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Metallurgical production: cast iron	961	949	933	1,034	1,104	1,123	1,207	1,188	1,162	1,165	1,180
Metallurgical production: steel	1,348	1,343	1,239	1,433	1,538	1,560	1,650	1,669	1,620	1,627	1,690
Rolled ferrous metals	1,254	1,245	1,177	1,356	1,457	1,517	1,614	1,647	1,600	1,610	1,661
Steel tubes	98	106	93	107	117	117	129	137	133	132	133
Metallurgical production, Δ %	3.2	-0.7	-5.3	13.6	7.1	1.6	6.5	0.0	-2.6	0.4	2.8
Rolled ferrous metals, Δ %	1.4	-0.7	-5.4	15.2	7.5	4.1	6.4	2.0	-2.8	0.6	3.2
Steel pipes, Δ %	-2.7	8.2	-12.5	15.1	9.8	0.1	10.3	6.2	-3.2	-0.8	0.6

Fig. 3. Global dynamics of metallurgical production, million tons, % (according to WSA statistics).

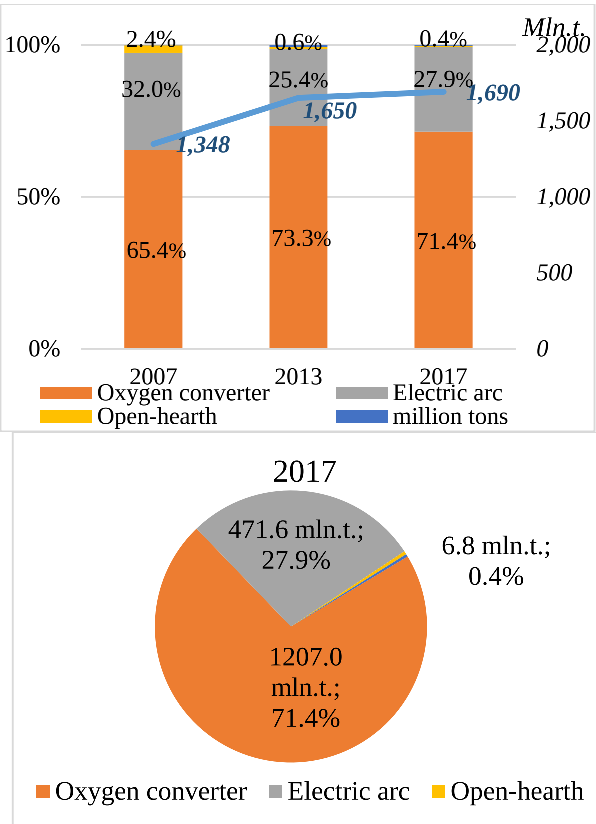


Fig. 4. Metallurgical production by processes, 2007-2017, % (according to WSA statistics).

Also, the world is intensively developing and implementing the *production process of continuous casting, which can also be attributed to the features of the circular economy*, covering in 2017 about 96% of steel produced. In Ukraine, as of 2017, this method produces only 48.8% of metal products, in Russia – 81.9%, the United States and Turkey – 99.9%, Germany – 95%, India – 85.8%, Italy – 94.8%, China – 98.3%.

Environmental requirements as a source of competitive advantage

Due to more lenient environmental requirements for production, individual countries gain a competitive advantage that reduces production costs. This leads to a change in the geography of global metallurgy. Director of the IEA N. Tanaka notes that "the introduction of restrictions on carbon emissions in some countries in the absence of similar measures in others threatens unfair competition, can lead to carbon leakage, facilitate the relocation of production to regions with less stringent environmental requirements" [8].

According to the OECD, the metallurgical industry has shifted its major metallurgical industries to Asia, North Africa, and South America in the 21st century [9]. If in 1980, the leading countries in steel production included the USSR (21% of world steelmaking), Japan (16%), the United States (14%), Germany (6%), China (5%), Italy (4%), France and Poland (3%) [10], then in the XXI century, according to the WSA, China came in the first place by a huge margin (in 2017 with a figure of 50% of world steel production). The share of the following 11 producer countries is 43.7%: EU (10%, of which 1/3-Germany), Japan and India (6%), USA (5%), South Korea and Russia (4%), Turkey and Brazil (2%), Italy (1.4%), Taiwan and Ukraine (1.3%) (Fig. 5).

China also has a significant share in the production of pig iron (60%), and the top 10 includes Japan (6.9%), India (5.42%), Russia (4.45%), and South Korea (4%), Germany (2.35%), Brazil (2.23%), in eighth place – Ukraine (2.04%), then – the United States (1.92%), and Taiwan (1.28%). It should be noted that China is a world leader in all metallurgical markets: steel and steel pipe production, the export of metal products, non-ferrous metallurgy markets (nickel, aluminum), while four countries occupy the 2nd-5th places in various markets: Japan, India, Russia, and the United States.

Environmental requirements as a push to eliminate structural crisis phenomena

Overcoming excess capacity is a necessary condition for more environmentally sustainable conditions for doing business in metallurgy. This will allow the industry to meet long-term challenges better and continue investing in value creation, adapting to the fundamental changes in economic activity caused by the "next production revolution".

Global output growth has led to steel overproduction and under capacity, and the associated imbalance between supply and demand in the global metal market. As of

January 1, 2018, the world's nominal steel production capacity reached 2,251.2 million tons, with more than 68% of nominal production capacity concentrated in Asia (of which 46.5% in China) and 12% in Europe. 7% – in North America, 6% – in the CIS, 7% – in the rest of the world. The world share of available Ukrainian capacities is about 1.9% (Fig. 6). According to the results of 2017, the level of world average capacity utilization does not exceed 75%, leaving more than 600 million tons of excess steelmaking capacity (Fig. 6).

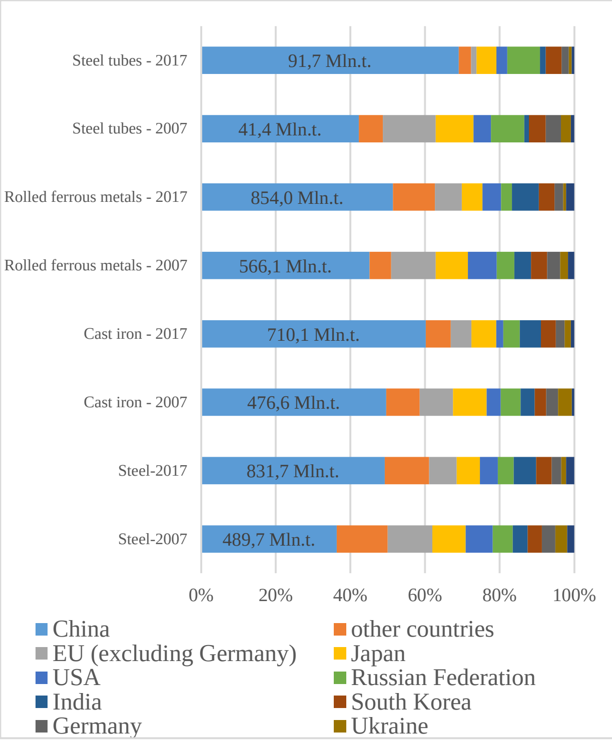


Fig. 5. Production of metallurgical industry products by regions of the world in 2013, 2017 (top countries), % (according to WSA statistics).

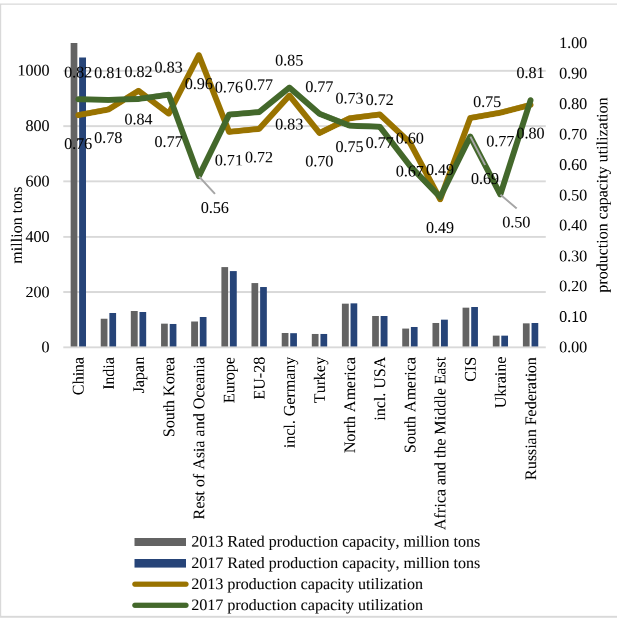


Fig. 6. Use of metallurgical capacity, 2013-2017 (according to [9]).

As shown in Fig. 6, the maximum use of production capacity in the world is only 80%. At the same time, Ukraine is characterized by a much larger excess of production capacity, resulting in a significant part of them (50%) is not used. Such data indicate the need to rethink and develop targeted actions to increase the efficiency and effectiveness of the industry's production potential and its optimization. In general, in most regions of the world, there is a positive trend in reducing overcapacity. However, overcapacity continues to be a major concern for the steel industry globally. Their presence affects profitability, creates trade imbalances, creates regional imbalances, and undermines the fight against environmental challenges.

3.2 Environmental performance of the metallurgical industry in Ukraine

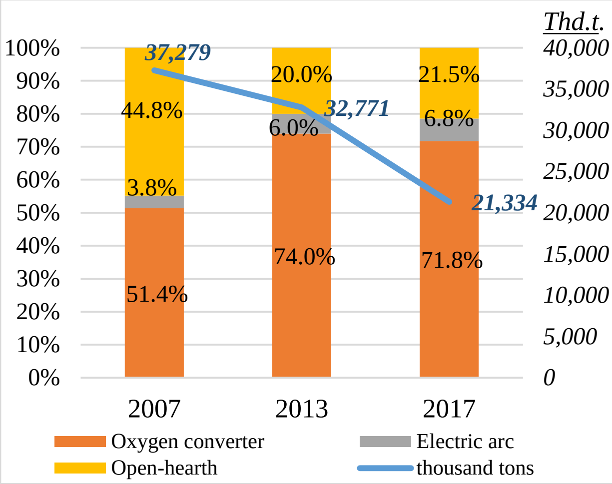
Metallurgy is one of the strategically important sectors of the economy in Ukraine, providing, in 2017, 2.4% of GDP, 7% of industrial production, and 19% of exports. As a consumer of natural monopolies' products and services, the industry used 22% of electricity, 25.4% of heat, 6% of natural gas from the country's total domestic consumption. It accounted for 43% of rail freight [11].

The main activities in the Ukrainian metallurgical production are the production of cast iron and steel. In current conditions, cast iron, steel, rolled products, ferroalloys, and pipes occupy 25% of the country's total industrial production (18% is steel production, 5% – iron ore production, 2% – coke production) [12].

Ukraine's metallurgical industry's peculiarities are the large size of production of semi-finished products and the critically small relative share of finished products. 36% of metallurgical production is the production of cast iron (16.5 million tons in 2018), .39% – steel (21 million tons), 22% – rolled products (12.2 million tons), 2% – steel pipes (1.2 million tons) and only 1% – other finished products 90.6 million tons). This is *one of the reasons for low environmental performance.*

Ukrainian ferrous metallurgy structure differs significantly from the structure in developed countries, and this has immediate environmental consequences. Production processes in Ukraine are characterized by technological backwardness: the use of outdated technologies and units, primarily all-open-hearth production process (21.5% of the steel in 2017). At the same time, on a global scale, top producers have already completely abandoned it except for the Russian Federation.

According to data for 2018, in Ukraine only 51.6% of metal products are manufactured using continuous casting technology. This is the lowest level of use of this technology globally (against 96% in the world). In total, as of January 1, 2019, the main operating production facilities are in operation: 20 out of 21 blast furnaces, 8 out of 9 open-hearth furnaces, 15 out of 16 converters, 6 out of 15 electric furnaces, and 15 out of 15 continuous casting machines.



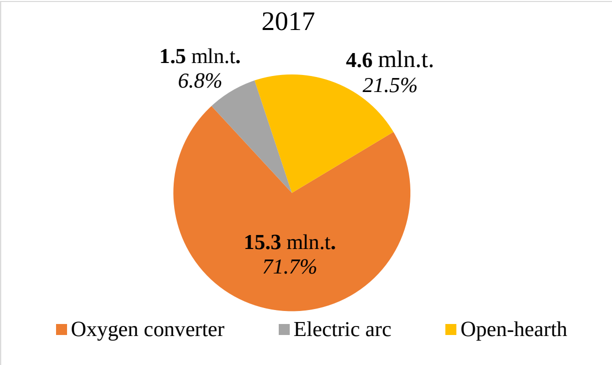


Fig. 7. Steel production by processes in Ukraine (WSA Steel Statistical Yearbook 2009, 2014, 2018).

The technological state of Ukrainian metallurgy is largely explained by the fact that the ferrous metallurgy of Ukraine is the "heir" of this branch of the USSR. In 1990, it accounted for up to 40% of the all-Union production of all product groups [13]. The aging of fixed assets in the industry is accompanied by increased costs for fuel and energy and material resources, reduced productivity, deteriorating quality of finished products, large increases in repair costs, and a significant amount of capital investment in the reconstruction and renovation of equipment. Because of technological backwardness, finished metal products of Ukraine are not competitive enough in foreign markets. Ukraine is forced to sell it at discounted prices, which causes anti-dumping lawsuits, because of which Ukraine loses billions of dollars annually. More than 70% of the industry's output is exported annually. In comparison, about 30% of domestic consumption of metal products is imported, determining the dependence of the structure and dynamics of production on foreign trade in metal products.

Energy consumption as an ecological problem of metallurgical industry in Ukraine

The energy consumption of the metallurgical industry is one of the most significant factors influencing its environmental performance. It should be noted that in Ukraine, metallurgy is one of the most energy-intensive industries. Metallurgical production accounts for 52% of total electricity consumption and 28% of heat in the processing industry (corresponding shares: 25% and 24% of total industrial use, 26% and 15% of total use). On average for the year (according to 2018), metallurgists consume about 1840 million cubic meters of natural gas, 11.76 billion kWh of electricity. The characteristic feature of metallurgical processes is that the most significant part (up to 80 – 90%) of energy resources is spent on processes of own technological needs. The main energy raw material is coal and coke (the share of consumption of this raw material by metallurgy is 93.5% of the volume consumption by the industry as a whole, and 22% of the total supply of this type of energy to the Ukrainian market) and natural gas (60% and 6% in 2017, respectively).

The factor of limited resources explains the current trend of increasing the share of expenditures on the energy component due to hostilities in the east of the country and the anti-terrorist operation, as well as the price factor at the global level. Between these two factors, there is a close relationship. Given that the primary raw material for the metallurgical industry is iron ore and coal, which turns into coke in the production process, it is important to understand the trends in the provision of metallurgical enterprises in Ukraine (Fig. 8).

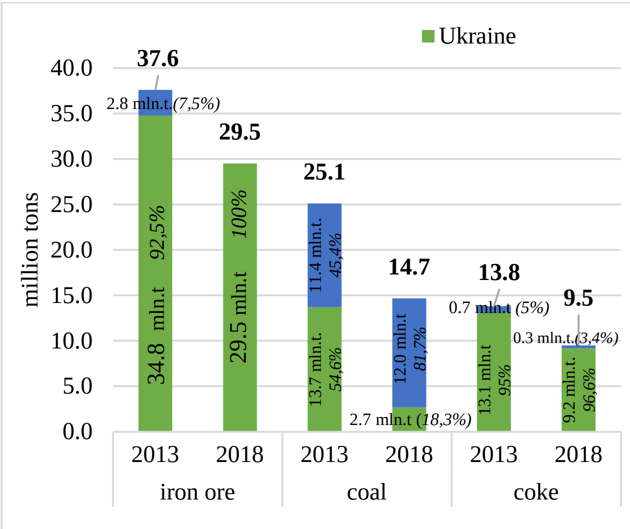


Fig. 8. Provision of metallurgical enterprises of Ukraine with primary raw materials in 2013 and 2018.

This situation with the energy intensity of products dictates the need for a targeted energy-saving policy. Strategic approaches should be associated with the reconstruction of production and the introduction of new energy-saving technological processes. In this regard, some measures that are successfully used in metallurgical enterprises of developed countries should be noted. In Western countries, to reduce the cost of production allows the widespread use of some advanced energy-saving technologies, including the continuous casting of steel (lowers energy costs by 20%), dry quenching of coke (in foreign practice, wet quenching of coke). Evaporative cooling of metallurgical units reduces energy costs by two to three times compared to the open cooling scheme [14].

According to the Ukrainian Center for Economic and Political Studies named after Razumkov, the greatest reserves for energy efficiency in ferrous metallurgy are cast iron and steel production. We are talking about reducing unit costs by about 25%, or 5 million tons of conventional fuel per year with production volumes at the level of 2013 (for cast iron) and reducing unit costs by about 70%, or 1.5 million tons of conventional fuel per year – on steel.

3.3 Recommendations for improving environmental performance based on the results of global benchmarking

The external environment analysis emphasizes the global nature of the industry and the high dependence of performance indicators on the actions of global competitors, who act as leaders and “engines of progress”. The lagging position of domestic metallurgy in terms of innovative changes, the reactive nature of achieving competitive advantages in and purely production orientation determine the feasibility of using the strategy of “following the best world practice”.

The use of benchmarking research can help realize domestic enterprises' potential and achieve higher economic results by creating and maintaining competitive advantages in the global market. We believe that the results of benchmarking of global industry leaders should be used to apply Ukrainian metallurgical enterprises' targets. The use of benchmarking is in line with the philosophy of Sustainable and Resource Efficient Business Performance Measurement Systems (SuRE BPMS).

For benchmarking of the metallurgical industry, we have selected eight largest world companies (Table 4): ArcelorMittal (Luxembourg), Nucor (USA), POSCO (South Korea), China Baowu Grou (China), Nippon Steel & Sumitomo Metal Corporation (NSSMC) (Japan), JSC Novolipetsky Metallurgical Plant” (NLMK) (RF), Crown Holdings, Inc. (the USA), Lindab group., Inc. (EU). The proportion of the sample is fully consistent with the scale of enterprises' activities, both globally and nationally.

The selected companies are the leaders in the national context among companies, ahead of almost all industry values indicators. According to the selected companies, the performance indicators described in 2.1 are calculated. Table 5 presents the results of the calculation of environmental performance indicators.

To test the use of benchmarking to improve Ukrainian enterprises' functioning, we formed a sample of 16 largest companies, which provided 88% of total sales of the metallurgical industry of Ukraine. The first six (Metinvest Holding) (43%), ArcelorMittal Ukraine (16.2%), Privat Group (9.2%), EastOne Group (Interpipe) (7%), Donbass Industrial Union (ISD) (4.8%) and DCH-Evraz (3.8%)) accounted for 84% of industry-wide sales.

The 16 largest companies accumulate 80% of assets and 56.6% of employees in the industry. The results of calculations in terms of environmental performance analysis and possible directions for its improvement are presented in table 6.

Table 4. A sample of global industry leaders as bearers of “best practices” for achieving environmental performance (based on company data, WSA, CSI).

Company / Country	Geography of activity	World share of crude steel production,%
ArcelorMittal / Luxembourg	60 countries (18 of which have production facilities, including 47 integrated plants and mini-mills)	5.8%
Nucor / USA	25 scrap processing mini-mills in North America, production facilities in Italy and Mexico (under construction)	1.3%
POSCO / South Korea	40 Korean subsidiaries, 139 foreign subsidiaries and 111 associates and joint ventures	3.6%
China Baowu Group / China	90.7% of assets are in China, the rest – 27 foreign branches and 8 PJSCs in the regions: USA, Japan, Germany, Singapore, Thailand and Hong Kong.	3.9%
Nippon Steel & Sumitomo Metal Corporation (NSSMC) Group /		
Japan	13 metallurgical plants of Japan + capacities in 15 countries (USA, Brazil, China, Mexico, etc.)	2.8%
PJSC “Novolipetsk Metallurgical Plant” (NLMK) / RF	20 production sites located in Russia, USA, Belgium, Denmark, Italy, France and India.	1.0%
Crown Holdings, Inc. / USA	36 countries (America, Asia, Europe, Africa): 143 subsidiaries	8.9%
Lindab group., Inc. / Sweden, Germany	32 countries, 136 branches in the European market	11,0%

The directions for increasing environmental performance are an investment in resource-saving technologies, production of higher value-added products, investments in energy-saving and new technologies, improvement of management systems, and certification. These recommendations complement ideas for improving environmental performance based on the philosophy of the Concept of Circular Economic and Industry 4.0.

In addition, a tool for improving environmental performance should be a regular environmental audit of production activities and investment projects of Ukrainian enterprises, including for compliance with the ISO 14001: 2015 “Environmental Management System” standard. Based on the audit, complemented by global benchmarking of industry leaders, it is proposed to develop programs to improve environmental performance. An important component of the program should be increasing the level of environmental awareness of staff and stakeholders. This is achieved by publishing the results of environmental audits, developed programs on the websites of Ukrainian companies, which is not yet available.

Application of the Concept of Circular Economy to solve environmental problems of metallurgical enterprises

Metallurgical products are recognized as one of the most circular materials due to their endless processing properties. Broader implementation of the circular economy's principles, such as reduction, reuse, and restoration of production, will have a long-term impact on the metallurgical industry due to its impact on demand in metal-intensive sectors [16].

Price fluctuations for primary resources and finished products, combined with the inability to respond flexibly to changes in demand, increase the need to find ways to improve existing resources' efficiency, develop alternative production technologies based on traditional and universal resources, and resource utilization technologies.

Table 5. Monitoring the environmental performance of world leaders in the industry.

Company	Result / deviation / direction of correction	Indicator			
		Greenhouse gas emissions	Energy consumption	Material efficiency	Environmental management systems
Average		1,9	19,1	97,6	97,1
ArcelorMittal	2019	2,1	23,8	88,6	98,1
	ARC*,%	-0,9	-0,8	13,3	0,1
	↑↓	↑	↑	↑	↑
Nucor	2019	0,9	4,9	82,0	100
	ARC*,%	0,0	-3,4	2,5	0,0
	↑↓	↑	↑-	↑	↑
POSCO	2019	1,9	11,5	98,4	92,3
	ARC*,%	6,1	-0,6	0,0	0,3
	↑↓	↓	↑	↑	↑
China Baowu Group	2019	1,0	17,0	99,2	92,0
	ARC*,%	0,0	-4,0	0,0	0,0
	↑↓	↑	↑	↑	↑
NSSMC	2019	2,0	23,0	99,0	96,7
	ARC*,%	0,5	0,4	0,0	0,7
	↑↓	↓	↓	↑	↑
NLMC	2019	2,1	23,0	86,9	89,1
	ARC*,%	0,5	-1,8	-7,2	0,2
	↑↓	↓	↑	↓	↑
Crown Holdings, Inc.	2019	4,0	12,2	100	99,0
	ARC*,%	2,1	17,3	0,0	0,0
	↑↓	↓	↓	↑	↑
Lindab group., inc.	2019	7,9	1,8	89,0	97,0
	ARC*,%	-13,2	-4,4	0,0	0,0
	↑↓	↑	↑	↓	↓

* Annual rate of change

In other words, the main trend of metallurgical producers should be the production of products by processing secondary raw materials instead of using mineral resources. Such ideas are an element of the Concept of Circular Economics [17].

Table 6. Benchmarking of environmental performance indicators of world industry leaders and Ukrainian companies.

Indicator	Greenhouse gas emissions	Energy consumption	Material efficiency	Environmental management systems
World leaders	1,9	19,1	97,6	97,1
Ukrainian companies	2,2	25,3	62,7	n/d
Directions of influence for environmental performance increase	*Investments in resource-saving technologies*	*Production of higher value-added products, investments in energy-saving and new technologies*	*Following the principles of circular economy*	*Improvement of management systems and certification*

Today in Ukraine, the regulation of the circular economy is still in its infancy. Such regulation is at different stages of development in different regions of the world. The EU Circular Economy Action Plan provides a solid basis for accelerating the transition to a circular economy and sustainable growth. In China, thinking based on a circular economy has been part of legislation and regulations for at least the last ten years. In other regions, such as Brazil, Japan, and Korea, the circular economy's principles are gaining momentum and changing business laws. In general, the transition of a society to a circular economy is only at an early stage. However, this change will likely accelerate in the light of recent trends: the globalization of the economy, changes in government legislation, and innovative business models of the circular economy.

The many advantages of scrap metal as an important steel resource are based on its high-energy efficiency, low carbon emissions, and easy recycling. For the sustainable development of ferrous metallurgy, more attention should be paid to the use of steel scrap in the steel production process. Making full use of scrap metal resources can play a key role in easing pressure on mineral needs. The recycling of steel scrap can significantly reduce iron waste and environmental pollution [18]. The benefits of using scrap metal include the optimization of both energy costs and metal products, demonstrating the ETSAP-TIAM global energy scenario assessment model and the scrap availability assessment model (SAAM).

Application of the Industry 4.0 Concept to increase the environmental performance of metallurgical enterprises

To increase efficiency, productivity, sustainability, sound process management, and optimal use of resources, Ukrainian metallurgists need to make the most of the Industry 4.0 Concept's capabilities. In this context, the advantages for the metallurgical industry can be such: vertical integration based on Cyber-Physical Production System (CPPS), 100% traceability of intermediate and

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final products, "Intelligent" product with knowledge of its quality and production history (one aspect of systems engineering), horizontal integration inside and outside the company, appropriate processing and use of all data, decentralized solutions, self-organization.

Using the Industry 4.0 Concept changes interactions with suppliers and customers using new online platforms, applications, and other systems that offer order tracking and other services. This, in turn, opens up opportunities for entirely new business models and provides for the development of a whole digital "production ecosystem" in which the accumulated data is included in the value chain, helping to maximize the level of environmental performance.

Examining innovations in analytics, mobile solutions, and automation at the global level, we can conclude that the following trends will further contribute to a significant increase in efficiency in the metallurgical industry. First, it is an exponential rise for data available. This leads to a wider implementation of a range of different sensors, including vibration, optics, and sound sensors, reducing storage costs. Second, increasing computing power and developing new analytical methodologies. Traditional statistical methods give way to machine learning methods to simultaneously analyze multiple factors, even if they do not have a linear relationship. Third, mobile technology's deployment to the shop floor contributes to a significant increase in productivity through more efficient field management and process optimization. Fourth, greater automation of support functions combined with data analytics to provide greater flexibility and performance.

4 Conclusions

Considering all of the above, we can say that the development of sustainable development ideology has stimulated the emergence of relevant models for Performance Management and Measurement Systems. Such models pay significant attention to environmental problems and approaches to their measurement. Another feature of modern performance assessment models is the use of indicator systems. The use of benchmarking is an instrumental implementation of performance measurement systems since it allows you to set targets for improving performance. We have tested benchmarking to develop the philosophy of tripl sustainable and resource-efficient systems for improving business performance (SuRE BPMS) for development.

With sufficient attention to the formation of indicator systems for management purposes based on the philosophy of sustainable development, sectoral and environmental aspects require further study and implementation. As a global industry, Metallurgy generates its unique opportunities and threats that need to be applied in appropriate performance management models. This article substantiates the need to identify indicators in three areas: for assessing Environmental performance; indicators of Social performance, indicators of Economic performance. To evaluate the environmental performance, we proposed to use such indicators as Greenhouse gas emissions, Energy consumption, Material efficiency, Environmental management systems.

An analysis of the metallurgical sector's environmental aspects showed that Environmental requirements should be viewed as an incentive for innovation and as a source of competitive advantage. Environmental requirements are also a push to eliminate structural crisis phenomena. Environmental performance efficiency of the metallurgical industry in Ukraine is insufficient, and Energy consumption is the most painful point of metallurgy in Ukraine

To conduct the benchmarking, the article proposes a logical and informational model, the main elements of introducing a high-tech spectrum of metallurgical markets, analysis of tendencies in the global development of metallurgy, the establishment of standard Ukrainian companies, demonstrations of the best practices.

For benchmarking of the metallurgical industry, we have selected eight largest world companies: ArcelorMittal, Nucor, POSCO, China Baowu Grou, Nippon Steel & Sumitomo Metal Corporation (NSSMC), JSC Novolipetsky Metallurgical Plant ", Crown Holdings Inc., Lindab group. Inc. and compared their results in terms of the proposed environmental performance indicators with the values obtained from the analysis of the activities of 16 Ukrainian companies, which together account for about 90% of production volumes in Ukraine. Environmental benchmarking of the metallurgical industry made it possible to formulate recommendations for Ukrainian companies.

The scientific novelty of this work lies in the substantiation of a methodological approach to benchmarking tools, adapted taking into account the global nature of the industry and the specifics of environmental problems in it. It should be noted that the implementation of benchmarking in the global industry is somewhat simplified due to the "openness" of world-leading companies, which in general allows collecting the necessary information for analysis. At the same time, it is more efficient to implement the benchmarking information into management practice on an ongoing basis. It is possible to implement it in the context of digital tools, which allows us to maximize the quick presentation of strategic forms of transformation of global solutions the scope of activity of the enterprises.

Promising questions for further research in this direction, in our opinion, are the development of empirical models of target results of the industry; establishment of correlation-regression links between indicators of environmental performance and the variables that determine them (proxy variables); development of management mechanisms that support the introduction of benchmarking research into management practice.

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Sustainability and reliability ensurance models for automated technological systems in chemical industry: systemic ergonomic approach

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Abstract. The paper considers accidents and potential hazards of the world chemical enterprises, and provides statistics of accidents and human casualties. The authors investigate harmful factors affecting the production process and a human-operator, showing the central role of a human in the technological process (both as a source of errors and as an active element that eliminates errors, failures and cyber attacks' consequences). We essentially consider automated technological complex as a Human-Machine-Environment system, thus a human-system approach should be applied. The authors developed a complex of systemic components and morphological models, which describe the human-machine system in the sections required for analysis, to ensure sustainable and reliable design with initial data. The authors also propose a method and information technology for interfaces' ergonomic assessment; the principles for adaptive interfaces design; and mathematical models and information technology to assess safety and timeliness indicators of the chemical production operators' activities. The models are based on the principles of the functional-structural theory by Anatoly Gubinsky, Vladimir Evgrafov, Akiva Asherov, Pavel Chabaneko and others, and on the mathematical apparatus of functional networks. Further, the authors develop an optimization model for decision supporting organizing the human-machine control technology, using the criterion of minimizing losses from unreliability and unsustainability. Both the models and the information technology have undergone extensive testing, including solving the tasks of: choosing the automation level for the control process; distributing functions between operators; control algorithms design; user interface design, design of agent-managers to support the operators' activities. The results can be used as the basis for a decision support system to ensure sustainability and reliability of automated technological systems in chemical industry.

1 Introduction

Recent years are associated with increasing risks and threats not only to the sustainable development, but to the existence of mankind [1-5].

The number of industrial accidents, environmental disasters, deaths and threats to their health is increasing [6-12].

In these conditions, the need for a radical improvement in the methods of safety management in complex industries increases [13-17].

2 Problem analysis and research goals setting

Chemical industry is one of the leading world's industries in terms of the number of accidents and the amount of damage [18-20]. Figure 1 shows the numbers of incidents and deaths in the chemical industry in OECD and non-OECD countries. Figures 2 and 3 show a fragment of accident rate statistics in the chemical industry of China.

Let us see an example that characterizes the scale of the problem, considering one of the most developed economies in the world – the United States. According to the American Federation of Labor, there are 2,178 OSH [21] inspectors to inspect 8 million American workplaces, i.e. each supervised object can be checked only once every 130 years. Therefore, American experts believe that the principle of the company's presumption of safety must be abandoned, and the socially responsible business must be obliged to demonstrate and prove the sufficiency of the measures taken to ensure industrial safety as a prerequisite for carrying out production activities [21].

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Analysis [22] of the accidents main causes makes it possible to identify the following interrelated groups of factors:

– Erroneous actions of the personnel (58%);

– Equipment malfunctions and failures (21%);

– Depressurization of storage facilities and other related issues (17%);

– External influences of natural and man-made causes (4%).

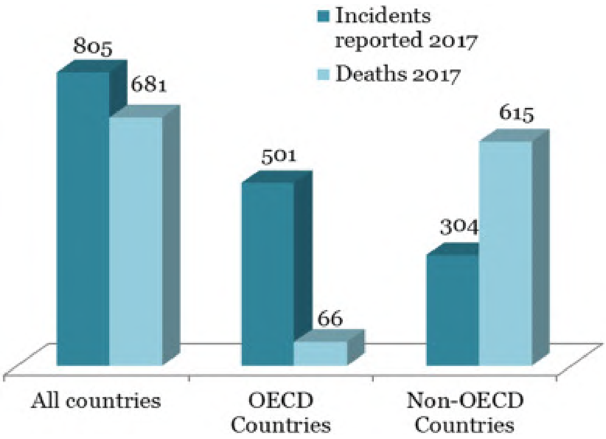

Fig. 1. Chemical incidents occurredin2017 and reported in the global media [18-19].

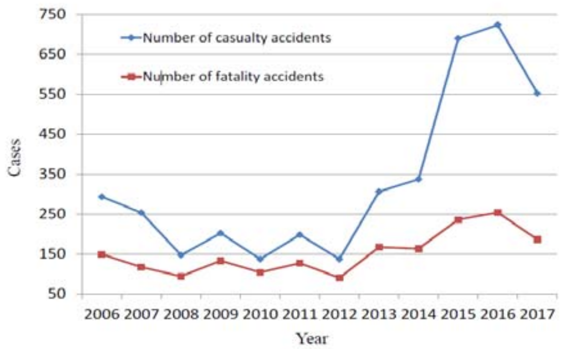

Fig. 2. Number of casualty and fatality accidents in China (2006 – 2017) [20].

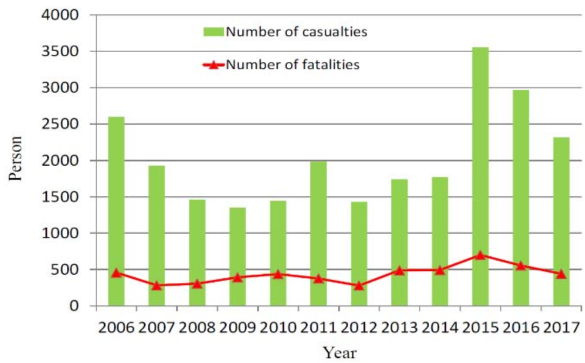

Fig. 3. Number of casualties and fatalities in China (2006 - 2017) [20].

According to other data, for example [23-25], about 80 percent of accidents are caused by human-operator errors.

The percentage values characterizing the causes of accidents may differ. However, it is obvious that the factors are interrelated and a significant reduction in the accident rate is possible only if we consider the chemical production system as an integrated Human-Machine-Environment system, in which a human can be [25]:

– a potential source of problems,

– an active element capable of eliminating and preventing problem situations.

It should be borne in mind that each person has individual psychophysiological characteristics, experience, and motivation. Besides that a human-operator works:

– with specific equipment,

– with specific user-interface,

– in specific environmental conditions (chemical, physical, psychological),

– in the context of possible sabotage, and cyber-attacks.

Taking into account and optimizing the mutual influence of these elements will make it possible to develop measures aimed at minimizing risks.

Many studies are devoted to the development of methods for assessing and optimizing individual elements of human-machine systems. Among them are the analysis of working conditions [26], the design of interfaces [25], anthropometry and the impact of production equipment on health and injuries [27-31], activity intensity [32-34], ergonomic expertise [35-39] and others [40-42].

As the analysis of the papers shows, the authors investigate only individual local issues related to human work in complex man-machine systems. At the same time, as a rule, researchers collect statistics on accidents and the influence of certain factors on human health; analyze the severity of injuries that occur in the process of equipment control; study the reach zones for operators; analyze methods of improving the psychological climate in the teams of operators; describe technologies for professional selection and training of operators, develop methods for monitoring the functional state of operators and solve other important problems. In addition, unfortunately, researchers do not study issues related to the activity concept of investigating sustainability and reliability [23], when a human operator is studied in a comprehensive manner, taking into account the algorithms of activity and the functional structure of the chemical production management system as an element of the "human-technology-hazardous environment" system.

Thus, it is obvious that today there is increasing attention to the issues of reliability of the human operator, technical means, computer equipment, software for control processes, as well as technological processes of chemical production. However, a computer-oriented system for complex modeling of human-machine interaction, focused on supporting decision-making to ensure the sustainability and reliability of critical-type systems (including automated systems in chemical industry), and taking into account the entire complex of influencing factors, have not yet been developed.

In this regard, in the present work we set the task of developing models that can be used as the basis for decision support systems for managing the sustainability

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and reliability of automated systems in the chemical industry, taking into account the reliability of personnel, automation tools, and software.

3 Results

3.1 Human-system approach to reliable design of control systems

In practice, the following approaches to the sustainable and reliable design of human-machine systems are used [22, 43]:

– system-engineering approach – the system is considered as consisting only of technical elements, the person is taken into account as a factor of the external environment;

– equal-element approach – the system is considered as consisting of equal elements "human" and "technology";

– human-system approach – the main element of the system is a human, and technology is a subordinate means of labor;

– narrowly anthropocentric approach – the system is considered as consisting only of the "human" element without taking into account the elements of "technology";

– narrow technical approach – the system is considered as consisting of technical elements, the "human" son is not taken into account.

Taking into account the central role of a human in the management of chemical production and the many diverse influencing factors (see Fig. 4), it is advisable to apply a human-system approach, the basic principles of which are formulated as follows:

– human-operator is the central element of the system that determines the reliability of production processes, which is determined by a set of interrelated factors (Fig. 4),

– potential risks are minimized based on the assessment and optimization of operators' activities, taking into account the effects of the environment, the reliability of automation equipment, software and information support, as well as the psychological characteristics of group activities (activity approach),

– sustainability and reliability of the technological process is ensured by a decision support system, including a system for ensuring ergonomic quality.

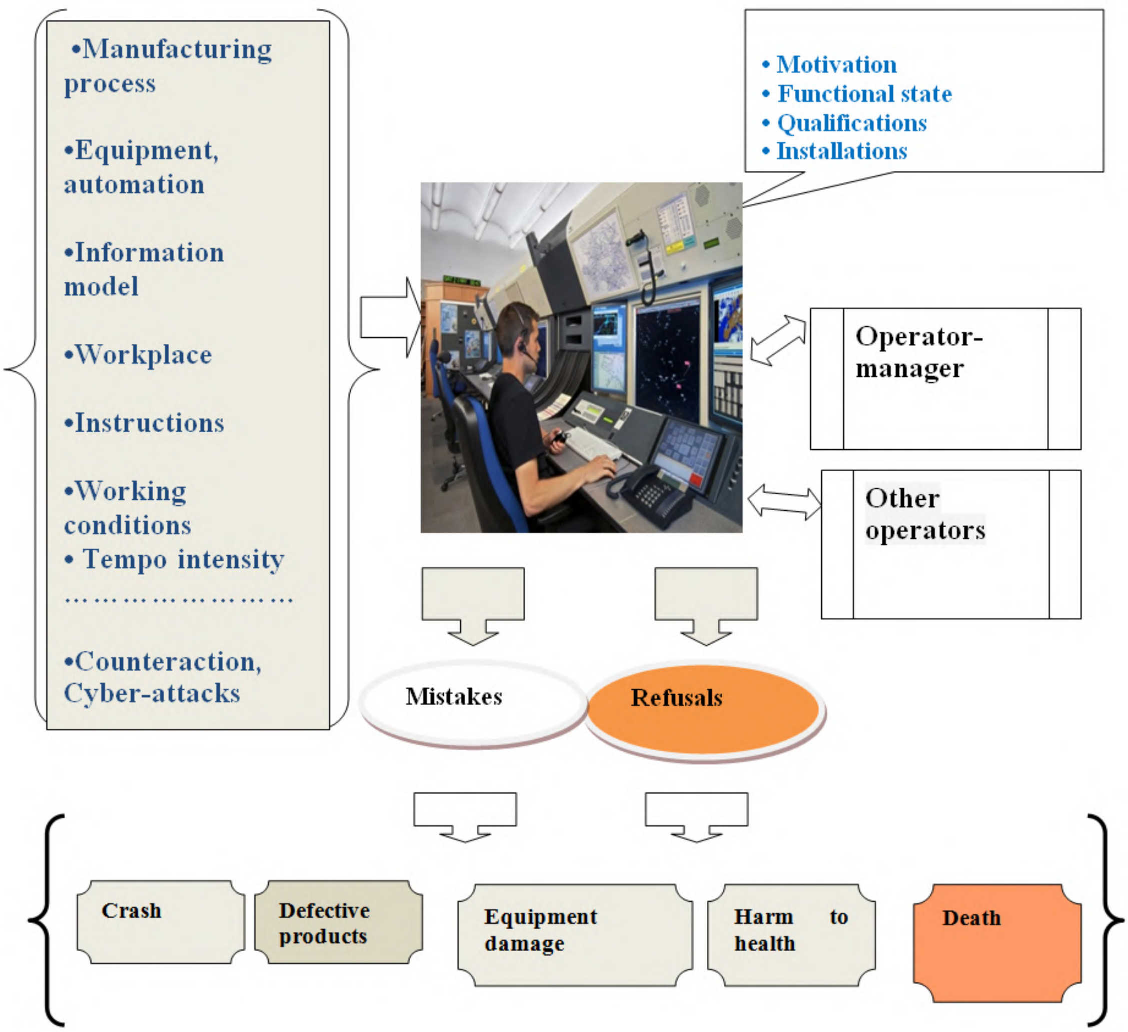


Fig. 4. Computer control system for chemical production as a human-machine system (influencing factors and risks).

3.2 Models for system analysis of an automated technological system in chemical industry (as a human-machine system)

Modeling risks in a human-machine system (MMS) is possible only if there is complete information support about functional and structural elements, about the connections between them, about the required characteristics, etc.

No modeling in a decision support system will be successful if the data are not available.

To form the structures of knowledge bases and data about the system, we use the approach of the scientific school of Professor Anatoly Ilyich Gubinsky [22, 43], who proposed to describe MMS in all required sections (human, technology, environment, connections between them, goals, technologies, damage from violations, etc. etc.), while highlighting two types of models – component (KB), describing all the necessary entities, and morphological (MP), describing all possible relationships between entities, incl. processes of implementation of functions, working conditions, how elements interact with each other, what are the reliability characteristics of structural and functional elements.

One of the possible models we use to solve the problems of reliable and ergonomic support of chemical-technological systems is as follows [43] (for notation, see Fig. 5):

$$MMS =< CSs, CFs, CRs, CEs, Err, Rs, Ft, OpFt,$$

$$VPo, FKv, Mpl, MCo, MPro >$$

We gave a complete description and structure of the models in [44]. Thus, the system of MMS models allows a formalized (in the form of functional networks [22,43,45]) to describe the hierarchical system of functions (model ***Ft***) with options for their implementation and provides the process of calculating and optimizing reliability with all the necessary initial data for structural and functional elements with taking into account all significant influencing factors.

For different tasks, some modification of the models composition and structure is possible, however, the component-morphological approach to modeling and the predicate description [23, 44] of the system can certainly be recommended for widespread use in decision support systems for managing the sustainability and reliability of technological processes in the chemical industry and other advanced industries.

3.3 Decision support for ensuring the ergonomic quality of chemical production management system interfaces

Our survey of a number of chemical enterprises revealed in a number of cases the developers' ignorance of the ergonomic principles of user interface design (Fig. 6).

Therefore, we offer the following models and computer technologies:

Int_1 – Interface assessment and certification,
Int_2 – Adaptive interfaces design.

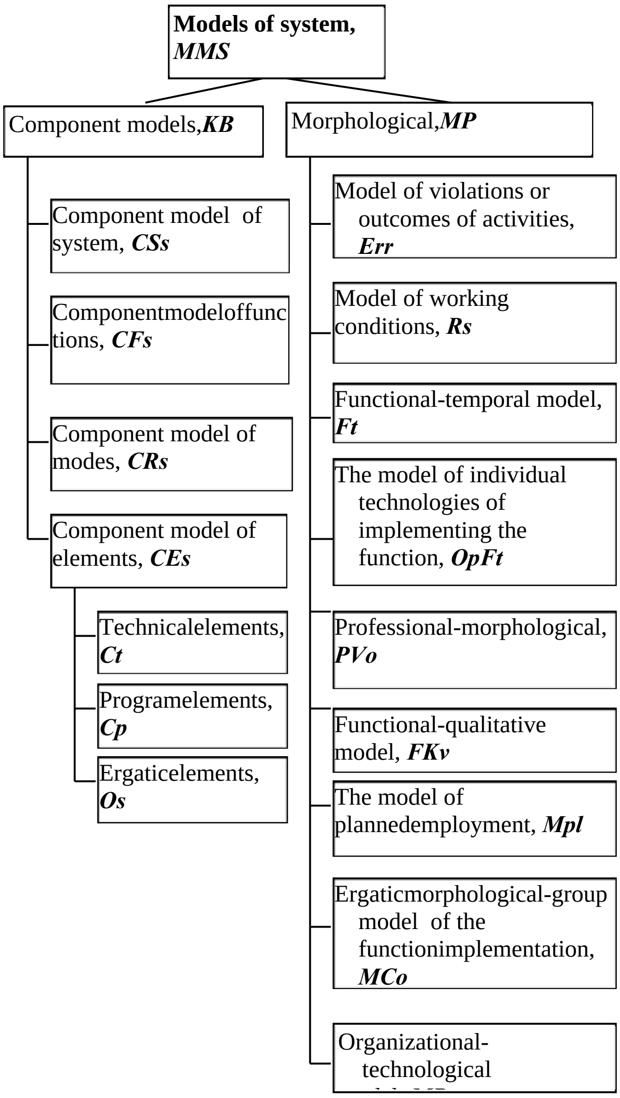


Fig. 5. Models for system analysis of control systems in the chemical industry (a fragment).

<u>Int_1technology principle (Fig. 7):</u>

- Formation of a group of qualified experts;
- Formation of a set of local criteria for interface assessment;
- Formation of a convenient system for assessing the quality of local criteria (visual interface with a customizable dialogue system – both numerical input and qualitative assessment;
- Automatic assessment of the ergonomic quality of the interface using a database of models (fuzzy inference, hierarchy analysis method, etc.);
- Only certified interfaces are accepted for operation.

We have developed a hierarchical classification of local indicators (more than 100 indicators, one can ajust the classification for each specific case).

See below an example of local quality indicators of the interface for process control systems in chemical industry:

- Visual design (graphics, aesthetics);
- Graph-design, font design;
- Animation for attention control;
- Convenience of navigation and options menu;
- Interactivity (including script customization);
- Simplicity and intuitive clarity (ease of use);
- Standardization (design consistency), uniformity of fonts, colors;
- Feedback (the possibility of dialogue with the support service and the operator-manager);
- Completeness (variety of information and services);
- The breadth of the information field, variety of ways to access information;
- Reliability (resistance to errors, crashes, and freezes);
- Sustainability.

Int$_2$ technology principle:

- Preliminary testing of the psychophysiological characteristics of operators with the determination of the optimal modalities for information presentation;
- Clustering operators with taking into account:
  - o psychophysiological characteristics;
  - o work experience, attitudes (for faultlessness or speed);
  - o the need to control actions by the operator-manager;
- Creation of alternative scenarios for dialogue interaction and alternative options for interfaces;
- Prompt (on-line) determination of the optimal dialogue scenarios that maximize the probability of error-free performance of the activity, taking into account the time constraints and limitations on the degree of the operator's cognitive comfort.

The degree of cognitive comfort characterizes the degree to which the presentation of information meets the expectations and preferences of the operator. We define it in the range from 0 to 1, for estimation we use a special system of knowledge bases about users and interfaces (see Figure 6) and a system of fuzzy inference. A fragment of this dependence one can see in Fig. 8.

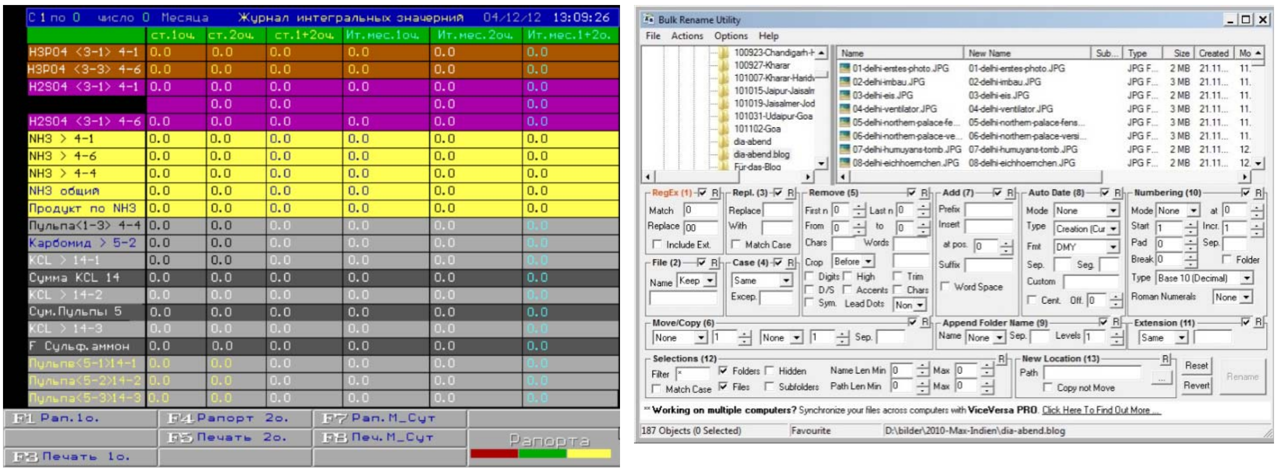


Fig. 6. Examples of interfaces to be improved.

3.4 Reliability assessment of human activity

To describe the human-computer dialogue in the management system for hazardous chemical production, we use the alphabet of typical functional units (TFU):

- functionaries who correspond to the performed actions – operations:
  - o workers
  - o control the correct functioning,
  - o equipment diagnostics,
  - o database and software diagnostics,
  - o diagnostics of the human-operator's functional state,
  - o organizational control, etc.
- composers who establish logical and temporary connections between functionaries (organize parallel processes, cyclic processes, etc.)

Using TFU and combining them together into a single functional network (FN) using the methodology of Professor Anatoly Ilyich Gubinsky [22,43,45,46] allows one to model almost any discrete processes in the management of chemical production:

- pre-production,
- implementation of the main functions of the production process control,
- diagnostics and equipment repair,
- detection of cyber-attacks and security incidents management.

For typical functional structures (TFS), i.e. the most common combinations of operations (57 of them were identified, and the library is constantly expanding) we obtained a set of calculated dependencies to assess the probability of error-free performance and the characteristics of the task execution time as of a random variable. Examples of the dependencies one can see in Table 1.

FN allows one to describe both the system's functioning in normal modes, and the processes of the human errors' occurrence and elimination, malfunctions and failures of technical and software-informational facilities.

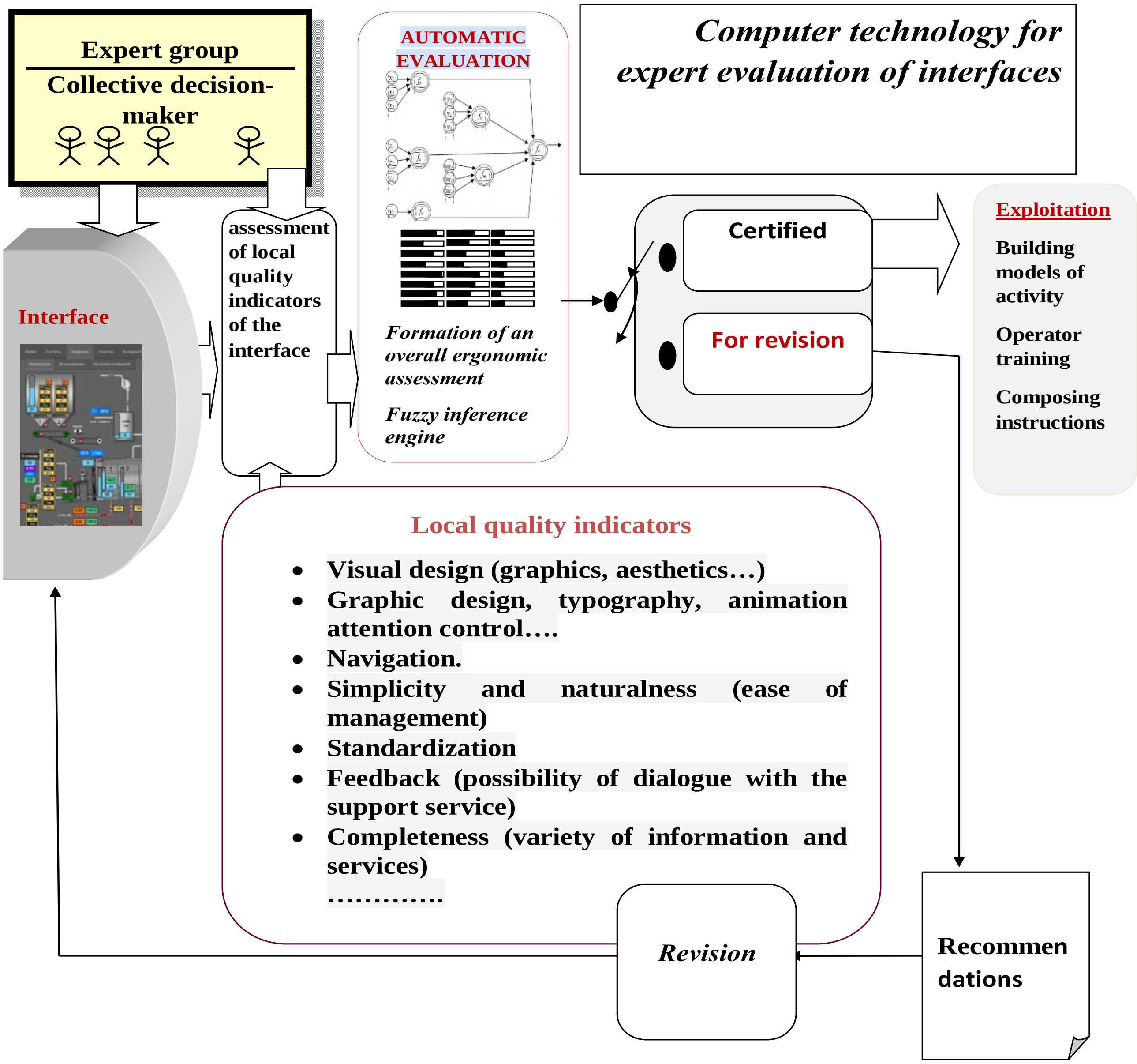


Fig. 7. Information technology for ergonomic quality analysis and interface certification.

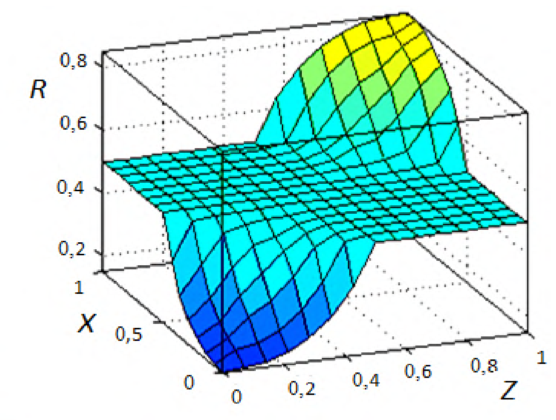
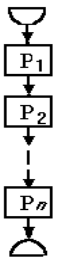
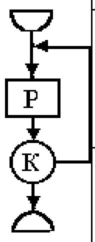
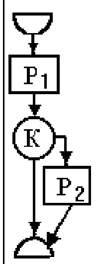


Fig. 8. Assessment of cognitive comfort (R) depending on the correspondence of the interface to the characteristics of the human-operator by the visual (X) and verbal (Z) components (developed with the help of N.L. Barchenko).

For the variant modeling of activity, a special computer technology has been earlier developed [47-50]. The reliability assessment is carried out by identifying the TFS and “reducing” the activity algorithm (FN). In this case, we use the same models as shown in Table 1. All calculations (parsing of activities, reduction and evaluation) are carried out fully automatically.

Example. We considered the production process of fertilizer of the complex mineral fertilizer “Superagro”. A joint neutralization of sulfuric and phosphoric acids with gaseous ammonia is carried out, the resulting pulp is enriched with urea, which contains a coloring pigment and is sent for granulation and drying of the resulting pulp with feeding the external recycle of NPK-fertilizer and potassium chloride to the spray zone. The dried product is classified with the release of the marketable fraction of granules. Let's consider a fragment of the operator's activity “Setting parameters and starting a technological process.”Possible options for the structure of activities one can see in Fig. 9.

Table 1. Examples of typical functional structures*

Content of typical functional structure	TFS diagram	Index	Formula for computation
1.Consistent implementation of operations		Probability of error-free operation	$B = \prod_{i=1}^{n} B_i$
		Expected value of the time of operation	$M(T) = \sum_{i=1}^{n} M(T_i)$
		Dispersion of the time of operation	$D(T) = \sum_{i=1}^{n} D(T_i)$
2.Cyclic functional structure “An operation with action control without restrictions on the number of cycles”		Probability of error-free operation	$B = B^1 * K^{11} * \frac{1}{1-(B^1 * K^{10} + B^0 * K^{00})}$
		Expected value of the time of operation	$M(T)=(M(T_p)+M(T_к))*M(L)$ $M(L) = \frac{1}{1-(B^1 * K^{10} + B^0 * K^{00})}$.
		Dispersion of the time of operation	$D(T)=D(T)*(M(T_p)+M(T_к))^2 +$ $(D(T_p)+D(T_к))*M(L)$ $D(L) = \frac{B^1 * K^{10} + B^0 * K^{00}}{(1-(B^1 * K^{10} + B^0 * K^{00}))^2}$
3. Functional structure “An operation with action control and without restrictions on the number of cycles”		Expected value of the time of operation	$B = B_1^1 * K^{11} +$ $(B_1^0 * K^{00} + B_1^1 * K^{10}) * B_2^1$
		Expectation value of the time of operation	$M(T) = M(T_{p1}) + M(T_к) +$ $(B_1^0 * K^{00} + B_1^1 * K^{10}) * M(T_{p2})$
		Dispersion of the time of operation	$D(T) = D(T_{p1}) + D(T_к) +$ $(B_1^0 * K^{00} + B_1^1 * K^{10}) * D(T_{p2}) +$ $(B_1^0 * K^{00} + B_1^1 * K^{10}) *$ $(B_1^1 * K^{11} + B_1^0 * K^{01}) * M^2(T_{p2})$

* operations symbols from [23]; P – working operation; K –functional check

Where:

- B^1 – Probability of error-free performance(work operation),
- K^{11} – Probability that correctly executed work operation during control will be recognized as completed correctly,
- K^{00} – Probability that an incorrectly executed work operation during control will be recognized as completed incorrectly,
- $M(T)$ – math. expectation of the random runtime,
- $D(T)$ – dispersion of the random runtime variable,
- Subscript shows the action number.

Operations description:

- Implementation of a request for the history of the previous shift operator (work step P1),
- Print data from the previous shift operator’ work. (work step P2),
- Transition to the Setting Work Parameters form. (work step P3),
- Setting values for ammonia (work step P4),
- Monitoring values for ammonia (control operation K1),
- Setting values for sulfuric acid (work step P5),
- Monitoring values for sulfuric acid (control operation K2),
- Setting values for phosphoric acid (work step P6),
- Monitoring values for phosphoric acid (control operation K3),
- Monitoring values of all parameters (control operation K4),
- Start of the technological process (work step P7).

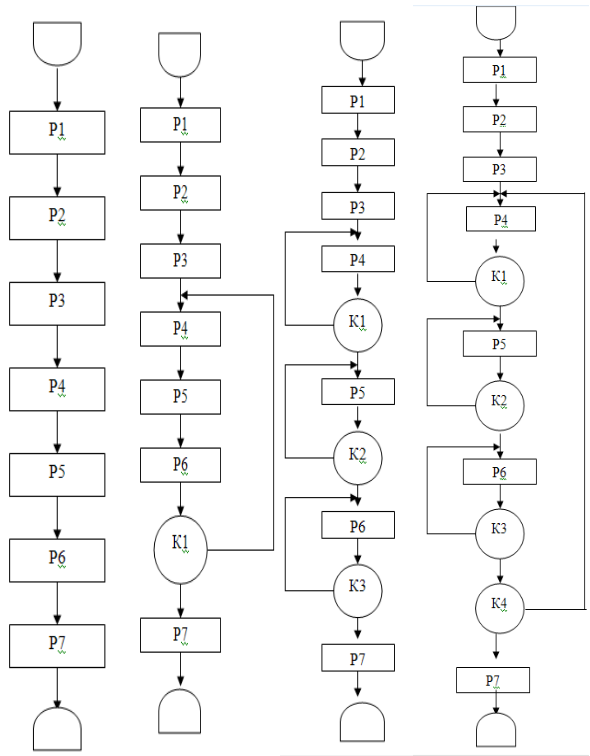


Fig. 9. Variants of the model (fragment) of the operator’s activity in the technological process of manufacturing NPK-fertilizer “Superagro” brand 15:15:15 (developed by student Alesandr Skidanenko).

Initial data for calculations (from the statistical databases of the company) are given in Table 2 and Table 3.

Table 2. Reliability-time indicators for the technological process operator of NPK-fertilizer production. Working operations.

Indicator		Operation						
		P1	P2	P3	P4	P5	P6	P7
FaultlessnessB[1]		0,988	0,978	0,998	0,987	0,997	0,997	0,998
Time	M, s	41	100	55	27	25	30	40
	D, s^2	0,3	0,4	0,7	0,4	0,5	1,1	0,8

Table 3. Reliability-time indicators for the technological process operator of NPK-fertilizer production. Monitoring operations.

Indicator		Operation			
		K1	K2	K3	K4
Monitoring quality	K^{11}	0,997	0,997	0,997	0,996
	K^{00}	0,995	0,995	0,995	0,998
Time	M, s	40	40	40	50
	D, s^2	0,7	0,8	0,8	0,9

One can see the calculation results (carried out automatically by a computer program) in Table 4.

Table 4. Calculation results*

Indicator	Dir. time	Opt.1	Opt.2	Opt.3	Opt.4
B		0,9821	0,9928	0,9929	0,9930
M, s		318	439,8	376	473,07
D, s^2		4,2	4,8	5,1	7,5
P_t	400	1	0,0002	0,9778	0,00001
	430	1	0,1950	0,9998	0,0068
	450	1	0,8106	1	0,0934
	600	1	1	1	1
B*P_t	400	0,9821	0,0001	0,9771	0,00001
	430	0,9821	0,1935	0,9927	0,0067
	450	0,9821	0,8047	0,9929	0,0920
	600	0,9821	0,9928	0,9929	0,9930

*B – probability of error-free execution, M and D – expected value and variance of execution time,

P_t – probability of timely execution,

B*P_t – probability of error-free and timely execution

Thus, it is obvious that mathematical models and computer technology provide a variant modeling of an automated technological complex functioning processes.

Since the qualifications of an operator, the functional state, the technical characteristics of the equipment, the quality of the interface, and the degree of cognitive comfort, determine the quality of the performance of individual operations, the influence of all these features is taken into account at the stage of forming the initial data (see component and morphological models in Fig. 6).

3.5 Optimization models of human-machine interaction processes to minimize damage risks

Obviously, in the case of a large number of options, it is rather difficult to solve the problem of choosing the organization of activities by evaluating all options for activities. In this regard, we have developed a bank of all kinds of models for optimizing activities, which are well tested for various human-machine systems. Here we will focus on a model that takes into account the multiple disruptions of the technological process typical for chemical production. To formulate the problem, we will use the technique of transition from a work graph (for example, as in Fig. 10) to an event graph. In this case, the events will be the results of the execution of individual operations – without violations or with violations of certain types.

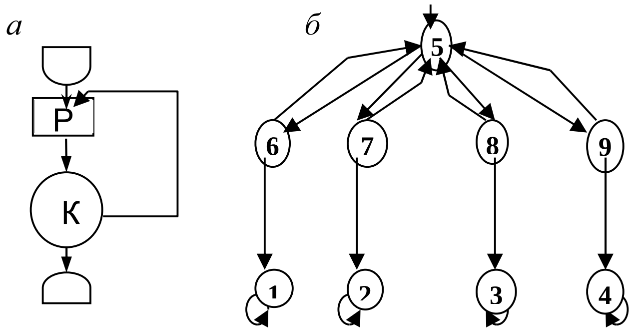


Fig. 9. An example of transition from a work graph to an event graph. *a* – work graph, *b* – event graph (on the event graph, absorbing vertices correspond to: 1 – process execution without errors, 2 – type 1 error, 3 – type 2 error, 4 – type 1 and type 2 errors occurring simultaniously).

Let N be a total number of vertices. At every vertex i there are K_i options to perform an operation, i.e., each solution corresponds to it's specific set of transitions, characterised by $P_{ij}^{(k)}$ -the probability of transition from the vertex i to the vertex j when choosing the k–solution, $k \in K_i$. Moreover: $\sum_j p_{ij}^{(k)} = 1$ for all i and for all $k \in K_i$.

$T_{ij}^{(k)}$ – average execution time of the i-operation within k-solution when transiting to the vertex j. Average expected time for the i-operation within the k-solution: $T_i^{(k)} = \sum_j P_{ij}^{(k)} T_{ij}^{(k)}$. To each variant of the end of functioning on the graph of events, we associate an absorbing vertex. We number the absorbing states with first r natural numbers (r – is the number of absorbing vertices). We consider vertices $s, m, \ldots, n$ being dependent if the operator needs to make the same decisions. For non-absorbing vertices, we set the vector of initial probabilities: $a = (a_{r+1}, a_{r+2}, \ldots, a_n)$:

$$\sum_{i=r+1}^{N} a_i = 1 \cdot$$

It is necessary to choose such a solution at each vertex that will ensure minimum losses from unreliability. Let L be a set of all possible combinations of types of violations, and $B^0{}_l(X)$ – the probability of performing an activity with errors determined by the combination $l \in L$; α_l – the amount of damage from the implementation of the function with violations $l \in L$. The value of damage from errors of different types will have the form:

$$V(X) = \sum_{l \in L} \alpha_l \sum_{s_l} \sum_{i=r+1}^{N} \sum_{k \in K_i} P_{is_l}^{(k)} x_i^{(k)},$$

where:
$x^{(k)}{}_i$ – is a variable that characterizes the choice of solution: $x^{(k)}{}_i > 0$, if in the i-vertex to execute the operation the k-solution was chosen, and $x^{(k)}{}_i = 0$, in the other case. To take into account dependent vertices, we use boolean variables $\delta_i^{(k)}$ (for the k-solution in the i-vertex). Then, the problem can be formalized as follows :

$$V(X) = \sum_{l \in L} \alpha_l \sum_{s_l} \sum_{i=r+1}^{N} \sum_{k \in K_i} P_{is_l}^{(k)} x_i^{(k)} \to \min$$

$$\sum_{k\in K} x_j^{(k)} - \sum_{i=r+1}^{N} \sum_{k\in K} P_{ij}^{(k)} x_i^{(k)} = a_j \,,$$

$$j=r+1, r+2, \ldots, N$$

$$\sum_{i=r+1}^{N} \sum_{j} \sum_{k\in K_i} P_{ij}^{(k)} T_{ij}^{(k)} x_i^{(k)} \le T_0$$

$$\sum_{k\in K_i} \delta_i^{(k)} = 1 \qquad \text{for all } i,$$

$$\delta_s^{(k)} = \delta_m^{(k)} = \ldots = \delta_n^{(k)} \qquad \text{for all } k\in K_i$$

$$x_i^{(k)} - M\delta_i^{(k)} \le 0 \qquad \text{for all } i \text{ and all } k\in K_i.$$

$$x_i^{(k)} - m\delta_i^{(k)} \ge 0 \qquad \text{for all } i \text{ and all } k\in K_i$$

$$\sum_{j=1}^{r} \sum_{i=r+1}^{N} \sum_{k\in K_i} P_{ij}^{(k)} x_i^{(k)} = 1 \,,$$

$$x_i^{(k)} \ge 0 \qquad \text{for all } i \text{ and all } k\in K_i.$$

Let m be a tiny, and M – a very large number, then for each i only one $x_i^{(k)}$ will not be zero, and, in this way, we find the optimal solution at each vertex.

The convenience of the proposed model is that the problem is reduced to a linear programming problem and can be easily solved in any software environment.

Different variations of target functions and limitations are possible, which can be used in various problem situations.

In the database of the decision support system, we recorded 56 various ready-made templates of optimization (single-criterion and multi-criteria problems), used by the decision-maker, depending on the task at hand.

In addition, the optimization problem is embedded in the agent-manager, which prompts the operator in the process of work based on the analysis of the technological process, and on the available reserve of time and resources.

3.6 Approbation

Models and information technology are used in the design and operation of automated control systems for chemical production and other critical systems (gas pumping stations, machine building) in Ukraine and Russia.

Models are used to solve problems:

- Selecting the level of process automation,
- Distribution of functions between operators,
- Control algorithms design,
- User interface design,
- Designing agent-managers to support operator activities.

The implementation of the results made it possible to significantly reduce the risk of accidents and improve the quality of products, as well as (according to surveys) – to increase the degree of cognitive comfort of operators and the attractiveness of their work.

Practical research has shown that the reliability of assessing the probabilistic indicators of error-free and timely implementation of algorithms of activity is determined only by the quality of the initial statistical data and the error does not exceed 0.019%.

In addition, the results are introduced into the educational process of the Ukrainian Engineering and Pedagogical Academy and Sumy State University and are used in the preparation of bachelors (discipline “Decision Theory”, “Theory of Risks” and in the preparation of masters (discipline “Ergonomics of Automated Systems”), as well as in the diploma designing.

4 Conclusions

Accidents and damages in automated production systems of a critical type (which include, among other things, chemical plants) actualize the task of finding reserves for increasing the reliability and sustainability of technological processes.

The human-operator in automated systems is both a source of errors and an active corrective element.

The sustainability and reliability of the entire system significantly depends on the organization of activities and working conditions of the operator.

At enterprises of the chemical profile, decision support systems should be introduced, related to ensuring the sustainability and reliability of technological processes and the ergonomic support of operators' activities.

The decision support system should include system models of an automated technological complex (as elements), in the form of component and morphological models that describe the complex in the required sections and are a source of initial data for modeling.

For the interface design and certification (acceptance into operation), expert groups should be created to carry out a comprehensive assessment and certification.

Automated control systems should provide mechanisms for adaptation to the characteristics of operators, built on the basis of formalized models of operators.

To evaluate and optimize the activities of operators of automated complexes, it is convenient to use the formalisms of functional networks.

The models and information technology proposed in the work make it possible to choose design solutions aimed at minimizing losses from unsustainability and unreliability.

The scientific novelty lies in the fact that, in contrast to the well-known models of sustainable and reliable design, the proposed set of models takes into account the joint functioning of technical and ergatic elements and ensures decision-making using objective quantitative indicators. The practical significance lies in the fact that models and information technology have been developed to allow solving a set of problems of assessing and optimizing reliability, and are convenient for use both at the design and operation stage of automated technological systems, and are minimizing the risks of losses from unreliability

The reliability of the results we ensure by:

- Using the proven mathematical apparatus of functional networks
- Analytical derivation of dependencies (for tasks of calculating reliability)
- Using approved models for solving linear programming problems.

The reliability of the results is confirmed by the high convergence of the assessment results with experimental studies (the error is determined by the quality of the initial data and does not exceed 0.019% for the probabilistic indicators.

The proposed method is associated with additional costs for ensuring sustainability and reliability; however, it makes it possible to reasonably economically substantiate the system of measures, taking into account the reduction of losses from unsustainability and unreliability.

Models for assessing and optimizing reliability and sustainability, as well as approbation, were carried out for technological systems of chemical production, however, the approach and information technology are universal and can be used for a wide class of technological processes.

Research prospects we relate to:

- Comprehensive analysis of losses from cyber-attacks and modeling the activities of attackers, as well as models for identifying security threats based on machine learning methods,
- Contactless methods of monitoring the functional state of employees to prevent negative consequences,
- Integration of analytical models with simulation and Data Mining models.

The authors dedicate this article to the memory of their teacher the first president of the Soviet Ergonomic Association, Doctor of Technical Sciences, Professor Anatoly Ilyich Gubinsky (1931-1990, St. Petersburg, Russia), who was the founder of the scientific school “Efficiency, quality and reliability of human-machine systems” and who first formulated the ideas that formed the basis of our study.

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The price for sustainable development of renewable energy sector: the case of Ukraine

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Abstract. While implementing state support mechanisms for renewable energy deployment, each country faces the problem of assessing and forecasting their consequences and must timely adjust their set to ensure sustainable energy development. The article estimates the price for sustainable development of the renewable energy sector on the example of Ukraine based on evaluating the effectiveness of the key mechanism of state support for the industry advancement - the feed-in tariff. The comparison of feed-in tariff rates with the LCOE indicators for the electricity generated from solar and wind power plants has shown that the current feed-in tariffs for two of the most popular renewable energy technologies are inflated several times and do not meet global trends in reducing the cost price of electricity generated by these technologies. The consequence of applying economically unreasonable tariffs is the annual over-expenditures of the state budget of Ukraine, which recently count hundreds of millions of euros. In the context of the country's growing green energy generation, the conditions for further use of the feed-in tariff and the transition to other state support mechanisms are substantiated.

1 Introduction

Renewable energy (RE) deployment is a progressive trend in modern world development that contributes to the achievement of the Global Sustainable Development Goals #7 "Affordable and clean energy" and #13 "Climate action" [1]. However, RE technologies' technical imperfection still causes the high generation cost of green energy compared to its analog generated from fossil fuels. The higher price significantly reduces the RE competitiveness in the global market and hinders the implementation of green energy technologies in business entities and households' everyday activities. Therefore, while developing the RE sector, countries apply state support mechanisms for the RE generation and consumption. The most popular schemes include feed-in tariffs, renewable portfolio standards, net metering, green auctions, tax, financial privileges, etc. [2-8].

When choosing and implementing support instruments, it is advisable to consider the stage of the RE development in a country and the energy policy goals as well as estimate possible social, economic, environmental and political consequences of the introduced levers. Unreasonable and inconsistent application of economic mechanisms for the RE development can not only fail to achieve the state green energy policy goals but also negatively affect the national economy through state budget overspending, deteriorating the investment climate, discouraging business entities and households from introducing RE technologies, etc. In particular, Spain is an example of such a negative experience. In the early 2000s, the country faced a heavy financial burden on the state budget due to high feed-in tariffs introduced for developing the RE sector. To solve the problem, the national legislation was changed, and feed-in tariffs were cut. However, the country was forced to pay compensations to the RE projects' investors close to 1 billion euro on lawsuits won for violations of their rights due to changes in the RE legislation [9]. Thus, each state that implements state support mechanisms for green energy faces assessing and forecasting their consequences and must timely adjust the toolset for the RE sector's sustainable development.

Organizational, legal, economic, and other RE deployment mechanisms in different countries of the world are studied in plenty of research papers, for example [2-6; 10-11; 12]. The authors of [5; 13-15] note the high efficiency of the feed-in tariff application at the initial stages of national RE sectors' development since these tariffs could provide sufficient profits to the owners of green energy generating facilities. Therefore, at the expense of feed-in tariffs, it is possible to ensure the RE supply's formation on the domestic energy market. Many scientists indicate that the application of

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quota obligations or RE portfolio standards is an effective mechanism to provide both supply and demand for green energy [16-19]. However, this scheme must be supported by net metering and financial instruments (in particular, credit lines, partial compensation of loans for the construction of RE facilities by local and state authorities) to encourage active RE development. As the green energy sector expands, it is advisable to use green auctions and tender systems to ensure the creation of a competitive environment in the field [7; 20-22].

Overall, the necessity of evolutionary changes in management mechanisms for sustainable development of the national RE sectors is highly recognized by the researchers. However, few papers examine the feasibility of using specific state support schemes and the criteria for the transition from one tool to another to ensure sustainable RE deployment. As a rule, scientists focus on assessing the benefits and basic parameters of the RE development mechanisms while paying far less attention to the consequences of such incentives for countries' state budgets. For example, E. Dijkgraaf et al. [23] studied the feed-in tariff impact on the green energy advancement by modeling the duration of feed-in tariffs' implementation, their rates, government targets in the RE field, etc. P. del Río [24] evaluated the dynamic efficiency of feed-in tariffs considering technology-specific fixed-tariffs, their degression in the long-run, cap and floor prices, reductions of support over time for existing RE plants, the burden of green energy costs to consumers, maximum RE plant size, and other factors. The author noted the need to cut feed-in tariffs over time to reduce the financial burden on energy consumers while not quantifying such an impact.

S. Matsuda and H. Kubota [25] proposed the concept of "marginal cost of power facility" to analyze the effectiveness of the feed-in tariff mechanism in Japan. They justified the need to take the effect of replacing imported fossil fuels with green energy into consideration. P. Milanés-Montero et al. [26] analyzed the feed-in tariff influence on Spanish companies' profitability, noting its positive impact on business development. M. D. Leiren and I. Reimer [22] substantiated the transition from feed-in tariffs to green auctions in Germany in a historical institutionalist perspective.

Thus, the recent scientific literature has a gap in research concerning quantitative assessments of the price for sustainable RE sector development based on the feed-in tariff and other economic support tools' use. The lack of these studies negatively affects the effectiveness of national energy policies for the RE advancement, causing management errors and reducing the results of the state support instruments' implementation.

Hence, the purpose of this research is to estimate the price for sustainable development of the RE sector on the example of Ukraine based on evaluating the effectiveness of the feed-in tariff as a key state support mechanism for the industry deployment and justifying the feasibility of its further use in the country. To our knowledge, this is the first attempt to substantiate the feed-in tariff implementation regarding the financial loading on the Ukrainian state budget.

2 Problems of the feed-in tariff application to ensure sustainable RE development in Ukraine

Considerably depending on energy import, Ukraine has been actively developing the RE sector over the last decade, using several mechanisms of economic support, including [27]:

1) credit/loan programs offered by commercial banks in Ukraine and the European Bank for Reconstruction and Development (EBRD);

2) tax and customs incentives (value-added tax exemption for equipment and components used for green electricity generation; custom duty exemption for the imported materials, equipment and components used for the production of alternative fuels or green energy);

3) long-term fixed feed-in tariffs;

4) an allowance to feed-in tariffs for using domestic equipment during the RE plants construction;

5) the guaranteed purchasing of 100% of electricity generated from RE sources;

6) free license obligation for connecting household RE plants to the grid;

7) the simplification of the procedure for connecting new RE plants to the electrical grid.

Today the feed-in tariff, which rates are the highest in Europe [28], is the main support scheme used in Ukraine. Legislatively introduced for enterprises in 2008 and households in 2014, the feed-in tariff ensured the active RE development in the domestic business and residential segments in 2009–2020. In particular, the most significant growth in RE capacities and the amount of green electricity generated was in the last 5-6 years (2014–2020) and was caused by several reasons. The first one is high feed-in tariff rates, which are fixed until the end of 2029 and make RE projects economically profitable. The second reason is the 100% guarantee of green electricity purchase by the state. The third one is the governmental plan to reduce feed-in tariffs gradually in the next decade, which encourages investors to construct RE facilities today and obtain higher feed-in tariffs.

The RE deployment's intensification based on the feed-in tariff application has exacerbated financial problems related to the payments for green electricity generated in the country. The growth of RE generation significantly increases the burden on the state budget. As the legislation of Ukraine does not indicate special sources for the feed-in tariff financing, the rise in the green electricity generation causes an increase in payments for it, which are made at the expense of all taxpayers. This affects the escalation of the weighted average price of electricity in the country, necessitating an increase in electricity tariffs for all consumers. Given the energy poverty of a large part of the Ukrainian population, it threatens to worsen the national socio-economic situation and provoke social protests.

The issue with the payment for the generated green energy was especially aggravated in spring 2020 during the first lockdown. On the one hand, RE generating capacities continued to operate as usual while the overall energy demand decreased due to enterprises' partial shutdown. At that time, it would be expedient to partially turn off the RE facilities and replace expensive green energy with the cheapest one generated by nuclear power plants. However, due to the 100% guarantee of green electricity purchase by the state, the lack of sufficient maneuverability in the Unified Energy System's capacities, and the reluctance of RE plants owners to lose their profits during the lockdown, the share of expensive RE in the overall energy mix increased significantly. The latter caused the deficit growth of SE "Guaranteed Buyer," which paid for the green energy to its suppliers on behalf of the state. At the end of 2020, this enterprise's deficit reached 24.6 billion hryvnias, threatening the national energy billing system collapse [29]. Hence, the current situation requires reforming the economic mechanisms used to support the RE industry in Ukraine. In particular, it is advisable to move to a green auctions system, which the Ukrainian government has not yet launched due to many obstacles [30].

Another alternative is urgently revising the feed-in tariffs and cutting them to a greater extent than planned by law. However, the reduction of feed-in tariff rates is possible only for new RE projects to keep green energy facilities owners and potential investors' trust. In addition, the feed-in tariffs can be cut only based on an objective assessment of the real cost price of green electricity generation, distribution, and supply regarding the stage of RE technologies development. Suppose such a reduction in feed-in tariff rates does not balance the state budget payments for the generated green electricity. In that case, it is expedient to involve other economic incentives for the RE deployment in Ukraine.

Given the above, the research questions are: (1) whether the current feed-in tariff rates in Ukraine are economically justified in terms of ensuring sustainable RE development; (2) how the changes in feed-in tariff rates and green energy generation volumes affect the financial loading of RE on the state budget and (3) whether it is advisable to involve new economic levers to regulate the national RE sector advancement.

3 Approaches to assessing the feed-in tariff economic feasibility

The justification of the feed-in tariff financial burden on the country's state budget can be conducted based on the compliance of the feed-in tariff rates set by the government for a certain RE technology with the average cost price of electricity generated with this technology. In the study, the green energy cost price estimation is based on the Levelized Cost of Electricity (LCOE) method [31]. Carrying out the comparisons for all RE technologies used in the country and determining the weighted average values on their basis make it possible to identify both the degree of feed-in tariffs' justification and their financial burden on the state budget. However, the feed-in tariff rates should be higher than the average cost price of electricity generation for a particular RE technology, as they must at least consider the normal profitability of green energy facilities.

To justify the feed-in tariff rates, the factor of feed-in tariffs' proportionality to the real cost price of green electricity generation (k_{REit}) is proposed. It can be calculated as the ratio of the feed-in tariff for the *i*-th RE technology in the *t*-th year to the cost price of green electricity generated with the *i*-th RE technology in the *t*-th year:

$$k_{REit} = \frac{FIT_{REit}}{LCOE_{REit}}, \qquad (1)$$

where FIT_{REit} is the feed-in tariff for the *i*-th RE technology (or the weighted average feed-in tariff for all RE technologies used in the country) in the *t*-th year, euro/MWh; $LCOE_{REit}$ is the cost price (calculated with the LCOE method) of green electricity generated with the *i*-th RE technology (or the weighted average cost price of electricity generated with the set of RE technologies used in the country) in the *t*-th year, euro/MWh.

The euro was used to calculate the indicators included in the proportionality factor formula. It is due to the fact that feed-in tariffs are fixed in euros in Ukraine to avoid hryvnia devaluation risks. This precaution guarantees a stable income from the operation of RE generating capacities to their owners.

The proposed proportionality factor reflects the degree of the state pricing policy efficiency in the RE sector in the current period. It can be calculated for both the RE technologies mix used in the country and a certain RE technology. If the proportionality factor values are far from 1, there is a divergence between the feed-in tariff rates and the real cost prices of green electricity generation. It indicates the ineffectiveness of the state pricing policy in the RE field. On the contrary, the convergence of the proportionality factor components and its values close to 1 indicates growing compliance of feed-in tariffs with the real green energy cost price and, accordingly, optimizing the feed-in tariff financial burden on the state budget.

It is important to monitor and analyze the value of the proportionality factor in dynamics as the development of the RE sector technological base can significantly reduce the cost price of green electricity generation over time. It should be reflected in the periodic review and adjustment of feed-in tariff rates in order to reduce state budget expenditures.

The amount of the country's state budget over-expenditures (OE_{sbREit}) associated with excessive payments at inflated feed-in tariffs for the *i*-th RE technology in the *t*-th year can be calculated as:

$$OE_{sbREit} = (FIT_{REit} - LCOE_{REit} \times (1 + k_{adREit})) \times Q_{REit}, \qquad (2)$$

where k_{adREit} is a coefficient that considers additional economically justified factors influencing the increase in the unit price of electricity generated in the *t*-th year with the *i*-th RE technology (for example, the normal profit of the RE facility owner, the risk of doing business in the country, credit risks, etc.); Q_{REit} is the amount of green electricity generated in the *t*-th year with the *i*-th RE technology.

The amount of the state budget over-expenditures can be calculated both for an individual RE technology and their set used in the country. Over time, the growth of this indicator shows an increase in unreasonable state budget expenditures due to unbalanced feed-in tariffs.

4 Evaluation of the feed-in tariffs' economic feasibility in Ukraine

Based on the above indicators, let us assess how reasonable the Ukrainian feed-in tariffs and the corresponding state budget expenditures are on the example of large solar power plants (with a capacity of more than 10 MW) and wind power plants (with a capacity of more than 2000 MW per turbine). Solar and wind power plants have been chosen for calculations due to the following considerations. First, feed-in tariffs for solar and wind power plants in Ukraine are the highest compared to other RE technologies. Attractive tariffs have led to the predominant development of solar and wind power facilities, which today provide most of the green electricity generation. Accordingly, state payments for them are the largest. Second, the cost price of generating electricity for large solar and wind power plants is lower than for small and medium-sized RE facilities that should be reflected in feed-in tariffs. Third, the last decade has been marked by significant progress in reducing the cost price of solar and wind energy technologies on the world market. Therefore, it is important to ensure that the change in feed-in tariffs is consistent with the downward trend in these technologies' cost prices (other things being equal) since the growing volume of green electricity generation significantly affects the state budget expenditures.

The initial data for assessing the economic feasibility of feed-in tariffs for large solar and wind power plants are given in Table 1. Data on LCOE [32-33] are provided in euros, taking into account the euro / US dollar exchange rate of the European Central Bank [34] in the relevant period.

Table 1. Initial data for feed-in tariffs' economic justification (developed by the authors based on [27; 32-33]).

Year	Feed-in tariff on electricity, euro cent/kWh		LCOE, euro cent/kWh	
	SPP*	WPP**	SPP	WPP
2009	25.85	11.31	25.74	9.68
2010	25.85	11.31	18.71	9.35
2011	25.85	11.31	11.28	5.10
2012	25.85	11.31	9.73	5.60
2013	18.85	11.31	7.83	5.27
2014	18.85	11.31	5.95	4.44
2015	16.96	10.18	5.86	4.96
2016	15.99	10.18	4.97	4.25
2017	15.03	10.18	4.43	3.98
2018	15.03	10.18	3.64	3.56
2019	15.03	10.18	3.57	3.66

Table notes: *SPP – solar power plants with a capacity of more than 10 MW; **WPP – wind power plants with a capacity of more than 2000 MW per turbine.

Fig. 1 presents the results of calculating the proportionality factors of feed-in tariffs to the real cost price of green electricity generation obtained on the LCOE basis for two RE technologies, according to formula (1).

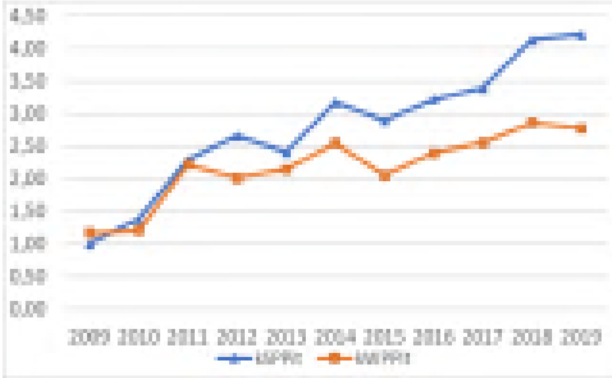

Fig. 1. Proportionality factors of feed-in tariffs to the real cost price of green electricity generation (by the LCOE method) for solar power plants (capacity of more than 10 MW, k_{SPPit}) and wind power plants (capacity of more than 2000 MW per turbine, k_{WPPit}) in Ukraine in 2009-2019 (calculated by the authors).

The calculations show that the feed-in tariff for solar power plants with more than 10 MW capacity was almost equal to LCOE in 2009 while slightly exceeding its value. In that year, the feed-in tariff for wind power plants with a capacity of more than 2000 MW per turbine exceeded LCOE by 17%, which is acceptable in ensuring a normal return on the investment and considering the risks of doing business in the country. Thus, the starting feed-in tariff rates were economically justified. During the study period, there was an increase in the divergence between feed-in tariffs and LCOE for the corresponding RE technologies. This is evidenced by the growing values of the proportionality factors. In 11 years, the gap between feed-in tariff and LCOE for solar energy increased to 4.21 times, whereas for wind power plants up to 2.78 times in 2019. Thus, in 2009–2019, there were formed essential reserves to reduce feed-in tariff rates. They indicate the state RE pricing policy's inefficiency and the economic unreasonableness of current feed-in tariffs, which are significantly inflated and need to be corrected. The obtained results are consistent with the trends of cutting feed-in tariffs in the 2000s by developed countries' governments, which actively deploy the RE sector, due to the cost price reduction of RE technologies [22; 35].

5 Estimation of financial over-expenditures of the state budget of Ukraine due to inflated feed-in tariffs

To calculate the state budget over-expenditures for each of the two considered RE technologies in 2009–2019 due to inflated feed-in tariffs, it is necessary to make several assumptions. First, taking into account the Ukrainian realities (credit risks, the profitability of the green energy business, and other factors), economically justified feed-

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in tariffs should exceed the cost price (LCOE) at least by 25%. Thus, k_{adREit} = 0.25. Secondly, the calculations will be performed only for the business sector, excluding households as the technical, economic, and other operating conditions of RE facilities for these two types of energy suppliers differ significantly. Third, open and detailed statistical data concerning green energy generation by solar power plants with a capacity of more than 10 MW and wind power plants with a capacity of more than 2000 MW per turbine are absent for 2009–2019. Therefore, it is assumed that all volumes of green energy generated by solar business facilities were provided by the operation of solar power plants with the capacity of more than 10 MW. The same assumption is applied to the green electricity generated by wind energy facilities. Feed-in tariffs for large power plants are usually lower than for smaller power plants, considering lower specific fixed and investment costs. Therefore, our estimates of budget overruns, calculated for the entire energy generation of the respective solar or wind sector, can be counted as the state budget financial losses' minimum threshold. The results of calculations according to formula (2) are given in Table 2.

Table 2. Estimates of the state budget over-expenditures on electricity generated by solar and wind power plants in Ukraine in 2009–2019 due to inflated feed-in tariffs (calculated by the authors based on [36-42]).

Year, *t*	Solar energy sector			Wind energy sector		
	k_{adSPPt}	Q_{SPPt}, mln kWh	OE_{sbSPPt}, thousand euro	k_{adWPPt}	Q_{WPPt}, mln kWh	OE_{sbWPPt}, thousand euro
2009	0.25	0.0	0*	0.25	41.1	0*
2010	0.25	0.5	12	0.25	49.2	0*
2011	0.25	30.0	3526	0.25	89.0	4392
2012	0.25	334.0	45720	0.25	257.5	11085
2013	0.25	562.8	50999	0.25	636.4	30049
2014	0.25	485.2	55394	0.25	1171.5	67462
2015	0.25	475.2	45795	0.25	973.7	38788
2016	0.25	492.2	48132	0.25	924.5	45045
2017	0.25	714.7	67879	0.25	973.5	50630
2018	0.25	1080.0	113171	0.25	1180.2	67680
2019	0.25	2932.0	309728	0.25	2022.0	113274

Table notes: k_{adSPPt}, k_{adWPPt} are coefficients of additional energy price factors for solar and wind power plants respectively; Q_{SPPt}, Q_{WPPt} are amounts of green electricity generated by solar and wind power plants respectively; OE_{sbSPPt}, OE_{sbWPPt} are the state budget over-expenditures for feed-in tariffs for solar and wind power plants respectively; 0* means no overspending.

Thus, the obtained data (Table 2) show an exponential increase in state budget overruns for green electricity generated by solar facilities in 2016–2019, while budget over-expenditures for green electricity generated by wind turbines are much lower. In particular, in 2018, with the ratio of electricity generation by solar and wind power plants 0.92:1, the proportion of state budget overruns was 1.67:1. This indicates extremely high feed-in tariffs for solar energy even compared to feed-in tariffs for wind energy, which are also inflated. It confirms that Ukrainian legislators do not monitor the downward trend in the cost price of electricity generation from renewables and do not adjust feed-in tariffs on time. The result is irrational spending of taxpayers' money, which is recently counted of millions of euros. Today all Ukrainians pay for green energy, and only a few oligarchic clans receive extra profits from it. It threatens the sustainable development of the RE industry in the near future.

It is worth noting that each country, which deploys green energy through the feed-in tariff introduction, faces the problem of budget overspending due to the RE volumes' growth and high feed-in tariffs. In particular, Spain, Germany, the Netherlands, and other developed states had to solve this issue at a certain stage of their RE advancement [9; 22; 35]. A national government's task is to monitor the existing feed-in tariffs' compliance with trends in reducing the green energy cost price. On this basis, the government should timely adjust the set and parameters of state support instruments for RE development while avoiding or minimizing state budget overspending.

6 Prospects for change of feed-in tariffs in Ukraine

Based on the data from Table 1, in 2019, the cost prices of generating electricity from solar energy became lower than from wind energy for the considered types of solar and wind power plants for the first time. While maintaining the current trends of cheapening technologies until 2030 (Fig. 2), the cost price of solar energy generation per unit will be 1 euro cent/kWh, and the cost price of wind energy generation per unit will be 2 euro cents/kWh. In addition, both green energy cost price indicators will be lower than their analogs for energy generated from non-renewable sources.

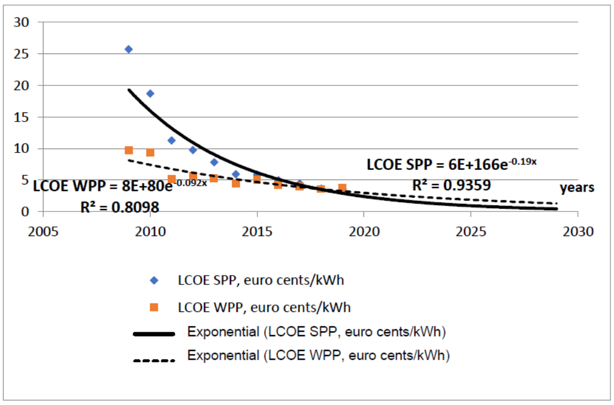

Fig. 2. Cost price reduction forecast of green electricity generation (by the LCOE method) for solar power plants (capacity of more than 10 MW, *LCOE SPP*) and wind power plants (capacity of more than 2000 MW per turbine, *LCOE WPP*) in 2020-2029 (calculated by the authors).

According to the planned decline in feed-in tariff rates in Ukraine in 2021–2029, the lowest feed-in tariff will be 12.01 euro cents/kWh for the considered solar power plant type and 7.92 euro cents/kWh for the considered wind power plant type starting 2025 [27]. Compared to the forecast data on LCOE, feed-in tariff rates will be several times higher than the expected LCOE for the two RE technologies. That is, in the absence of the further legislative revision of the feed-in tariff rates, the divergence between tariffs and the real cost price of green energy generation will increase. The consequence will be continuing excessive growth in the state budget overspending covered by Ukrainian taxpayers.

Given the projected significant reduction in the cost of green electricity, the latter may gradually become a real competitor for traditional electricity. Under such conditions, the feed-in tariff as an economic support instrument for the development of solar power plants with a capacity of more than 10 MW and wind power plants with a capacity of more than 2000 MW per turbine will exhaust itself. It should be abolished for new similar projects in the RE field in Ukraine. However, the feed-in tariff may be preserved for small and medium-sized RE plants, which have a higher cost price of green electricity generation. Relevant practices for small RE facilities are successfully used by many countries worldwide, ensuring the decentralization of energy supply by involving green energy sources [22; 24; 35; 43].

7 Conclusions

The study results on the example of large solar and wind power plants show that current feed-in tariffs in Ukraine are inflated several times and do not correspond to the economically justified level. Such an imbalance in pricing policy for the RE sector causes the disproportionate development of large green energy capacities in the country and devastates the state budget, the losses of which are already estimated at hundreds of millions of euros. Today ordinary Ukrainians pay an exorbitant price for green energy. Preservation of existing and planned reduction of feed-in tariff rates threatens sustainable RE sector development and may cause the industry's financial crisis.

On the one hand, to avoid the mentioned negative consequences, it is advisable to revise the current feed-in tariffs and bring them in line with global trends of the cost price reduction for green electricity generation. However, it is important to consider the additional factors that can increase the unit price for green electricity and refer to the conditions of doing RE business in Ukrainian realities.

On the other hand, with the preservation of feed-in tariffs, the amount of electricity generated by RE facilities operating on feed-in tariffs will only increase. Consequently, state budget expenditures will rise further even with fair feed-in tariffs. Therefore, it is necessary to gradually move away from using the feed-in tariff mechanism, which ensured the successful start of RE development in Ukraine, and apply other levers to regulate sustainable RE development. The latter may include introducing green auctions, renewable portfolio standards, net metering, green certificates market, and other instruments, which will ensure the continued sustainable advancement of the RE sector without creating excessive loading on the Ukrainian state budget.

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Application of fuzzy time series forecasting approach for predicting an enterprise net income level

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Abstract. To ensure the sustainable development of an enterprise, it is necessary to properly analyze the enterprise development, to ground the plans and management decisions on effective diagnostics and prediction of current and future economic situation at the enterprise. The article presents a study on the application of fuzzy time series forecasting methods. A new approach is applied to forecasting an enterprise's net income using a fuzzy technique. For testing the methodology, there were used statistical data on the enterprise net income level of the Ukrainian enterprise from 2002 to 2017. In the method of Stevenson and Potter, it is proposed to use as the universe of discourse, in the process of applying the method for all defined fuzzy sets, the intervals of variation of such indicator as growth rate. The same background as in Stevenson and Porter's model is used in this article for forecasting the time series levels using the growth rates of the actual data as the universe of discourse. The forecasting results, obtained by this approach, are supposed to have more accuracy rate than other fuzzy time series models. Some modifications of this technique are proposed to obtain a higher accuracy rate and a point forecast one step forward.

1 Introduction

To strengthen its market position in a competitive environment and guarantee sustainable development, each company must constantly seek reserves to improve its efficiency. The methodology of decision-making processes under the uncertainty in various sectors of the economy are based on the different forecasting methods and models. However, the conditions of uncertainty and variability of the external environment require the use of scientifically sound approaches to management decisions at all stages of production process management, which requires quality planning and forecasting of most important production indicators, as well as systematic adjustment of current and future plans.

As we know, a forecast is any statement about the future, and economic forecasting is a huge subject [1]. Any operational theory of economic forecasting must allow that any characteristic of the data moments (especially measures of averages and spread) might alter because of changes in technology, legislation, politics, weather, and society [1]. The aim of numerous recent researches is to develop effective and reliable methods for economic forecasting. But the most existing forecasting models impose considerable limitations on the random sequences describing the change of economic indicators (Markovian property, stationarity, monotony, scalarity, etc.) [2]. Therefore, the main requirement for forecasting methods, which can be used in decision-making processes, in the absence of any significant restrictions on random sequences that describe changes in economic indicators.

Nowadays, time series forecasts are used in a wide range of economic activities, such as setting monetary and fiscal policies, state and local budgeting, financial management, and financial engineering [2]. At the same time, these forecasting methods use economic theory mainly as a guide to variable selection and rely on past patterns in the data to predict the future [2].

After the publication of Zadeh's fundamental paper on the basics of fuzzy set theory, this theory has become widespread in many areas of research, including economic.

In the latter years, a wide variety of methods have been developed and implemented using fuzzy sets for a description of the uncertainty present in the values of time series. Using fuzzy methods allows to improve the adequacy of description of real-world processes and obtain the sound forecasts of future levels.

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The main objectives of this study are: comparing forecasts based on the obtained models; determining the point estimator for the future net income level obtained by the applied methods for the analysis of this time series of economic indicators; providing recommendations for further use of fuzzy forecasting methods for short-term and operational forecasts of similar economic indicators for economic analysis and modeling of state of the enterprise.

This article consists of six sections. The first section contains the background of the study. The second one provides an overview of the scientific literature on the topic of research. The third part reveals the theoretical details of the proposed fuzzy time series method. The sequence of the study and its main results are presented in the fourth and fifth parts of this work. The final part contains conclusions based on the research results and discussion of further research areas in the field of studying fuzzy time series methods and adapting them to an enterprise economic indicator predicting tasks.

2 Literature review

In modern conditions, the importance of forecasting in various spheres of human activity does not require additional substantiation and proof. Forecasting plays a leading role in management decision-making processes. Forecasting gives a certain idea of the future state of various objects and processes, which allows with some confidence level to assess the possible consequences of certain decisions.

Naturally, any forecasting does not give 100% confidence that the state of objects will be exactly as predicted. That is because any forecasting result contains some uncertainty. Furthermore, the data on which the forecast is based are rarely so deterministic that it is possible to say that there is no uncertainty in them. The uncertainty in the actual data makes it necessary to find new methods of taking it into account.

Fuzzy set theory has been applied to problems of forecasting in different branches of science. The first application of forecasting using fuzzy set theory appeared in Economakos [3]. A simulation-based model was used to forecast the demand for electrical power when load components at various times of the day were described in linguistic terms [4]. Interest in fuzzy forecasting has grown considerably since this initial article [4]. Research on fuzzy forecasting is divided into three categories: qualitative forecasting by the Delphi method, quantitative forecasting by time series analysis, and regression analysis [4]. The second category is the subject of our study.

In particular, the uncertainty of the fuzzy nature is investigated in the so-called fuzzy time series. Many papers on fuzzy time series prediction appeared between 1993 and 2013 (later works mainly developed existing techniques), and many researchers have turned their attention to the fuzzy time series models. Most of the papers published so far have used enrollment data from the University of Alabama as a test sequence over a nearly 20-year period, and proposed models have been compared by the criteria AFER and MSE to choose the best technology by its accuracy rate.

It should be noted that the first work in this direction belonged to Song and Chissom [5]. They introduced the method of creating the time-invariant and the time-variant fuzzy time series models for forecasting the enrollment of the University of Alabama [5]. There were considered the stationary and time-varying fuzzy forecasting models, which provided average forecasting error rates (AFER) of 3.18% and 4.37%, respectively.

Then, Chen [6] developed three heuristic rules ("informal, intuitive strategies" that express the expectations of expert analysts regarding the trend of student enrollment next year) to calculate the forecasted values by using the midpoints of intervals to derive the forecasted values [7]. Chen's model revised Song and Chissom's time-invariant model in order to simplify the calculations and obtain precise forecasting results. The proposed model used arithmetic operations instead of max-min composition operations found in Song and Chissom's model. As a result, this technique provided an average forecasting error rate of 2.38%.

After that, Huarng [8] improved Chen's model by designing an average-based length method for effectively determining the appropriate interval length. In this direction, Li and Chen [9] proposed a new interval partitioning approach that applies the rule of natural partitioning (4-3-2) to the enrollment data of the University of Alabama.

The next solution was presented by Jilani et al [10], where the first order and time-variant model was built by the frequency density-based partitioning of the historical enrollment data of the University of Alabama, and applied improved fuzzy metric for forecasting [10]. For this purpose, the universe of discourse was initially divided into equal intervals and a weighted aggregation of the historical enrolments was obtained in each interval [11].

Then, that approach was modified, and a new method was presented by Stevenson and Porter [12], also applying it to modeling enrollment of the University of Alabama using year-to-year percentage change as the universe of discourse (UoD).

Abd Elaal et al [13] proposed model employed eight main steps in time-invariant fizzy and time-variant fuzzy time series for selecting membership functions based on fuzzy clustering [7]. Ismail Z. and Efendi R. [14] presented the weighted fuzzy time series based on a collection of variations of the chronological number in the fuzzy logical group for forecasting trend series data [7].

A summary of most fuzzy forecasting applications in the field of time series forecasting is presented in table 1 [4, 7].

In these applications, the fuzzy set theory allows taking into account the uncertainty in the actual data and the different parameters of the models. In general, the structure and application of fuzzy forecasting models are relatively simpler than non-fuzzy models, which makes these models more user-friendly.

Finally, we can confirm that the main goal of all modifications of the original Song and Chissom's model [5] was the reduction of the average forecasting error rate, but some models give the same or not better results than the original model. At the same time, a number of techniques have been developed that have significantly improved the accuracy of fuzzy time series models. Some applications of the proposed methods to real problems are presented in [21-27], which confirms the practical value and prospects of these model's application.

Table 1. Fuzzy time series forecasting models in 1989-2011.

Author(s)	Forecasting Model	Application
Shnaider and Kandel (1989) [15]	Time series	Forecast corporate tax revenues
Song and Chissom (1993) [5]	Time-invariant time series	Forecast University of Alabama enrollment
Song and Chissom (1993) [16]	Time-invariant and time-variant time series	Outline procedure for conducting forecasts
Sullivan and Woodall (1994) [17]	Markov model and time series	Forecast University of Alabama enrollment
Song and Chissom (1994) [18]	Time-variant time series	Forecast University of Alabama enrollment
Song et al. (1995) [19]	Time series	Modification of earlier model
Chen (1996) [6]	Time series	Forecast University of Alabama enrollment
Huarng (2001) [8]	Time series	Forecast University of Alabama enrollment
Li S.T., Chen Y.P. (2004) [9]	Time series	Forecast University of Alabama enrollment
Melike and Konstantin (2005) [20]	First order fuzzy time-invariant time series	Forecast University of Alabama enrollment
Jilani et al (2007) [10]	First-order and time-variant time series	Forecast University of Alabama enrollment
Stevenson and Porter (2009) [12]	First-order and time-variant time series	Forecast University of Alabama enrollment
Abd Elaal et al (2010) [13]	Time-invariant and time-variant time series	Forecast University of Alabama enrollment and the world production of iron and steel
Ismail Z. and Efendi R. (2011) [14]	Weight fuzzy time series	Forecast for University of Alabama and the University of Technology Malaysia

3 Research methodology

In our research, we used Stevenson and Porter's model with some modifications made to improve the accuracy rate and obtain the forecast point estimate one step forward. We used the same background as in Stevenson and Porter's model for forecasting time series using percentage change of the actual data as the universe of discourse (UoD).

In the method of Stevenson and Potter, it is proposed to use as the universe of discourse [12], on which fuzzy sets are given, the intervals of variation of such indicators as the percentage change of year to year rates [12], which we will hereinafter call "chain growth rates" or "growth rates".

Consider the time series of a certain economic indicator, which levels are denoted by $y_i,\ i=\overline{1,n}$.

To model time series, the proposed method uses the following dynamics indicator as a chain growth rate:

$$T_i = \left(\frac{y_i}{y_{i-1}} - 1\right) \times 100\%,\ i=\overline{2,n}. \qquad (1)$$

The algorithm of proposed by Stevenson and Porter method contains the following steps [12]:

Step 1. Determine the universe of discourse as the set $U = \left[\min_{i=\overline{2,n}} T_i;\ \max_{i=\overline{2,n}} T_i\right]$, and divide it into m equal intervals (in the Stevenson and Porter's model $m = 7$). It is desirable to round the boundaries of this set to the nearest integer values. But, in our case, for better accuracy, we left the calculated values without correction.

Step 2. Find the frequency distribution of the values of the growth rates that fall into each interval of the partition. By the rule of natural partitioning (4-3-2), for the three largest values of frequencies that fall into certain intervals, make an additional dividing of these intervals into smaller 4, 3, and 2 sub-intervals, respectively. The number of intervals m recalculates here, and it takes a new value.

Step 3. Define fuzzy sets $X_j,\ j=\overline{1,m}$ on each partition interval as triangular fuzzy numbers, which carriers are described by three values: lower limit, middle point, and upper limit. For the actual data of the time series, determine which fuzzy set will describe each value, thereby fuzzifying the data of the initial series.

Step 4. Perform the defuzzification of fuzzy data using the formula:

$$t_j = \begin{cases} \dfrac{1+0.5}{\dfrac{1}{a_1}+\dfrac{0.5}{a_2}}, & j=1 \\ \dfrac{0.5+1+0.5}{\dfrac{0.5}{a_{j-1}}+\dfrac{1}{a_j}+\dfrac{0.5}{a_{j+1}}}, & 2 \le j \le m-1 \\ \dfrac{0.5+1}{\dfrac{0.5}{a_{j-1}}+\dfrac{1}{a_j}}, & j=m \end{cases} \qquad (2)$$

where a_{j-1}, a_j, a_{j+1} are the middle points of the intervals of the carriers of fuzzy sets X_{j-1}, X_j, X_{j+1}, respectively.

Step 5. Determine the predicted values of each level of the series, using the obtained t_i and consistently applying them to previous levels by the formula:

$$\hat{y}_i = y_{i-1}\left(1+\frac{t_i}{100}\right),\ i=\overline{2,n}. \qquad (3)$$

As shown on the data of the University of Alabama enrollment [12], the forecasting results, obtained by this approach, are supposed to have more accuracy rate than other fuzzy time series models.

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4 Case study: Net income forecasting using fuzzy time series

Consider such an indicator of the enterprise production activity LLC (Limited Liability Company) "Ukrelektroaparat" (Khmelnytskyi) as net income (revenue) from sales. Data on the net income (revenue) from sales in cash equivalent for the period from 2002 to 2018 were obtained from the reporting documentation of the enterprise LLC "Ukrelektroaparat" from open sources of information and presented graphically in Figure 1.

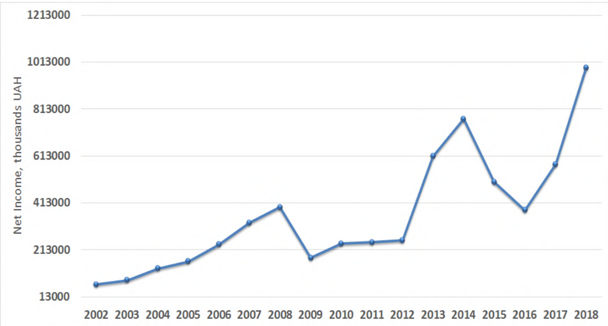

Fig. 1. Dynamics of the net income in 2002-2018.

So, we considered this time series of a real economic indicator and applied to it the fuzzy time series forecasting method described above. Firstly, the growth rates were calculated and aggregated in Table 2.

Table 2. Actual values and the growth rates of net income.

Year to Year	y_i	Growth rate, T_i
2002-2003	82576	28.02
2003-2004	132605	60.59
2004-2005	163642	23.41
2005-2006	235708	44.04
2006-2007	327632	39.00
2007-2008	393463	20.09
2008-2009	178079	-54.74
2009-2010	239518	34.50
2010-2011	244659	2.15
2011-2012	253295	3.53
2012-2013	610840	141.16
2013-2014	769940	26.05
2014-2015	501278	-34.89
2015-2016	382031	-23.79
2016-2017	576795	50.98
2017-2018	986778	71.08

Given the actual interval of variation of the growth rates from -54.74% to 141.16%, it is proposed to determine the universe of discourse as the set U = [-54.74; 141.16], and divide it into the seven intervals. The frequencies of growth rates in occurred in each interval are calculated and presented in Table 3.

Then, we applied the rule (4-3-2) of natural partitioning. As we can see, the largest numbers of net income growth rates have fallen in the fourth, fifth, and sixth intervals, which we divided then into 4, 3, and 2 equal subintervals, respectively. Finally, we obtained the fuzzy sets with triangular membership functions as described in Figure 2.

Table 3. Actual values and the growth rates of net income.

Interval number	Lower limit	Upper limit	Frequency
1	-54.74	-26.76	1
2	-26.76	1.23	1
3	1.23	29.22	1
4	29.22	57.20	6
5	57.20	85.19	4
6	85.19	113.17	2
7	113.17	141.16	0

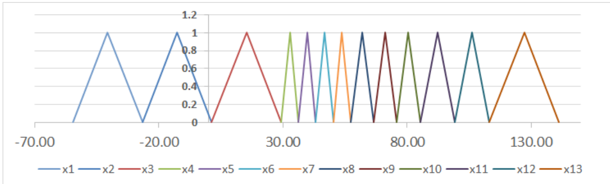

Fig. 2. Fuzzy sets with triangular membership functions.

The final partition of the universe of discourse, the description of the fuzzy sets' carriers with corresponding triangular membership functions and the defuzzified values, are given in Table 4.

Using the obtained defuzzified indicators t_i we determined the predicted values for each time series level, consistently applying them to the previous levels by the formula (3).

The results of calculations of the predicted levels for the considered time series are summarized in table 5. Also, there are represented the determined average forecasting error rates (AFER) obtained by the proposed method by the formula:

$$AFER = \frac{|y_i - \hat{y}_i| / y_i}{n} \times 100\% \,. \tag{4}$$

Table 4. Fuzzy sets and their parameters.

Fuzzy set	Carrier of fuzzy set			Defuzzified value, t_j
	Lower limit	Middle point, a_j	Upper limit	
X_1	-54.74	-40.75	-26.76	-23.54
X_2	-26.76	-12.76	1.23	-34.61
X_3	1.23	15.22	29.22	47.85
X_4	29.22	32.71	36.21	26.31
X_5	36.21	39.71	43.21	39.08
X_6	43.21	46.71	50.20	46.18
X_7	50.20	53.70	57.20	53.46
X_8	57.20	61.87	66.53	61.54
X_9	66.53	71.19	75.86	70.58
X_{10}	75.86	80.52	85.19	80.43
X_{11}	85.19	92.18	99.18	91.88
X_{12}	99.18	106.18	113.17	106.53
X_{13}	113.17	127.16	141.16	119.30

The values of the initial time series and the obtained forecasted levels are represented in Figure 3, and they also can be compared with the values of the simple moving average (Figure 4), which shows that deviations of fuzzy forecasting results from initial values are much lower than of the moving average.

Table 5. Forecasting results for the net income.

i	y_i	T_i	X_j	t_j	$\hat{y}_i$	$AFER$
1	64500	–	–	–	–	–
2	82576	28.02	X_3	47.85	95364	0.1549
3	132605	60.59	X_8	61.54	133396	0.0060
4	163642	23.41	X_3	47.85	196058	0.1981
5	235708	44.04	X_6	46.18	239206	0.0148
6	327632	39.00	X_5	39.08	327833	0.0006
7	393463	20.09	X_3	47.85	484407	0.2311
8	178079	-54.74	X_1	-23.54	300838	0.6894
9	239518	34.50	X_4	26.31	224939	0.0609
10	244659	2.15	X_3	47.85	354130	0.4474
11	253295	3.53	X_3	47.85	361731	0.4281
12	610840	141.16	X_{13}	119.30	555485	0.0906
13	769940	26.05	X_3	47.85	903133	0.1730
14	501278	-34.89	X_1	-23.54	588689	0.1744
15	382031	-23.79	X_2	-34.61	327767	0.1420
16	576795	50.98	X_7	53.46	586281	0.0164
17	986778	71.08	X_9	70.58	983882	0.0029
Total		–	–	–	–	2.831
AFER		–	–	–	–	17.7%

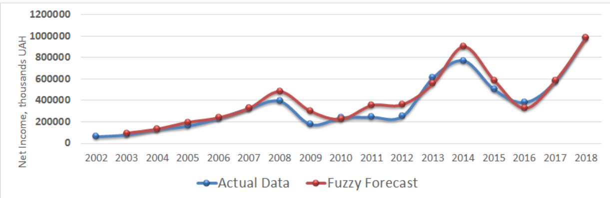

Fig. 3. Comparison of the modeling results with the actual data.

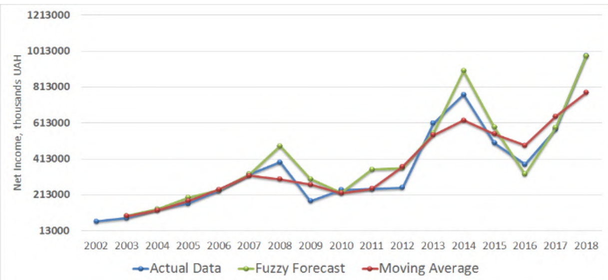

Fig. 4. Forecasted levels compared with the simple moving average.

Another way to test this methodology is to take the time series values from 2002 to 2017 as the initial values and to build the fuzzy time series model on them. Using the fuzzy sets describing the predictive level of each time series level, we can consider a defuzzified value of the time series as a point forecast estimate for each level. Therefore, we suggest calculating the forecasted value for 2018 using the last fuzzy set definition X_7 (for the year 2017), and to obtain the predicted value by the formula:

$$\hat{y}_{17} = y_{16}\left(1+\frac{t_7}{100}\right). \tag{5}$$

The result of estimation is $\hat{y}_{17} = 899733$ thousand UAH (Figure 5), and the average forecasting error rate for this model is AFER = 9.8%, which is slightly lower than for the previous model (table 4). The actual value for 2018 is 986778 thousand UAH, so the relative error is 8.8%.

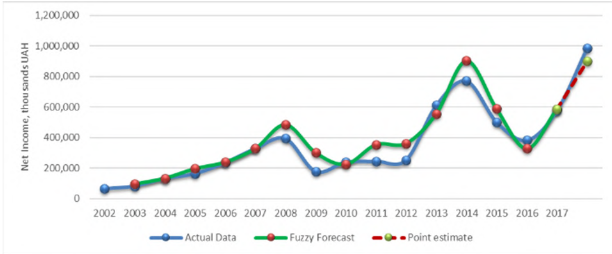

Fig. 5. Point forecast estimate of the net income for 2018.

The accuracy of this forecasting model could be improved if we try to minimize the average forecasting error rate by adjusting some of the values in the defuzzification formula (2). We suggest using four parameters $\alpha_1, \alpha_2, \beta_1, \beta_2$ instead of the values 0.5 in (2):

$$t_j^{adj} = \begin{cases} \dfrac{1+\alpha_1}{\dfrac{1}{a_1}+\dfrac{\alpha_1}{a_2}}, \; j=1; \\[2ex] \dfrac{\beta_1+1+\beta_2}{\dfrac{\beta_1}{a_{j-1}}+\dfrac{1}{a_j}+\dfrac{\beta_2}{a_{j+1}}}, \; 2 \le j \le n-1; \\[2ex] \dfrac{\alpha_2+1}{\dfrac{\alpha_2}{a_{j-1}}+\dfrac{1}{a_j}}, \; j=n. \end{cases} \tag{6}$$

These parameters could be optimized using the Excel Solver GRG Nonlinear method, where AFER is to be set as the objective function, which needs to be minimized. In our study, one set of the obtained adjusted values is: $\alpha_1 = -0.104$, $\alpha_2 = -0.334$, $\beta_1 = 0.076$, $\beta_2 = 0.325$. These values are not unique for each case, but we tried to achieve better accuracy for our model. For the obtained adjusted values, the average forecasting error rate is equal to 5.5%, which is much less than this accuracy indicator for the previous model. These results are illustrated in figure 6, where we can see the forecasted values obtained by the formula (6) with the adjusted parameters.

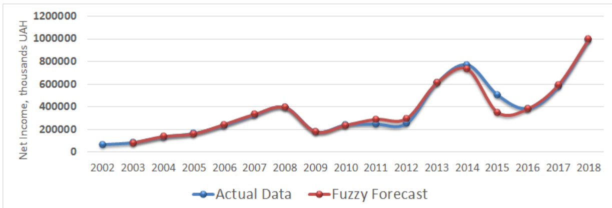

Fig. 6. Net income forecasting model with adjusted parameters.

Comparing to the previous results in Figure 3, this chart shows the closer points to the actual time series levels, which demonstrates the better accuracy of the last obtained model.

5 Results and discussion

As we can see, Stevenson and Porter's method can be applied to the time series of the enterprise's net income level and gives a relatively small error of the result. The conducted analysis shows that the proposed algorithm is quite simple, which makes further searches for the effective methods for modeling time series using fuzzy approach promising, and we should look for the most accurate and convenient fuzzy estimation procedures for time series of economic indicators which take into account the uncertainty of the original data.

Besides, the proposed modification of this technique allows to obtain a point forecast estimate one step ahead, which will give us a piece of information about the possible future level of the time series considered in the research and could be useful for short-term and operational forecasts of similar economic indicators for economic analysis and modeling of state of the enterprise.

6 Conclusion

The presented in the article method of fuzzy time series modeling allows obtaining the forecasting estimates by analyzing the growth rates of the actual time series levels using fuzzy estimation based on the fuzzy sets. This approach makes it possible to use all available information on the dynamics of any economic indicator presented with time series, and achieve a relatively low value of the average error rate.

Further research in this direction should be aimed at developing a unified general formula for defuzzification purposes, which will include a set of parameters, which optimization will allow to obtain better accuracy of the predicted values compared to the actual ones. Another priority for further study is to find possible ways to obtain forecasts a few steps ahead, as there is currently a lack of works in this field. Moreover, a lot of published studies have shown that the accuracy of forecasting is directly affected by the method of the partitioning of the universe of discourse into the set of fuzzy subsets. So, the recommendations should also be developed for the optimal distribution of values over split intervals. Therefore, the use of fuzzy time series approaches opens wide prospects in the field of simplifying the analysis and modeling of time series of economic indicators. Improving such methods will provide an opportunity to implement better forecasting procedures in decision-making systems on enterprises.

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Organizational and economic mechanisms of qualitative modeling of sustainable development of the enterprise

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Abstract. In modern conditions the successful operation of enterprises and maintaining the sustainability of their development depend on the adaptive model of strategic management of the enterprise. The development of such a model using traditional econometric approaches was proposed in the paper. It was suggested by the authors to take into account the prerequisites and specifics of operating activities using the method of PLS (Partial Least Squares), when it is possible to find several important (result) indicators out by the transition from the original set of features to the set of major components of a smaller dimension while maintaining causal relationships allows. The PLS-PM model of sustainable development of the mining enterprise as a complex economic system was done. The essence of latent variables and the relationship between them were identified and substantiated as well as the numerical modelling was performed using the methods of scientific generalization and abstraction.

1 Introduction

The PLS-PM tool (Partial Least Squares Path Modeling) allows to build complex models of causal interactions between latent variables on the basis of component-oriented approach as well as to evaluate general factor models that can be part of multicomponent analysis in addition to this [4, 6, 12]. Moreover, the use of PLS-PM modeling can turn the interaction between implicit indicators and generate predictive values of quantitative changes off.

The stages of identifying model variables and determining the relationships between them proceed without the involvement of the software. The need for the use of software products arises at the stage of determining development scenarios, when direct calculation of the characteristics of the built model are in progress. The researchers are engaged in the processes of interpretation and analysis of the results.

Partial least squares path modeling (PLS-PM) has begun to achieve a widespread practical usage [4-7] if there is a need to make a model of the social contribution of enterprises to the development of the territories or regions. In this study a set of indicators to assess the strategy of sustainable development of the enterprise and further modeling was formed using the resulting and attributive approaches. This means that it can be used to analyze any complex systems that depend on available statistics.

Maintaining the sustainability is possible through a combination of traditional econometric approaches, taking into account the prerequisites and specifics of operating activities on different levels (including the regional one) [2]. So it should be noted that latent variables are considered to be general qualitative indicators, while explicit variables are statistics ones. The model of the description of the target variable consists of quantitative indicators and implicit variables.

Considering the features of building a regression model using the least squares method it should be noted that this mathematical method helps to minimize the sum of the squares of the deviations of some functions from the variables that are searched [10]. This method can be represented as a set of four successive stages: 1) collection of statistical data; 2) determination of correlation coefficients between variables; 3) estimation of regression parameters; general estimation of the model relevance.

The PLS-PM method differs from covariance-based modeling (variability of random variables) since it is not about the constructing a general model of factors for data. On the contrary this method corresponds to composite (consolidated) modeling [8]. This means that it can be used to analyze large data sets to assess the performance of the latent variables.

It is worth noting that there is no need for statistical distribution of variables and random deviations while using the method of projection on latent structures for modeling.

The modeling is performed according to the following algorithm: hypotheses about the existence of latent variables and the relationship between them are put forward, whereupon their indicators are determined and numerical modeling and evaluation of the model quality is performed, followed by interpretation of the obtained results.

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The task for modeling using the PLS-PM method has the form of a data matrix Z of the dimension $Z_n \times Z_i$:

$$Z = \begin{matrix} z_{11} & z_{12} & \cdots & z_{1i} \\ & z_{22} & \cdots & z_{2i} \\ & & \ddots & \vdots \\ & & & z_{ni} \end{matrix}, \qquad (1)$$

where n – the number of modeling objects, a_i – the number of features.

Although the formal development of the composite models [4, 8] and the projection on the latent structure using PLS-PM/PCA-PM methods [1, 7] have been studied previously, the use of an adapted composite model for modeling complex economic systems (in our case - mining enterprises) was not considered.

Each data array Z can be divided into blocks. If to take the fact that each artifact is modeled as a composite as a basis – then it is determined by a unique block of Z_{ni} – indicators.

Table 1. Variable PLS-PM models of sustainable development.

Latent variable	Explicit variable	Designation / unit of measurement
Sustainable development	Number of jobs in the industry	k_{1sd} / thsd
	The structure of gross value added in the gross domestic product	k_{2sd} / %
Economy	Profitability of activity	k_{1econ}/ %
	Return on investment	k_{2econ}/ units
	Equity maneuverability ratio	k_{3econ}/ units
	The ratio of capital investment to gross output	k_{4econ}/ %
	Labor productivity in value terms	k_{5econ}/ thsd UAH
	Costs for modernization and implementation of innovations	k_{6econ}/ (yes/no)
Society	Remuneration with deduction for social insurance	k_{1soc}/ %
	Pension liabilities	k_{2soc}/ thsd UAH
	Deductions for social events	k_{3soc}/ thsd UAH
Ecology	Revenues to the state from emissions of pollutants into the atmosphere	k_{1ecol}/ thsd UAH
	Use of fuel and energy resources	k_{2ecol} / %
	Rent for special use of water	k_{3ecol} / thsd UAH
	Initiatives to reduce the impact of production on the environment	k_{4ecol} / (yes/no)
Integrative dimension	Coefficient of stability of economic growth	k_{1int} / %
	Payments in favor of the state	k_{2int} / thsd UAH
	The relative share of the enterprise in the market of iron products (industry market)	k_{3int} / share units

Sustainable development of a mining enterprise should be considered on the basis of an integrated approach as an integration of all of the components (economic, environmental, social, integrative). In this study four latent variables associated with explicit (quantitative) variables are used (see Table 1): the level of the sustainable enterprise development (Sustainable Development); the level of economic development (Economy); the level of social development (Society); the level of ecological development (Ecology); the level of integrative development (Integrative dimension).

At the same time the intra-block covariance matrix Z_{ni} is not limited (latent variables are related to each other), which allows the indicators of one block to effectively perform covariance.

In contrast to the intra-block covariance matrix, the inter-block covariance matrix is limited because the composites (latent variables) carry information between the respective blocks.

2 Method

A feature of analytical research of such a multifaceted phenomenon as sustainability of development is the use of both quantitative and qualitative indicators. Therefore, the indicators for comparison were separated according to this principle. The dynamic (time) series are represented by a set of statistical indicators in a chronological order.

Step by step one can assess the level of sustainable development of enterprises on the example of the Ukrainian mining enterprises (Metinvest Group (Ingulets, Central and Northern GOK), Arcelor Mittal (AM Kryvyi Rih), Ferrexpo AG (Poltava GOK) and DCH Group (Evraz Sukha Balka) taking into account the period for the last 5 years starting from 2014. Since the value of explicit variables of the largest GOK for five years is taken into account, the representativeness of the sample is confirmed by sufficient volume and quota (a certain number of variables in each direction) [9].

It is assumed that each block Z_i is associated with a latent (implicit) variable LV_i. Taking into account that latent variables are abstract, the internal model of relationships between variables can be presented analytically:

$$LV_{sd} = \alpha_0 + \alpha_1 LV_{econ} + \alpha_2 LV_{soc} + \alpha_3 LV_{ecol} + \alpha_4 LV_{int} + \beta_{sd}, \qquad (2)$$

where LV_{sd} – a latent variable of sustainable development; α_0 – a free member; $\alpha_1 ... \alpha_3$ – path coefficients to indicate the strength and direction of communication between latent variables; LV_{econ} – a latent variable of the economy; LV_{soc} – a latent variable of society; LV_{ecol} – a latent variable of ecology; LV_{int} – a latent variable of integrative dimension; β_{sd} – a residual member.

The internal model must meet a number of requirements, in particular: the system of linear equations is characterized by recursiveness; random deviations are allowed; the model itself is regressive.

The initial model is shown in Fig. 1 (latent variables are represented by colored rectangles, and explicit variables are not).

Analyzing the sustainable development of mining enterprises on the basis of reporting data, one can identify a number of indicators that characterize the components of the sustainable development (these are explicit variables from Fig.1, the source of which were the official financial and non-financial published reports of the mentioned enterprises (Metinvest Group (Ingulets, Central and Northern GOK), Arcelor Mittal (AM Kryvyi Rih), Ferrexpo AG (Poltava GOK) and DCH Group (Evraz Sukha Balka) for the period of 2014-2018).

The relationship of latent variables is an internal model while the relationship between latent and explicit variables is an external model.

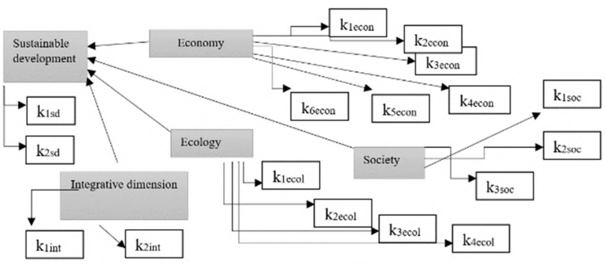


Fig. 1. The initial model of sustainable development.

The external model characterizes the relationship between explicit and latent variables. There are two types of external models by types of connections – reflective (preference is given to latent variables) and formative (latent variables arose due to explicit) one.

In the method of modeling path coefficients using the Partial Least Squares method, the concept of estimating the latent variable (linear combination of the corresponding explicit variables) arises.

Since each latent variable is directly related to two or three explicit variables, the external model of the reflective type in this case can be presented in a form of a system of equations:

$$\left\{\begin{array}{c} Z_{k1sd} = \alpha_{0k1sd} + \alpha_{1k1sd} LV_{sd} + \beta_{k1sd} \\ Z_{k2sd} = \alpha_{0k2sd} + \alpha_{1k2sd} LV_{sd} + \beta_{k2sd} \\ \dots \\ Z_{k1econ} = \alpha_{0k1econ} + \alpha_{1k1econ} LV_{econ} + \beta_{k1econ} \\ Z_{k2econ} = \alpha_{0k2econ} + \alpha_{1k2econ} LV_{econ} + \beta_{k2econ} \\ \dots \\ Z_{k1soc} = \alpha_{0k1soc} + \alpha_{1k1soc} LV_{soc} + \beta_{k1soc} \\ Z_{k2soc} = \alpha_{0k2soc} + \alpha_{1k2soc} LV_{soc} + \beta_{k2soc} \\ \dots \\ Z_{k1ecol} = \alpha_{0k1ecol} + \alpha_{1k1ecol} LV_{ecol} + \beta_{k1ecol} \\ Z_{k2ecol} = \alpha_{0k2ecol} + \alpha_{1k2ecol} LV_{ecol} + \beta_{k2ecol} \\ \dots \\ Z_{k1int} = \alpha_{0k1int} + \alpha_{1kint} LV_{int} + \beta_{k1int} \\ Z_{k2int} = \alpha_{0k2int} + \alpha_{1k2int} + \beta_{k2int} \\ \dots \end{array}\right. \quad (3)$$

where $Z_{k1sd}...Z_{k2int}$ – explicit variables; $\alpha_{0k1sd}...\alpha_{0k2int}$ – free members; $\alpha_{1k1sd}...\alpha_{1k2int}$ – load factors; $\beta_{k1sd}...\ \beta_{k2int}$ – residual members.

Latent variables are not directly measured, so in order to denote their evaluation Y_i is used:

$$Y_i = \widehat{LV}_i = \sum_n^i \gamma_{in} Z_{in}, \quad (4)$$

$$\begin{array}{c} LV_{sd} = Y_{sd} = \delta_{k1sd} Z_{k1sd} + \delta_{k2sd} Z_{k2sd} \\ LV_{econ} = Y_{econ} = \delta_{k1econ} Z_{k1econ} + \delta_{k2econ} Z_{k2econ} + \delta_{k3econ} Z_{k3econ} + \\ + \delta_{k4econ} Z_{k4econ} + \delta_{k5econ} Z_{k5econ} + \delta_{k6econ} Z_{k6econ} \\ LV_{soc} = Y_{soc} = \delta_{k1soc} Z_{k1soc} + \delta_{k2soc} Z_{k2soc} + \delta_{k3soc} Z_{k3soc} \\ LV_{ecol} = Y_{ecol} = \delta_{k1ecol} Z_{k1ecol} + \delta_{k2ecol} Z_{k2ecol} + \delta_{k3ecol} Z_{k3ecol} + \\ + \delta_{k4ecol} Z_{k4ecol} \\ LV_{int} = Y_{int} = \delta_{k1int} Z_{k1int} + \delta_{k2int} Z_{k2int} + \delta_{k3int} Z_{k3int} \end{array} \quad (5)$$

where $\delta_{k1sd}...\delta_{k3int}$ – external scales of the model.

Therefore we can distinguish the main stages of calculation in the process of PLS-PM-modeling, in particular: external scales of the model to obtain estimates of latent variables, path coefficients of the internal model and correlation coefficients between latent and explicit variables.

The first stage of PLS-PM modeling is an iterative process. Therefore to obtain the values of the estimates of the latent variables Y_i, the initial values of the external weights $\delta_{k1sd}...\delta_{k3int}$ are set.

It should be noted that this stage is a key one, because the calculation of the values of external weights allows the evaluation of latent variables. After this stage the system of linear equations can be solved using the PLS method and the correlation coefficients can be calculated.

Taking into account the weights (to the required degree of convergence of external weights) the results of recalculation of values of estimates of latent variables using internal rather than external model (one calculate the values of estimates of latent variables as linear combinations of estimates of other latent rather than explicit variables) can be described like:

$$V_i = \sum_{n<->j} e_{nj} Y_n, \quad (6)$$

where V_i – the sum of the estimates of those latent variables, which are related to n-latent variable; e_{nj} – internal scales of the model.

Accordingly, the recalculation of the values of external weights for the external model of the reflective type can be described according to the formula:

$$\delta_{jn} = (Y_j' Y_j)^{-1} Y_j' Z_{jn} \quad (7)$$

It is important to note that with each new step of the iterative process the degree of convergence (convergence) of external weights also changes.

Similarly, the calculation of the path coefficients of the internal model can be described according to the formula:

$$\alpha_{jn} = (Y_n' Y_n)^{-1} Y_n' Y_j \quad (8)$$

Regarding the calculation of load factors they are equated to the correlation coefficients between latent and explicit variables.

Modeling by the method of PLS-PM and the necessary calculations were implemented in the software environment SmartPLS 3.0, using which one can present the visualization of the coefficients of external loads of the external model.

The authors do not take into account the variables of the PLS-PM models of sustainable development k_{6econ} (the costs of modernization and innovation) and k_{4ecol} (the initiatives to reduce the impact of production on the environment) which have constant binary values.

Analysis of the model of sustainable development by the PLS-PM method involves the sequential implementation of the following steps: 1) verification of the blocks for internal consistency; 2) assessment of the significance of external variables; 3) detection of cross-correlations of variable blocks with latent variables of other blocks; 4) studying of the consistency of the internal model; 5) checking the quality of the model; 6) further optimization.

The first stage (verification of blocks for internal consistency) in the framework of PLS-PM modeling can be done by using several criteria, in particular: Cronbach's alpha coefficient, a structural reliability and an average variance extracted (AVE).

The acceptable value of the AVE indicator is in the range starting from 0.50 and above because the constructed model explains more than half of the variance of the indicator values in this case. The blocks “Ecology” and “Sustainable Development” meet this criterion.

It is shown in the Table 2 that the blocks “Economy”, “Ecology” and “Sustainable Development” have high values of Cronbach's alpha coefficients and blocks “Society” and “Integrative Dimension” are characterized by low internal consistency.

Table 2. Checking internal consistency in blocks.

Block	Cronbach's alpha coefficient	Composite reliability (CR)	Average variance extracted (AVE)
Economy	0,277	0,472	0,269
Society	-0,370	0,468	0,301
Ecology	0,755		0,493
Integrative dimension	-0,363	0,315	0,332
Sustainable development	0,875	0,014	0,824

As for the Cronbach's alpha coefficient – it characterizes the reliability and internal consistency of the model based on the existing relationships between the observed variables.

The calculation is performed on the basis of ranking the indicators according to the level of reliability provided by the algorithm of the PLS-PM method. If its value is greater than 0.5, it indicates confirmation of the assumption of equal reliability of all indicators.

All observed variables show the existence of a load on the corresponding component, which confirms the convergent validity. The variables of the block “Sustainable development” are characterized by the greatest reliability.

At the same time the Cronbach's alpha coefficient in the case of an increase in the number of objects of observation may slightly contribute to the underestimation of the internal consistency in the calculations.

Therefore, to assess the degree of compliance of indicators with latent variables the composite reliability indicator is used with the help of which it is possible to trace the degree of compliance of indicators included in the model with latent variables [11].

In this case, some indicators of the model have a fairly high value (for example, for the economy – 0.472, for the society – 0.468), which suggests the presence of high structural consistency.

It is also important to determine the validity of the model, i.e. the degree to which the indicators correspond to the planned characteristics, namely the numerical expression of aspects of sustainable development.

3 Results and discussion

In order to ensure that the model characterizes the phenomena not covered by other components, one can use not only the average extracted variance. The Fornell-Larker test [5] and the heterotrait-monotrait ratio are the other estimates, which are also based on a step transition. Since latent variable models do not contain conceptually similar constructs, one can use both.

The Fornell-Larker calculation criterion is shown in Table 3. As we can see, the square of correlations between each pair of components of the model of sustainable development is less than the average extracted variance, so this meets the requirements of the criterion.

Table 3 The Fornell-Larker criterion.

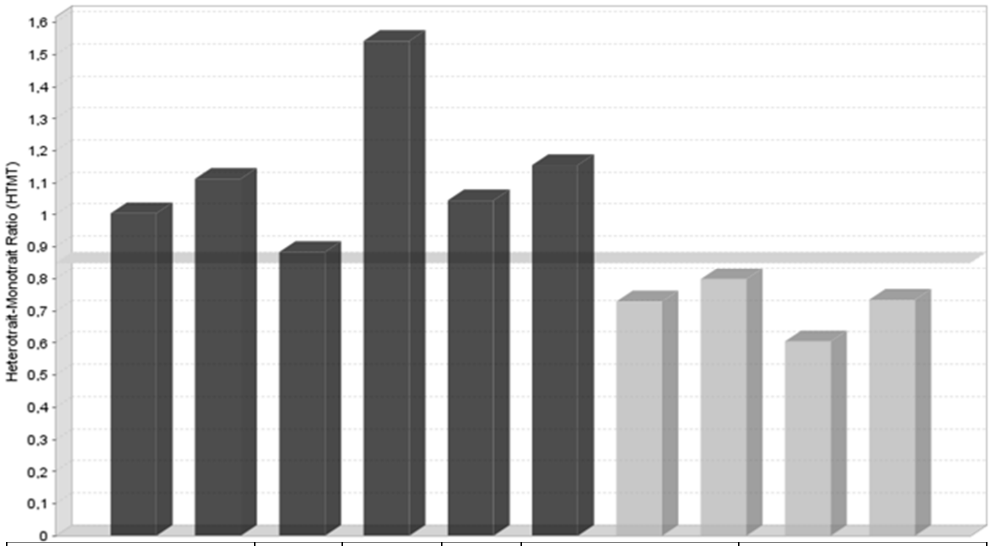
	Ecology	**Economy**	**Society**	**Integrative dimension**	**Sustainable development**
Ecology	0.702	-	-	-	-
Economy	0.324	0.518	-	-	-
Society	0.384	0.362	0.549	-	-
Integrative dimension	0.440	0.007	0.406	0.576	-
Sustainable development	0.606	0.598	0.549	0.524	0.908

Estimates by the criterion of hetero- and monocharacteristics, shown in Fig. 2, indicate the presence of discriminant validity of blocks (when the value of the criterion is less than 0.90). It follows that the used reflective evaluation construct is discriminant-valid.

As for the course of further hypotheses – the impact of four latent variables on sustainable development will be used. The adequacy of the constructed model with the actual data for the period from 2014 to 2018 will be established by Fisher's criterion, which evaluates the statistical significance of the determination index R_2. In this case the estimate is 0.0014, which is less than the specified level of significance (0.05). This means that factors significantly affect the provision of sustainable development.

The verification of internal consistency also occurs by determining the eigenvalues of the correlation matrix of explicit variables (Table 4).

All blocks have a positive correlation with the latent variable, which indicates the internal consistency in the blocks. Once we have obtained the consistency indicators of the model, we can present the schemes of correlations.



	Ecology	Economy	Society	Integrative dimension	Sustainable development
Ecology	-	-	-	-	-
Economy	1.005	-	-	-	-
Society	1.113	0.884	-	-	-
Integrative dimension	1.542	1.046	1.155	-	-
Sustainable development	0.729	0.798	0.605	0.734	-

Fig. 2. Criterion of hetero- and monocharacteristics.

Table 4. Correlation of latent variables.

Latent variables	**Ecology**	**Economy**	**Society**	**Integrative dimension**	**Sustainable development**
Ecology	-	0.324	0.384	0.440	0.606
Economy	0.324	-	0.362	0.007	0.598
Society	0.384	0.362	-	0.406	0.549
Integrative dimension	0.440	0.007	0.406	-	0.524
Sustainable development	0.606	0.598	0.549	0.524	-

Table 5. The values of the coefficients of the external model.

Block	**Variable**	**External scales**	**External loads**
Sustainable development	k_{1sd}	-0.445	-0.872
	k_{2sd}	0.650	0.942
Economy	k_{1econ}	0.493	0.560
	k_{2econ}	-0.277	-0.284
	k_{3econ}	0.341	0.702
	k_{4econ}	0.222	0.180
	k_{5econ}	0.563	0.651
Society	k_{1soc}	0.530	0.448
	k_{2soc}	0.923	0.835
	k_{3soc}	-0.102	0.075
Ecology	k_{1ecol}	0.714	0.923
	k_{2ecol}	0.006	0.150
	k_{3ecol}	0.437	0.778
Integrative dimension	k_{1int}	-0.281	-0.191
	k_{2int}	0.000	0.192
	k_{3int}	0.986	0.960

The second stage is the assessment of the significance of external variables, which is possible using the software capabilities of the SmartPLS 3.0 package. In particular, the external model was tested (Table 5).

Shown in Fig. 3 correlation coefficients of explicit variables and latent variables (by blocks) indicate the following: low correlation (close to or equal to zero) is observed for one variable in the blocks "Integrative Dimension" and "Ecology", which leads to internal inconsistency.

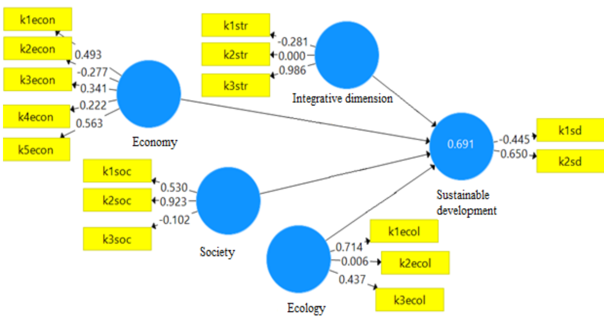


Fig. 3. External scales of the model.

To assess the significance of the obtained values of external weights and their relevance by the method of bias correction (BC), one can obtain additional information for the analysis of the reliability of the results (Table 6).

Since the given values of the coefficients differ from zero, there is a significant strength of the links of exogenous structures with endogenous.

The third stage is the verification of cross-correlations. Such verification is necessary to trace the relationships of explicit variables with latent ones within the respective blocks and, if necessary, to exclude those indicators whose connection with the latent variables of other blocks is higher in comparison with a similar variable of the corresponding block. In this case, no significant deviations in loyalty to the variables of certain blocks were detected (except for isolated cases with k_{1sd}, k_{2econ}, k_{2ecol}, k_{1int} and k_{2int}) which indicates the admissibility of their consideration. The presence of deviations is explained by the fact that the method of "convenient sampling" was used, which serves as a limitation due to the objective difficulties of data collection. It means that the presented results are an analytical (not a statistical) generalization.

Table 6. Offset of confidence intervals.

Trajectories	Initial sample	The average value for the sample	Offset	
			2.5%	97.5%
Ecology → Sustainable development	0.245	0.217	-0.187	0.523
Economy→ Sustainable development	0.464	0.004	-0.650	0.637
Society → Sustainable development	0.143	0.084	-0.322	0.413
Integrative dimension → Sustainable development	0.355	0.342	-0.089	0.716

The presence of lateral collinearity (when the model is estimated by several interrelated high-probability variables) can be traced if we pay attention to the maximum within the sample values of the variance inflation factor (VIF) [3]. In this case, the value of this indicator for the blocks "Ecology" and "Society" are 1.445 and 1.439 and the internal values of each indicator of the block are less than the threshold (<5%).

In the fourth and fifth stages, we will consider the internal model of sustainable development, check it on the index of compliance and obtain estimates of latent variables in the form of a system of equations.

Since the "path" coefficients and values of R^2 for endogenous latent variables (in this case $R^2 = 0.691$) are significant, that indicates a close relationship between the performance trait and the studied factors, ie the model explains approximately 69% of the variance of this indicator, and only 31% explain other factors. It is also assumed that the latent variable determines the variance of each indicator by at least 50%.

Checking the quality of the model involves the following procedures: calculation of the coefficients d_ULS (square Euclidean distance) and d_G (geodetic distance) [4]. Both coefficients characterize the quality of internal and external models of the system and serve as an indicator of the predictive reliability of the model. The d_G criterion is based on the calculations of the eigenvalues of the PLS model. A model is considered to be qualitative when the difference between the correlation matrix resulting from the model and the empirical correlation matrix is so small that it can be attributed to the sampling error. If this difference is insignificant (criteria d_ULS and d_G are higher than 0.05), then the model is qualitative. In our case both criteria are much higher than the minimum allowable values (d_ULS = 4.409; d_G = 2.749), which indicates the prognostic reliability of the model.

The sixth stage is the further optimization. The PLS-PM simulation method is used for multidimensional data analysis (however there is no data distribution) which can cause standard errors. Therefore structural modeling of results is performed additionally on the basis of a nonparametric statistical method, which does not require a normalized data distribution. This means that a bootstrap is used to check the significance of the coefficients. At this stage the estimates of path coefficients are analyzed as well as the results of checking the criterion of T-statistics (the ratio of the original sample to the standard deviation).

The values of the cumulative effect of the coefficients of the trajectories (Table 7), indicate the validity of the selected trajectories. According to the generally accepted approaches, the limit values of P (significance) are considered to be the following: for the value of T-statistics over 1.65 - 10%, over 1.96 - 5%. It is a consequence of the statistical probability of error in cases where the empirical value of significance exceeds the norm.

Table 7. The values of the cumulative effect of the coefficients of the trajectories.

Trajectories	Original sample	The average value for the sample	STDEV	T-statistics	P
Ecology → Sustainable development	0.245	0.217	0.185	1.327	0.185
Economy→ Sustainable development	0.464	0.004	0.452	1.027	0.305
Society → Sustainable development	0.143	0.084	0.189	0.760	0.448
Integrative dimension → Sustainable development	0.355	0.342	0.193	1.842	0.066

By estimating the magnitude of the effect f^2, it is possible to investigate the relevance of the components to substantiate exogenous influencing factors. Such an analysis is possible by excluding a certain component of the model to assess the impact of the removed element on the stability of the structure. It is assumed that the value of f^2 at a level above 0.02 means the presence of a significant effect of the latent variable. In our model the value of f^2 in all cases exceeds 0.02 (the magnitude of the effect of the components "Economy", "Society", "Ecology" and "Integrative dimension" for the endogenous latent variable "Sustainable Development" are 0.539, 0.046, 0.134 and 0.281). This shows that all of the components have a significant impact on the sustainable development.

As for the interpretation of the obtained results, the performed modeling revealed the following feature: in the absence of stable trends in the object of modeling (mining enterprises) changes in trends will not be recognized in case of a sharp change in development conditions. Thus, the chosen approach to building a multidimensional model that reflects the most significant and stable internal and external relationships was correct. At the same time, the assessment and analysis of the strategy of sustainable development of the enterprise in case of changing external and internal parameters requires a study of whether there can be a transition from stable to unstable state. So enterprise sustainability management should include a rapid response to threats and risks.

Based on the principle that it is better to prevent a crisis than to eliminate its consequences, the policy of modern business should include the following steps: reducing the level of disparities (paying more attention to only one aspect of sustainable development); the ratio of resource consumption and recovery or renewable changes (for non-renewable); increasing the level of innovation implementation; increasing the level of social and environmental responsibility of the enterprise.

4 Conclusions

The scientific novelty of the obtained results is to provide the organizational and informational strategy of sustainable development of the enterprise, the elements of which are the development of a qualitative model of sustainable development strategy taking into account the industry characteristics and the forecasting mechanism using latent variables and the method of private least squares in order to build a PLS-PM model of sustainable development of the enterprise as a complex economic system, which allows to assess the degree of impact specific quantitative and implicit qualitative indicators on a particular phenomenon (sustainable development of the enterprise) by the introduction of explanatory variables.

Therefore, during the calculations to verify the relevance of the PLS-PM model of the sustainable development, it was proved that the tripartite approach, relevant for macroeconomic objects requires specification by highlighting additional aspects (considering the integrative dimension) of sustainable development at the micro level. The proposed component of sustainable development includes the provision and balance of resources, the state of property and an innovation activity. Accordingly it is proposed to include production and technological subsystems that were not taken into account in the components which were mentioned above.

Using the methods of scientific generalization and abstraction the essence of latent variables and the relationship between them was identified and substantiated as well as the numerical modeling was performed. Using the method of abstraction it was possible to seemingly separate the characteristics of sustainable development that are irrelevant for modeling from itself (such as binary indicators for the costs of modernization and implementation of innovations and initiatives to reduce the impact of production on the environment).

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Catastrophes, fractals and chaos in geoengineering and water treatment systems

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Abstract. The present paper provides the assessing scale of the actual state of the geoengineering complexes and the model for predicting the behavior of supporting structures. To predict accidents in geoengineering and water treatment facilities it is proposed to apply the results of the theory of catastrophe theory, fuzzy sets, chaos theory and the theory of possibilities for the selection of optimal models of system behavior for a particular situation. It is shown that determination the limit boundaries in which the operation of the system can exist is impossible without the consideration of geoengineering treatment facilities and their components as fractal structures, functioning under conditions of “chaos”. To minimize risks of damages of sewage geoengineering systems the monitoring with measurement of the toxic gases concentration and comparing it with the obtained one should be provided. The use of models of internal and external corrosion which includes the elements of the theory of fuzzy sets helps to evaluate completely the state of water supply and treatment facilities network.

1 Introduction

In the processes of water treatment and water purification, there are very often the problems that are clearly nonlinear and, at the same time, can not be analysed with the methods used in “classical” nonlinear systems, or give the results that are far from the optimal ones (and even plausible). These problems include quasiperiodic changes in the states of shallow water basins (such as, for example, water intakes and artificial seas), which may receive stormwater or wastewater; behavior of biological treatment systems; general behavior of the entire complex of water treatment systems in different spatial and temporal boundaries and scales, etc.; and finally, the behavior of individual components of treatment facilities, pipelines and collectors under the conditions of a man-made disaster emerging in their depths. All these problems can be successfully solved only when we turn to the use of a new mathematical apparatus based on the results of the theories of fuzzy sets, catastrophes, fractals and chaos [1-5].

The aim of the work is to determine the conditions that ensure the normal functioning of a complex system under conditions of uncertainty, as well as an effective assessment of its parameters.

As the World Health Organization underlines, corrosion monitoring is very important for the water supplies functioning [6]. Concrete corrosion is one of the most significant failure mechanisms of sewer pipes, and can reduce the sewer service life significantly [7]. Result of presented research indicate that water is corrosive at 10.6%-89.4% of drinking water supply reservoirs [6].

The wastewater system as a system functioning under conditions of fuzzy data needs the regular monitoring and control of its parameters. The proposed performance-rating system evaluates each parameter and combines them mathematically through a weighted summation and a fuzzy inference system that reflects the importance of the various factors [8].

An analysis of the results of observations and analogies suggests that the structures and functioning of natural and geoengineering water treatment systems demonstrate in a broad sense the self-similarity of water purification processes from pollution both in natural conditions and in engineering treatment facilities – the same principles are applied, the only difference is in productivity and quality of treatment. In other words, both those and other systems more or less equally fit into a wide range of spatial, temporal and quantitative scales, which indicates the presence of a certain symmetry of the scales. In this case, for the study of such systems, one can fully use the methods of fractal analysis and elements of the chaos theory [9-10]. But such an approach is suitable not only for analysing the structures of water treatment and the processes occurring in them, but also for optimizing the geometry of tree-like configurations of water distribution systems, for displaying contamination isolines caused by man-made accidents and natural disasters, and also for using similar displays obtained at

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different stages of monitoring and to analyse the dynamics of pollution migration.

It is also perspective to use the methods mentioned above in the analysis of a number of biological catastrophes associated with changes in water quality under the influence of external factors. Finally, it is interesting to apply the proposed approach together with the results of the theory of fuzzy sets and the theory of possibilities for the selection of optimal models of system behavior for a particular situation. The proposed approach also assumes the use of catastrophe theory, fuzzy set theory and chaos theory to predict accidents in geoengineering and treatment facilities.

2 Reliable assessment of the state of geoengineering structures

Let's consider some special cases of the proposed approach implementation. The behavior (dynamics) of the bottom layer and bottom sediments in shallow lake ecosystems, as well as in most artificial seas formed during the construction of hydroelectric power plants, is an example of a classic catastrophe with several attractors [11]. Usually two different states of such shallow water bodies are identified. In the state of the bottom layer under conditions of high transparency, there is a vegetation ecosystem at the bottom. With an increase in the intake of biogenic components of wastewater (municipal wastewater or storm water), turbidity in the water increases and the ecosystem crosses the catastrophic threshold and transforms into a hypertrophic turbid phytoplankton ecosystem in bottom sediments. In reality, there are lakes that regularly pass from one state to another (Lake Ontario in North America, for example, regularly experiences similar cataclysms). In some water bodies, the beginning of spring (loading of biogenic components) determines the state of the ecosystem in summer. This is an example of a bifurcation in the behavior of an ecosystem when it gets to the point of return of the seasonal “eight” (see Fig. 1).

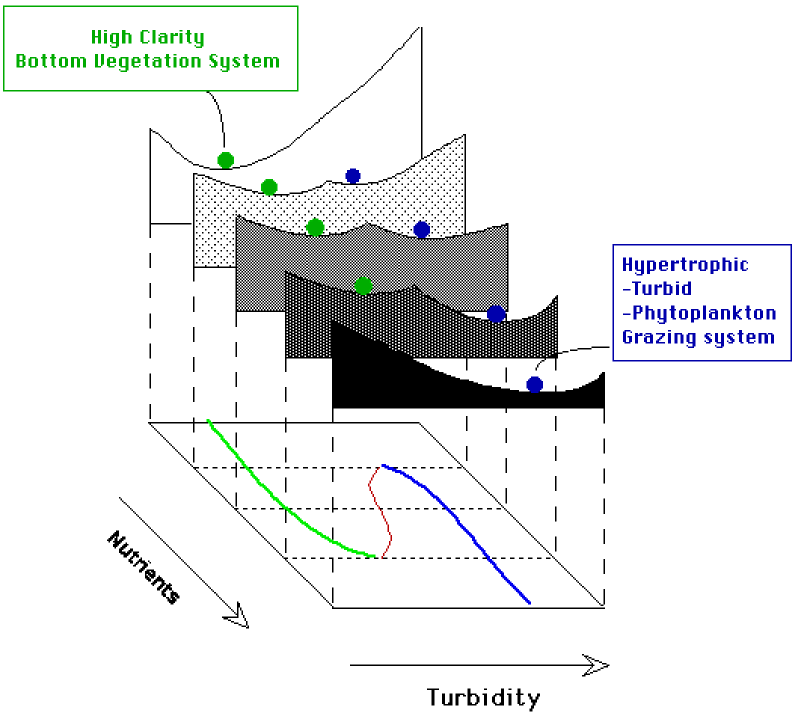

Fig. 1. Ecological disaster such as a catastrophic leap, when small changes in the value of the manager (nutrients supply) major changes in the state value (turbidity).

Discontinuous transitions from one mode to another regimes occur when the parameter in the system changes smoothly:

$$F(x; a, b) = (1/4)\cdot x^4 + (1/2)\cdot a\cdot x^2 + b\cdot x \quad (1)$$

with a phase state variable (turbidity *a*). On the plane of values of the parameter *b* (nutrients) and the phase variable, stationary modes form a smooth curve, which can be described by the equations:

$$(-a/3)^{1/2} = (b/2)^{1/3}, \quad (2)$$

$$(-a/3)^3 = (b/2)^2, \quad (3)$$

$$(a/3)^3 + (b/2)^{2\,=\,0}. \quad (4)$$

Its projection onto the parameter value axis has some peculiarities. When the parameter changes, one of the stable equilibrium positions disappears, merging with the unstable one, and the system is forced to jump to a new regime with sharply different characteristics. Understanding the essence of a disaster allows to anticipate a leap and develop heuristics that either prevent bifurcation or change the water treatment technology (by

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using other reagents, their concentration or the sequence of using different treatment technologies).

Predicting the behavior of supporting structures (columns, supports, brackets, etc.) of a treatment plant complex is an extremely important task, and the amplitude of the initial bending of the supporting structure can serve as a hazard indicator. In other words, the safe load is determined by the maximum safe bend (deforiation) [2]:

$$\Delta V(a_1=s;\, F_s,\varepsilon) = \varepsilon + \tfrac{1}{2}(\pi/l)^2(F_1 - F_s)s + (3/2^4)F_s l(\pi/l)^4 s^3, \quad (5)$$

where
$$F_s = F_c(s) - k(s)\,\varepsilon, \quad (6)$$

$$F_c(s) = \{F_1/(l - 3/8[as/l]^2)\}, \quad (7)$$

$$k(s) = \{(2/l\text{-}s/l)(l/\pi)^2\}/\{l\text{-}3/8(\pi s/l)^2\}. \quad (8)$$

Here $F_c(s)$ – the safe load in the absence of defects, F_1 – the maximum bearing capacity at which the bending amplitude reaches s, l – the coordinate of another end of the supporting structure, ε – the coefficient of dynamic sensitivity to defects, k – a positive constant.

Thus, the problem of assessing the actual state of the geoengineering complexes that are part of water treatment systems can be considered as a procedure for finding the maximum safe bend (stress), for which it is possible to use the data of a set of measurements (observations) of features studied in order to classify the state of structures as or another cluster. The first step in the assessing procedure is to define a scale of states (for example, a five-point one), where "0" corresponds to the absence of any problems (according to all estimates, the structure meets the requirements of the standard), and "4" – to an emergency state requiring destruction and reconstruction of the structure. All intermediate classes of states provide appropriate recommendations for repair and restoration work. From the point of view of the theory of fuzzy sets, these classes (d) can be characterized using Table 1.

The amount of physical wear is associated with the cost indicators of the structure. So, with an increase in physical wear, the initial cost of the structure decreases by the same percentage. Considering the fact that overhaul eliminates physical wear to a certain extent (if we do not take into account the general physical aging of structures, which is a consequence of the manifestation of material fatigue), there is an economic feasibility of overhaul if the cost of this repair does not exceed 40 % of the primary cost of the structure.

The set of signs suitable for classifying or assessing the state on the basis of visual inspection may include the identification of deformations and cracks in columns, beams, joints, etc. In addition, during the assessment of the state of structures there should be considered building materials, the height of structures, the actual duration of operation after next repair, as well as external conditions, conditions and total operating time, characteristics of the soil and foundation.

The formulation of the state evaluation problem is related to the method of decision-making under difficult conditions, when the information received from experts is characterized by uncertainty. It mostly determines the final decision, which has the nature of an inaccurate or approximate conclusion pursuing the achievement of the most reliable answer to the problem. If to take the numerical form of expressing the intermediate diagnosed state in the form, for example, of the function of membership $\mu(d)$ to the corresponding problem, requiring major repairs (see Table 2), and to interpret the values of the estimation truth in the following form: 0 – not true; 0.1-0.3 – weak level of truth; 0.4-0.5 – significant level of truth; 0.6-0.7 – high level of truth; 0.8-0.9 – the truth is almost revealed; 1.0 – the revealed truth, then it is possible to use the following scoring rule:

IF (the number of cracks *CN* is estimated at the level 0.3) *OR* (the presence of large cracks *LC* – at 0.2) *OR* (excessive deformation of structural elements – at 0.1), *THEN* (the overhaul of the *CN* is not needed);
or
IF (*CN* is estimated at 0.6) *OR* (*LC* is at 0.5) *OR* (deformation of structural elements – at the level of 0.5), *THEN* (overhaul of the *CN* is necessary).

Table 1. Scale for assessing the deterioration of structural elements.

Classes, *d*	Physical wear, %	Assessment of technical conditions	General characteristics of technical condition
1-2	0-20	Good	No damages or deformations. Some faults that do not affect operation and are eliminated during routine repair
3-4	21-40	Satisfying	The elements of the structure are generally serviceable, but in need of repair
5-6	41-60	Not satisfying	Operation of the elements of the structure is possible only under the condition of urgent repair
7-8	61-80	Decrepit	The state of the load-bearing structural elements is emergency, and of the not load-bearing ones is very decrepit. The limited performance by the elements of the structure of their functions is possible only under conditions of restrictive and protective measures, or the complete replacement of these elements
9-10	81-100	Kaput	Elements of the structure are in an unusable state. The structure needs to be demolished or radically rebuilt

Table 2. Evaluation of the overhaul problems.

$\mu(d)$	0,2	0,5	0,7	1,0	0,8	0,2
d	2	3	4	5	6	7

Belonging to the state corresponding to the need for the overhaul can be determined from the expression

$$\mu = max\{\mu_1, \mu_{2,\dots} \mu_n\}, \quad (9)$$

where the need for overhaul for data group *n:*

$$\bigcup_{ш=1}^{b} B_i \, , \quad (10)$$

where B_i – the state requiring the overhaul, obtained in accordance with the *i-th* data group (*i*=1 – information on the registered cracks, *i*=2 – data of physical measurements of stresses in structures, etc.).

B_i can be considered as the algebraic sum of damages to each of the components of the structure $j(j \leq n)$*:*

$$B_i = \sum_{o=1}^{m} D_{ij} \, , \quad (11)$$

where *Dij* – the state of serious damage to the *j-th* component, and

$$\mu(B_i) = 1 - \prod_{j=1}^{n} (1 - \mu_{Dij}), \quad (12)$$

For example, if there are three main components with the registered cracks, for which it is known that μ_{D11}=0,2, μ_{D12}=0,8, μ_{D13}=0,6, then

$$\mu_{B1} = 1 - \{(1\text{-}0{,}2)(1\text{-}0{,}8)(1\text{-}0{,}6)\} = 0{,}984. \quad (13)$$

Another approach is also possible. Let $X = \{x_1, x_2, \dots x_k\}$ – a set of signs, for example, x_1 – a big amount of cracks, x_2 – large cracks, x_3 – large deformations. Let $Y = \{y1, y2, \dots y_m\}$ – a set of types of potential damages, for example, y_1 – damage from fatigue or breaking, y_2 – plastic deformation, y_3 – instability, y_4 – progressive damage. Let *Z* – a state of severe damage. If we can find fuzzy relations *R* (from *X* to *Y*) and *S* (from *Y* to *Z*), then the signs of *X* can be associated with the state of severe damage to the structure *Z* using the composition $R \cdot S$. If to set the relationship *R* and *S* by data from the Tables 3 and 4, then the result can be presented in the form of Table 5.

This result indicates that the presence of the characteristics x_2 (large cracks) and x_3 (large deformations leads to a high assessment of the degree of belonging to a set of structures in a state of severe damage.

Table 3. Fuzzy relation *R.*

		y_1	y_2	y_3	y_4
R =	x_1	0,9	0,2	0,4	0,4
	x_2	0,8	0,3	0,7	0,8
	x_3	0,3	0,8	0,9	0,7

Table 4. Fuzzy relation *S.*

		Z
S =	y_1	0,4
	y_2	0,3
	y_3	0,8
	y_4	1,0

Table 5. Relationship *R* and *S.*

		Z
$R \cdot S$ =	x_1	0,4
	x_2	0,8
	x_3	0,8

In other words, if large cracks and large deformations are observed, then the structure is classified as badly damaged and requiring replacement or overhaul.

The considered approach allows for a more qualified and more reliable assessment of the state of treatment structures and at the same time taking into account the influence of individual components on the state of structures as a whole, which helps to minimize accidents and the corresponding environmental consequences.

3 “Chaos” and unpredictable development of events problem elimination

In the concrete vaults of the gravity collectors of the city sewage system, there is a specific problem: microbiological corrosion of concrete due to biogenic acid aggression (under the influence of hydrogen sulphide escaping from the collector vaults) reduces the resource of these objects in 3-3.5 times (i.e., from 50 up to 10-15 years). Up to 74% of accidents on reinforced concrete pipelines of drainage systems are caused by just such corrosion. Concrete, of course, is protected by waterproofing anti-corrosion coatings, but the last ones do not fulfill their role fully, mainly due to the presence of microcracks. The concentration of hydrogen sulfide C_{H2S} (mg/m^3) in a membrane of condensate moisture on the surface of a concrete structure, exposed to biogenic hydrogen sulfide aggression, at which the coating still retains its properties, can be determined from the following empirical formula:

$$C_{H_2S} = \left\{\frac{414{,}6 * t_{real}}{t_{demand}}\right\}^{0{,}45}, \quad (14)$$

where t_{real} – the real durability of the coating (in days), t_{demand} – the required durability of the coating (in days).

It should be noted that the standard deviation of the concentration C_{H2S} from the mathematical expectation of this concentration in the atmosphere of real sewerage facilities is $\sigma = \pm$ 50%, which, if the distribution of concentration values is close to the normal law, corresponds to a data uncertainty bandwidth of about 33%. Thus, periodical measurement of the C_{H2S} concentration and comparing it with the obtained one in accordance with the above formula, allows to determine the limit to which operation is permissible without changing the coating, i.e. with minimal risk.

It is also should be noted that the activity of microorganisms that ultimately cause the corrosion is carried out cyclically, and since the initial conditions for each cycle, as a rule, are not the same, there are opportunities for the emergence of “chaos”, that is, unpredictable development of events [1], which is very typical for biological treatment systems. In other words, in such systems it is only possible to predict the boundaries within which the processes can occur. These boundaries are set by "strange attractors". So, for example, the development of a population is under conditions of different initial data characteristic for the operation of treatment facilities, the expected population density of biologically active bacteria N at the time t+1, $Nt + 1$ can be represented as a nonlinear autoregressive model

$$N_{t+1} = N_t[1 + \check{r}(1 - N_t/K)], \quad (15)$$

where N_t – population density at time t, $\check{r}$ – the internal growth rate of the population (Malthusian parameter), and K – the maximum volume of a given population, possible under these conditions.

After certain transformations, this model can be represented as

$$x_{t+1} = rx_t(1 - x_t), \quad (16)$$

and

$$x_t = N_{t\check{r}} / [(1 + \check{r}K)], \quad (17)$$

$$r = 1 + \check{r}, \quad (18)$$

so that x_t turns out to be a dimensionless quantity characterizing the population. If the given model is used to carry out a number of iterations, choosing the values of r in the range 3-4 and at the same time changing the initial conditions, it is possible to obtain solutions within a fairly wide range, which, on the one hand, do not allow to unambiguously predict the result ("chaotic" solution), on the other hand, they determine the boundaries within which this result can be expected.

At the minimal value of r, the first type of dynamic behavior is observed (stable stationary state), in the interval middle, different limit cycles are realized. With a further increase in r, chaotic regimes arise (the values of x_n randomly fill a certain interval), alternating with the so-called r-windows in which limit cycles are observed. Each r-window is characterized by its main limit cycle with the smallest period. This limit cycle allows to determine the boundaries in the middle of which the system behaves to a certain extent predictably, which allows to assess the reliability of the data of specific measurements.

In water distribution systems, disasters such as pipe breaks often occur. Elimination of the consequences is associated with significant resource costs and interruptions in providing consumers. However, it is not giving much attention to how the process of gradual transition from the normal operation mode to the accident development mode is carried out in time, as well as under what qualitative and quantitative variations of variables and factors. Moreover, it is generally accepted that an accident occurs "suddenly", "inevitably", "accidentally".

If to ignore such factors as terrorism, sabotage or natural disasters (earthquake, flood, tornado, etc.), any technogenic accident develops in the bowels of a normally operating system as a result of negligence and lack of professionalism, because factors such as aging, wear, drift of parameters, etc. should be taken into account at all stages of operation of any systems. In other words, along with the performance of their direct functions, automated systems and personnel should ensure constant monitoring of the state of both each system as a whole and all its main components. Here, monitoring should be understood not only as a periodical fixation of the current state of each of the components of the system, but also the use of models of the behavior of these components in time and as a function of internal and external factors to predict future changes in the state of certain components and the system as a whole. Thus, for the state of the water supply network, it is necessary to use models of internal and external corrosion, which have the following general form:

$$\Delta h = 0{,}5\ \{d_o k_o C_o \exp\left(\frac{\alpha_o t}{\tau T} E\right) - d_i k_i C_i \cdot \exp\left(1 - \frac{\alpha_i t}{\tau_i T} E\right)\}, \quad (19)$$

where Δh – total decrease in pipe thickness due to internal and external corrosion, k_i and k_o – rate constants of oxidation reactions inside and outside the pipe, C_i i C_o – concentrations of oxidants accordingly, α_i and α_o – transfer coefficients (constants) that determine the influence of other factors on the exponential dependence of the reaction rate E accordingly, τ – time constant of the system in which this other reaction occurs, T – absolute temperature outside the pipe and the temperature of the carrier (water), t – operating time of this line link, d_i and d_o – internal and the outer diameters of the pipe (Fig. 2).

Taking into account the indicators of the soil (or insulation), in which the pipe is laid, and the water flowing in the pipe, as well as the corresponding temperatures, the date of commencement of operation of a particular section of the network, or it's the weakest link, as well as the maximum allowable total reduction in the thickness of the pipe Δh_{max} and the corresponding deterioration of the structure of the pipe material, it is possible to envisage the time when the strength characteristics associated with the thinning of the pipe walls due to corrosion and deterioration of the structural characteristics of the pipe material reach the limit Δh_{max}, beyond which (in the presence of certain transient processes in system) the pipe can break.

This model should also take into account pressure fluctuations (including dynamic shocks) and pumping rates. The heuristics for determining the need to update the pipeline are as follows:

IF [($h_1 > h_{1\ min}$) *AND* ($VaR(\Delta p/h_1) < VaR\ (\Delta p/h_1)_{max}$)*]*
OR [($\sum\Delta p < \sum\Delta p_{\ max}$)

AND

($Turb\ LF < Turb\ Lf_{max}$)*], THEN* (*«norm»*) *ELSE* (*«renewal»*) (20)

Here h_1 – actual or predicted pipe thickness; $h_{1\ min}$ – minimum permissible pipe thickness under operating conditions; $\Delta p/h_1$ – expected operational pressure surges in the pipeline related to the real or predicted pipe thickness; $(\Delta p/h1)_{max}$ – maximum allowable value of $\Delta p/h_1$; $\sum\Delta p$ – integral assessment of stresses that take place during the observation interval; $\sum\Delta p_{max}$ – maximum allowable integral stress for the entire life cycle of the pipeline; *Turb LF* – current (predicted) turbulence in the pipeline; $Turb\ Lf_{max}$ – maximum permissible turbulence.

But turbulence is a consequence of the fractal structure (tree structure) of the water distribution network, imperfect conditions for the flow of water, accompanied by pressure and velocity fluctuations. Therefore, *Turb Lf* and $Turb\ Lf_{max}$ should be determined on the base on the apparatus of the theory of fractals and chaos.

By the way, the tree-like structure of the network, one of the conditions for preventing (or weakening) of the turbulence, presupposes the fulfillment of the condition

$$\Sigma s_n \geq S_O, \tag{21}$$

where Σs_n – sum of the cross-sections of n branch pipelines coming out of this (root) pipeline with a cross-section S_O.

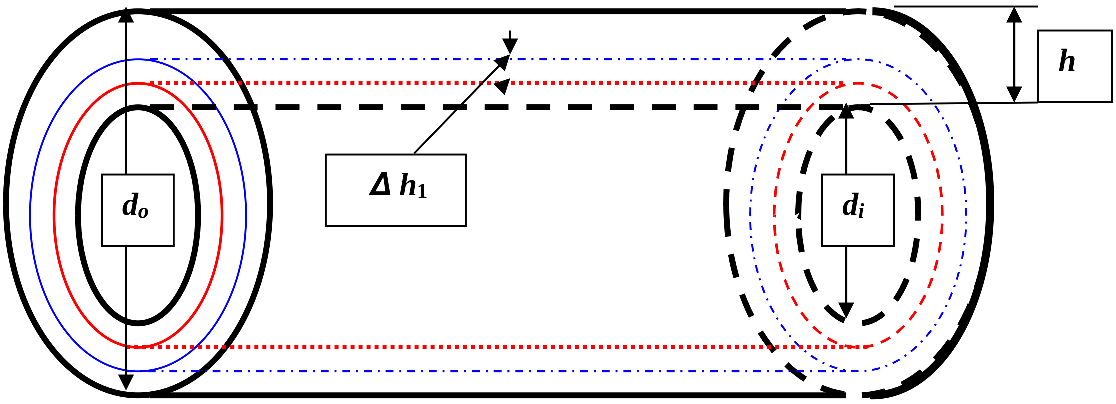

Fig. 2. Change in Δh under the influence of internal and external corrosion.

Conclusions

The consideration of geoengineering treatment facilities and their components as fractal structures, functioning under conditions of “chaos”, allows, on the one hand, understanding the processes and connections, and on the other hand, to identify the limit boundaries in which these processes and connections can exist.

The constant or periodical monitoring with measurement of the toxic gases concentration and comparing it with the obtained one allows to determine the limit to which operation is permissible without changing the coating, i.e. with minimal risk.

For the complete evaluation of the state of water supply and treatment facilities network, it is necessary to use models of internal and external corrosion, which includes the elements of the theory of fuzzy sets.

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The intergovernmental relations and their regulation in the context of decentralization of fiscal policy

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Abstract. The suspension of economic relations as a result of the global pandemic has severely affected the country's peripheries. Unequal development of territorial units and overcoming socio-economic problems is the biggest challenge of any country. To address these challenges, the country needs to mobilize large amounts of finance and make optimal allocations. Intergovernmental relations play an important role in the effective implementation of the transformation of the country's economic and political system. The aim of the paper is to study the characteristics of revenue mobilization and distribution between the levels of the fiscal system. There are developed some recommendations for improving inter-budgetary relations based on the experience of different countries. The recommendations proposed as a result of the research analysis can be used for both theoretical (for lecture) and practical (for legislative) purposes.

1 Introduction

The virus originated in 2019 has taken the form of a global pandemic by 2020. As a result, the global world is facing the conditions of the greatest economic recession and economic crisis has arisen in many countries (Fig. 1). Especially, developing and small open economy countries found themselves in a particularly difficult situation [1-4].

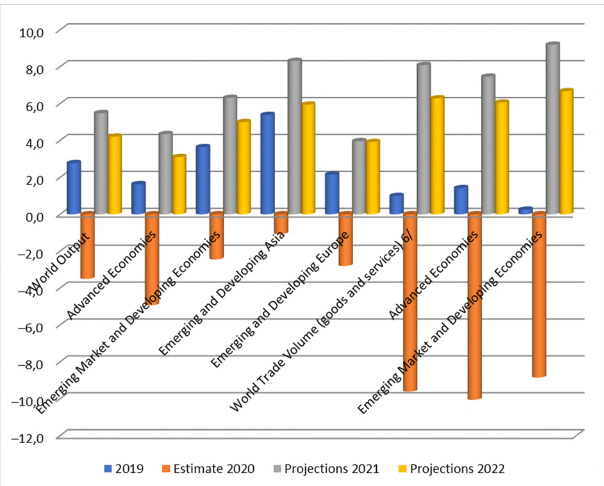

Fig. 1. World Economic Outlook [1-3]

Socio-economic problems are especially evident in territorial units. The suspension of economic relations has further aggravated the social situation and it increased unemployment, inflation and etc. To address these issues, states have implemented relevant budget policies. So, funding for the management and regulation program is reduced and funding for the subsidy program is increased [5, 6]. Despite the model of budget arrangement to get out of the economic recession of the country and achieve economic growth, it is very important to provide financial resources to the budgets of local self-governing units (municipalities), where one of the most important places is inter-budgetary relations. Inter-budgetary relations include not only economic subsidies, but also a fair distribution of revenues and expenditures between levels of the fiscal system.

In my opinion, to organize of inter-budgetary relations should be based on the following principles:

– Equality of rights and responsibilities of all municipalities must be protected in the process of financial relations with the centre;

– Areas of financial activity and responsibilities should be divided between the state government and all levels of local self-government;

– Different levels of government should not depend on subsidies, but also they should be able to receive revenues from their own sources and dispose of these funds independently.

Thus, the scope of the policy should be redistributed between the centre and the local self-government bodies. The centre should define the relevant legislative framework for action, within which local self-government will be free to make decisions, especially in solving socio-economic tasks.

Fiscal autonomy of local government is a relative concept that is determined by whether governing bodies have a sufficient amount of their own revenues and whether they have the right to manage them independently the functions they have to performed. This does not mean that they are completely isolated from each other. On the contrary, the centre and the municipalities have common interests for the public good and relevant coordinated strategic actions in economic and political priorities [7].

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2 Methodological foundations

2.1 Legislative regulation

The economic and financial basis of self-governing units is regulated by five main laws: the Local Self-Government Code of Georgia [8], the Budget Code of Georgia [9], the Tax Code of Georgia, the Law of Georgia on Grants and the Law of Georgia on Local Fees [10-12]. In addition, Georgia has ratified the European Charter of Self-Government and self-governing legislation is based on it.

Fiscal relations are mainly regulated by organic laws: the Local Self-Government Code, the Tax Code of Georgia and the Budget Code.

Local self-government is the right and opportunity of the citizens of Georgia to regulate and manage issues of local importance in accordance with the interests of the population through local self-government bodies. The Code of Self-Government defines the powers of self-government, which are divided into delegated, self-governing and voluntary categories [8].

In order to minimize socio-economic inequality between different territorial units, it is necessary to analyse the welfare conditions of the regions and adopt legal norms.

2.2 Literature review

The theoretical-methodological basis of the research is the papers of various scientists on the research problem, where the inter-budgetary relations [13], financial mechanisms for the development of territorial units [14-25], the characteristics of state fiscal arrangement models are studied [26-34]. This includes works by Aidt and Dutta, Ehrlich, Enikolopov, Ejobowah, Gaizatullin, Kline, Sow, Staehr, and others [35-38]. They studied in depth and published the issues of formation and improvement of the state governance system, budget regulation, financial equalization and organization of budget relations [30, 39-58]. These scientists have identified problems in this field, but the fiscal arrangement and fiscal system require continuous improvement and research.

3 Discussions

Decision-making at a low hierarchical level has a great importance for the establishment and improvement of the state governance system. This in turn is a prerequisite for decentralization. Understanding systemic actions at the level of territorial units, laying out appropriate ways and developing real self-government play a major role in the proper and efficient functioning of the state. In particular, the formation of stable sources of revenue for territorial units, the implementation of an objective and transparent process of redistribution of funds between upper and lower level budgets creates a precondition for stabilization of the country. Local self-government will inform the interests of the society at a high hierarchical level and will create a driving force for the effective implementation of relevant socio-economic policies.

One major theoretical issue that has dominated the field for many years is the absence of a well-grounded strategy leads to a further deterioration of the situation and a manifestation of the severity of fiscal policy [59]. Any action and any policy implementation at a high state or low hierarchical level, takes place within the existing legal space. It is the correct definition of this legal space that means avoiding the contradictions between the defined priorities of the common welfare in the society, as well as the contradiction between the common tactics and the strategy of action [5, 59].

The legal aspects that are of great importance for the harmonization of interests and actions between the governing bodies of the country are the budget legislation [9], according to which territorial (regional) budgets are independent and theoretically the supreme governing bodies have no right to interfere within their competencies (Budget Code of Georgia, Article 7) [9]. In fact, the budgets of territorial units (regional) are significantly dependent on the budget of the upper (central).

According to the Budget Code of Georgia, the legislation was limited to listing the sources of revenue of territorial budgets [9] and ignored a number of methodological and organizational issues of inter-budgetary relations. At the present stage, many things are disorganized and faulty in the relationship between different levels of the budget. In particular, the rights and responsibilities of each level in revenue mobilization and spending are not clearly defined. Also, the division of taxes between the centre and the budgets of the regions is not strictly defined, as well as the issue of economic subsidies and many other things. All of this leads to numerous misunderstandings and difficulties between the centre and other levels of budgets. It seems in the amount of tax revenue mobilization at the budget levels and their ratio to GDP (Fig. 2).

The lack of local budget funds in Georgia, which is filled with regulatory revenues, is the result of minimizing the quality of tax authority for local self-government. The centre is still trying to mobilize financial resources entirely in its own hands, while delegating its responsibilities for financing various activities entirely to entities and territorial unit budgets.

3.1 Foreign experience of fiscal arrangement

Over the past two decades, fiscal arrangement reform has taken place in all Central and Eastern European countries. However, the redistribution of powers and finances between central and local governments is still the subject of active debate in many countries.

The fiscal system of Germany as a state with a high degree of decentralization includes three levels: federal, land and local [40].

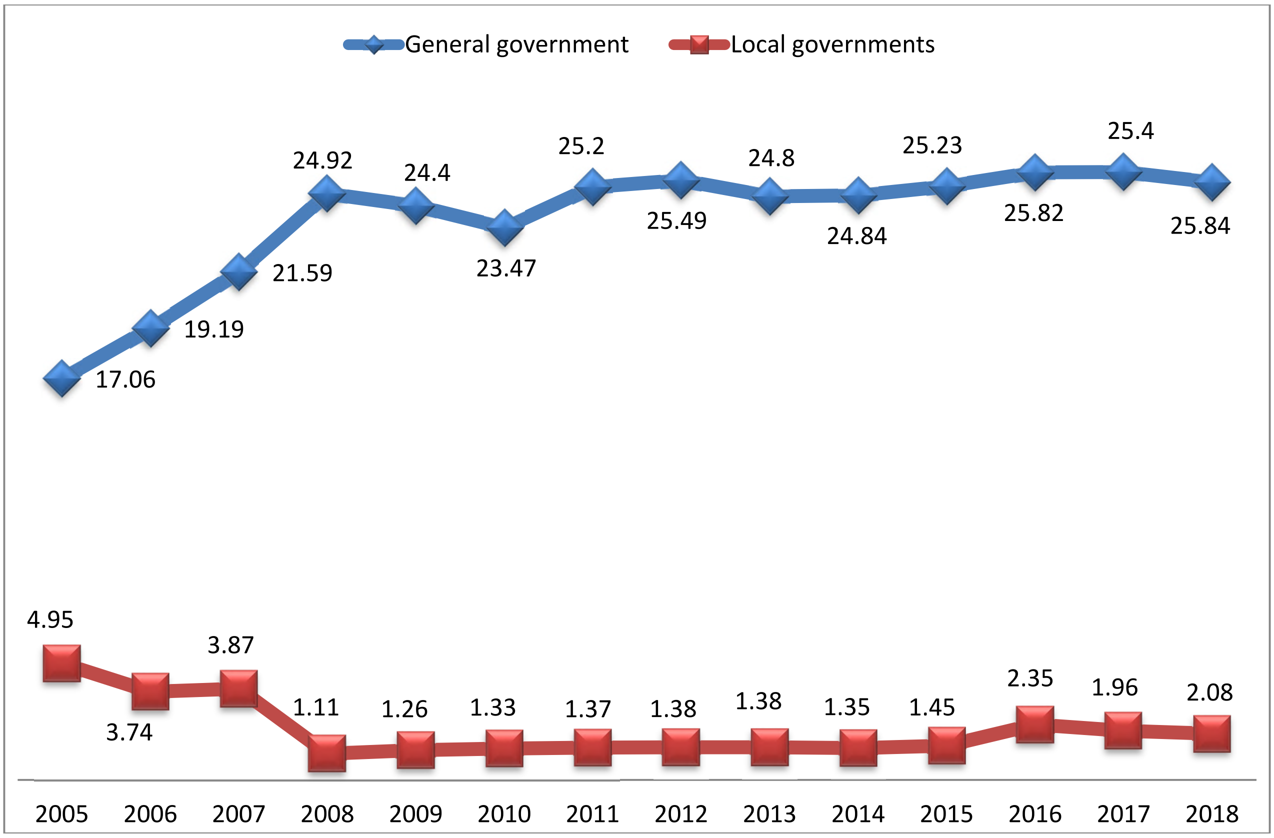

Fig. 2. Distribution of tax revenues between the budget levels of Georgia, % of GDP [60].

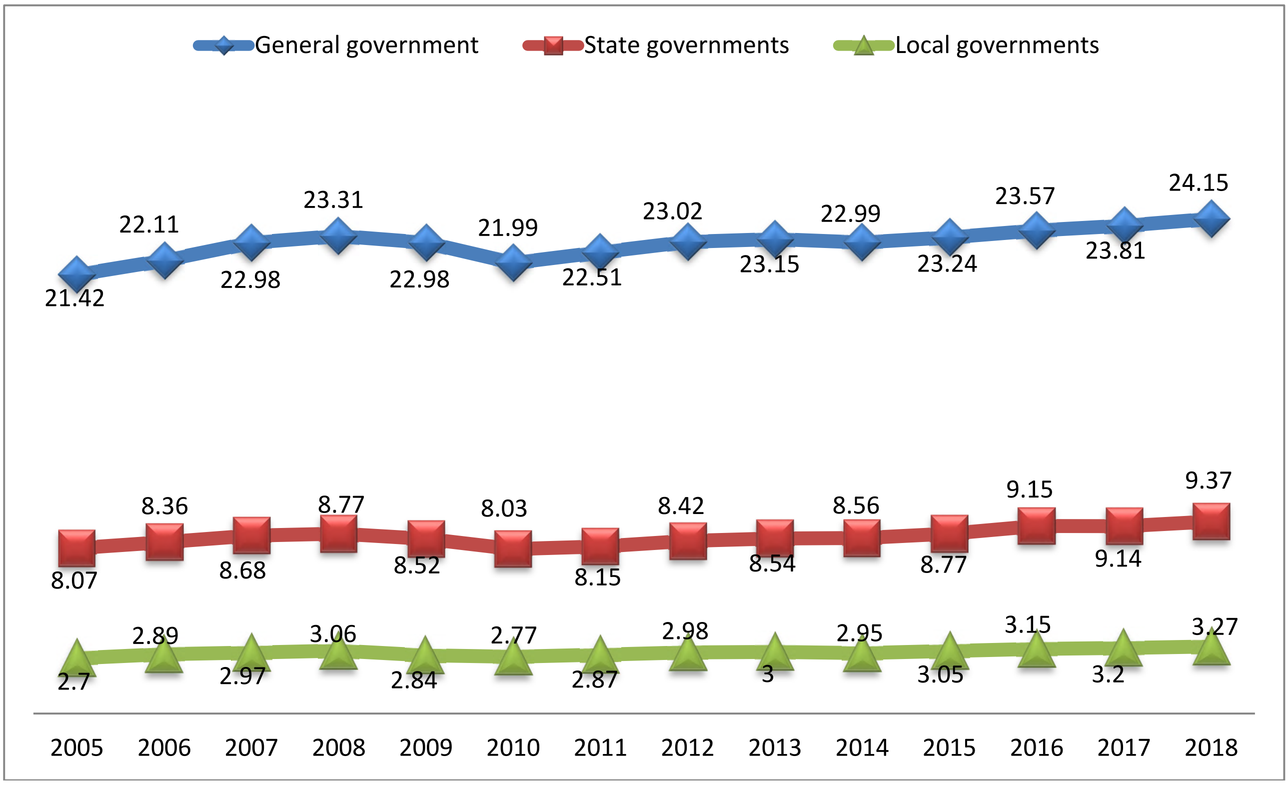

Fig. 3. Distribution of tax revenues between German budget levels, % GDP [60].

The tax revenues of the three levels of the budget of Germany in 2005-2018 are as follows (Fig 3). The German local government finances its own expenditures mainly from the local budget, whose tax revenues account for about 13.5% of total national tax revenues.

The Austrian fiscal system is divided into three levels: central government, land and local self-government. In accordance with the Budget Law, the amounts received from the income tax are distributed in the following proportions: 60% of the funds go to the central budget, 22% to the land budgets and 18% to the local self-government budgets. Also, 69% of value added tax go to the central budget, 19% to the state budget, and 12% to the local government budget (Fig. 4).

France, although a unitary state, is divided into regions, departments and municipalities. Municipalities and departments receive revenue from all taxes, while the region is financed by land and business taxes. The tax revenues of the three levels of the budget of France in 2005-2018 are as follows (Fig. 5).

Since 1990, the central government has delegated important powers to all three levels of regional government (region, department, commune) planning and developing areas such as infrastructure, education, health, culture, regional economic development, employment, etc. which are financed from local budget revenues (Fig. 6).

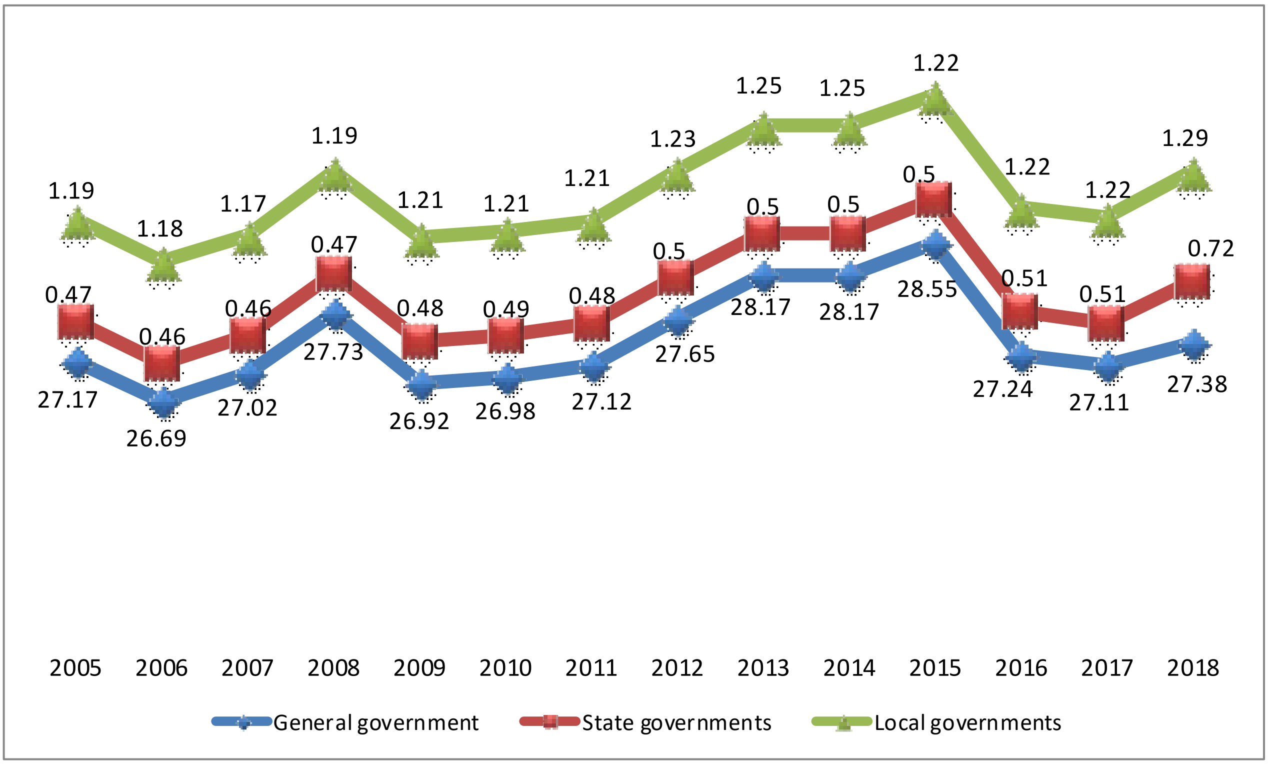

Fig. 4. Distribution of tax revenues between Austrian budget levels, % GDP [60].

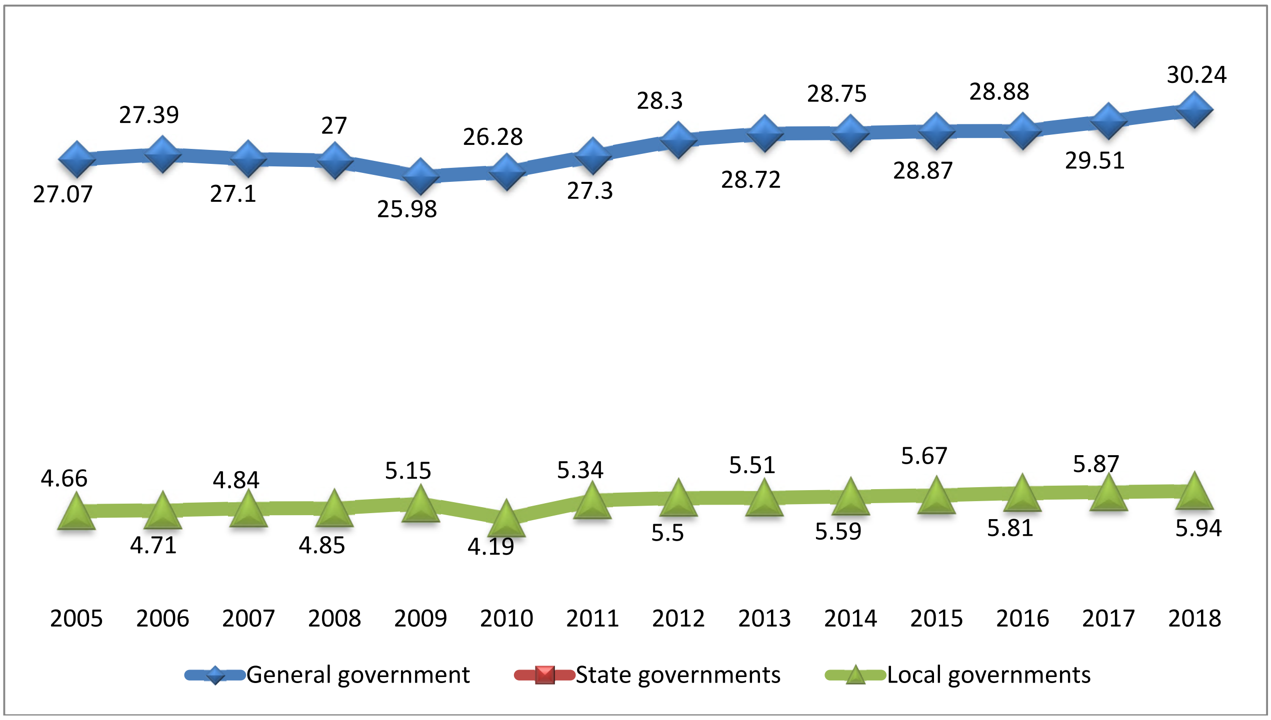

Fig. 5. Distribution of tax revenues between French budget levels, % GDP [60].

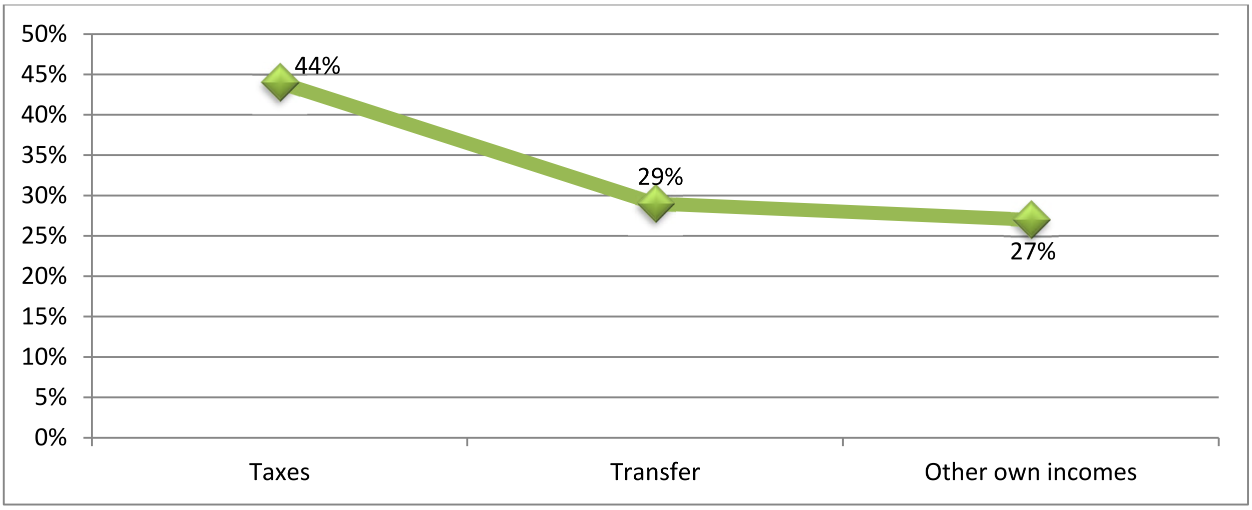

Fig. 6. French local budget revenue sources [61].

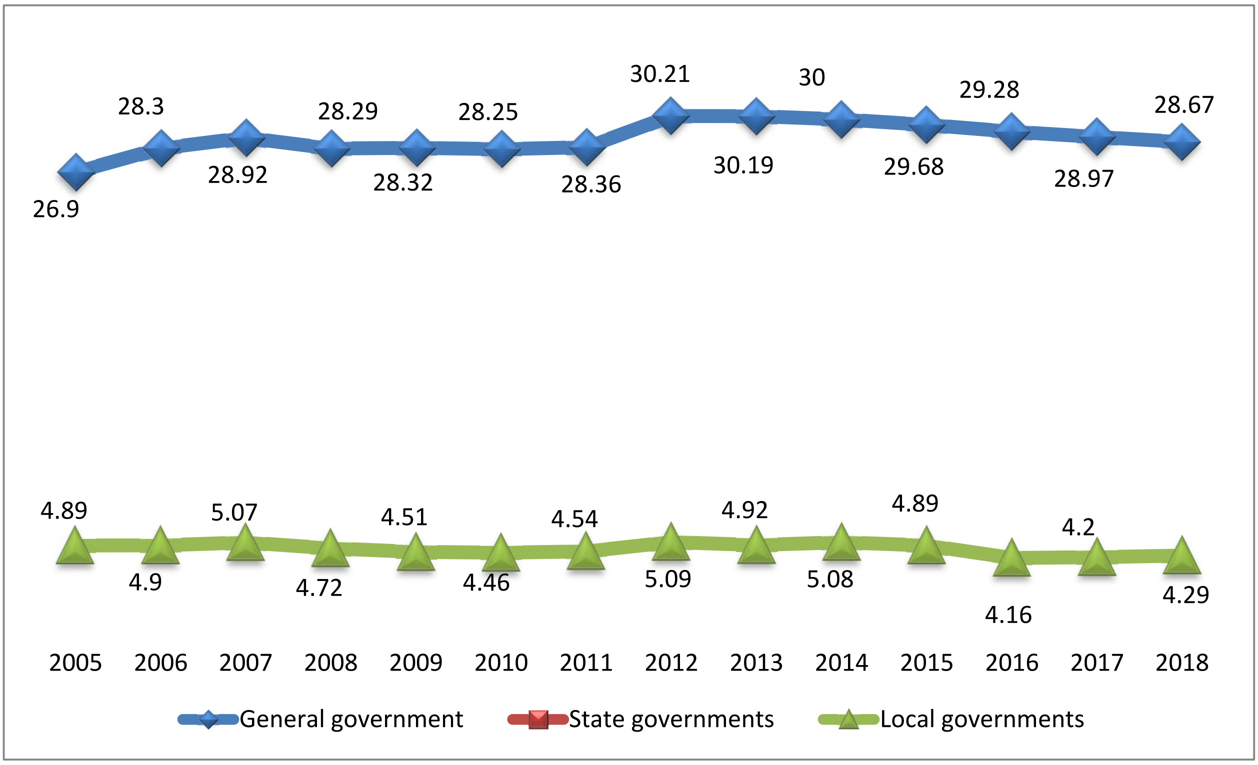

Fig. 7. Distribution of tax revenues between Italian fiscal levels, % GDP [60]

Table 1. German fiscal system.

Federal Budget	Land Budget	Local Budget
Income tax 42.5%	Income tax 42.5%	Income tax 15%
Corporate tax 50%	Corporate tax 50%	
Value-added tax	Value-added tax	
Industrial tax	Industrial tax	Industrial tax
Customs tax	Property tax	Land tax
Other federal taxes	Other land budget	Other local budget
48% of total tax revenue	34% of total tax revenue	13% of total tax revenue

Like France, the unitary parliamentary republic is Italy, which is divided into regions, provinces and municipalities [62]. Management functions are distributed at all levels. The ratio of tax revenues in the budget of Italy in 2005-2018 to the country's GDP looks as follows (Fig. 7). Local budget revenues consist of own taxes, shared taxes and transfers, and other revenues (Fig. 8).

Fiscal independence in Sweden is very high and 69% of tax revenues remaining in local self-government budgets. The budget revenues of the counties are: amounts received from taxes (68%), transfers (7%), amounts received from fees and taxes (25%). Tax revenues are formed entirely from income tax. The income tax rate is set by the county itself. The sources of revenue of the municipal budget are: funds received from taxes (60%), transfers (14%), funds received from fees and taxes (23%). Tax revenues are formed entirely from income tax (99.5%), while 0.5% comes from sales tax on goods and services (Fig. 9).

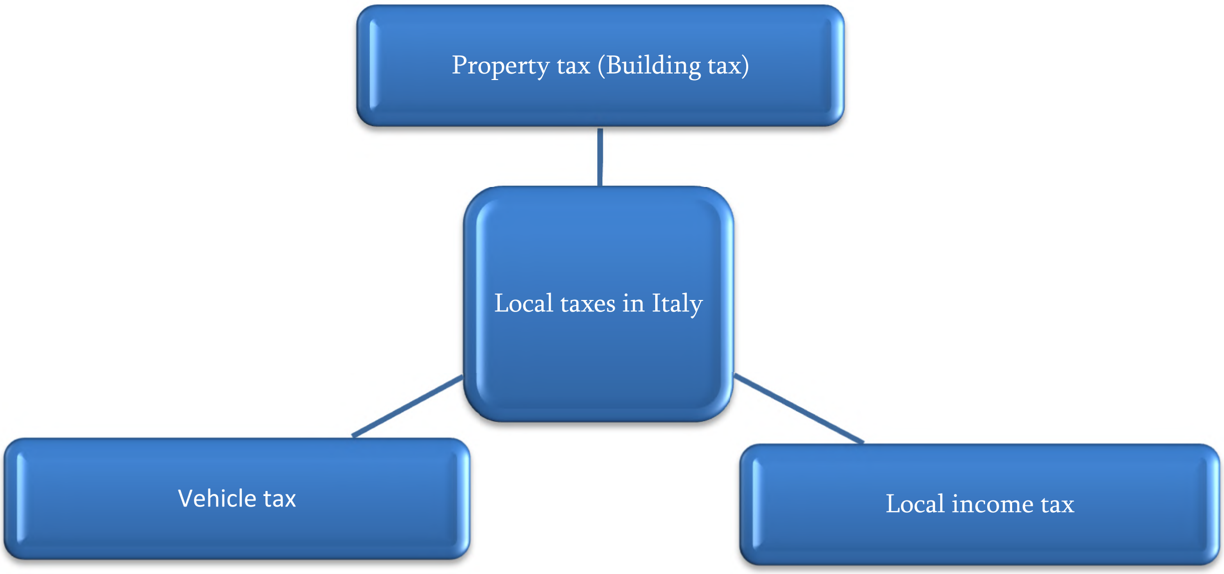

Fig. 8. Italian fiscal system.

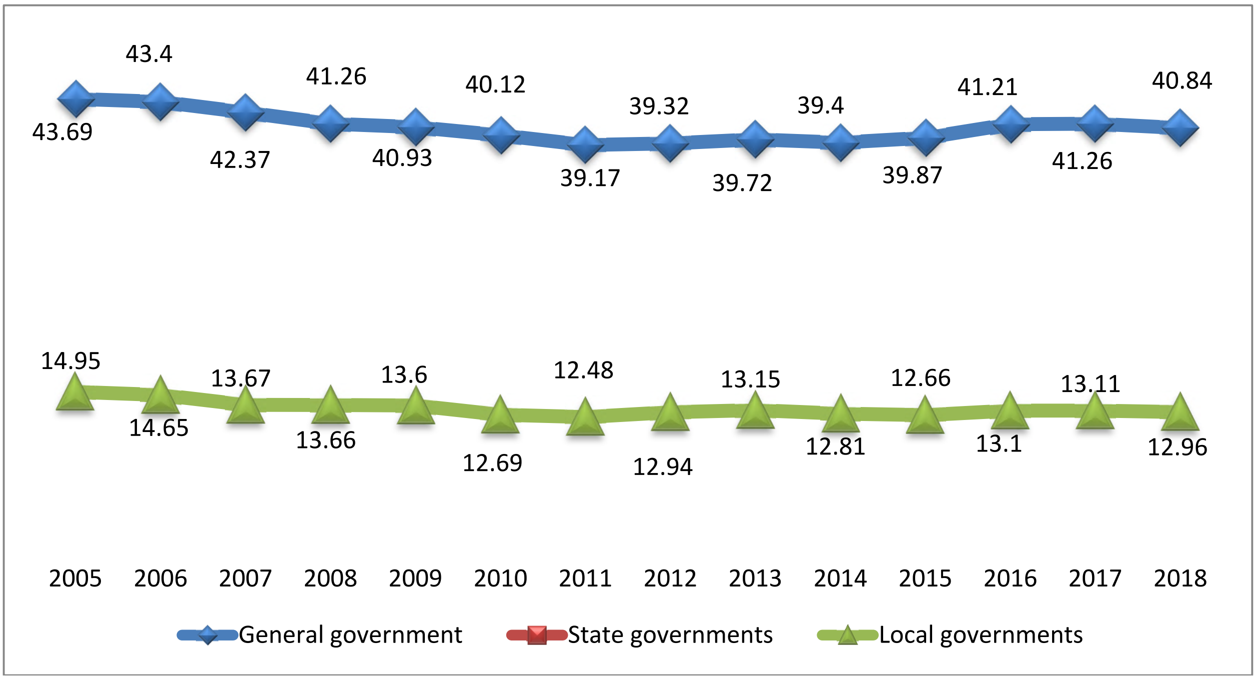

Fig. 9. Distribution of tax revenues between Swedish fiscal levels, % GDP [60].

The sum of tax revenues of the central budget of Estonia in 2014 is 6 656 949 euros, which is characterized by a growing trend in the coming years and by 2018 it amounted to 8 821 243 euros. As for the tax revenues of local self-governments, this figure is 859,527 euros in 2014, in the following years the budget tax revenues will also increase and reached 1,173,550 euros for 2018. As for the ratio between levels - the sum of tax revenues of local budgets is about six times less than the state budget. And the ratio of fiscal levels to tax revenues in relation to the country's GDP looks like this (Fig. 10).

Poland was one of the first to make the transition from the post-socialist system to the European system, which from the very beginning focused on the development of self-government and, unlike many other Eastern European countries, made it a priority to move to a decentralized model. Today, it is one of the most decentralized countries in Europe and it is far ahead of many European countries.

The territorial arrangement of Poland is based on three levels - region, side and municipality. The sources of revenue generation for each level are: 1) own revenues, mainly local taxes, the rate of which is set by the local government based on the right granted by law. However, at the same time the maximum rate is set by Parliament. 2) Shared income and profit taxes; 3) Basic and special transfers. The ratio of fiscal levels to budget revenues in relation to the country's GDP is as follows (Fig. 11).

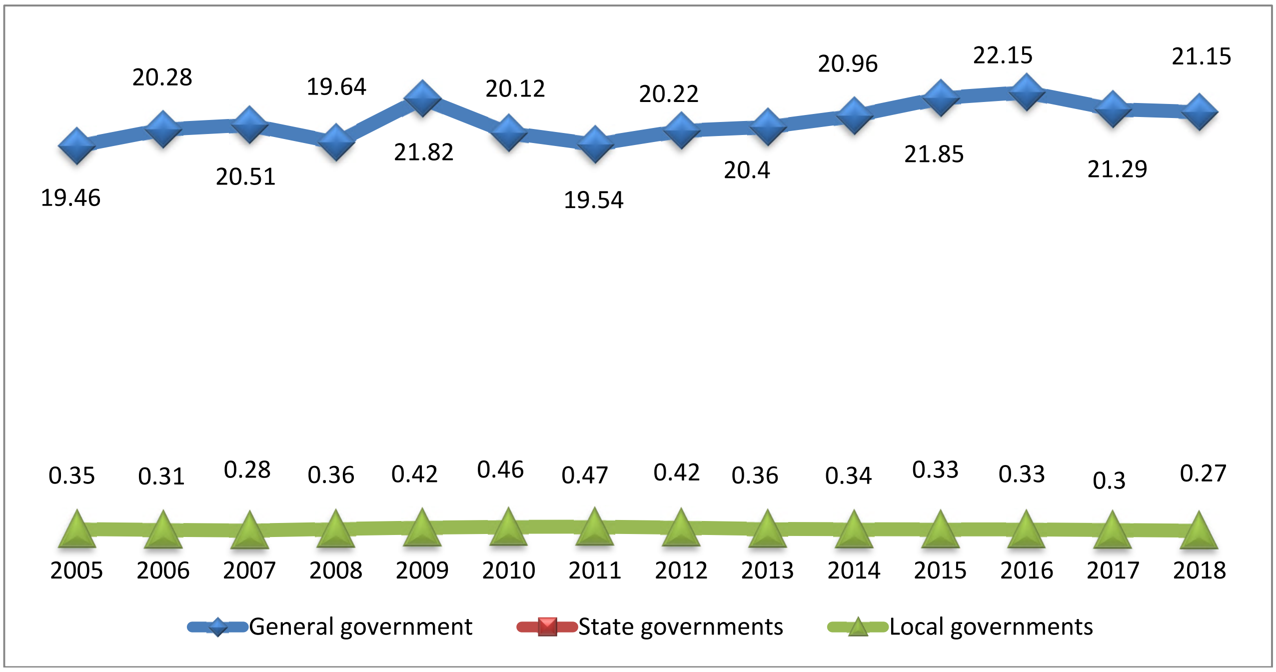

Fig. 10. Distribution of tax revenues between Estonian fiscal levels, % GDP [60].

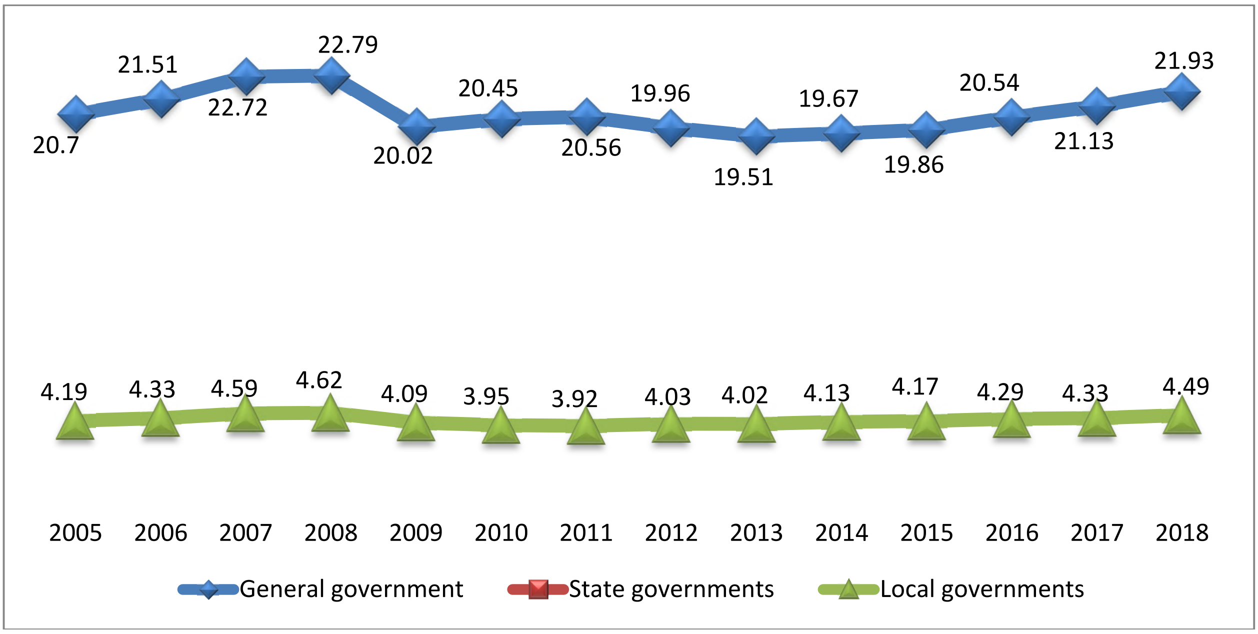

Fig. 11. Distribution of tax revenues between the fiscal levels of Poland, % GDP [60].

3.2 The peculiarities of the countries of the Caucasus and the Black Sea Region in fiscal arrangement

In Armenia, as a unitary, partially decentralized country, self-government operates only at the municipal level. They can set the tax rate within the limits set by law. Property and land taxes are 100% accumulated in the municipal budget. Profit tax and various fees are shared with the local budget each year. However, the ratio of tax revenues to GDP for 2005-2018 looks as follows (Fig. 12).

Azerbaijan is a unitary, partially decentralized state. Local self-government operates only at the lowest level - the level of the municipality. According to the constitution, municipalities have the right to impose local taxes and fees. Local taxes are: land tax, property tax, profit tax, which is taxed on municipal property. The share of own taxes and fees in the local budget is about 25%, tax revenues are a major part of them (about 22%), while the share of transfers in local budgets is about 10% [61] (Fig. 13).

In Turkey, municipal expenditures account for 11% of total state expenditures and revenues for 7%. Municipalities are funded from three main sources: 42% from general government taxes, 6.8% from utility taxes, 35.5% from non-tax revenues and 10% from local taxes. The central government collects the following types of taxes: personal income tax, corporate income tax, profit tax and value added tax. Local governments are left with 9.25% of the collected income taxes. Real estate tax accounts for 54.9% of tax revenues collected by local governments (Fig. 14).

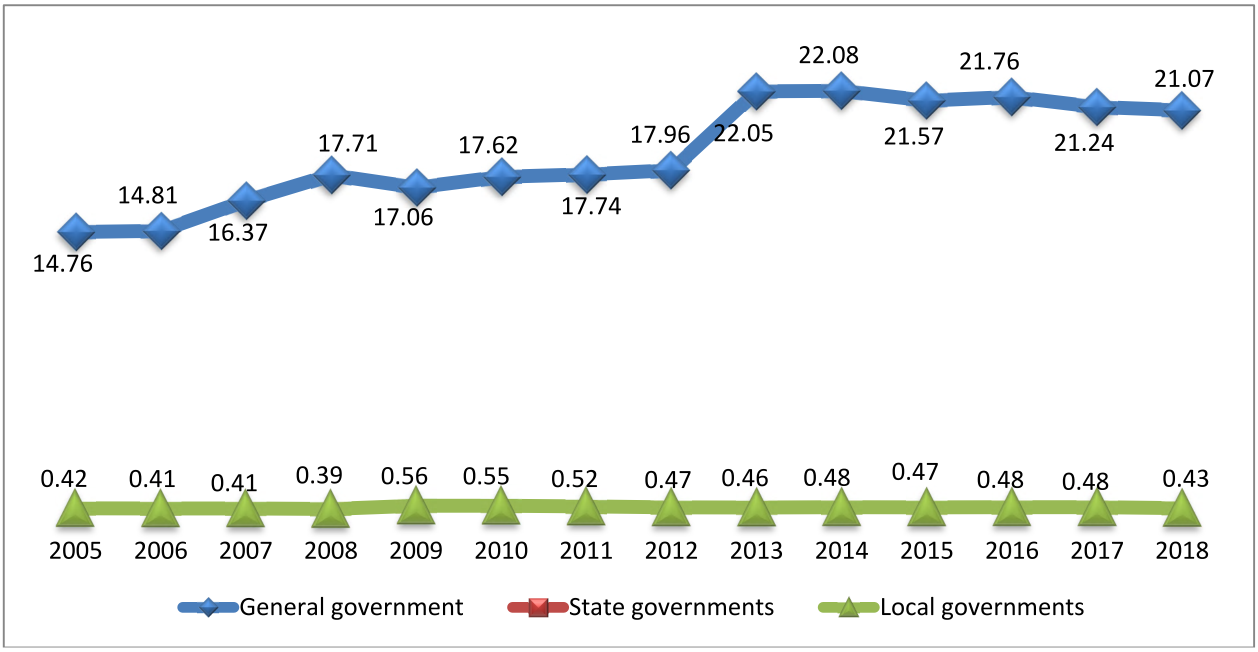

Fig. 12. Distribution of tax revenues between fiscal levels of Armenia, % GDP [60].

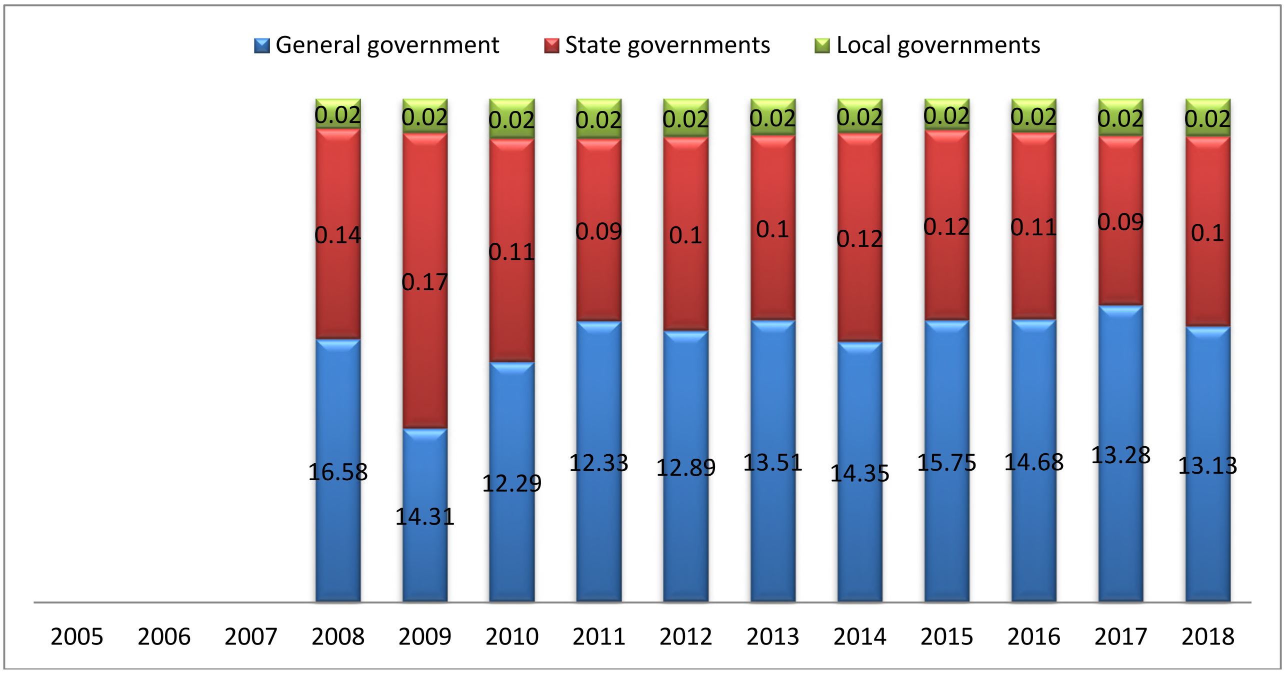

Fig. 13. Distribution of tax revenues among the fiscal levels of Azerbaijan, % GDP [60].

4 Research results

The research of the experience of different countries revealed that it was especially difficult to implement fiscal decentralization reform in post-socialist countries, where the pre-existing administrative-planning structure was characterized by a high degree of centralization. Successful implementation of decentralization requires a relevant institutional environment and development. Especially, in post-socialist countries where state institutions are at an early stage of development, the implementation of decentralization reform has solved some problems. Most of these countries have not yet emerged from these problems. In Central and Eastern European countries, the main goal of economic policy at the initial stage of transformation was to ensure macroeconomic stability. This was accompanied by structural changes in the economy, political and ethnic conflicts, which created an unfavorable conditions for fiscal decentralization [61].

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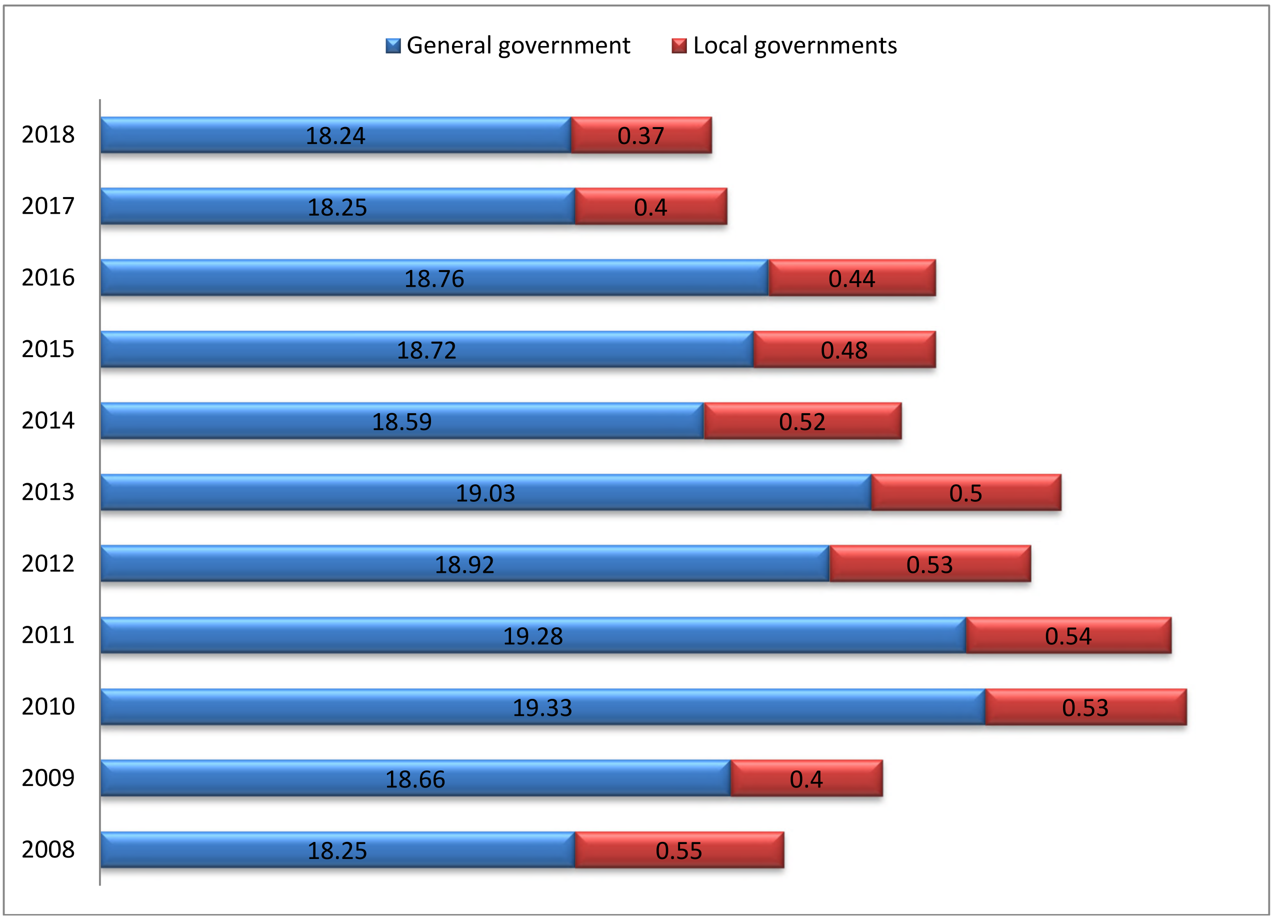

Fig. 14. Distribution of tax revenues between fiscal levels of Turkey, % GDP [60].

Local governments in Central and Eastern Europe have been financed through shared taxes and transfers. Income tax goes directly to local government in the Nordic countries and Switzerland. Income tax is shared in many countries, for example Austria, Germany, Hungary. In these countries the tax is levied by the central government and distributed to local governments.

Due to the simplicity of property tax administration, in almost all European countries, property taxes go entirely to the local budget [61].

Table 2. Distribution of taxes between budget levels [61].

Types of taxes	Local is in the following countries
Income tax	
a) direct	Nordic countries, Switzerland
b) shared	Austria, Germany, Poland
Income tax	Austria, France, Germany, Norway, Portugal
Property tax	All European countries (except Sweden)

Only a few developed countries have reached local governments autonomy in revenue, but they used to receive and still receive assistance in the form of transfers. In Slovakia, Hungary and Poland, for example, own revenues account for up to 40% of total revenues. Local budget revenues in local budget revenues are highest in Sweden, France, Italy, Germany, Poland and the Czech Republic (Fig. 15) and the smallest in Austria, Estonia, Georgia, Azerbaijan, Turkey, Armenia.

Inter-budgetary relationships vary according to different models. In particular, in Anglo-Saxon model countries (USA, UK, Canada, Sweden) regions have high fiscal autonomy and local taxes dominate budget revenues. In the Continental model countries (Germany, France, Italy, Spain, Belgium) the fiscal autonomy of the regions is relatively limited and the principle of financial equalization (granting subsidies and subsidies) is essential [5, 63].

Policies in the field of municipal finance should be directly related to the economic activity of the self-government. In this regard, against the background of the general crisis, the municipalities in Georgia are in a particularly difficult condition. Their situation is further aggravated by the price disparity in industrial and agricultural products, the monopolization of privatized processing enterprises and the lack of profitable enterprises. Many of the problems facing the territories are caused by the fast and reckless privatization of the service sector of processing enterprises and other sectors. Problems of economic development are particularly acute:

1. A general decline in production, which leads to a reduction in budget revenues;

2. Limited economic base in rural areas, which is manifested, first of all, in the absence of profitable enterprises in the territories;

3. Changes in municipal ownership caused by the transfer of social sphere facilities to local administrations;

4. Uncertainty in the status of branches of enterprises and organizations located in the districts;

5. Restriction of rights to natural resources of local authorities.

In our opinion, in order to improve the financial situation of the municipalities, it is necessary to solve the following problems: 1. Expanding the tax base of the area; 2. Ensuring social equality in the distribution of subsidies and the implementation of social protection measures for the population; 3. Resolve the territorial issues related to the relations between the local administration and the governing bodies of the republic.

Due to the tourism potential of Georgia and the large flow of tourists, the establishment of a tourist fee can be one of the important sources of income for self-governments. This type of fee is used by many European countries: including: Spain, Italy, Croatia, Belgium and others on average 0.15-7.5 euros per day. Tourist tax in Dubai ranges from $ 2 to $ 6. From November 1, 2015, a similar tax was introduced in the Emirate of Ras Al Khaimah. Also, every tourist who stays at a hotel in Abu Dhabi pays a daily fee of $ 5 and it does not matter what type of hotel they stay at. Tourists arriving in Rome have to pay from 1 euro to 7 euros as a tourist tax for overnight stay at the hotel and it depending on the type of hotel. According to the National Tourism Agency, up to 4.8 million tourists entered Georgia in 2018 (individuals who voluntarily travel outside their permanent residence for leisure, recreation, business or other purposes for at least 24 hours and not more than one year. And whose travel is not refund from the financial sources of the place of temporary stay). If we take the minimum tariff of 1 GEL per tourist (regardless of the number of days), it means an additional income of 4.8 million, and on average 3 GEL additional 14.4 million. This will significantly help self-governments to better meet public needs, implement infrastructure and other projects.

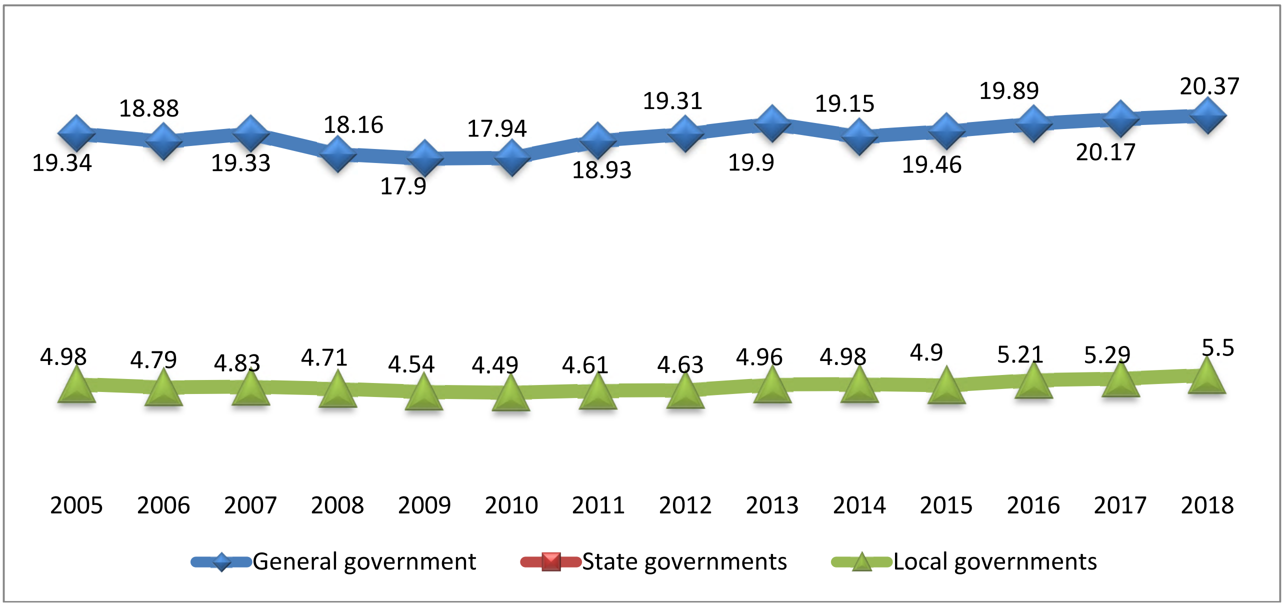

Fig. 15. Distribution of tax revenues between fiscal levels of Czech Republic, % GDP [60].

The second important issue of strengthening self-governments is the transfer of property to them. Only the transfer of finances and leaving taxes on the places will not lead to the development of the economy and will not create additional value on the places. Financial decentralization creates a mechanism to make economic activity profitable for municipalities [64-69]; And economic activity is possible only if land, property and other resources are transferred to local governments. With financial instruments, self-governments need to be motivated to see benefits and financial gains by using the property transferred to them in authority, to create investment projects, to find investors and to promote employment.

Georgia is one of the Post-Soviet countries in Eurasia, which has been actively involved in EU integration processes [5]. Therefore, for the success of the reform, it is necessary that the transfer of finances and property be carried out in parallel, and as soon as the new tax system enters into force. The municipalities will have the property resources by which they will be able to increase economic activity and revenues. Of course, such an approach does not mean the phasing out of both types of decentralization, when the rate of tax rates left on the ground and the transfer of property take place according to a plan outlined for a certain period of time. It should also be noted that due to the unequal economic development of municipalities, leaving part of the income tax on the ground can have a positive impact on only a small part of municipalities where the share of employees is relatively high. For some self-government, in terms of revenue growth, the transfer of agricultural and/or non-agricultural lands and natural resources may be more important. Therefore, creating the necessary basis for the economic development of municipalities requires a complex approach and focusing on only one area (either finance or property) will ultimately have less effect. One of the tasks of the policy should be, at the initial stage, to identify the municipalities that, through their economic development, can exercise their powers independently of the central budget. At the same time, the government should be given the opportunity to pursue an effective equalization policy for the development of economically weak, depressed economies [8].

One of the important issues of local self-government financial independence is the right to borrow, especially in terms of low income they have. As it is known, local self-governments have the right to economic activity, which is difficult to believe without the full right to take a loan. According to Article 21 of the Budget Code of Georgia, "Autonomous Republics and local authorities have the right to borrow from the Government of Georgia and/or other sources only with the permission of the Government of Georgia." The caution of legislators with respect to borrowing by the municipality based on negative practice when a local government took a loan from a commercial bank and then could not repay it, or it was repaid from a targeted transfer. In fact, in most cases, borrowing was done with the intervention of the central government for various political reasons. Consequently, the Budget Code continues to be a bad practice and the central government continues to restrict borrowing by the self-government. In our opinion, local self-government should have the right to take a loan. While exercising this right, there may be different conditions and mechanisms in this Code or other normative act defined by law.

Thus, it is important that the powers of the municipality should be adequate to its sources of revenue. However, this should not be understood in such a way that since the municipality does not have sufficient budget revenues, the scope of its authority should also be reduced. On the contrary, municipalities should be given the authority to address issues of local importance as much as possible and adequate funding should be provided for this. In this context, in addition to tax revenues, it is important that the municipality be given as much property of local importance as possible, the conditions for the proper use of which the municipality will have additional opportunities to generate revenue.

5 Conclusions and recommendations

Creating a universal model of decentralization is practically impossible, as every country has its own history and specifics of self-structuring. Thus, each of them must individually define the principles of separation of functions of central and local government and the degree of autonomy of self-governments.

The main function of fiscal policy in any arrangement state was and is to ensure the socio-economic status (welfare) of the society. The level of welfare of a country depends on how developed its economic system is and what security guarantees are created. Prosperity is defined by the material goods and services necessary for a comfortable and secure human life. The material progress and prosperity of a nation is achieved only if it leads to the moral and material well-being of each citizen.

Therefore, when forming the municipal budget, the following approaches should be taken into account:

1. Extended tax discretion of the self-government. Local governments should have the authority to impose both direct and indirect taxes. Basic tax categories should be introduced (one is not sufficient, property tax). Such segregation / attribution of tax revenues will minimize redistribution processes and establish a stable relationship between the centre and the municipalities.

2. Establishment of fixed interest rates for tax revenue sharing based on the starting economic indicators of self-governing units. In this case, tax revenues are divided between the autonomous state and local budgets according to certain types/percentages. This method will increase the ability to optimally allocate resources. Regions under the influence of the centre receive certain budgetary tax benefits by differentiating their respective interest rates.

3. Determining the percentage of transfers from the total amount of taxes collected in the territorial units to the budget of the centre.

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Modeling of the effect of a high-pressure jet of cement mortar on the surrounding soil environment when performing jet grouting columns using jet technology

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Abstract. The main idea of jet grouting technology is the implementation of processes aimed at changing the characteristics of soils, creating materials with the necessary properties on their basis and forming underground elements with specified parameters from these materials. The high pressure of the cement mortar jet leads to soil blending and its continuous destruction within the radius of impact of the jet. According to some authors, the jet outside the destructive radius does not affect the surrounding soil environment. In compliance with practical studies performed at construction sites in Kyiv, Ukraine, the data on changes in the physical and mechanical characteristics of the soil surrounding the soil-cement column were obtained. This fact led to a more detailed study of the effect of a high-pressure jet on the surrounding soil during the execution of columns using jet technology.

1 Introduction

Jet grouting is the destruction of the structure of the soil or soft rock and blending or partial replacement of it with a cementitious substance, while the destruction of the soil occurs due to a liquid jet with high energy, and the liquid itself performs a cementing function [1].

The research of the phenomenon of destruction of the natural structure and soil blending by jet grouting is well-known and provided by many scientists [2-27].

Jet grouting technology allows it to be used in solving various tasks of underground construction, namely: underground load-bearing and anti-filtration structures, horizontal or inclined slabs, elements of buildings and structures, artificial basements, walls and floors of sunk premises, including underground garages, the installation of roots of ground anchors, when strengthening the pinning of existing buildings and structures, retaining walls, pit fences, horizontal underground anti-filtration screens, anti-landslide structures, fixing ground massifs for sinking underground tunnels, wells of large diameter with bottoms and many other structures. Jet grouting elements are also used for reinforcing ground bases in earthquake-prone areas.

A high-pressure jet, striking the ground, destroys its original structure and according to Kanematsu research [28] the zones of a high-pressure jet (in the experimental work of a water jet) are: zone 1 – the core, the hydrodynamic pressure in which is constant, zone 2 – an intermediate zone and, as a rule, the distance to the end of zone 2 is 300 nozzle diameters, zone 3, where the flow loses focus, becomes intermittent and cavitation effects begin to prevail.

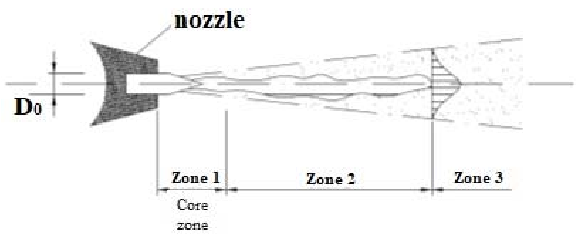

Fig. 1. Characteristics of the water jet according to Kanematsu.

The distribution of hydrodynamic pressure in zone 3 along the jet axis decreases with exponential distance. If you release a jet of water into a dense environment or clean water, it appears that zone 3 does not exist. This circumstance is typical for most cases of jet grouting.

The high pressure leads to soil blending and its continuous destruction within the radius of impact of the jet. Therefore, based on his findings, Kanematsu suggested that the use of jet grouting does not affect the stress-strain state in the soil beyond the impact radius. In fact, even when working with very high pressure, the injection process only leads to an increase in pressure within the collapsing area (zone 1 and 2). The same opinion is supported by C. S. Covil and A. E. Skinner [10].

At the same time, practicing organizations, based on experimental data, have shown that the implementation of jet grouting elements of circular cross-section affects the surrounding soil mass outside these elements.

Consolidamenti E Pali in Italy performed a series of laboratory tests of the soil surrounding the well made of intersecting jet injection columns (Fig. 2).

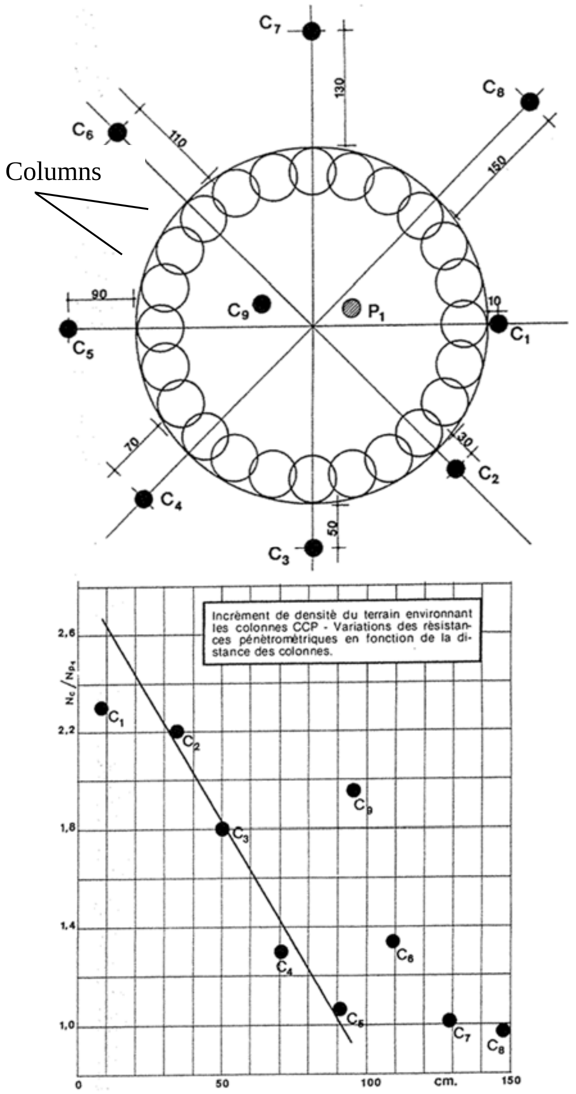

Fig. 2. Soil density around the jet grouting column depending on the radial distance.

The maximum effect of the high-pressure jet on the surrounding soil mass is observed at a distance of 10 and 30 cm (samples C_1 and C_2), the maximum effect on the physical and mechanical characteristics of the soil is observed at a distance of 110 cm (C_6), 130 cm (C_7) and 150 cm (C_8).

2 Research methods and results

During the implementation of the project to strengthen the ground base of the historical monument of architecture, St. Andrew's Church, in Kyiv, studies of soil samples from the space between jet grouting columns were performed. Physical and mechanical examination of the selected soil samples showed that there is a zone with improved characteristics around the column. The density of soil (sandy loam) increased from 1.6 t/m^3 to 1.65...1.67 t/m^3, and the impact zones reached 30 cm from the surface of the column. Analysis of experimental data and comparison with the statements of some authors about the absence of influence on the surrounding soil actuate the question of the future studying the effects of the implementation of jet grouting elements on the surrounding soil environment.

A jet of cement mortar coming out under high pressure from the nozzle located on the hydraulic monitor rotates and destroys the surrounding soil, mixing it with the cement mortar. If at the first rotation the jet destroys the soil, then at the second rotation the jet is already in the cement mortar and can be considered as a drowned jet of liquid.

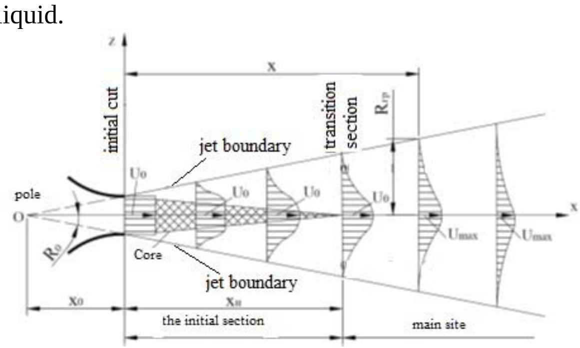

Fig. 3. Diagram of a drowned free turbulent jet.

For the design scheme, the nozzle radius is $R_0 = 1.2$ mm (the nozzle diameter located on the hydraulic monitor is 2.4 mm)

Speed of the cement mortar jet at the nozzle outlet:

$$U_0 = \frac{4 \cdot Q_p/(\pi \cdot d_c{}^2)}{n_c} = \frac{(400 \cdot 100)/(6 \cdot 3{,}1416 \cdot 2{,}4^2)}{2} = 184 \ {}^{m}/_{s} \quad (1)$$

Given that the diameter of the soil-cement column is 0.6 m, the destructive radius is $x = 0.3$ m.

Speed on the axis of the main section:

$$U_{max} = \frac{0.96}{\frac{a \cdot x}{R_0} + 0.29} U_0 = \frac{0{,}96}{\frac{0{,}08 \cdot 0{,}3}{1{,}2 \cdot 10^{-3}} + 0{,}29} 184 = 8{,}71 \frac{m}{s} \quad (2)$$

where a is the structural coefficient of 0.08.

Half of the height of the jet at a distance of $x = 0.3$ m from the nozzle:

$$R = \left(3.4 \frac{a \cdot x}{R_0} + 1\right) R_0 =$$

$$= \left(3.4 \frac{0.08 \cdot 0.3}{1{,}2 \cdot 10^{-3}} + 1\right) 1{,}2 \cdot 10^{-3} = 0.083\, m \quad (3)$$

Based on the fact that we know the fracture radius of the jet, to calculate the residual pressure acting on the surrounding soil that has not been destroyed, we calculate the hydrodynamic pressure of the liquid jet on the wall:

$$P = \rho_p \omega U^2 = 1500 \frac{3{,}14 \cdot 0{,}166^2}{4} 8{,}71^2 = 2458\, H \quad (4)$$

where ρ_p is the density of the solution, ω is the cross-section of the flow, and U is the average flow rate of the liquid.

When calculating the jet per 1 m^2, we obtain a residual hydrodynamic pressure of $P = 113.8$ kN/m^2.

The calculated data of the residual pressure that causes a high-pressure jet of cement mortar on the surrounding soil are used to create a model in the Plaxis 3D Foundation software package.

Engineering and geological characteristics of the soil and geometric characteristics of jet grouting columns made using jet technology are taken on the example of the object "strengthening foundations during the reconstruction of St. Andrew's Church in Kyiv", on the territory of which experiments were conducted on soil samples taken in the intercolumnar space.

The design solution for strengthening the foundations of St. Andrew's church was developed in 2009 and it was the implementation of soil-cement columns in the base from the middle of the under-porch, from the outside of the stylobate and from the middle of the church and stylobate premises with a total of 259 pieces, a length of 10.8 to 13.5 m with angles of inclination from 7° to 13° and a diameter of 600 mm with an extension of 800 mm, a step of 1.0–2.7 m. A schematic diagram of strengthening the foundations of the church is shown in Figure 4:

We accept the Mohr-Coulomb model for the soil and body material of the jet grouting column. To simulate the process of performing a jet grouting column and the effect on the surrounding soil, the column material is given low characteristics to reflect its liquid state.

The thickness of the experimental layer in which the samples were taken is IGE – 4–8 m. In the column model – 5 m and there is still 3 m under the columns. The introduction of soils below the experimental layer would not give a result, since they did not take soil samples, that is, it would be a mistake to compare them with the experimental results and assert the correctness of the simulated data obtained.

Characteristics of solid sandy loam: $\gamma = 1.6$ t/m^3, $\phi = 23^o$, c = 33 kPa, E = 17 MPa. Characteristics of the jet grouting column: $\gamma = 1.55$ t/m^3, $\phi = 3^o$, c = 3 kPa, E = 0.15 MPa.

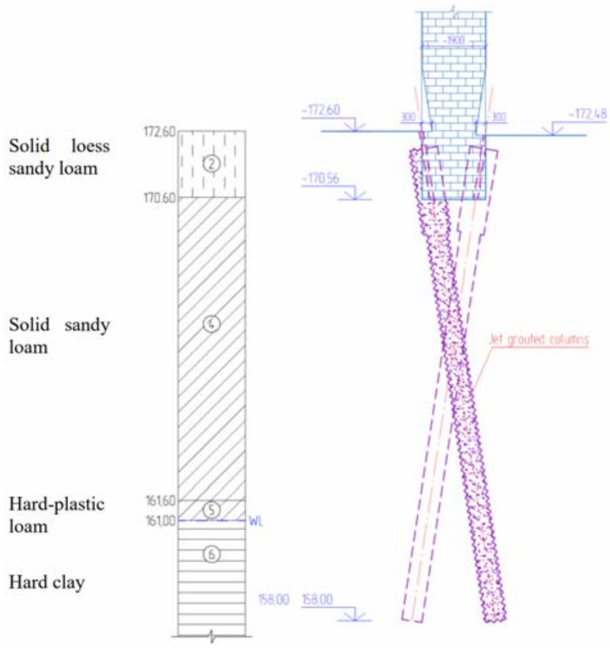

Fig. 4. Schematic diagram of strengthening foundations.

The model is the 5 meter column, the diameter is 0.6 m, the intercolumnar distance is 0.85 m, the pinning is brick, the depth is 2 m. The study of soil samples took place from the basement at a foundation depth of 2 m, the level of occurrence of the selected soil samples – 2.5 m from the basement floor level. In accordance with the software capabilities of the geotechnical design complex, the jet grouting columns are set vertical.

The main purpose of the simulation was to study the effect of the residual pressure of a high-pressure jet of cement mortar, a pressure that is directed horizontally. The platform for research is the inter-column space, and therefore only two columns are introduced in the model. That is, with the same soil environment, the same distance and the same residual pressure value (constant technological parameters when performing a column), the results of exposure in the inter-column space would also be the same.

The model reproduces experimental conditions: pitch, soil, depth of occurrence of the selected samples.

A calculated residual pressure $P = 113.8$ kN/m^2 is applied along the contour of the surface of the jet grouting column.

Figure 5 shows the deformed grid of the created model and the total displacements that occur in it. The maximum value of the total displacement is 8.5 mm and it occurs on the surface of the jet grouting column, and figure 5 clearly separates the deformation zones, i.e. the zones of impact that arise from the residual pressure of a high-pressure jet of cement mortar. The dimensions of these zones are 29.5 and 26.5 cm (Fig. 6). In comparison with the experimental data obtained during the study of soil samples taken in the intercolumnar space, the maximum impact zones were 15 and 30 cm from the surface of the first and second jet grouting columns.

If we select a single volume of deformed soil in the column space, we can calculate the change in the volume weight of the soil.

Soil density:

$$\gamma = \frac{m}{V} \quad (5)$$

Let's denote γ_1, V_1 the density and volume of soil before the columns are made, which is equal to 1.6 t/m^3, γ_2, V_2 is the soil that was compacted. Let's assume that the weight of the soil has not changed and equate the density expression for the first and second soils:

$$\gamma_1 V_1 = \gamma_2 V_2, \text{ hence} \quad (6)$$

$$\gamma_2 = \frac{\gamma_1 V_1}{V_2} = \frac{1{,}6\cdot(0{,}295\cdot1\cdot1)}{(0{,}295-0{,}008)\cdot1\cdot1} = 1{,}65\ t/m^3 \quad (7)$$

Returning to the results of testing soil samples from the object "reconstruction of St. Andrew's church", the density of the selected soil varied from 1.64 to 1.67 t/m^3. As a result of modeling the impact of performing jet grouting columns, the value (7) of changes in soil density from the impact zone was obtained – 1.65 t/m^3, which corresponds to experimental data (table 1).

When studying the object of reconstruction of St. Andrew's church, numerical values of the zone of influence equal to 15 and 30 cm were obtained, and the following results were obtained during modeling: 29.5 and 26.5 cm, corresponding to full-scale experiments. The results obtained in accordance with the simulation and experimental data are entered for comparison in Table 1.

Figures 7–9 show the effect of performing a jet grouting column using jet geotechnology on the stress-strain state of the surrounding soil environment.

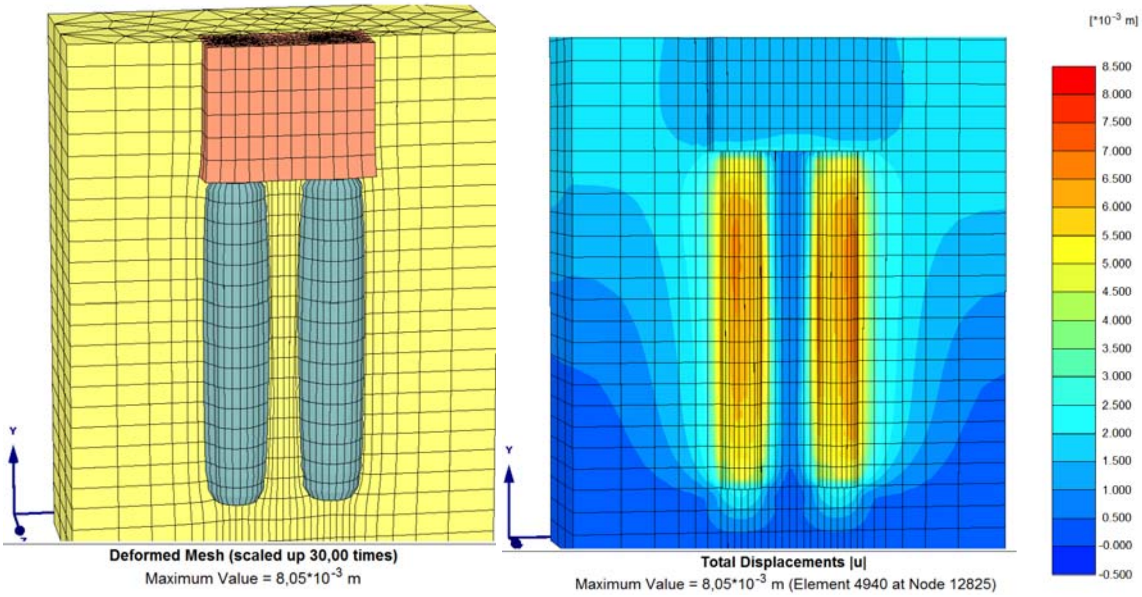

Fig. 5. Deformed finite element grid of the calculated model.

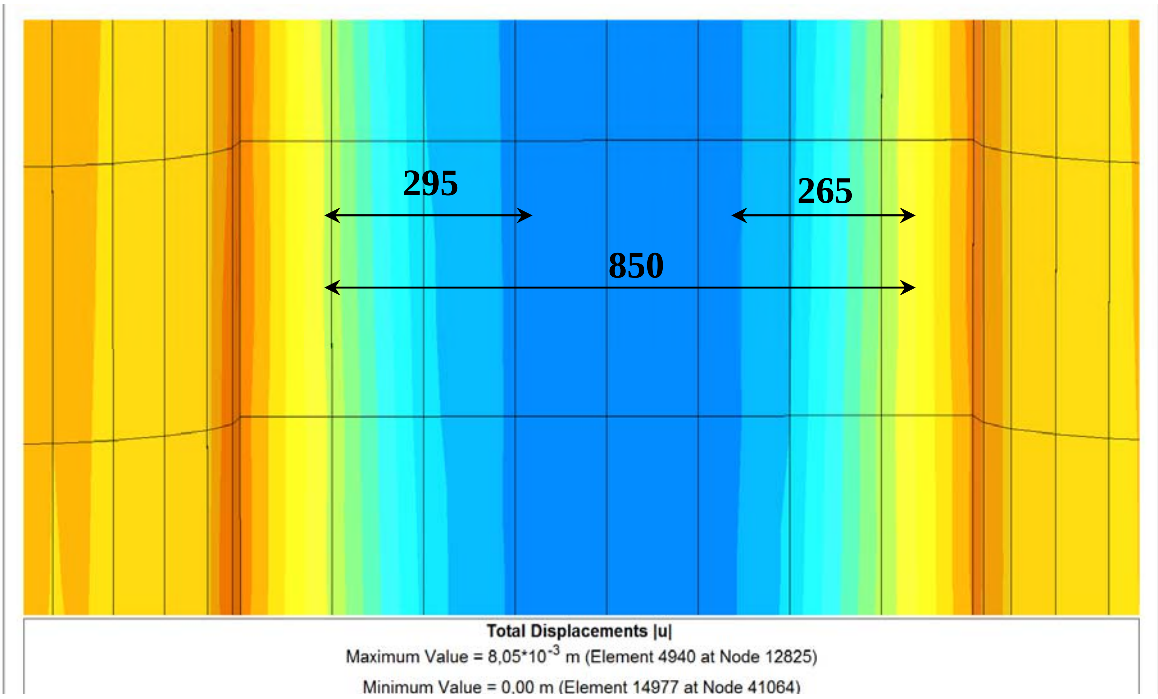

Fig. 6. Zone of influence on the soil in the intercolumnar space.

Table 1. Comparison of research results and results obtained during modeling.

Soil Type	The density of the soil sample intact structure	Density of soil samples, after accomplishment of soil-cement columns		The sizes of zones of influence on a soil massif	
		research data	according to the simulation results	research data	according to the simulation results
Sand of solid consistency	1,6 t/m^3	1,64…1,67 t/m^3	1,65 t/m^3	15 and 30 cm	26,5 and 29,5 cm

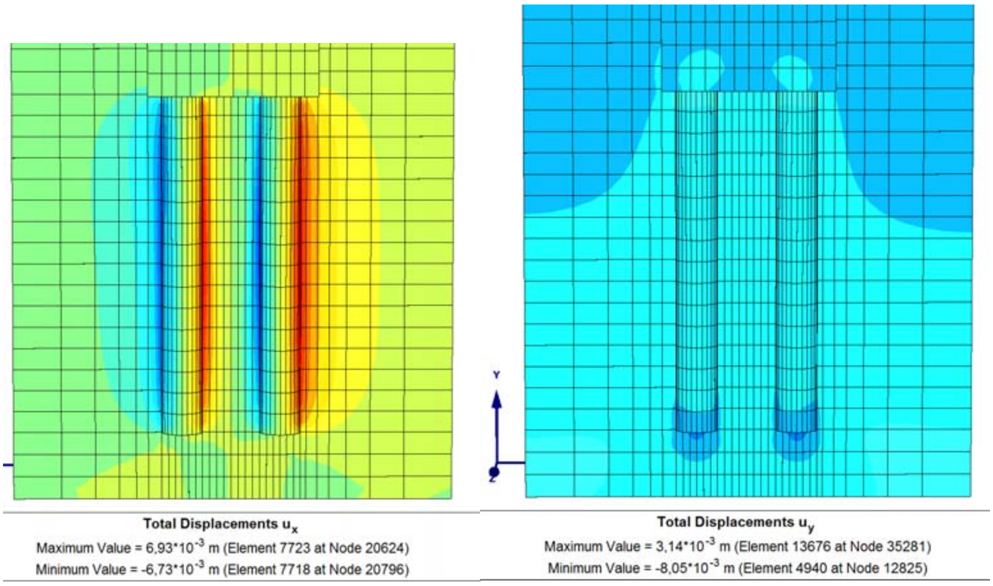

Fig. 7. Horizontal and vertical model movements.

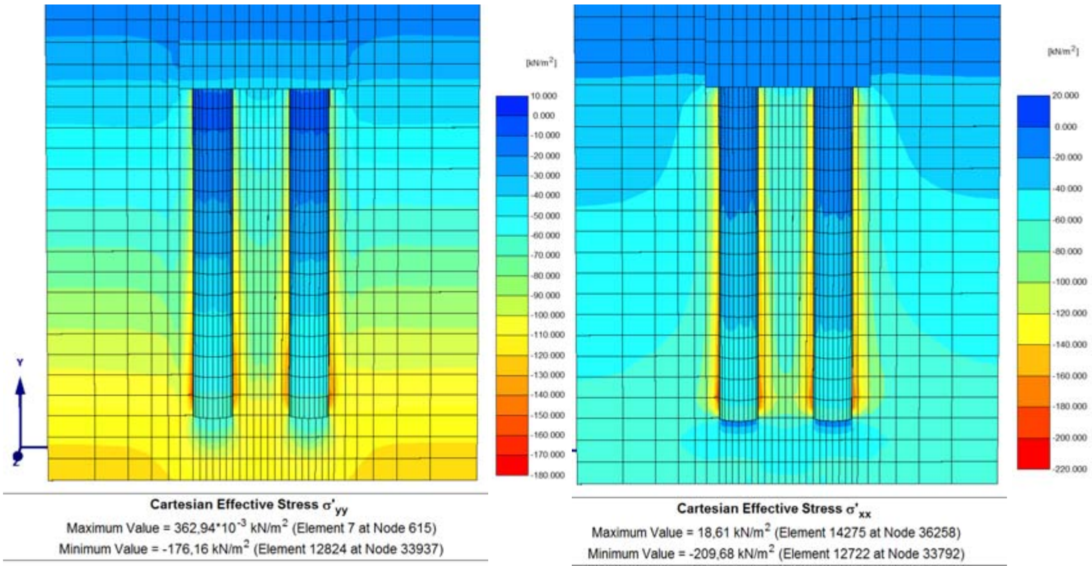

Fig. 8. Vertical σ_{yy} and horizontal σ_{xx} effective stresses.

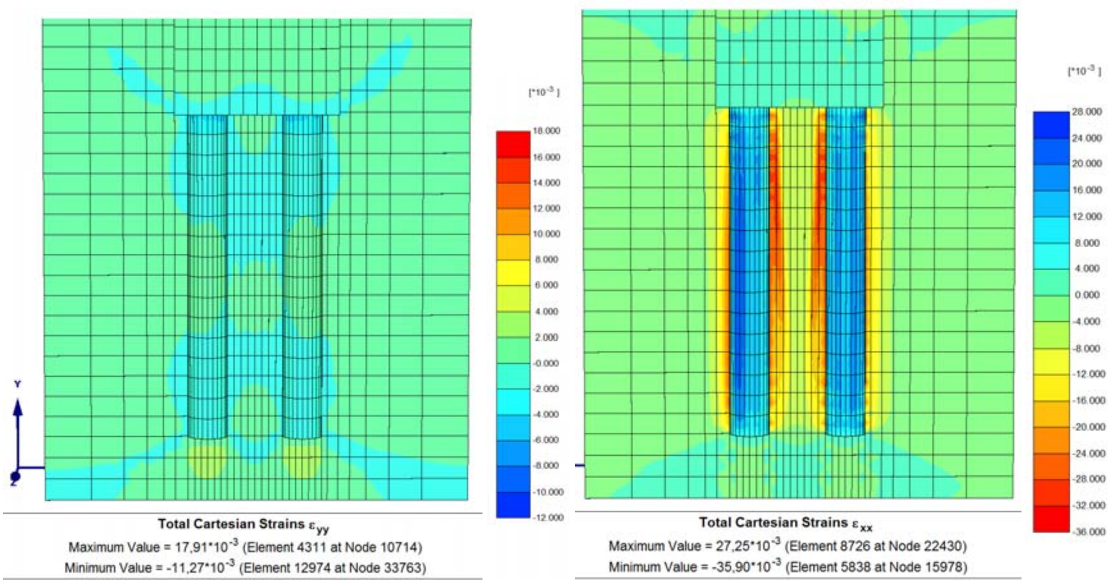

Fig. 9. Vertical ε_{yy} and horizontal ε_{xx}soil deformations.

3 Conclusions

To perform numerical modeling of the formation of zones with improved physical and mechanical characteristics in soil massifs, a hydraulic calculation of the drowned jet of cement mortar was performed. Using research data from the described construction sites and knowing the destructive radius of the jet, the residual pressure that causes a high-pressure jet of cement mortar on the surrounding soil mass is calculated after the destructive energy is spent on the destruction and removal of the soil during the formation of the jet grouting column.

The obtained residual pressure calculations were used to create a model in the Plaxis 3D Foundation software package.

In accordance with the research data on the object of reconstruction of St. Andrew's church, Kyiv, the zones of influence on the surrounding soil environment were *15* and *30* cm, and the simulation obtained results are *29.5* and *26.5* cm.

As a result of modeling the impact of performing jet grouting columns, the value of the change in soil density from the impact zone was obtained - *1.65* t/m^3 (before the impact of the jet *1.60* t/m^3), which corresponds to experimental data (the change in soil density after performing jet grouting columns on the construction site varied from *1.64* to *1.67* t/m^3).

A field study and simulations performed to study the impact proved the presence of improved soil zones around the jet grouting columns.

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Computational aerodynamics in architectural siting of the structures of agro-industrial complex

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Abstract. The article presents study of wind effect on silo parks, which was carried out by computer simulation methods. A special modeling technique was created as a software module for the Ansys Workbench platform. A finite element mesh was developed in accordance with two requirements. Through the use of this mesh, which doesn't contain needless elements which can be used for simplification of calculations and reduction of execution time, it is possible to describe the turbulent airflow in sufficient detail. The dimensions of all mesh elements are determined by special relations as the functions of the silo diameter and the Reynolds number. The major stage in this investigation was modeling of various options for flowing silos and their groups. As a result of the study, we have obtained aerodynamic characteristics of individual silos as part of silo parks and plotted charts of the distribution of pressure coefficients over the cylinder surface, changing the size of the silos, distances between them and local wind regime. Based on these data, we have drawn a conclusion about the optimal space planning locations of silos for different wind directions. Visualizations of turbulent flow around models at different speeds have also been obtained in this study.

1 Introduction

Construction of industrial buildings and structures requires significant resource spends. Effective use of materials is possible through rational design, construction, and operation practices, which is very important for sustainable development of modern industrial construction. One way to implement these approaches is to develop calculation methods, which must be based on accurate data. Computer simulation tools may help to obtain such data that cannot be predicted in real situations. This applies to the object of study of this article - silage parks under the influence of wind flow.

Empty cylindrical silos are very sensitive to wind loads. Their determination is performed according to normative methods [1-5]. There are also a lot of theoretical and experimental studies of these issues [6-10]. In general, the behavior of wind currents near the buildings of simple geometric shape is well studied [11-14]. However, a lot of factors related to modern silo complexes are not taken into account. It should be noted that, first of all, the issue of mutual influence of silos in groups has not been properly examined yet. The nature of the action of the wind flow on the silo park will be different from the action on the isolated cylindrical object [15, 16]. Strong suction forces, which are not taken into account in the classical calculation, arise between the silos. The silo can also be located in the area of wind shade from other objects. The second problem is the rough structure of the silo, as it has a corrugated wall and a large number of stiffeners. Wind exposure to such a structure causes complex wall effects, which, in its turn, will increase the load on the silo body and the roof.

Different experimental methods are often used to study such issues. However, the real blowing in the wind tunnel has a significant disadvantage, as it is impossible to reproduce the supercritical flow regime at Reynolds numbers greater than 10^7. Therefore, it is advisable to use the methods of construction aerodynamics, in particular computer modelling, in order to take into account the adverse effects of wind action. In order to achieve correct results, it is necessary to take into consideration a lot of factors, such as computational mesh generation and the choice of a mathematical model of air flow turbulence, which will give consistent results. The size of this computational mesh greatly affects the accuracy of the calculation and the computation time. It ought to be noted that a highly refined mesh increases the accuracy, but complicates the calculation. The next aspect is the formulation of the simulation problem, which can be flat (2D) and three-dimensional (3D). The calculations can be performed in stationary and non-stationary formulation with different time sampling steps. It is also necessary to consider different layouts of silos in groups, which can have different sizes, locations and positions in the wind flow. The last aspect is the form of the result. Numerical aerodynamic characteristics (wind pressure coefficient, drag and lateral force), which were found for a certain wind

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direction and specific position of the models, are not very informative. It is appropriate to present the results in the form of graphs, similar to building standards. Also, different computational situations for common silo configurations can be combined into an aerodynamic atlas. This form is convenient and has practical benefits.

2 Method

This article presents a computer simulation procedure in ANSYS CFX program for flow around the models of various cylinder configurations that schematize a silo park. Aanalysed silos, the sizes of which are most often built: from 11 meters to 30 meters. The roughness of the silo surface was taken equal to the height of the corrugation of the silo body. In general, the problem of aerodynamic calculation was considered in three versions. At first, the simplest case of a flat 2D flow was examined. The height of the computational domain was taken as one cell of the finite element mesh.

With a more complex quasi-two-dimensional flow, the height of the computational domain was taken to be equal to the two diameters of the model (silo). The last step was to perform spatial three-dimensional flow (Fig. 1).

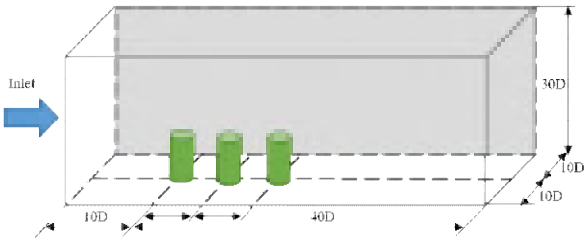

Fig. 1. 3D Geometry of the computational domain in case of three-dimensional modeling.

2.1. Justification of the calculation

For turbulent flows around cylindrical silos, which are characterized by wide separation zones, four mathematical models of turbulence are analyzed. These are Menter's Shear Stress Transport (SST), Slapart-Allmaras Turbulence Model (SA), Large Eddy Simulation (LES) and Detached Eddy Simulation (DES). Comparison of calculations showed a discrepancy in the results up to 40% when using different turbulence models [16]. However, the most consistent results are observed between the SST and DES turbulence models, which are recommended for use in construction aerodynamics.

A parametric form was used to build a finite element mesh as well as to set the dimensions of the fluid domain in the form of a parallelepiped (Fig. 1). In such a case, the dimensions of the mesh elements will depend on the Reynolds number and on the diameter of the silo, while the dimensions of the computational domain will depend only on the diameter of the model.

At this stage, the mesh quality was checked during the simulation. For this purpose, we have taken the initial data which had already been applied in numerical or physical experiments in a wind tunnel in previous works [17-19]. Subsequently, a number of verification tests based on SST and DES turbulence models was carried out for various types of meshes.

The task was to simulate on computer flow around a cylinder in two- and three-dimensional formulation and to obtain the pressure coefficient, drag and lift force. The results were compared with experimental data [17-19]. The optimal variant of the mesh was determined not only by the solution convergence, but also by the computation time. The maximum discrepancy of the obtained data when calculating the accepted variant of the finite element mesh was up to 15%.

Additionally, a comparison of wind pressure coefficients was performed for 5 points on the surface of silo body (Table 1) and for 4 points on surface of conical roof (Fig. 2). Table 1 above shows the data obtained by a full-scale field experiment in a wind tunnel [11]. Shown below are the data of the author's numerical modeling.

Table 1. Verification test results.

Angle β°	Point number			
	1	2	3	4
0	0,87 0,92	1,0 1,0	1,0 1,0	0,96 1,0
30	0,30 0,26	0,20 0,27	0,25 0,33	0,46 0,53
70	-1,54 -1,42	-1,89 -0,96	-1,64 -1,50	-1,15 -1,07
90	-1,96 -2,03	-2,09 -2,20	-1,80 -1,69	-1,30 -1,15

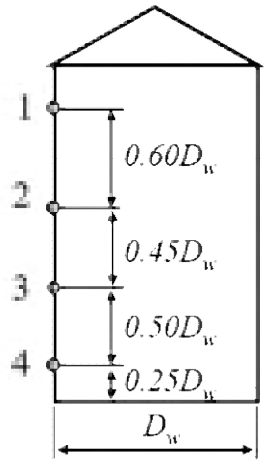

Fig. 2. Computational points on the silo surface.

2.2 General simulation diagrams

The main advantage of 2D modelling is the calculation speed. This procedure can be used for simple tasks when the silos of the same diameter are arranged in one row (Fig. 3).

Variable bench-mark data are wind speed and wind direction, the number of models, their diameter and the distance between them. The height of the silos is not taken into account in this calculation.

In the problems on modelling, the flow velocity at the input was given in the form of the Reynolds number.

Fig. 2. Arrangement of silos in a row at the warehouse of the enterprise.

In total, we have examined a sample of two, three and four silos with equal and various distances between. The position of each silo was expressed parametrically along two axes (Fig. 4). The size was expressed by the ratio of the peculiar distance between the centres of the cross sections of the silos to their diameter.

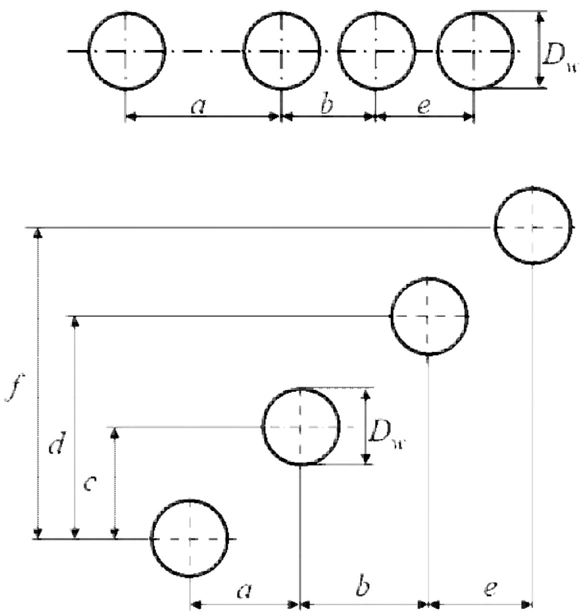

Fig. 4. Examples of silos layouts.

The results showed significant differences in the behavior of three-dimensional flow in near of silos at different initial data. For example, Fig. 5 shows wind flow isosurface for a variant of three silos with different initial data.

For all above considered options we have obtained wind pressure curves for each of the silos. For example, Fig. 6 shows a curve of changes in aerodynamic coefficients for two silos, located one after another.

Another experimental variable was the coefficient of drag C, the value of which was also found for all the schemes considered in the modelling process. A part of obtained results is summarized in table 2.

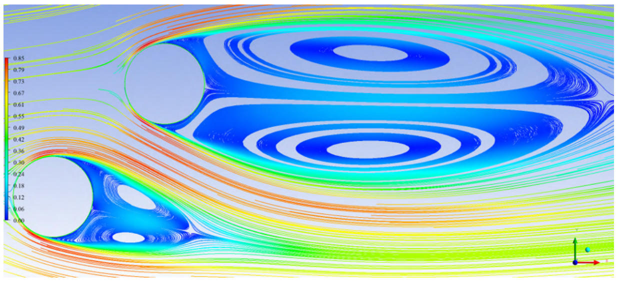

Fig. 5. Visualization of the flow around two silos.

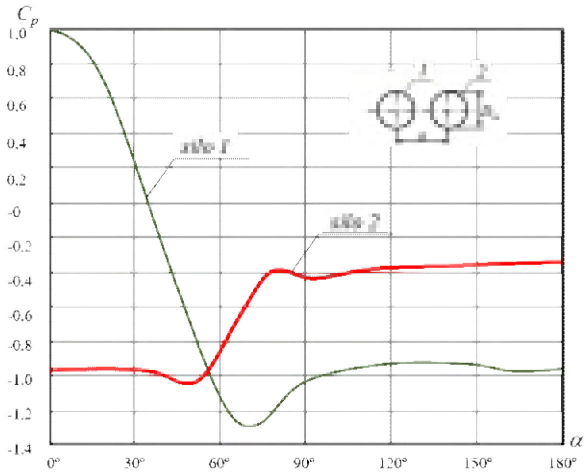

Fig. 6. The graph of variance in aerodynamic coefficients for two silos, located in succession.

Table 2. Coefficients of drag of silos.

<table>
<tr><th colspan="3">Distance parameter</th><th colspan="4">Coefficients of drag</th></tr>
<tr><td colspan="7">Two streamwise silos</td></tr>
<tr><td colspan="3">a/D_w</td><td colspan="2">C_1</td><td colspan="2">C_2</td></tr>
<tr><td colspan="3">1,4</td><td colspan="2">0,989</td><td colspan="2">-0,526</td></tr>
<tr><td colspan="3">2,0</td><td colspan="2">0,903</td><td colspan="2">-0,406</td></tr>
<tr><td colspan="3">3,0</td><td colspan="2">0,841</td><td colspan="2">-0,169</td></tr>
<tr><td colspan="7">Three spanwise silos</td></tr>
<tr><td>c/D_w</td><td colspan="2">d/D_w</td><td>C_1</td><td>C_2</td><td colspan="2">C_3</td></tr>
<tr><td>1,1</td><td colspan="2">2,2</td><td>1,492</td><td>2,256</td><td colspan="2">1,492</td></tr>
<tr><td>1,6</td><td colspan="2">3,2</td><td>1,302</td><td>1,883</td><td colspan="2">1,291</td></tr>
<tr><td>2,0</td><td colspan="2">4,0</td><td>1,241</td><td>1,586</td><td colspan="2">1,236</td></tr>
<tr><td colspan="7">Four streamwise silos</td></tr>
<tr><td>$\frac{a}{D_w}$</td><td>$\frac{b}{D_w}$</td><td>$\frac{e}{D_w}$</td><td>C_1</td><td>C_2</td><td>C_3</td><td>C_4</td></tr>
<tr><td>1,1</td><td>1,1</td><td>1,1</td><td>0,98</td><td>-0,59</td><td>0,04</td><td>0,09</td></tr>
<tr><td>1,4</td><td>1,4</td><td>1,4</td><td>0,95</td><td>-0,59</td><td>0,09</td><td>0,11</td></tr>
<tr><td>2,0</td><td>2,0</td><td>2,0</td><td>0,86</td><td>-0,5</td><td>0,16</td><td>0,16</td></tr>
</table>

3D modelling is often used when it is necessary to describe in full the actual building in near of the storage capacity. However, this causes big problems, as the development of detailed models of the silo park, taking into account the surrounding buildings and relief, is quite difficult and the calculation itself is time consuming.

This technique is also based on the construction of the optimal ratio of the parametric computational grid, the selection of turbulence models and special computational algorithms. In the interest of time, it is advisable, in the first instance, to perform a computation of a simplified two-dimensional model of a silo or a silo park. This would enable taking a tentative assessment of the design pressures on the body and conical roof of the silo in the park and subsequent generating three-dimensional loads based on the results of 2D-calculation.

Special macros and software modules should be used for fast and accurate calculations. This allows us to combine the necessary calculation procedures and to simplify them.

Based on the obtained results of modeling of any type, it is possible to determine the most dangerous wind directions, perform a preliminary assessment of the calculated loads and export loads to the strength analysis program.

2.3 Results

The nature of the placement of silos and the distance between them greatly affect the distribution of pressure on their surface. The result differs from those indicators that are taken for single structures and declared in the design standards.

For paired silos, modelling was carried out for various options with a stepwise increase in the distance between centres a from $1{,}1D_w$ to $10D_w$.

The formation of symmetrical stationary vortices of different elongation and shape was observed in the pattern of distribution of isosurface of closely spaced silos. These symmetrical stationary vortices are located near the leeward side of each of the flow bodies. Behind the first cylinder, two oversize side vortices and two middle vortices, which practically disappear at $a = 1{,}6D_w$, are clearly visible. With regard to the second cylinder, the classic formation of two elongated stable vortices is observed (Fig. 7).

An increase in the distance between the silos leads to the narrowing of the eddy zone, and at $a/D_w > 3{,}5$ they form a narrow isthmus with separation.

The graph of variance of the pressure coefficient for the first cylinder takes the typical shape. However, the aerodynamic coefficient curve for the second silo is completely in the negative zone. The value of the aerodynamic coefficient at an angular coordinate of 0º is $C_p = -0{,}98$ at $a/D_w = 1{,}1$. Subsequently, the values beyond the surface of the cylinder decrease very slowly, reaching a minimum at 50º $C_p = -1{,}05$ (the zone of medium vortices silo 1), and then increases more sharply at 45º-80º with the maximum $C_p = -0{,}38$ (the zone of lateral vortices silo 1).

After this point, the influence on the aerodynamic coefficient is exerted by the own eddy zones of the silo 2. With further increase in size between the models, the effect of silo zone 1 predictably decreases.

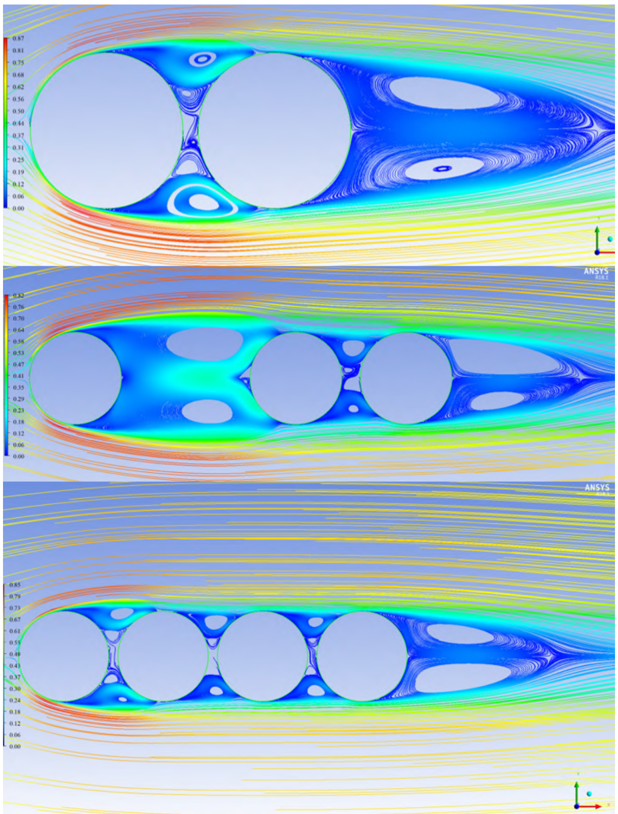

Fig. 7. Simulation of wind action on a system of silos, located in succession.

As the distance increases, the drag coefficients of silo 1 change within 19%, and for silo 2 they change doubly.

For a group of three and four cylinders in series, the flow pattern is similar. For silo 3, the graph of variance of aerodynamic coefficient is also in the negative zone. This is caused by the windy patch from silo 2. Quantitative values change slightly. For the distance $b/D_w = 1{,}2$, there is one maximum at 50º ($C_p = -0{,}1$) and one minimum at 95º ($C_p = -0{,}42$). At the distance of $a/D_w = 5$, the graphs C_p of silo 1 and silo 2 converge.

Graphs of variance of aerodynamic coefficients for silos placed in a group of four bodies can be projected (Fig. 8). Quantitative characteristics do not exceed the values for the groups of three bodies.

The instantaneous blowing pattern for the case of different direction of the wind flow is shown in Fig. 9. To simulate the flow, at first two silos were selected with the distance between the centres of $0{,}2D_w$, which was then increased. The visualization shows how a bevelled flow zone with high velocities is formed. The eddy zone of one silo is longer and has an asymmetry in the area close to the second silo. For the second silo, the eddy zone is smaller and develops sideways. Such nature of the flow causes combination of the stall points and zones of maximum pressure.

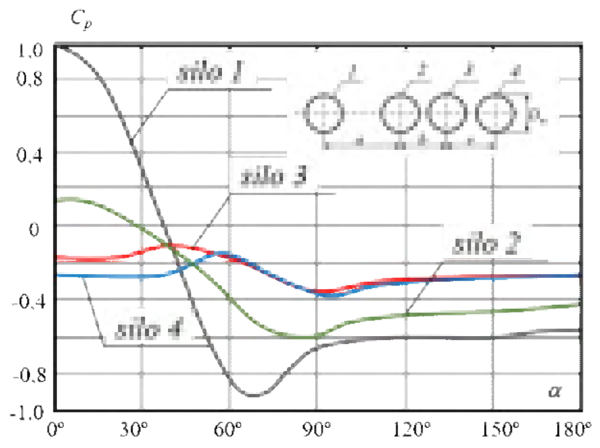

Fig. 8. Simulation $a/D_w = e/D_w = 5{,}0$, $b/D_w = 1{,}2$.

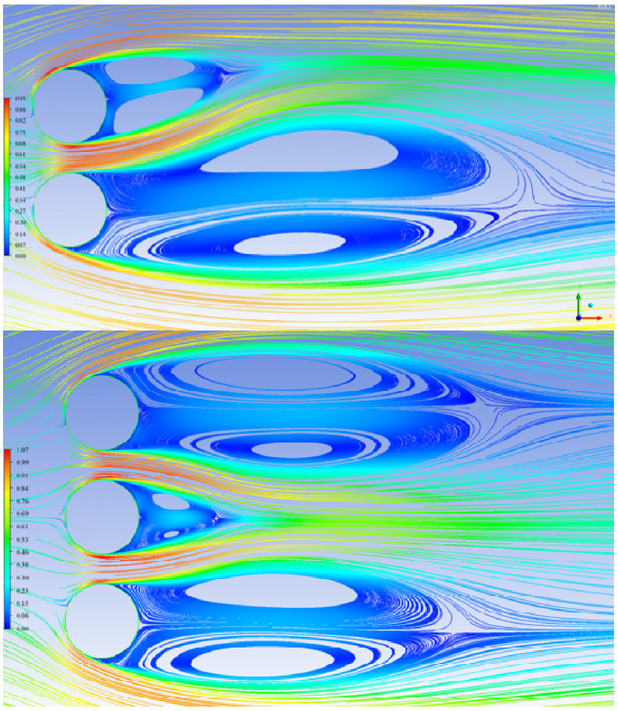

Fig. 9. Simulation of wind action on the system of parallel silos.

At $c/D_w = 1{,}1$ the value of aerodynamic coefficients of the upper silo, which has smaller eddy zone, up to 25%, is greater than the corresponding indicators of the neighbouring silo. With increasing distances between the silos, this difference is less noticeable. At $c/D_w = 2{,}5$ the graphs of the opposite parts are almost convergent, and at $c/D_w = 3{,}5$ they coincide. This indicates that there is no screening effect.

When three cylindrical bodies are placed in parallel, the specific formation of two huge vortices is observed in the windward area of the middle silo. Between the vortices there arise symmetrical flows, the air velocity in which reaches maximum values.

At the distance of $> 2{,}5D_w$, three independent flow regions are formed around each silo. For the aerodynamic coefficient, such an arrangement of the containers causes the following changes. With an equal distance between the centres of the silos, the middle silo has a symmetrical graph C_p .

At the minimum point, it reaches the values of $C_p = -1{,}7...-1{,}95$ at the distance between the centres $1{,}1D_w - 1{,}2D_w$, and at the distance of $c/D_w = 1{,}4$; $d/D_w = 2{,}8$ the minimum value of $C_p = -2{,}3$ is reached. For outer silos, the graphs are asymmetric for the upper and bottom surfaces.

With a very close arrangement of the silos (up to $1{,}4D_w$), a negative minimum of $C_p = -2{,}38$ is reached at around 100º. At the distances of $> 1{,}6D_w$, the graphs of aerodynamic coefficients are smoothed and drawn closer together.

A variant of simulation with diagonal arrangement of silos is shown in Fig. 10.

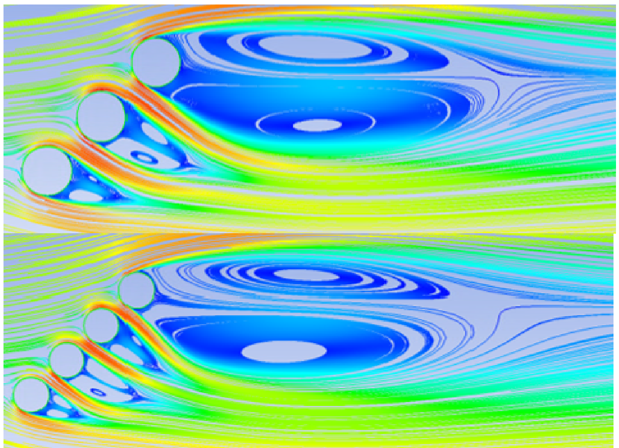

Fig. 10. Simulation of wind action on the system of diagonally located silos.

The position of the silos was regulated by the given values of the distances a/D_w , c/D_w (for two silos). The picture of the eddy zone changes. There is clear deviation of the isolines into the lateral side between the flow objects. As in the previous blows, two vortices are formed behind each of the cylinders in the windward zone; however, they are different in size and for the first object they are distinguished with discernable asymmetry and lateral direction. For the second silo, which is located more remotely, the asymmetry of paired vortices is practically indiscernible. The total length of the wake boundary is four times greater.

The distribution curve of aerodynamic coefficients also lacks symmetry. For the first silo the difference in zero points of the aerodynamic coefficient on the lateral surfaces is 15º, while for the second silo it is only 6º. At $a/D_w = c/D_w = 1{,}1$, the maximum values of the aerodynamic coefficient are within $C_p = -1{,}1...-1{,}16$, at $a/D_w = 1{,}2$, $c/D_w = 2$, they grow to $C_p = -1{,}15...1{,}27$, at $c = 3D_w$ they practically do not change $C_p = -1{,}18...-1{,}25$. The shape of pressure distribution graphs for three silos is asymmetrical in its upper and lower parts. It should be noted that angular displacement along the contour is caused by various stall points. Quantitatively, t aerodynamic coefficients are large. For the distances of $1{,}1D_w$ between the centres, the minimum aerodynamic coefficient of the middle cylinder is $C_p = -1{,}55$, for the most distant silo it is $C_p = -1{,}40$ and it will be $C_p = -1{,}38$ for the nearest one. At a distance, the minimums of silo 1 and silo 2 reach $C_p = -1{,}5$.

Development of the flow for a row of four silos is similar. It is characterized by the presence of two large-scale concentrated vortices behind silo 4 and curved eddy zones for the rest silos. At a distance of $1{,}0D_w$ in both directions, the maximum values of the aerodynamic coefficient were in silo 3 - $C_p = -1{,}38......1{,}5$, with the increase to $2{,}5D_w$ for silo 3 - $C_p = -1{,}3$. For other silos, the values did not exceed this value.

3 Conclusion

1. In computer modelling of the wind action on silos, it was found that the value of the aerodynamic characteristics (pressure, drag and lift coefficients) of experimental models depend heavily on the appropriateness of the taken turbulence model and on the quality of the computational meshes.
2. Based on the carried out verification tests, a special technique was developed for constructing finite element meshes for the tasks of modelling wind action on silos.
3. Simulation of two-dimensional and three-dimensional flow around simple silo parks at high Reynolds numbers has been performed.
4. Based on the results, the studying of the kinematic spectrum and interferential interaction of models of groups of two, three and four silos (400 variants of blowing) were carried out at various angles of attack of the wind current within the framework of 2D modelling.
5. We have obtained wind pressure curves for each of the cylindrical bodies in the group for different initial conditions. The analysis of their values has also been carried out in this academic research.
6. It has been discovered that wind actions on a silo in a silo park can significantly exceed the action on a separate silo.

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Construction technology for affordable housing with the use of space-braced concrete-filled steel tubular framing

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Abstract. Among many tasks to be done by the state, the most significant is a social-economic one i.e. provision of its citizens with affordable, long-lasting, energy- efficient and economical housing. One of the ways of doing the given task is the application of concrete-filled steel tubular (CFST) structures, for the elements of a building, of circular, square or rectangular type. It is also possible to use such structures not only for a new housing stock but in the reconstruction of present one at the expense of additional storeys (about 20); without demolition and total resettlement of tenants of the house under reconstruction. Alongside with this, there is an opportunity to increase total area of residential houses and make new types of comfortable place of various purpose.

1 Introduction

At present buildings from monolithic reinforced concrete in shallow and large-panel formwork are erected using large-block and frame construction technology. Volume of brick, panel and frame-panel house construction has declined strongly. Expansion of monolithic-framing house construction causes considerable capital investments connected with frameworks, depends on weather conditions, it is characterized by big material consumption and accordingly construction cost and terms.

In foreign construction practice the most widely used are not bearing monolithic building envelopes or reinforced concrete columns but as well as combined frame-core system with a bearing core made of monolithic reinforced concrete and external frame made as a bearing shape of columns peripherally located to a building, which is rationally combined with horizontal outrigger-foundation frame work located in every 15-25 storeys [1-4].

In Australia the first residential building (46 storeys) was built in 1990 in Melbourne. The core of the building was formed with steel concrete shafts. 24 CFST columns were located peripherally the building. In Japan 57-storey building was built with the use of concrete-filled steel tubes. The base of the building is a CFST framing. Concrete-filled steel tubes are widely used in China in the last decades. A large number of skyscrapers were built in China using CFST frames.

In practice of industrial construction in Ukraine CFST structures are used limitedly until now; there are single examples of the use of CFST columns in residential construction that proved their technological efficiency [5-7].

Concrete-filled steel tubes possess extremely high bearing ability herewith having significantly less cross section of a column. It is the bright example of complex materials that combines optimally strong sides of concrete and metal. Metallic shape functions as a permanent formwork in a CFST column and after concreting process, it reinforces the column either in cross or longitudinal direction that allows to meet any loads applied at any angles. Concrete in such a column is in an optimal state for itself, all-around compression and in such a condition, it withstands loads significantly exceeding its prism strength [1]. The fact is that CFST structures differ in their ability to withstand large loads for a long time in extreme conditions for high-rise and large-span buildings; unlike with steel and reinforced concrete structures losing their bearing ability immediately.

Concrete-filled steel tubes have also their constructive disadvantages. Because of differential Poisson ratios ($\nu s = 0.3$; $\nu b \approx 0.2$), one of the main problems is occurrence of significant enough tensile stresses on the border of concrete core and metallic shape. Such stresses as well as concrete setting can lead to the separation of concrete core from mantle pipe during operation process. When concrete separates, durability of an item is reducing and bearing ability as well in a certain level.

Taking into account such single buildings having been erected before, there was elaborated advanced construction technology using steel concrete framing [10;11], herewith we have an opportunity to reduce steel and concrete consumption as well as we can simplify the structure of braced steel concrete frame of a multi-storeyed building at the expense of the reduction of labour consumption and construction cost.

Technology improvement is provided with mutually perpendicularly located supporting columns and spandrel beams as well as their junction on flooring level; joints are pin connected and frame itself is provided with supporting systems as bracings, joint is pin connected between columns and spandrel beams. Making a frame as a steel concrete one with bracings that are fitted in every span and every storey by the height of a building, includes simultaneously the operation of vertical and horizontal stresses, all elements of framing – columns, spandrel beams, and bracings. Using concrete instead of steel in compression and its filling in compressed elements of a structure causes increasing of local strength of walls, resistance of local failure of thin-wall steel structures in assembling not only in columns and spandrel beams but in joints allowing to reduce total steel consumption.

Bracings are simultaneously interior supports for spandrel beams, that turns them into three-span whole beam, at the expense of that the value of bending moment reduces in spandrel beams and allows significantly (by 1.5…2 times) to reduce their height as well as spans of spandrel beams and columns grid. Pin-connected joint of spandrel beams allows with columns to unify the structure of spandrel beams and bracings, as strains in spandrel beams and bracings slightly differ by dimension independently on their location by the height of a building [3]. The essence of the base of technology is presented on Fig.1. Fig. 2 illustrates the erection stages and the plan of a typical storey.

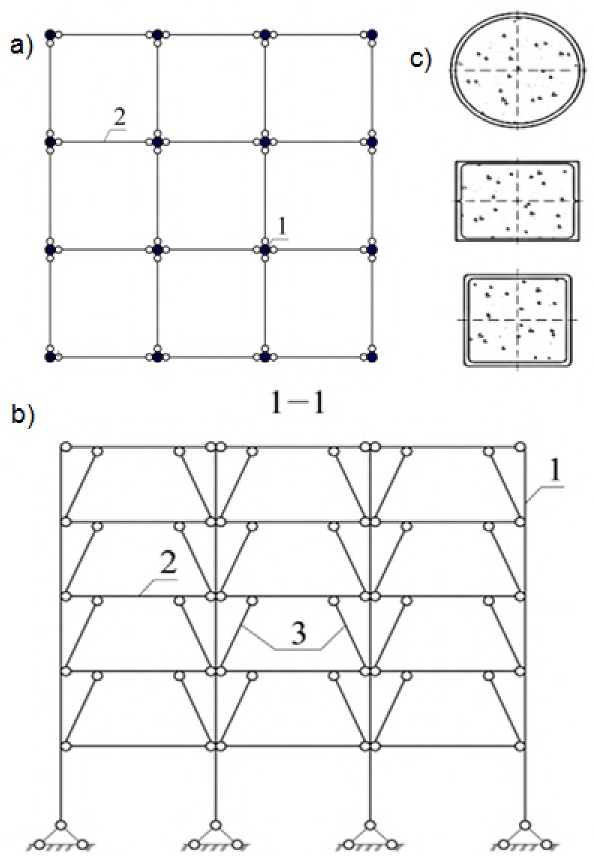


Fig. 1. a) cross section of bracing steel concrete frame; b) longitudinal section of bracing steel concrete frame; c) cross sections of a column and spandrel beams. Where: 1 – CFST column; 2 – spandrel beam; 3 – bracings.

Framing consists of steel concrete columns (1), steel concrete spandrel beams (2) pin-connected with columns and bracings (3), pin-connected with columns and spandrel beams. Therefore, the essential advantage of such a bracing steel concrete framing with bracings is a significant reduction of construction cost.

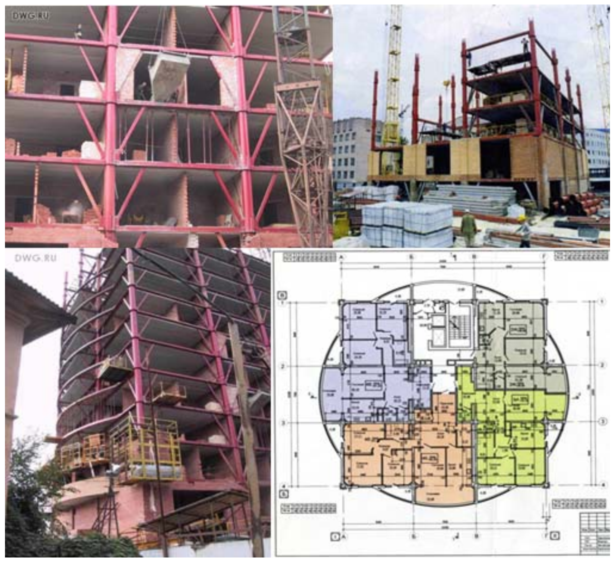


Fig. 2. Erection of buildings with CFST framing in various construction stages.

Reconstruction of residential buildings demands special attention to choose engineering solutions in the improvement of volume-constructive solutions and provision of operating factors with the demands of present regulations [8; 9; 10].

According to the present constructive solutions, there are three types of a superstructure (Fig. 3):

a) General, without strengthening a present building, superstructure is a high extension of a building saving its constructive scheme; it allows 2-3 additional storeys;

b) Changing its constructive scheme. The given method suggests redistribution of load transmission scheme from the weight of additional storeys and existing building on bearing members loading them equally allowing additional 4-5 storeys.

c) Superstructure plant that is not connected with bearing structures of the present building and supports on individual structures. Such a superstructure can be erected over any building. Essentially, with additional storeys their stress is given to reinforced concrete slab located on columns which are located uniformly by the perimeter of a building and support on their own foundations allowing to add 10-20 storeys. Fig.1 shows the considered variant of additional storeys. More often similar superstructures are made of reinforced concrete or metallic structures, however, in comparison with metal structures with the same bearing ability, metal consumption reduces twice on average for CFST members but comparing with reinforced concrete ones – section of shotcrete members and concrete consumption reduce twice.

In a technological way a steel pipe plays a role of a formwork that significantly simplifies work operations but constructively it plays a role of a case and longitudinal rigid reinforcement. Simple production technology, high construction velocity in the erection of monolithic buildings, essential metal economy at the expense of increased bearing ability and significant fire resistance make the structures made of steel pipes filled in with concrete more attractive. Researches show much higher strength of columns in comparison with traditional reinforced concrete ones; it is determined by concrete operation in the condition of triaxial compression. [12-16].

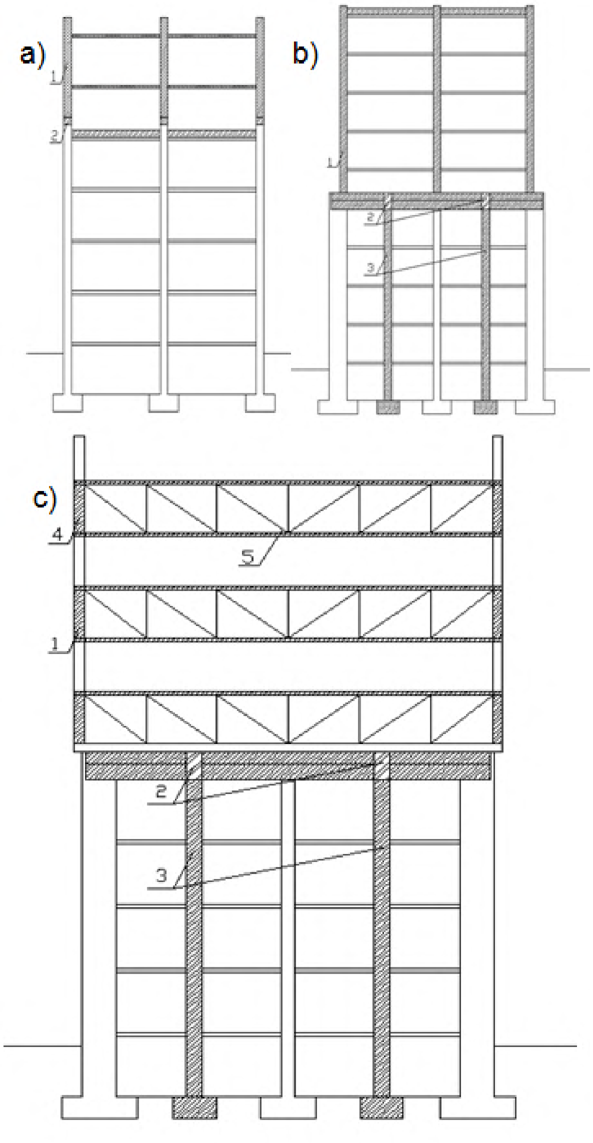


Fig. 3. a) Scheme of an ordinary superstructure: 1 – additional storeys; 2 – stiffening ring. b) Scheme of the superstructure with a changing constructive scheme: 1 – superstructure; 2 – main beams of a monolithic platform; 3 – columns. c) Scheme of the superstructure supporting on separate structures: 1 – additional storeys; 2 – main beams of a monolithic platform; 3 – columns; 4 – walls of additional storeys; 5 – metallic bearing girders.

2 Methods

As concrete-filled steel tubes are a complex material, there are some difficulties in calculation complex. With this purpose we used the methods of unit stiffness, herewith section of a shotcrete member carried into an equivalent section of concrete with a diameter by the formula:

$$D_{red} = \sqrt[4]{D^4 + 8\alpha\delta D_s^3} \qquad (1)$$

where: α — ratio of inertia and concrete modulus of elasticity and outer metallic shape;

D_s – outer diameter of steel shape;

D_b – outer diameter of concrete;

D_{red} – outer given diameter of section.

According to the given method in calculation the presented value of concrete section increases by 2-5 cm depending on concrete grade, steel grade and thickness of a tube wall. Results are given in Table 1 [16].

Table 1 Presented section of CFST members.

Outer diameter of a pipe, cm	Thickness of a pipe wall, δ cm	Concrete grade, B	Outer presented diameter of outer presented section, D_{red}, cm	Modular ratio, α
42.6	0.5	B20	47	0.8
		B30	45	0.6
		B40	44	0.6
		B50	44	0.5
		B60	44	0.5
53.0	0.5	B20	56	0.6
		B30	55	0.5
		B40	54	0.5
		B50	54	0.4
		B60	54	0.4

3 Results and discussion

As the possible variant of using steel reinforced concrete structures in mass civil construction of a new housing or the reconstruction of an old one, there was elaborated the structure of a superstructure of five-storey residential building (‘Khrushchev-era house’) with the aim of its redevelopment, its frame consists of CFST members.

The structure of a superstructure represents itself as a stack-frame with vertical bearing members, it is two-member columns connected between each other with П-shaped multi-layered frames by girder system, beams and bracings of shaped pipes of square and rectangular section filled in with concrete that ensure space stiffness of a building in cross and longitudinal directions. Step of portal frames was 6.3 and 8.4 m and associated with the location of partition walls in the present building (Fig. 4).

Loads on the present frame members were taken according to the present regulations. Joint between constructive members of the scheme is presented as pin-connected; eccentricity of load transmission from a girder to columns was considered in calculation as well. Strains occurring in the design model are given in Table 2.

According to DSTU (National Standards of Ukraine) I.1.2.-3:2006 «Bendings and motions» (v.4, p.1) regulations limited horizontal motion of multi-storeyed building should be at most h/500, i.e. – 100 mm.

according to the calculation results, minimum bending occurring in a superstructure does not exceed 34 mm. Mosaic of motions is presented in Fig. 5.

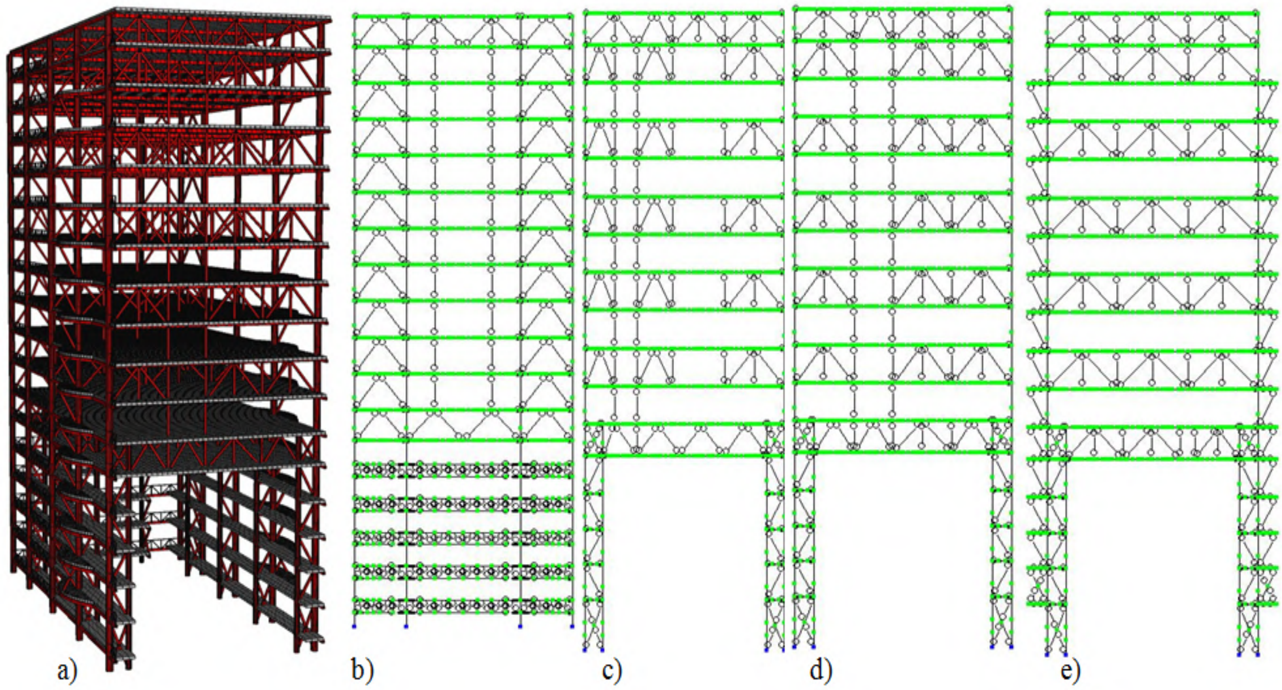


Fig. 4. General design model; b, c, d, e). Various cross-sections of a superstructure.

Table 2. Strains acting in the design model.

Maximum strains in an outer part of column	
Variant «a»	
Compressive force	N=-8950 kN
Bending moment	M_y = 803 kNm
	Mz = 58 kNm
Maximum strains in an internal of column	
Variant «a»	
Compressive force	N = -4285 kN
Bending moment	My=89kNm
	Mz= 19 kN
Maximum strains in chords	
Variant «a»	
Compressive force	N= - 530 kN
Bending moment	M_y= 156 kN
Maximum motions	
Variant «a»	
Axis motion	X = 30.5 mm, Y= 11 mm, Z= 50 mm
Maximum strains in an outer part of column	
Variant «b»	
Compressive force	N= - 9570 kN
Bending moment	M_y= 1289 kNm
	M_z= 62 kNm
Maximum strains in an internal of column	
Variant «b»	
Compressive force	N= -1440 kN
Bending moment	M_y= 24 kNm
	M_z= 187 kNm
Maximum strains in chords	
Variant «b»	
Compressive force	N= - 1440 kN
Bending moment	M_y= 34 kNm
Maximum motions	
Variant «b»	
Axis motion	X= 30.5 mm, Y= 11 mm, Z= 50 mm

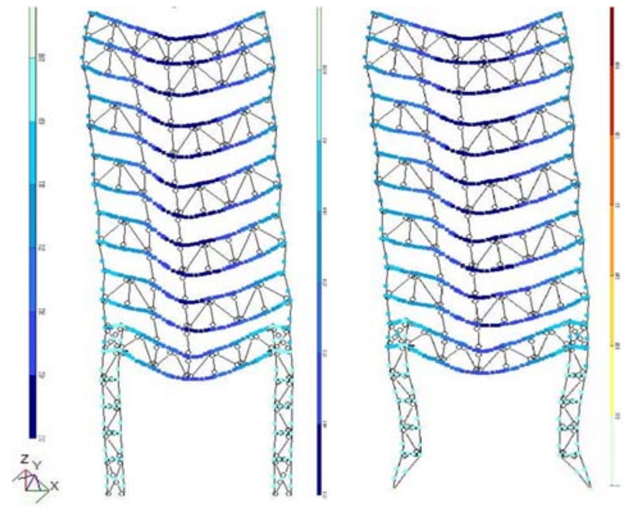
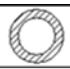
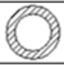
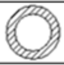
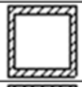
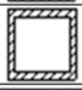
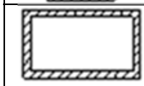


Fig. 5. Mosaic of motions of members a) column with two supporting points on a foundation; b) column with one supporting point on a foundation.

From designing experience and obtained results, it is known that shotcrete framing with flooring of hollow slabs allows to reduce cost of a frame 20-30% and shorten construction terms twice. Table 3 demonstrates the parameters of the used CFST frame members.

Flooring is made of pre-fabricated hollow slabs with connectors on lateral areas. Connectors taking main closing strains occurring during the operation of a stiff floor in covering can become monolithic. Provision of strain transfer between members and redistribution of locally applied stresses on neighbouring slabs excludes 'key' effect proper for flooring structures of pre-fabricated slabs without connectors on a lateral surface (Fig. 6).

Table 3 Section parameters of the members of CFST framing.

Column members	Sketch	Sections, mm	Supporting strains		Steel grade
			M kH×m	N kH	
Section “b, c’’		Pipes 630x10	From 234 to 288	From -890 to -5223	St3ps
Section “e”		Pipes 630x10	From 586 to -753	From -1390 до -8840	St3ps
Section “d”		Pipes 630x10	From 586 to 994	From -796 to 8940	St3ps
Girder members in all sections		200x200x6	-	From -343 to -1680	St3ps
		180x180x6	-	From -157 to -7776	St3ps
		100x200x11	From -51.3 to 47.5	From -1036 to 1010	St3ps

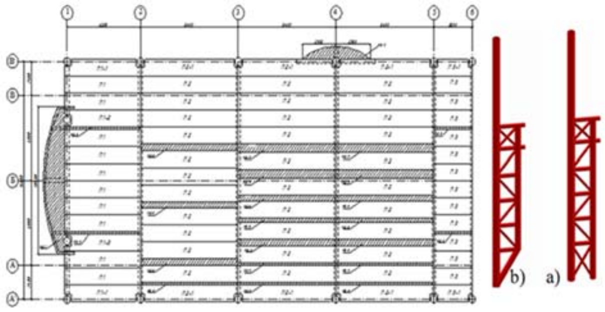


Fig. 6. Monolithic scheme of slabs (7-17 storeys) and two types of columns.

Statistically the floor is the only system where flooring slabs support on spandrel beams of framing and jointed at the expense of longitudinal linear pins. Only cross and longitudinal strains can be transferred through these pins. To make proper stiffness it is necessary to make monolithic stitches and connectors in floorings in vertical and horizontal directions. To reduce bendings it is necessary to make all the flooring members prestressed, herewith the possibility of uneven failures reduces significantly and thus conditions of cooperated work of floorings in slabs can improve. Flooring members acquire the ability to work with shear after hardening of mortar in all stitches.

Calculation of strains and section selection in the scheme elements were made in DK LIRA 9.6 R7. Two variants of a design model were considered (Fig. 9.): two-member lattice column with two supporting points on a foundation (a); lattice column with one supporting point on a foundation (b);

Having obtained strains in the complex LIR-STK there were selected sections of metallic profiled pipes.

Section of CFST members was selected by the methods of L.I. Storozhenko offered in the project of DSTU (National Standards of Ukraine) to DBN (Ukrainian National Construction Regulation) I.2.6 – 160 – 2010 «Steel reinforced concrete structures».

Metal consumption was: columns – 9.1 t; one girder – 3.7 t; whole framing - 423 t. The consumption of monolithic concrete (grade V40) for filling in columns and compressed forms– 355 m3

4 Conclusion

1. Saving steel at the expense of : usage of concrete instead of steel in compression not only in columns and spandrel beams but in bracings; filling in with concrete and increasing of local strength of pipe walls, resistance increasing to local failures of thin-walled steel structures in assembling; three-dimensional operation of framing under horizontal stresses; absence of significant bending moments in columns causing eccentricity in joints as a result of pin-connected spandrel beams with columns; reduce of bending moment in spandrel beams at the expense of bracings which are like additional intermediary supports.

2. Reduction of labour intensity for assembling, construction terms due to: reduced cost of borrowed financial means at the expense of transferring a large number of operations connected with steel structure production from a construction site to a plant, i.e. metal structures production, partial filling in with concrete; unification of steel concrete spandrel beams and bracings independently on the location of members by the height of a building; assembling of prefabricated structures, reduced length of weld seams as the result of pin-connected joints and absence of stiff joints.

3.Reduction of size and cost of foundations at the expense of: reduction of total mass of steel concrete framing in comparison with reinforced concrete framing; absence of bending moment in supporting pin-connected joint of a column and foundation.

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Prospects of application of roller compacted concrete in hydro schemes of Ukraine

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Abstract. Prospects of application of roller compacted concrete in hydro schemes of Ukraine are considered. The number of dams erected with application of roller compacted concrete is growing year after year in the world. Roller compacted concrete is an especially dry concrete mixture with decreased content of cement and increased content of pozzolana (fly ash). The broad physico-mechanical peculiarities of roller compacted concrete depend not only on its composition but also on technology of its laying and compacting in dam. Rapid construction of gravity dams with use of equipment for earth-moving works enables the more economic construction of protective embankments. Prospects of application of roller compacted concrete during erection and restoration of existing protective embankments in regions with increased flood hazard in the west of Ukraine are considered. The use of roller compacted concrete allows reducing construction deadlines by a factor of 2–3, and, in so doing, reducing the labor content by a factor of 4–5 at the expense of full mechanization of works. Decrease in content of binder in composition of roller compacted concrete by 30–80 kg/m^3 favors decrease in heat release and, correspondingly, the occurrence of temperature contraction cracks, which in its turn favors economy during construction of hydro-technical structures of hydro schemes.

1 Critical review of the present state of art of application of roller compacted concrete in hydro-technical construction

Application of roller compacted concrete is the most important achievement in technology of erection of concrete dams over the last forty years. The use of roller compacted concrete allows reducing deadlines of construction of dams by a factor of 2–3 and, in so doing, reducing the labor content by a factor of 4–5 at the expense of full mechanization of works [1]. Besides, application of roller compacted concrete gives designers the possibility of economical restoration of existing concrete dams that do not have sufficient resistance against shear and require installation of counterforts, and also the possibility of reconstruction of dams made of soil materials.

Rapid worldwide acceptance of roller compacted concrete is a result of its economically successful application in combination with high technological properties. The idea of combination of advantages of laying of loose materials and concrete as a construction material for dams was developed in 1960s. Materials that can be considered as roller compacted concrete were used during 1960s–1970s [2–3].

The idea of roller compacted concrete arose not by chance, and already in 1961–1964 years in Italy in construction of gravity dam Alpe Gera (height 174 m, volume of concrete 1.7 million m^3), and also in 1969–1979 yr. in USSR in construction of Toktogul’skaya dam (height 215 m, concrete volume 3.2 million m^3), for the first time the technology of single-layer concreting (layers thickness 0.5–1 m) of big blocks with area up to 2.5 thousand m^2 was successfully used [4]. At the above-mentioned hydro schemes for the first time dry lean concrete with cement consumption of 115–150 kg/m^3 was used, which levelling was performed by small-sized bulldozers, and compaction – by suspended packs of vibrators.

Rapid construction of gravity dams with the use of equipment for earth-moving works including big rollers for compaction was proposed in 1965 as a viable approach to the more economical building of dams [5]. Nevertheless, it had not attracted big attention till in 1970 J.M. Raphael presented it as “optimum gravity dam” [6]. Later, a number of ideas based on the theory of soil cement were presented, and also the conception of laying and compaction of embankment with material enriched with cement with the help of complex equipment for compaction was proposed. In time, this resulted in considerable decrease in cross-section of dams made of roller compacted concrete compared with traditional rock-fill dams [3]. Later, the ideas of J.M. Raphael were realized by other engineers in application of enriched

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mixtures instead of lean ones in upstream and downstream faces of dams [3].

In 1970s a number of organizations carried out a complex of laboratory tests to study properties of monolithic roller compacted concrete. In time, designing dams made of roller compacted concrete was developing in three different directions. Those were alternatives developed by Corps of Engineers of USA, British engineers, and the group of researchers from Japan. Corps of Engineers of USA developed the alternative of lean concrete on the basis of the technology of processing of soil. The British engineers concentrated on the method with high content of paste, and the group of Japanese researchers created a new conception known as RCD (dam of rolled concrete) [3].

The goal of the investigation is a critical review of tendencies of application of roller compacted concrete, existing in the world, in hydrotechnical construction, determination of main advantages and disadvantages of this technology. The tasks of the investigation are determination of the area of application of roller compacted concrete to erect new and restore existing hydrotechnical structures to satisfy vital needs in Ukraine.

2 Technological aspects of application of roller compacted concrete in hydro-technical structures

According to ACI 207.5R-89 terminology the roller compacted concrete is defined as "concrete compacted by roller rolling". Concrete mixture in unhardened state permits motion of construction machines over its surface [7]. Bulletin 126 ICOLD determines the roller compacted concrete as "concrete with non-shrinking consistency in its unhardened state, which is transported, laid, and compacted with the use of equipment for construction of earth-fill dams" [8]. Dynamics of increase of the number of dams of roller compacted concrete in the world by data [9–10] is presented in Fig. 1.

Technological peculiarities of roller compacted concrete are determined by the fact that it is concrete with zero shrinkage, which properties strongly depend on proportions of the mixture and on quality of compaction. Roller compacted concretes are produced from especially dry concrete mixtures that defy compaction by internal vibrators. Their compaction is performed by rolling by vibration rollers, heavy motor cars, pneumatic-tired rollers, and other mechanisms during laying mixtures 0.25–0.75 m [11].

The prepared mixture of roller compacted concrete must be so dry that heavy cars could move over it, and, in so doing, must contain enough water and binder to be amenable to compaction during rolling by mechanisms selected for this purpose.

Because lesser amount of water is used, lesser cement is necessary to prepare equivalent water-to-cement ratio. Lesser amount of water in the mixture causes decrease in shrinkage during solidification, and lesser amount of cement gives lesser heat generation. Decrease in shrinkage during solidification and in heat generation jointly decrease occurrence of temperature contraction cracks. Besides, decreased content of water and rolling by vibration rollers increase specific gravity of roller compacted concrete.

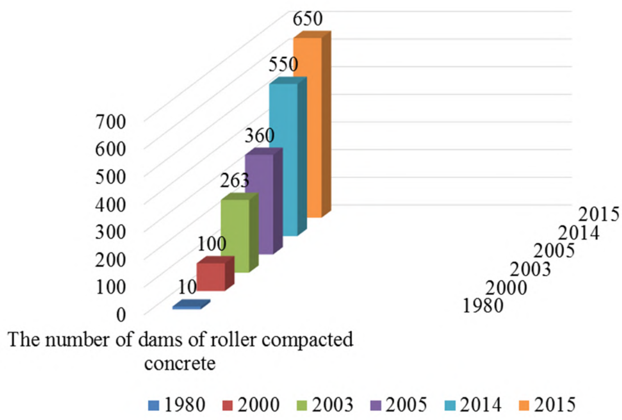

Fig. 1. Dynamics of increase of the number of dams of roller compacted concrete in the world.

Some mixtures of roller compacted concrete can have properties and characteristics similar to conventional concrete, but, for the most part, roller compacted concrete has unique properties that can substantially differ from properties and characteristics of conventional concrete. Roller compacted concrete, as a rule, is transported by trucks or by another way and is kept in heaps or spoil banks in the area of laying. During laying, roller compacted concrete is spread with layers with help of bulldozers and is compacted with help of vibration rollers.

Peculiarities that distinguish roller compacted concrete from conventional concrete are:

– binder content lesser by 30–80 kg/m^3;

– high initial strength, which ensures the possibility of motion of heavy cars and mechanisms over it (with unit pressure up to 1.0 MPa) immediately after laying and compaction;

– low shrinkage (1–5) × 10^{-4};

– low heat release, adiabatic increase of temperature for concrete with astringent content 100–130 kg/m^3 does not exceed 12–14°C;

– density is decreased by 1–5%;

– higher filtration coefficient $1\times10^{-4} - 1\times10^{-8}$ cm/24h;

– deformation modulus is lesser by 10–20%;

– increased nonuniformity: for grain size of aggregate up to 40 mm coefficient of variation of strength value C_v is 0.20–0.22, for aggregate grain size 100–200 mm – respectively 0.27–0.3.

Continuous increase of intensity of laying of roller compacted concrete is observed. Average intensity of laying at large dams reaches 10–14 thousand m^3/24h and 220 thousand m^3/month, which corresponds to intensity of filling of earth dams. Additional increase of intensity is possible at the expense of acceleration of delivery of mixture to a dam.

In world practice there is experience of application of roller compacted concrete not only to build high dams but also to restore small dams of earth materials with insufficient spillway power [12].

On this basis, roller compacted concrete in hydro-technical construction can be actively used in two directions – in new construction and to restore dangerous dams of earth materials.

3 Prospects of application of roller compacted concrete in hydro schemes of Ukraine

The authors of the paper ask themselves a question about prospect and expediency of application of roller compacted concrete in conditions of Ukraine. Proceeding from the real assessment of economic state of our country we consider that application of roller compacted concrete is the most expedient for new construction and also for repairs and reconstruction of existing hydro technical structures.

The performed analysis of existing hydro technical structures of Ukraine has proved that the most prospective direction is application of roller compacted concrete to restore the existing small hydroelectric power plants and to construct new dykes at territories that suffer from floods. Ukraine has significant potential in the field of small hydropower – more than 60 thousand small rivers in the country. This resource can be used to supply energy to both regional centers, and remote areas and villages. Experts from the United Nations and the International Center for Small Hydropower believe that more than 100 neglected Ukrainian small hydropower plants can be reconstructed, and several hundreds of small hydropower projects can be implemented. The relevance of such decisions is reflected in the "Energy Strategy of Ukraine for the period until 2030" and in the updated "Energy Strategy of Ukraine for the period until 2035" [13].

The Carpathian Mountains area is the most promising in terms of reconstruction of former small hydropower plants and construction of new ones. If we consider the most vulnerable elements of the existing dams of small hydropower plants, we should pay special attention to the dam spillways. Due to the use of roller compacted concrete, it is possible to solve a number of such problems as the arrangement of the overflow over the dam crest, the arrangement of the cascade spillway, which extinguishes the energy of the water flow effectively, and strengthening of the existing berm etc. This experience is thoroughly covered in [12].

The urgent issue for Ukraine is the construction of protective and enclosing structures to protect the areas from flooding. First of all, areas in western Ukraine are concerned. According to [14], the floods of 1995, 1998, 2008, 2010 and 2017 in this region caused losses of more than eight billion hryvnias. Large losses to this region were caused by the flood in the summer of 2020.

In Ukraine realization of several state target programs of complex flood protection in the basins of rivers Tisza, Dniester, Prut, and Siret is performed. To date, a complex of protective flood structures that includes 3.5 thousand km of embankments, 1.2 thousand km of coast-protecting structures, more than 600 pumping and compressor plants to pump over surpluses of water is already created. But the complex of protective structures at rivers and reservoirs is insufficient and requires substantial reconstruction of the operating and construction of new ones [15–17].

According to data [18] the protective flood structures are made from local materials, which substantially reduces the cost of construction (see Fig. 2).

Fig. 2. Arrangement of the downstream slope of an earth-filled protective embankment dam [18].

But in earth embankments during each moistening for many years, the smallest particles of ground are washed away, i.e. mechanical suffosion takes place, which leads to natural ageing of the dam and decrease of its reliability [19]. The most typical example of the destruction of the waterside slope protection is presented in Fig. 3. You can clearly see the fact of mechanical erosive leakage, exposure of the reinforcement and its surface corrosion.

Fig. 3. Damaged area of the waterside protection.

Among the 215 existing dams, 16 are in unsatisfactory condition and, correspondingly, require repair (see Fig. 4).

Fig. 5 presents the number of dams classified proceeding from the annual probability of exceeding (provision) the estimated maximum of water consumption.

The main number of dams that are in poor condition and need repairment were built in the 60s and 70s of the last centuries. Accordingly, they are in operation during 57 to 44 years.

Analysis of the number of dams in unsatisfactory condition is shown in Fig. 6.

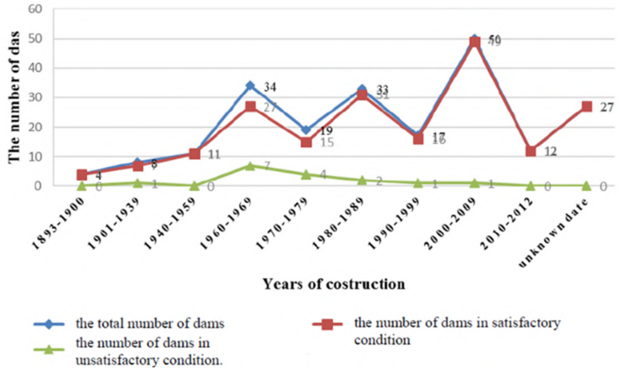

Fig. 4. Number and condition of protective dams in western Ukraine.

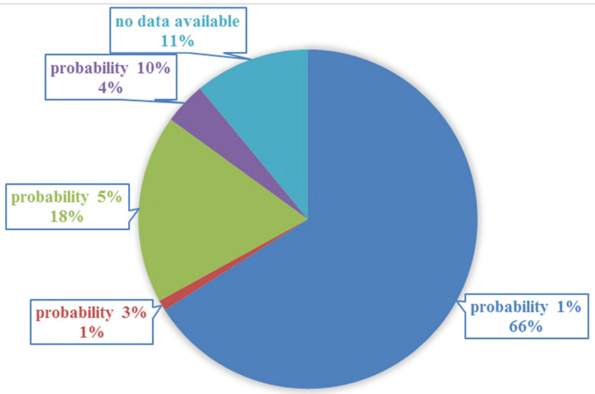

Fig. 5. The number of dams that are classified proceeding from the annual probability of exceeding the estimated maximum of water consumption.

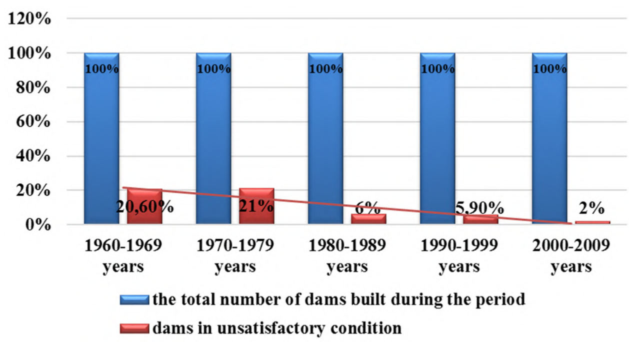

Fig. 6. Number of dams that are in unsatisfactory condition.

On average, 20% of dams that have been operating for more than 50 years are in unsatisfactory condition (see Fig. 6). And accordingly, the shorter the operating time, the lower the percentage of dams in poor condition is.

All these structures belong to the CC2 and the CC1 consequences classes [20]. Respectively, 66% of these dikes/dams belong to the CC2-1 consequences class, 1% to CC2-2 and 18% to CC1.

Assigned service life for buildings that belong to the CC2-2 and the CC1 consequences classes makes 50 years, and for CC2-1 – 100 years [20]. This means that almost half of the existing dikes are approaching their design life or their design life has already expired. Therefore, there is the need for implementation of modern technologies for the restoration or new construction of this type of protective structures.

Significant funds are allocated for repairs every year. But the main constructive decision on reconstruction and restoration of protective and enclosing dams is dumping of rock filling (Fig. 7) sometimes using tinning.

Fig. 7. Reconstructed protective dam to protect the city of Khust from floods (2011) [21].

The fair question arises, why a lot of money should be spent every year on repair and restoration work to face the same problem next year. Maybe it is better to make a reliable building that is resistant to destruction for many years and solve the problem of flooding in this region.

It is the technologies of roller compacted concrete that can solve the problems of construction of new protective dikes and give the possibility to perform high quality reconstruction of already existing ones.

When considering such indicator like the cost of construction, it is necessary to pay attention to accident-free operation of hydro technical protective structures for a long time. Protective structures made from roller compacted concrete are less amenable to eroding action of water stream and permit overflow over the crest unlike dams made of earth materials.

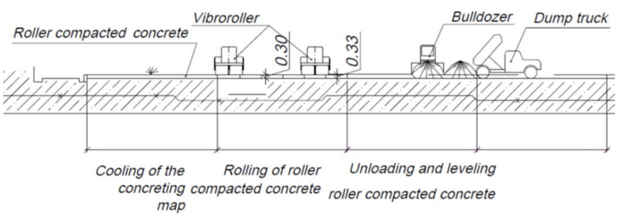

Fig. 8. Technology of roller compacted concrete placing.

Technology of erection of dams from roller compacted concrete should be considered as a part of the uninterrupted construction process with high degree of mechanization of transportation of concrete to the place of laying, its distribution by maps, and compaction. The minimum width of the area of concreting should be considered equal to two vehicle widths (see Fig. 8).

When performing work, it is recommended to have three sites at the same time:

– on the first site the rolling of the placed concrete mix should be performed;

– on the second site the unloading and spreading of the concrete mix should be performed;

– on the third site the preparation of the base for the concrete mix placing should be performed.

The dimensions of the concreting maps should be related to the performance of the mechanisms, concrete pouring intensity and thickness of the RCC layer.

The width of the maps is taken to be at least twice the width of the compacting mechanism, and the length coincides with one of the dimensions of the concreting unit. When compacting the adjacent map, the compacting mechanism must overlap the previous one by at least 0.2–0.5 m.

With limited supply intensity of the concrete mix, the minimum length of the grips should be such that the mix would be placed in a reasonable time and ensuring the effective operation of the compacting mechanism at the same time.

Regardless of the method of supplying of the hard-concrete mix on the concreting map – the height of the pile should not exceed 0.65 m.

When placing RCC, its screeding is done by bulldozers using flat dumps.

The layer should have a slight slope towards the downstream area.

The use of towed vibratory rollers is allowed, if the configuration of the structures allows.

Placing of the concrete mix should be conducted in layers of 33 cm, the calculated thickness of a layer in the compacted condition should be accepted equal to 30 cm (Fig. 8). The deviation of the thickness of the mix layer after screeding is ± 5 cm.

Rolling of the concrete mix requires 4-6 passes of a vibrating roller. The number of passes is specified during the research work.

The first and the last two passes must be made with the vibration exciter off.

One of the main factors that facilitates economic and high-quality construction of dams of roller compacted concrete is their relatively simple construction that requires minimal interference into the process of concrete placement and allows a contractor to perform construction without interruptions and quickly. Due to technology of roller compacted concrete it is not construction that influence technology but technology determines construction of structure. Flood protective dams have simple construction and the technology of roller compacted concrete is the most expedient for their erection.

Quick placement of roller compacted concrete has advantages also in reconstruction of dams that can have only limited time till completion of construction works before re-introduction of structure into operation.

New construction is performed by the traditional technology of roller compacted concrete. Delivery of concrete to a place of laying should be performed in dump trucks.

4 Analysis of composition of binding substances of roller compacted concrete

To prepare rolled concrete, it is necessary to use local materials, crushed stone, sand. Composition of roller compacted concrete is selected by experiment.

Replacement of a part of cement in a composition of roller compacted concrete by fly ash or by natural pozzolana will allow decreasing heat release, and correspondingly will decrease formation of cracks, increases longevity, and allows decreasing a cost of dam construction.

The world experience allows contending that it is due to inclusion of fly ash or pozzolana that this experience can be used in conditions of Ukraine [4]. The data are presented in Table 1.

Table 1. Statistical data on content of binder in roller compacted concrete of dams.

Co-untry	Num-ber of dams/ dikess	Cement consumpti-on, kg/m^3: average/ maximal	Pozzolana consumption, kg/m^3: avera-ge/ maximal	Total binder consumption, kg/m^3: ave-rage/ maximal
China	62	79 / 140	94 / 140	173 / 230
Brazil	52	70 / 80	15 / 50	85 / 100
Japan	41	87 / 96	35 / 78	122 / 130
USA	37	85 / 184	53 / 173	138 / 252
Spain	22	75 / 88	133/ 170	208 / 270

5 Analysis of results

The technology of layer wise erection of dams with the use of rolled concrete is the most effective for construction of concrete dams. It allows decreasing deadlines of construction of hydro schemes by a factor of 2–3 and to reduce the laboriousness by a factor of 4–5 due to full mechanization of concrete works with the use of present-day highly productive equipment, and also due to simplification and more rational organization of construction. Technology of rolled concrete allows creating firm reliable and safe dams (a number of such dams endured several strong earthquakes and did not get any damage).

Dams of roller compacted concrete can be erected in different natural and climatic conditions (hot climate, low temperatures, considerable amount of precipitation).

Regulated technological systems used in erecting dams by single-layer blocks are defined by increased reliability and durability, which allows planning concrete works accurately, and, in so doing, design and actual schedules of concreting as a rule concur. This allows using all highly productive equipment for concrete placement fully.

6 Conclusion

The presented investigations can be used for new construction and reconstruction of existing small hydro power plants and protective dams in regions with increased flood hazard primarily in the west of Ukraine.

In our country there is an urgent problem and potential opportunities for construction and restoration of a significant number of hydraulic structures. Thanks to modern and highly productive technology of roller compacted concrete it can be carried out in the minimum terms and with the maximum productivity.

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Analytical calculation of tube confined concrete elements with strengthened cores

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Abstract. The approach to the formation of the analytical method of evaluation of the stress-strain state of complex rod bearing structural elements is considered in the paper. The prerequisites described cover all the fundamental features of deformation of the components in conditions of tube confined concrete with a strengthened core. This is confirmed by the results of our own experimental studies. The case of central axial compression is considered in detail. From the beginning of loading to destruction of a structural element, two fundamentally different stages of work are distinguished: in the beginning – elastic; closer to destruction – plastic. The method of variable elasticity parameters is used to describe the performance of concrete in the plastic stage. The mutual influence of components during deformation is revealed by solving the contact problem. The methodology was tested by comparing the results of our own experimental and theoretical results.

1 Introduction

Every day the world needs more resources conservation, more efficient use of materials and raw materials conservation. The construction industry is one indicator of this. Consider the use of tube confined concrete as one example.

It is known that in compressed tube concrete elements the active force is perceived by both a tube shell and concrete cores [1, 2]. If in some way to increase the carrying capacity of the core, then it is possible to reduce the cost of steel to obtain a tube confined element with a predetermined bearing capacity [3], which will lead to significant savings in the construction. However, conducting experimental research requires considerable material costs. In such circumstances, it is advisable to attract analytical and numerical research opportunities. Nevertheless, the question of calculating these structures is not straightforward, and there are different views on how to solve them.

The purpose of the presented studies is to formulate the prerequisites for performing the analytical calculation of compressed tube confined concrete elements with a strengthened core, taking into account the previously conducted experimental studies; as well as an assessment of the performance of structural tube confined concrete elements with strengthened cores compared to steel elements.

Analysis of research and publications. Today, buildings and structures that are designed and constructed using tube confined concrete are presented practically all over the world [4, 5]. At the same time, the question of ambiguity in the calculation of such structures hinders the widespread introduction of this combination of steel and concrete, including taking into account the strengthening of their cores.

Considering a number of advantages that draw attention to the presented structures [5-7], the previously conducted experiments were aimed at clarifying the mechanism of development of the stress strain-state of tube confined concrete elements with a strengthened core for a more accurate and specific evaluation of their characteristics [7, 8].

Thus, based on practical experience it is necessary to formulate the prerequisites and construct a general algorithm for the possibility of theoretical evaluation of the stress-strain state of tube confined concrete with strengthened cores.

2 Results

The above-mentioned material is based on the experimental studies conducted by the authors earlier [7-9]. According to the results of these experiments, it was possible to establish the nature of the destruction of the tube confined concrete with strengthened cores of

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different structural forms, the distribution of deformations at all stages of loading. Based on all this experience, the following prerequisites have been formed for the theoretical evaluation of the stress-strain state of a tube confined concrete with strengthened cores:

– the materials used for the manufacture of tube confined concrete elements, which are isotropic bodies;

– – work under load of steel reinforcing rod and steel shell is presented in the form of Prandtl diagram (Fig. 1);

– work under concrete loading is presented in the form of its own work diagram (Fig. 2);

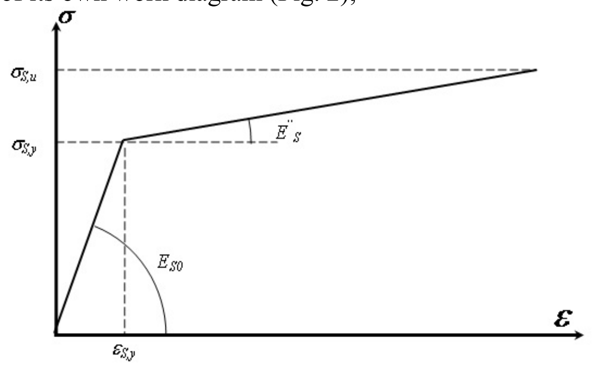

Fig. 1. Dependence of the steel shell deformation module on deformations.

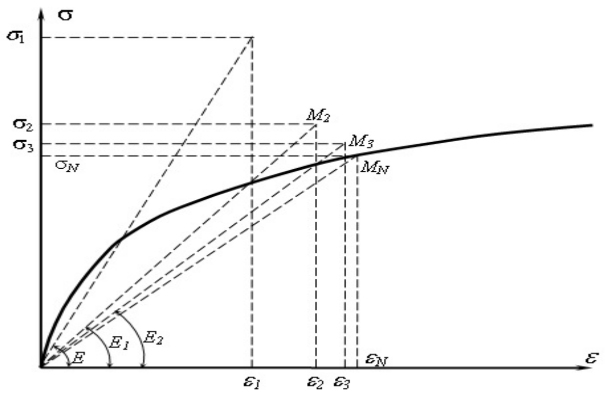

Fig. 2. Dependence of the concrete core deformation module on deformations.

– concrete core, core reinforcement and steel shells work together throughout the loading period;

– in tube confined concrete elements with strengthened cores due to high-strength concrete, the concrete core and the tube-shell work in parallel until the fluidity is reached in the tube-shell and do not affect each other;

– during the whole deformation process the concrete core works with structural and reinforcing steel jointly;

– the materials that make up the tube confined concrete element are considered as isotropic elastic-plastic;

– between stresses and strains in the materials of the tube confined concrete element, a linear dependence is assumed upon reaching the first limit state in strength;

– throughout the deformation process, the longitudinal axis of the concrete element remains straight;

– the flat section hypothesis is considered valid;

– the geometric dimensions of the cross-section and the physical properties of the materials along the length of the concrete element do not change;

– we consider tube-shell, concrete core and reinforcement deform jointly;

– static condition remains: the amount of effort on the longitudinal axis is zero;

– the tube shell works in a flat stress state; concrete core – in bulk; additional rod reinforcement – in uniaxial compression.

2.1. Stage of elastic work of materials

From the beginning, the work of tube confined concrete elements with strengthened cores under the condition of elastic work of steel and concrete is considered. In the general formulation, the task of evaluating the stress-strain state of tube confined concrete elements with strengthened cores is to find fifteen unknowns: displacement (u, v, w); deformation (e_x, e_y, e_z, γ_{xy}, γ_{yz}, γ_{zx}); stress (σ_x, σ_y, σ_z, τ_{xy}, τ_{yz}, τ_{zx}). In this case, a set of such unknowns must be found for each separate component of the tube confined concrete with a strengthened core.

The values of the unknowns must satisfy the equation of continuum mechanics in the area occupied by the experimental element [9]; in particular, the equation of equilibrium equation, and the conditions on the lateral surfaces and on the surfaces of the edges

$$\frac{\partial\sigma_x}{\partial x}+\frac{\partial\tau_{xy}}{\partial y}+\frac{\partial\tau_{xz}}{\partial z}=0;$$
$$\frac{\partial\tau_{yx}}{\partial x}+\frac{\partial\sigma_y}{\partial y}+\frac{\partial\tau_{yz}}{\partial z}=0;$$
$$\frac{\partial\tau_{zx}}{\partial x}+\frac{\partial\tau_{zy}}{\partial y}+\frac{\partial\sigma_z}{\partial z}=0,$$

$$\begin{aligned}&\sigma_x\cos(n,x)+\tau_{xy}\cos(n,y)=X_n=0; && \tau_{xz}=f_1;\\ &\tau_{yx}\cos(n,x)+\sigma_y\cos(n,y)=Y_n=0; && \tau_{yz}=f_2;\\ &\tau_{zx}\cos(n,x)+\tau_{zy}\cos(n,y)=Z_n=0, && \sigma_z=f_3,\end{aligned} \quad (1)$$

where f_1, f_2, f_3 – given functions on the edges with $z = 0$ and $z = l$.

The stresses are represented by deformations by Hooke's physical equations:

$$\begin{aligned}&\sigma_x=\lambda\theta+2\mu\varepsilon_x; \quad \sigma_y=\lambda\theta+2\mu\varepsilon_y; \quad \sigma_z=\lambda\theta+2\mu\varepsilon_z;\\ &\tau_{xy}=\mu\gamma_{xy}; \quad \tau_{yz}=\mu\gamma_{yz}; \quad \tau_{zx}=\mu\gamma_{zx},\end{aligned} \quad (2)$$

where

$$\theta=\varepsilon_x+\varepsilon_y+\varepsilon_z; \quad \lambda=Ev\big/\left[(1+v)(1-2v)\right]; \quad \mu=E\big/\left[2(1+v)\right]$$

Deformations are shown by moving along the equations of Copies:

$$\begin{aligned}&\varepsilon_x=\frac{\partial u}{\partial x}; \quad \varepsilon_x=\frac{\partial v}{\partial y}; \quad \varepsilon_x=\frac{\partial w}{\partial z};\\ &\gamma_{xy}=\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}; \quad \gamma_{yz}=\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}; \quad \gamma_{zx}=\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}.\end{aligned} \quad (3)$$

2.2 Stage of plastic work of materials

It is experimentally proved that the relationship between the compressive force and the deformation does not retain a linear dependence, when reaching 70-90% of N_{1i} and becomes curvilinear. The reason for this is the appearance of plastic deformation. Application of the provisions of the theory of elastic-plastic deformations, as pointed out by A.A. Ilyushin [10], is possible only in conditions of simple loading. That is, when all components of the strain tensor change in proportion to one parameter. Under these conditions, the law of generalized curves works. In any stress state, the diagram $\sigma_i - \varepsilon_i$ is similar to the diagram $\sigma - \varepsilon$ with uniaxial compression (Fig. 1, Fig. 2). In this case, the elasticity modulus is replaced by the variable module E':

$$\sigma_i = E' \cdot \varepsilon_i, \tag{4}$$

where σ_i – intensity of stress,

$$\sigma_i = \frac{1}{\sqrt{2}}\sqrt{\left(\sigma_x - \sigma_y\right)^2 + \left(\sigma_y - \sigma_z\right)^2 + \left(\sigma_z - \sigma_x\right)^2 + 6\left(\tau_{xy}^2 - \tau_{yz}^2 + \tau_{xz}^2\right)};$$

ε_i – intensity of deformations,

$$\varepsilon_i = \frac{\sqrt{2}}{2(1+\mu)}\sqrt{\left(\varepsilon_x - \varepsilon_y\right)^2 + \left(\varepsilon_y - \varepsilon_z\right)^2 + \left(\varepsilon_z - \varepsilon_x\right)^2 + \frac{3}{2}\left(\gamma_{xy}^2 + \gamma_{yz}^2 + \gamma_{xz}^2\right)};$$

$E' = tg\alpha$ – secant modulus of deformation.

In order to describe the work of steel tube shell and steel reinforcement, the dependence in the form is taken [8]:

$$\sigma_i = E'\left(1 - \omega\right) \cdot \varepsilon_i, \tag{5}$$

where $\omega = f\left(\varepsilon_i\right)$, – function of intensity of deformations, nonzero only after the appearance of plastic strains.

The diagram of the steel work is presented in the form of two-branch (Fig. 1). The first branch is the zone of elastic deformation and is characterized by a modulus of deformation $E' = tg\alpha = E_s$; the second is the zone of strengthening and is characterized by $E' = tg\alpha = E_s$. Then

$$\sigma_{si} = E_{s0}\left[1 - \lambda\left(1 - \frac{\varepsilon_{sy}}{\varepsilon_{si}}\right)\right]\varepsilon_{si}, \tag{6}$$

where $\lambda\left(1 - {}^{\varepsilon_{sy}}\!/_{\varepsilon_{si}}\right) = \omega$; $\lambda = 1 - {}^{E_s''}\!/_{E_{s0}}$;

$$\varepsilon_{si} = \frac{2}{3}\sqrt{\frac{1 - \nu + \nu^2}{\left(1 - \nu\right)^2}\left[\varepsilon_{sx}^2 + \varepsilon_{sz}^2 + \varepsilon_{sz}\varepsilon_{sx}\left(\frac{3\nu}{1 - \nu + \nu^2} - 1\right)\right]}$$

2.3 Determination of contact forces

In the case of transferring the load to the tube confined concrete element through a stamp on a complex section, the proportion of force is distributed between the concrete core and the shell in accordance with the ratio:

$$P = P_C + P_S, \tag{7}$$

where P_C та P_S – the proportion of the external force that is perceived by the separate parts of the cross-section of the tube confined concrete element, namely the concrete and the tube shell.

The intensity of the external load on the top edge:

$$q_Z = \frac{P}{A}, \tag{8}$$

where A – area of the complex section of tube confined concrete element.

External load intensity for separate section elements:

$$q_{cz} = \frac{P_C}{A_C}, \quad q_{sz} = \frac{P_S}{A_S} \tag{9}$$

The distribution of the external force between the concrete and the steel part remains unknown. Movement of the edge sections of concrete and steel along the Z axis occurs together:

$$\varepsilon_{cz} = \varepsilon_{sz}, \tag{10}$$

where $\varepsilon_{cz} = \frac{\sigma_{cz}}{E_c}$, $\varepsilon_{sz} = \frac{\sigma_{sz}}{E_s}$, $\varepsilon_{cz} = \frac{P_c}{A_c E_c}$, $\sigma_{sz} = \frac{P_s}{A_s}$.

Thus

$$\frac{\sigma_{cz}}{E_c} = \frac{\sigma_{sz}}{E_s}, => \quad \sigma_{sz} = \sigma_{cz}\frac{E_s}{E_c} = \sigma_{cz} \cdot n, \tag{11}$$

where $n = \frac{E_s}{E_c}$.

To determine the value of the contact force, we used the results reported in [11] D. Weinberg. Fig. 3 shows the geometric part of the problem.

Thus, if the length of the shell and the core are the same size, then the value of the contact pressure is equal to:

$$p = \frac{\frac{\Delta}{d}}{\frac{1}{E_1}\left(\frac{1+k_1^2}{1-k_1^2} - \mu_1\right) + \frac{1}{E_2}\left(\frac{1+k_2^2}{1-k_2^2} - \mu_2\right)}, \tag{12}$$

where Δ – the difference of the diameters of the contact surfaces before the joint, sm;
d – diameter of the contact surface, sm;
$k_1 = \frac{d_1}{d}$ – the ratio of the diameters of the inner body;
$k_2 = \frac{d_2}{d}$ – the ratio of the diameters of the outer body;
d_1 – the inner diameter of the inner body;
d_2 – the outer diameter of the outer body;
E_1, μ_1 – the deformation modulus and the coefficient of lateral distortion of the inner body;
E_2, μ_2 – the deformation modulus and the coefficient of lateral distortion of the outer body.

The calculation algorithm includes the following steps:

1. To identify the proportion of force which is distributed between the elements of the cross section of the concrete

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(concrete, steel outer pipe, steel inner pipe, additional reinforcement), depending on the design of the prototype.
2. Evaluate the stress-strain state of the concrete core.
3. Evaluate the stress-strain state of the steel shell.
4. Evaluate the stress-strain state of the additional reinforcement.
5. Calculate the values and sign of the difference between the initial radius of contact surface between the concrete core and the steel tube.
6. Determine the value of the contact pressure between the concrete and the steel tube.
7. Return and carry out items 2-6.
8. Refine the values of the modulus of the materials elasticity and compare with the values at the beginning of the calculation.
9. In the case of differences in the values of the modulus of elasticity by more than 3%, repeat the items 2-8 with the specified values. Otherwise, proceed to item 10.
10. Compare the value of longitudinal deformation of a steel tube with a limit value (approximately 200×10^{-5}).
11. Subject to item 10, complete the calculation is and fix the value of the external force and the longitudinal stress in the concrete core. Otherwise, increase the external force by the incremental value (ΔN) and repeat the calculation according to items 2-10.

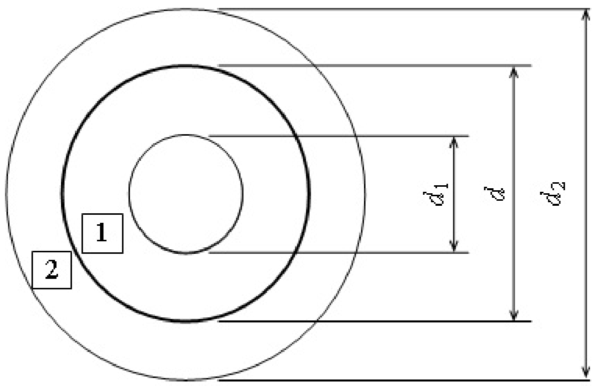

Fig. 3. Scheme before determining the value of the contact force between the elements of the cross-section of the tube confined concrete element.

Fig. 4 shows a block diagram for calculating the carrying capacity of tube confined concrete elements with strengthened cores.

2.4 Implementation of the methodology

Implementation of the methodology, including and design circuits of the elements is presented in detail in [8]. During the development of the method for evaluating the stress-strain state of the investigated structures, it was assumed that the tube shell and the concrete core work in parallel until the tube shell fluidity occurs. As experimental studies of tube confined concrete elements with a core of high-strength concrete have shown that by the time when fluidity occurs in the shell, the latter with the concrete core work in parallel. Later the concrete core and shell work together. Feature of deformation of prototypes is symmetry with respect to the central axis. For convenience, the stress-strain state is described with cylindrical coordinates.

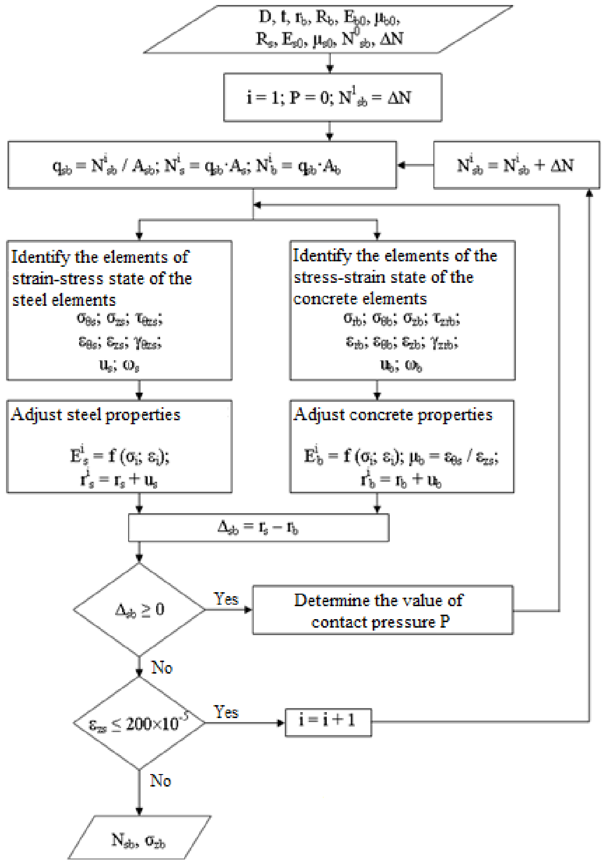

Fig. 4. Block diagram of the calculation algorithm of tube confined concrete elements with strengthened cores.

In addition, we consider it necessary to mention that several factors given in this paper have been taken into account in order to construct a method for evaluating the stress-strain state of a steel tube [8]. They are the following: the calculation of tube confined concrete is performed by an iterative method with changing the parameters of elasticity; within a separate stage of calculation, the work of the steel tube is considered elastic; we consider the stress-strain state of a tube as the sum of states at simple loads. So as simple loads we accept: longitudinal compression; uniform internal compression; uniform external compression. To do this, we use known results from [12].

2.5 Testing of methodology

During the experiments, the following series of samples were tested:

Samples series	Tube external diameter, D, [mm]	Tube wall thickness t, [mm]	Concrete strength, fck.prism, [MPa]
T-I-1	110,6	2,75	–
T-I-2	163,0	5,50	–
T-I-3	204,4	5,20	–
T-I-11	110,6	2,75	50,0
TC-I-12	110,6	2,75	64,2
TC-I-13	110,6	2,75	80,0

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Samples series	Tube external diameter, D, [mm]	Tube wall thickness t, [mm]	Concrete strength, fck.prism, [MPa]
TC-I-21	163,0	5,50	50,0
TC-I-22	163,0	5,50	64,2
TC-I-23	163,0	5,50	80,0
TC-I-31	204,4	5,20	50,0
TC-I-32	204,4	5,20	54,2
TC-I-33	204,4	5,20	80,0

Experimental investigations of tube confined concrete elements with high-strength concrete cores have proven that, by the time of the appearance of fluidity in the shell, the latter with concrete core work in parallel. Therefore, when developing a method for evaluating the stress-strain state of such structures, we believe that the tube-shell and the concrete core work in parallel until the fluidity of the tube shell begins (Fig. 5). At a later stage, the concrete core and the shell work together.

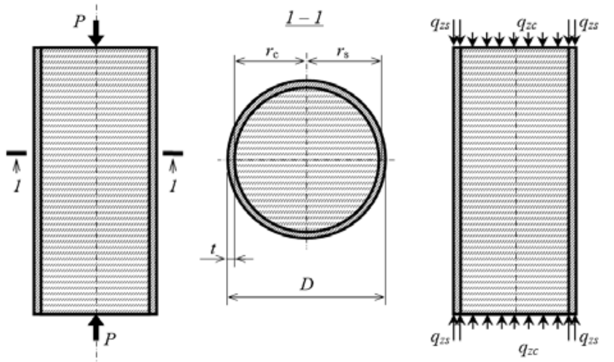

Fig. 5. Design diagram of tube confined concrete element with high-strength concrete core.

The peculiarity of the deformation of the studied samples is the symmetry about the central axis. For convenience, the stress-strain state is described using cylindrical coordinates. In this case, the components of the stress-strain state are not dependent on the angle θ (Fig. 6) [8].

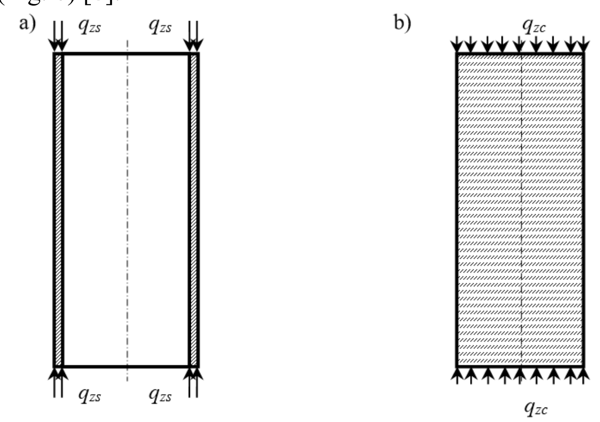

Fig. 6. Design diagram of tube shell (a) and high-strength concrete core (b).

Using the above calculation method, the carrying capacity of centrally compressed concrete elements with strengthened cores was calculated. The boundary condition is the moment of transition of the outer shell material from the elastic to the elastic-plastic stage of operation. The results of comparing the experimental results of the carrying capacity with the theoretical data are shown in Table 1.

Table 1. Comparison of theoretical and experimental data.

Sample series	Carrying capacity, [kN]		
	experimental	**theoretical**	**difference, %**
TC-***I***-11	652	567	-13
TC-***I***-12	716	652	-9
TC-***I***-13	869	834	-4
TC-***I***-21	1840	1693	-8
TC-***I***-22	2100	2016	-6
TC-***I***-23	2400	2160	-6
TC-***I***-31	2970	2584	-10
TC-***I***-32	3386	3251	-11
TC-***I***-33	3636	3163	-12

The rational use of tube confined concrete can also be judged by the efficiency coefficients [4, 5, 7]. The first of them characterizes the efficiency of the tube concrete element work as a whole ($m_{b,cf}$), the second coefficient takes into account the efficiency of concrete work in the tube confined concrete element ($\eta_{b,cf}$). Also in the research of this subject we use the coefficient n, which characterizes the relationship between the forces N_1, when the sample reaches the limit state of the bearing capacity when reaching the yield strength in the shell to the complete destruction of the sample N_2

Table 2 compares the results of determining the coefficient of the concrete work efficiency in tube confined concrete elements with strengthened cores.

Table 2. Comparison of theoretical and experimental data of the coefficient η values.

Sample series	Efficiency coefficient η		
	experimental	**theoretical**	**difference, %**
TC-***I***-11	4,13	3,22	-28,3
TC-***I***-12	4,11	3,56	-15,4
TC-***I***-13	3,69	3,31	-11,5
TC-***I***-21	1,75	1,66	-5,4
TC-***I***-22	1,60	1,54	-3,9
TC-***I***-23	1,51	1,59	+5,0
TC-***I***-31	1,49	1,23	-21,1
TC-***I***-32	1,42	1,42	0,0
TC-***I***-33	1,41	1,34	-5,2

3 Conclusion

An analytical method for determining the carrying capacity of tube confined concrete elements with strengthened cores by establishing the stress-strain state of separate cross-sectional elements has been developed. This approach allows us to establish the effectiveness of using concrete of different classes as a core. And also it is possible to evaluate the effectiveness of structural tube confined concrete element with strengthened cores compared to steel elements. The proposed methods for determining the carrying capacity and performance of concrete in tube confined concrete elements with strengthened cores ensure satisfactory coincidence of theoretical and experimental data.

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Features of structures and calculation of steel spiral-fold silos

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Abstract. The advantages of metal silos in comparison with reinforced concrete are given. Types of silos depending on a wall design are considered. The construction of steel spiral-fold silos and the method of forming a cylindrical body are considered. The general design of a spiral-fold silo is illustrated. Features of the folding lock, its geometry and location are described. The specifics of the construction of spiral-fold silo, which affects their stress-strain state, are analyzed. Listed two calculation schemes of silo depending on the complexity of input information for the computer. The standard documents which regulates the design of steel silo tanks on the territory of Ukraine are analyzed. The main loads and influences which are accepted at calculation of silos are listed. The basic formula of check of the general durability of a wall of a silo is resulted, the components of the formula are decrypted. The algorithm for calculating the spiral-folded silage is given.

1 Introduction

There are many industries which are related with processing of raw materials. They are constantly developing their technologies. This requires the sustainable development of the construction industry, without which the existence of any industry is impossible. One of the most necessary stages in the technological process is material storage. Conventional store is not a rational solution, as it requires significant human labor costs to load and unload material. The solution to the problem was silos for bulk materials. The requirements for modern store for bulk materials are economy, environmental friendliness, larger capacity, rational operation.

For a long time, reinforced concrete structures were used to store the material. These include bunkers and silos, which are used in all industries, agriculture and transport. Silos can be used as warehouses for finished products, or as intermediate containers for storage of raw materials or semi-finished products. Metal silos for storage of bulk materials began to be used relatively recently and they have already confirmed their ability to meet all the requirements for warehouses of this type. In comparison with reinforced concrete silos, they have the following advantages:

– the possibility of factory production of structures;
– less mass;
– ease of transportation;
– speed of installation works;
– lower cost.

For now metal capacitive structures for storage of various types of bulk materials are one of the most common types of building structures. The dimensions of the silos, their shape, methods of support on the foundation, as well as the location in the plan, are assigned in accordance the requirements of the technological process, loading conditions and unloading, as well as based on technical and economic prerequisites. Silos are available in round, square, rectangular, hexagonal and multifaceted. Round silos are preferred due to ease of manufacture. With this shape, the walls work in mainly tensile forces. Therefore, their thickness can be small.

Depending on the type of wall, there are the following types of metal silos: welded silo, panel silos, spiral-fold silo.

The body of the welded silo (Fig.1) is formed of metal sheets, which are connected by welding The advantages of such silos are tightness and durability.

Welded silos are suitable for storage of bulk materials with the smallest sizes of firm parts, such as: cement, coke, slag and others. Disadvantages of these structures are high material consumption and a large number of welds.

The body of the panel silo (Fig. 2) is made of corrugated or smooth panels connected together with bolts. The advantages of panel silos are the opportunity to take large radial load on the material, no welds, high strength. The disadvantages of this option silos are a large number of bolted connections. This type of silo construction is most common in Ukraine and abroad.

One of the most advanced types of thin-walled spatial constructions are highly industrial and economical metal silos of the spiral-fold type (Fig. 3).

The development of these progressive structures is constrained by the lack of studies of the stress-strain state of these shells because these structures have a folding lock.

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Fig. 1. Welded silo [1].

Fig. 2. Panel silo [2].

Fig. 3. Spiral-fold silo.

A number of domestic and foreign scientists have been engaged in the analysis of structures, calculation methods and experimental studies of cylindrical shells of metal silos for strength and stability [3-17]. Mileykovsky et al. [5] in their work presented a computational model of the shell in the form of a scan of a cylindrical surface, which is considered as a ribbed plate with inclined edges. To simplify the calculation, the folding ribs are placed horizontally. The solution of the problem is reduced to the calculation of a cylindrical shell with annular ribs for axisymmetric loading. Trofimov et al. [6] in their work presented the results of an experimental study on full-scale spiral-fold silos.

Studies conducted by the authors showed that the horizontal pressure around the perimeter of the tank can be taken as a uniform, and in height – according to the Jansen's formula with a coefficient of friction – 0,3. It was also found that the initial imperfection of the silo wall between the folding locks has the shape of a sinusoid, which is located symmetrically about the axis of the folding rib. Based on the obtained results, the authors concluded that the leakage of bulk material (grain) is uniform, and additional (ring or local) horizontal pressure can be ignored. Goldenberg [7] describes the experiment of stability of a closed cylindrical shell of a filled silo with often placed horizontal ribs of the folding type. The axisymmetric form of loss of stability of an isotropic shell is accepted. The most unfavorable combination of operating loadings which consider real conditions of deformation of a silo is considered: initial curvature of the wall and its compatible work with the elastic filler. In Heisen's work [8] was investigated the influence of initial imperfections of the surface of the silo shell on the local stability and strength of the wall in the stage of elastic deformation. Nascimento [9] in his work conducted a research of the horizontal pressure in a metal silo with a corrugated wall, and compared the obtained theoretical data, according to different standards. Coelho [10] presented software for calculating the pressure in cylindrical containers with different types of bulk material.

However, the development of spiral-fold silos is constrained by the lack of studies of the stress-strain state of these shells, as these structures have a number of specific design features. There are also no developments regarding the reliability of these silos, though the basic principles of calculation of reliability of metal constructions are developed [16].

The task of this article is to review the design features and analysis of the method of calculation of metal spiral-fold silos and the algorithm of their calculation.

2 Basic material and results

The construction of the spiral-fold silo was developed in 1968 by a German scientist Xavier Lipp, who used the special equipment for processing of sheet metal and used it for the construction of silos spiral-fold [18]. The first silo was built in 1969 in Germany (Fig. 4).

Since the late 60's in Europe they began using the silos with this type of construction. Within ten years of study and research, in practice, this technology has proved successful, and since the early 70's large-scale production of galvanized steel spiral-fold silos has begun.

Fig. 4. The first spiral-fold silo of Xaver Lipp, 1969, [18].

Process of assembling the silo structure is very simple. Steel coils, machines and accessories are transported to the building site where the silo is then constructed – the process is fast, efficient and flexible in terms of silo height and diameter. Unique technology allows for compact and fast installation of high-strength and hermetical silos directly at the construction site, without the use of bolts and welded joints (Fig. 5)

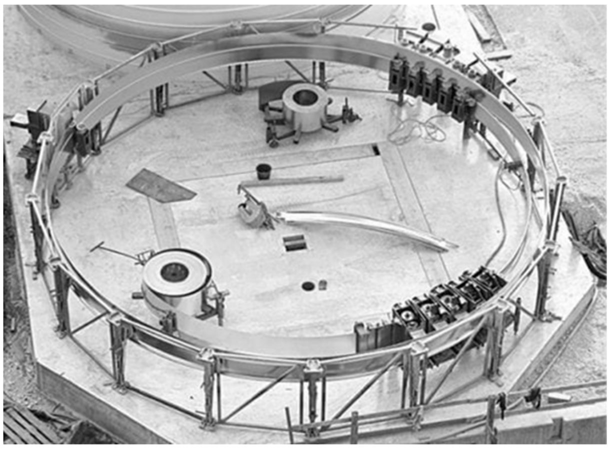
First step of construction (Fig.5, a) is two machines, steel coils and a profile ring are set up on the foundation slab. Once the profile ring and the two machines are in position and have been set up, the construction of the silo starts. The first machine (profiling machine) feeds the steel strip at a slight angle to form a profile. Once the steel strip has completed a revolution, the adjacent profiled strips are brought together in the second machine. They are then folded together tightly. The method of construction is comparable with a screw that moves forward with each revolution as the silo takes shape. The two machines remain in position feeding the steel strip while the silo is formed, growing higher in a spiral.

Second step of construction (Fig.5, b) starts when the silo has reached a height of approximately 2 metres, the top edge is cut level. The roof is then installed or further connectors and parts are fitted or openings are made.

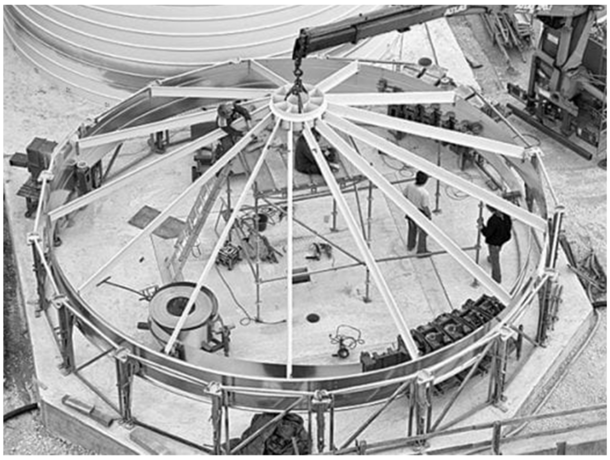
When the roof is installed then starts third step of construction (Fig.5, c). The silo will continue to be formed slowly until it reaches its predetermined height. Ladders and supports will be added during the construction process.

As soon as the desired height has been reached, the bottom edge is cut level and the components are removed from inside the silo. The silo is set down on the foundation slab by reversing the direction of revolution and is then fixed in position, marking the completion of the construction process.

The construction of the spiral-fold cylindrical silo is formed with the help of special equipment, which connects a metal strip (495 mm wide and 2-4 mm thick) in a spiral with the simultaneous formation of the folding lock. The folding lock is located outside the silo wall at a slight angle to the horizontal plane and forms annular ribs. Folding ribs have a height of l_0, consist of the upper and lower halves. They have different geometry, rigidity and pliability. The step of the ring ribs is 365 mm (Fig. 6).



a) first step



b) second step

c) third step

Fig. 5. Process of assembling the silo structure [19].

Spiral-fold silo shell designs are significantly different from traditional corrugated metal prefabricated silos with bolted joints.

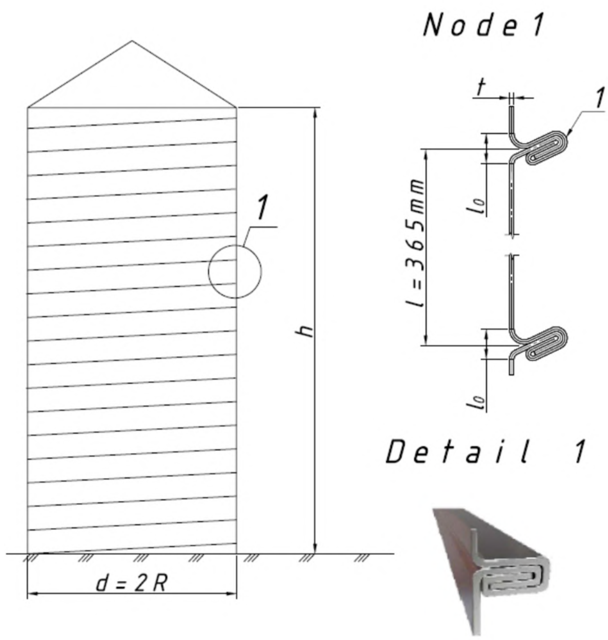


Fig. 6. Construction of a spiral-fold silo.

The specifics of the design of the spiral-fold silo, which affects to their stress-strain state, is as follows:

- The ribs are placed in a spiral, but at a slight angle of inclination of the folding lock, close to 1º.
- These folding ribs work in a complex stress state. They not only increase the rigidity of the silo shell structure in tension and bending in the annular direction, but at the same time reduce the stiffness of the structure, in the transition of the wall to the folding lock. Longitudinal forces generated in the wall of the cylindrical shell, at the location of the ribs, are transmitted from top to bottom with eccentricity, which leads to additional deformation, both in the wall of the shell and between the layers of the rib.
- Depending on whether the silo shell is extended or compressed along the forming line, the stiffness and pliability of the folding lock will be different. In some cases of external influences, such as wind load, requires consideration of the shell as a structural nonlinear system.
- Quite frequent placement of the ribs and the small angle of their inclination allow us to consider it as a system of closely spaced horizontal ribs, and the stress state of the filled silo as axisymmetric.

3 Analysis of normative documents of Ukraine on the calculation of metal spiral-fold silos

The main normative document in Ukraine that regulates the design of metal structures, including thin-walled shells is DBN B.2.6-198: 2014 [20]. This document contains general recommendations for assessing the strength and stability of torsion shells.

Another normative document in Ukraine that regulates the design of steel silo tanks, classification of their structures, determination of loads and forces in the elements is DBN B.2.2-8-98. [21], which was issued to replace SNiP 2.10.05-85 [22]. Additionally, some requirements are given in SNiP 2.09.03-85. [23].

The calculation of spiral-fold silos is considered in detail in [24]. In [24] the calculation scheme is accepted, which in the case of a filled silo, can be solved for all the loads specified in the DBN B.2.2-8-98. [21], both in a simpler and in a more precise formulation.

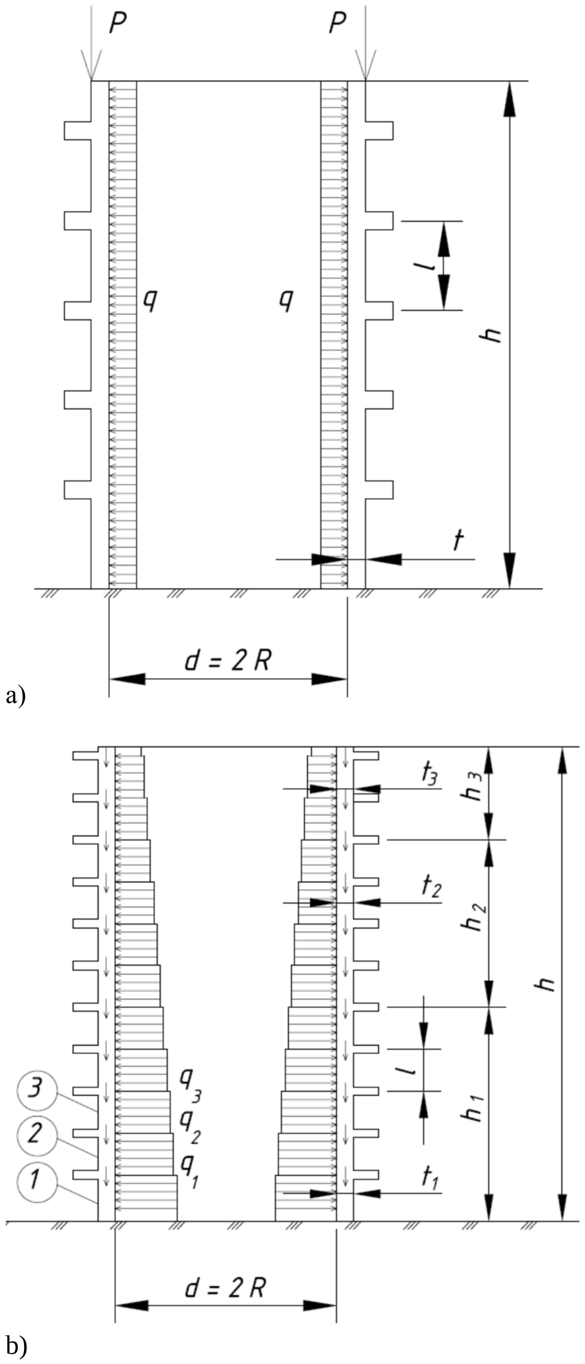


Fig. 7. Calculated schemes of silo a) Simplified; b) Precised.

Simplified calculation scheme (Fig. 7, a) (in the sense of entering the source information for the computer) is reduced to the calculation of a single shell under the assumption that the height of the same thickness, the calculated horizontal load and total vertical pressure are constant and equal to their maximum value. For the lower zone, the maximum values are taken at the level of the upper lower shell.

A more precise calculation scheme (Fig. 7, b) is reduced to the calculation of the entire silo as a cylindrical shell with frequent discrete placement of annular ribs. The calculation is performed on the action of horizontal and vertical load. In each shell, these loads are assumed to be constant and equal. The horizontal load corresponds to the maximum value of the design load at the bottom of each shell. The longitudinal force from the vertical load corresponds to the maximum value of force in this shell, which is applied to its lower edge.

As a calculation scheme of the whole silo, a component system of short shells connected by horizontal folding ribs is accepted (Fig. 6). The height of the short components of the shell is equal to 1^0. The height of folding lock is equal to l_0. It consists of the upper and lower halves, which differ in their geometry, rigidity and pliability.

The main loads and effects on the silo are:

– horizontal and vertical (due to friction) loads from the pressure of bulk materials, taking into account the central unloading of the silo;
– own weight of a construction;
– loads from snow on a covering;
– temperature fluctuation;
– loads from heat cables;
– loads from wind pressure (for unfilled silo).

These loads are temporary (long-term, and short-term), except for its own weight.

4 Algorithm for calculating the spiral-fold silo

Analysis of the normative literature allows to give the calculation algorithm. According to DBN B2.2-8-98 [21], the standard horizontal pressure of bulk materials (kg / m^2) which evenly distributed around the perimeter on the walls of the silos at a depth of Z (m) from the top of the backfill is determined by the formula:

$$P_h^n = \frac{\gamma\rho}{f}\left(1 - e^{-\lambda f z/\rho}\right), \tag{1}$$

where ρ – hydraulic radius of the cross section of the silo, m, which is determined by the formula:

$$\rho = \frac{A}{U} = \frac{\pi r^2}{\pi d},$$

where A, U – area and perimeter of the cross section of the silo, respectively, m^2 and m;
λ is the coefficient of lateral pressure of the bulk material, λ characterized by the ratio of the average values of horizontal and vertical pressure according to paragraph 4.6 [21] and is determined by the formula:

$$\lambda = tg^2\left(45^\circ - \frac{\phi}{2}\right),$$

where e is the basis of the natural logarithm;
γ is the specific weight of bulk materials, kg / m^3;
φ is the angle of internal friction, deg;
f is the coefficient of friction of bulk materials against the walls of the silo, which is taken in accordance with table A.1 [21].

Calculating the structures, the top of the backfill may be taken for silage with a diameter of 12 m and more – at the level of 1/3 of the bottom of the height of the backfill cone. In this case, the depth z (m) from the top of the backfill is determined by the formula:

$$z = h + \frac{d}{2} tg\phi \frac{1}{3}.$$

The annular horizontal pressure of bulk materials is taken to be evenly distributed around the perimeter of the wall with the height of the zone of the annular load equal to 1/4 of the diameter of the silo. The zone can occupy any position on height. Normative value of annular horizontal pressure P_{h1}^n determined by the formula:

$$P_{h1}^n = a_1 P_h^n, \tag{2}$$

where a_1 is the coefficient of local pressure increase, which is accepted in accordance with the requirements of 4.11. [21] depending on the ratio h / d.

The sum of the limit design values (the uniformly distributed horizontal pressures and the annular horizontal pressures) is determined by the formula:

$$\sum P_i = \gamma_{fm}(P_h^n + P_{h1}^n),$$

where γ_{fm} – load reliability factor.

The normative value of the vertical pressure of the bulk material, which transmitted to the walls of the silo by friction is determined by the formula:

$$P_f^n = f P_h^n.$$

The calculated vertical pressure is determined by the formula:

$$P_f^n = 1{,}3 f P_h^n.$$

Under the condition $h<1{,}5\sqrt{A}$, the walls of the silo must be tested for effort on the requirements of pressure, as the walls of the hopper, according to the formulas:

$$P_{hz}^n = \lambda\gamma Z, \; P_{fz}^n = f P_{hz}^n.$$

The calculated vertical pressure is determined by the formula:

$$P_{fz}^n = 1{,}3 f P_{hz}^n.$$

Depending on which results of the calculation of the load from the horizontal and vertical pressures on the wall are bigger (for the silo or for the hopper). Those values are taken into account in the calculations of the silo wall.

The change in the outside air temperature and the temperature difference in the wall thickness by additional horizontal pressure of the bulk material on the silo wall is also taken into account. In order to facilitate the calculations, the pressure is taken evenly distributed around the perimeter and height.

The normative value of this pressure P_{ht}^{n}, MPa (kg/cm^2), is determined by the formula:

$$P_{ht}^{n} = \frac{k_t a_t T_1 E_m}{\frac{d\,E_m}{2t\,E_c} + (1-\nu)}, \qquad (3)$$

where T_1 is the average daily amplitude of fluctuations in ambient air temperature (deg), which is accepted $2\theta_1$, where θ_1 is determined according to DBN B.1.2–2: 2006 [25];
E_m – the deformation modulus of compression of the bulk material is determined by the formula:

$$E_m = 250 \cdot (P_h^n)^{0,63},$$

E_c – modulus of elasticity of the material of the silo walls;
k_t – coefficient, which for steel walls is equal to 2.5;
α_t – coefficient of linear temperature deformation of the wall material, 1 / deg;
d is the inner diameter of the silo, m;
t – wall thickness, m;
ν is the initial coefficient of transverse deformations (Poisson's ratio).

The maximum design load from the additional horizontal pressure of the grain on the wall of the silo, taking into account the temperature difference is determined by the formula:

$$P_{ht}^{p} = \gamma_{fm} P_{ht}^{n},$$

γ_{fm} – load reliability factor.

The maximum calculated snow evenly distributed load is calculated in accordance with current building codes.

The maximum calculated wind is evenly distributed along the perimeter of the silo wall, depending on the type of terrain.

Checks of the total strength of the wall, which is in a momentless stress state, according to 14.1 [20] are performed by the formula:

$$\frac{\gamma_m}{R_y \gamma_c}\sqrt{\sigma_x^2 - \sigma_x\sigma_y + \sigma_y^2 + 3\tau_{xy}^2} \le 1, \qquad (4)$$

where σ_x and σ_y – normal stresses in two mutually perpendicular directions;
τ_{xy} – tangential stresses at the point of the wall of the shell under consideration;
γ_c – coefficient of working conditions of the structure.

The strongest stress of a shell depending on wall thickness is checked for durability.

5 Conclusions

1. The advantages of metal silos in comparison with reinforced concrete are given.
2. Types of silos depending on a wall design are considered.
3. The design of steel spiral-fold silo is illustrated.
4. The specifics of the construction of spiral-fold silo, which affects their stress-strain state, are analyzed.
5. The normative documents of Ukraine regulating the issues of designing steel silo tanks are analyzed.
6. The algorithm for calculating steel spiral-fold silo is resulted: from load collection to strength testing.

Based on the above material, the authors are planning to conduct an experiment on a full-scale silo to compare theoretical calculations with the experiment results.

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Simulation of two-dimensional distribution laws of random correlated quantities of natural-climatic factors in context of probabilistic assessment of reliability of hydraulic structures of cascades of hydroschemes

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Abstract. When performing calculations to assess reliability of hydraulic structures of cascades of hydroschemes on the basis of probabilistic methods, the necessity to simulate random natural-climatic phenomena producing loads and effects on hydraulic structures arises. In particular, statistical series of random quantities of such important natural-climatic phenomena are considered: annual lowest average monthly temperatures, annual maximal amplitudes of average monthly temperatures. Each of the enumerated natural-climatic phenomena is characterized by presence of close correlation connections between random quantities when passing from one hydroscheme of the cascade to another. The necessity to consider correlation connections requires construction (simulation) of joint distribution law of random quantities system. The purpose of the work is simulation of joint distribution law of system of random variables that do not satisfy the normal distributions, taking into account correlation connections between random variables when passing from one hydroscheme of the cascade to another. Methods of the theory of correlation and methods of mathematical statistics with the use of software package MathCad were used in the course of the investigation. Simulation of joint law of distribution of system of random variables that do not satisfy normal distributions, taking into account correlation connections between random variables when passing from one hydroscheme of the cascade to another, and also assessment of accuracy of results, that were performed, have shown advantages of this approach from the viewpoint of accuracy of results obtained by different procedures. The results can be used in probabilistic calculations of reliability of hydraulic structures and cascades of hydroschemes.

1 Introduction

Assessment of safety and reliability of hydraulic structures on the basis of probabilistic methods is regulated by normative documents [1–9]. Taking into account the extremely high potential danger of hydraulic structures, improvement of methods of assessment of their reliability is an important and relevant problem. During performing calculations on assessment of reliability of hydraulic structures of hydroscheme cascades, necessity to simulate distribution laws of random natural-climatic phenomena that create loads and effects on hydraulic structures arises. In this investigation the approaches that allow simulating a joint law of distribution of system of random quantities that do not satisfy the normal distributions in the closed form, and also obtaining the conditional distribution laws of random quantities of natural-climatic phenomena taking into account correlation connections, are realized.

2 Analysis of recent researches

Statistic series of random quantities of such important natural-climatic phenomena, obtained by direct measurements in dam sites of hydroschemes of the Dnieper cascade of hydroelectric stations: annual maximal flood discharges $Q_{max,i}$, annual maximal ice thickness $h_{max,i}$, annual lowest average monthly temperatures $t_{min,i}$, annual maximal amplitudes of average monthly temperatures $\Delta t_{min,i}$ were investigated by methods of probability theory and mathematical statistics with substantiation of the proposed distribution laws in investigations [10–12]. Each of the enumerated natural-climatic phenomena is characterized by presence of close correlation connections between the random quantities when passing from one hydroscheme of the cascade to another. Investigations [11, 13] deal with revealing correlation connections between random quantities of

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natural-climatic phenomena in hydroschemes of the Dnieper cascade of hydroelectric stations. The necessity to take into account correlation connections between natural-climatic phenomena requires construction (simulation) of joint distribution law of random quantities system, which is realized in investigation [11]. In the mentioned sources, distribution laws of random variables of natural-climatic phenomena, that enter into the system, do not satisfy the normal distributions, therefore approaches to transform them into the normal laws by way of the use of the corresponding transformations were used. Principles of construction of the joint distribution law of system of random variables that satisfy the normal distributions are widely presented in present-day investigations [14–16]. Investigations of two-dimensional and multidimensional joint distribution laws of systems of discrete and continuous random variables that do not satisfy the normal distributions are proposed in investigations [15–31]. Two-dimensional and multidimensional distributions with multiple correlation connections are presented in investigations [21, 23–26]. Application of non-linear regression models is presented in investigation [22]. Multidimensional distribution laws of random variables simulated with the use of the copula theory are presented in investigations [29, 32–39], in particular, hydrologic mode of hydrosystem in flood period is simulated in investigation [32].

The performed critical analysis of the present-day investigations and publications made it possible to formulate the purpose and determine the objective of the investigation. The objective of the investigation is development of the algorithm of construction of joint distribution law of random variables system taking into account correlation dependences between the natural factors: between annual maximal flood discharges of the watercourse (r. Dnieper); between annual lowest average monthly temperature at hydroschemes of the Dnieper cascade; between annual maximal amplitude of variations of temperature of outdoor air at the hydroschemes of the Dnieper cascade; between annual maximal ice thickness at the hydroschemes of the Dnieper cascade.

The purpose of the work is simulation of joint distribution law of system of random variables that do not satisfy the normal distributions, taking into account correlation connections between random variables when passing from one hydroscheme of the cascade to another.

Methods of the theory of correlation and methods of mathematical statistics with the use of software package MathCad were used in the course of the investigation.

3 Results and discussion

Joint density of distribution of continuous system of random variables (X_1, X_2), that satisfy the lognormal distributions [15, 19, 27, 28, 31] is presented by expression (1):

$$f(\gamma_1,\gamma_2) = \frac{\xi^2}{2\pi\sigma_1\sigma_2\sqrt{1-r^2}\gamma_1\gamma_2} \times$$

$$\times\, exp\left\{-\frac{1}{2(1-r^2)}\begin{bmatrix}\left(\frac{10\,log_{10}\gamma_1-m_1}{\sigma_1}\right)^2+\\ +\left(\frac{10\,log_{10}\gamma_2-m_2}{\sigma_2}\right)^2-\\ -2r\left(\frac{10\,log_{10}\gamma_1-m_1}{\sigma_1}\right)\times\\ \times\left(\frac{10\,log_{10}\gamma_2-m_2}{\sigma_2}\right)\end{bmatrix}\right\}, \quad (1)$$

where $\xi = \frac{10}{ln(10)}$, $\gamma_1 = 10^{\frac{X_1}{10}}$, $\gamma_2 = 10^{\frac{X_2}{10}}$;

σ_1, σ_2 – root-mean-square deviations of random variables X_1, X_2;

m_1, m_2 – mathematical expectations of random variables X_1, X_2;

r – correlation coefficient of random variables X_1, X_2.

Distribution (1) presents lognormal distribution on the plane. In this case each of random variables X_1 or X_2 has density of lognormal distribution:

$$f(\gamma) = \frac{\xi}{\sigma\sqrt{2\pi}\gamma}exp\left\{-\frac{(10\,log_{10}\gamma-m)^2}{2\sigma^2}\right\}. \quad (2)$$

Conditional law of distribution of random variable X_2 at a fixed value of variable X_1 has form [31]:

$$f(\gamma_2|\gamma_1) = \frac{\xi}{\sigma_2\sqrt{2\pi(1-r^2)}\gamma_2}\times$$

$$\times\, exp\left\{-\frac{1}{2(1-r^2)}\begin{bmatrix}\left(\frac{10\,log_{10}\gamma_2-m_2}{\sigma_2}\right)-\\ -2r\left(\frac{10\,log_{10}\gamma_1-m_1}{\sigma_1}\right)\end{bmatrix}^2\right\}. \quad (3)$$

But in practical calculations it is more convenient to use expressions (2–3) in closed form [14]:

$$f(\gamma_1) = \int_{-\infty}^{\infty} f(\gamma_1,\gamma_2)d\gamma_2, \quad (4)$$

$$f(\gamma_2|\gamma_1) = \frac{f(\gamma_1,\gamma_2)}{\int_{-\infty}^{\infty} f(\gamma_1,\gamma_2)d\gamma_2}. \quad (5)$$

Conditional mathematical expectation of random variable X_2 at a fixed value of variable X_1 has form [14]:

$$m(\gamma_2|\gamma_1) = \int_{-\infty}^{\infty}\gamma_2\frac{f(\gamma_1,\gamma_2)}{\int_{-\infty}^{\infty} f(\gamma_1,\gamma_2)d\gamma_2}d\gamma_2, \quad (6)$$

and conditional dispersion and standard deviation of random variable X_1 are determined by expressions:

$$D(\gamma_2|\gamma_1) = \int_{-\infty}^{\infty}(\gamma_2-m_2)^2\frac{f(\gamma_1,\gamma_2)}{\int_{-\infty}^{\infty} f(\gamma_1,\gamma_2)d\gamma_2}d\gamma_2, \quad (7)$$

$$\sigma(\gamma_2|\gamma_1) = \sqrt{D(\gamma_2|\gamma_1)}. \quad (8)$$

Conditional mathematical expectation $m(\gamma_1|\gamma_2)$, dispersion $D(\gamma_1|\gamma_2)$ and standard deviation $\sigma(\gamma_1|\gamma_2)$ of random variable X_1 at a fixed value of variable X_2 are calculated analogously By this means five parameters are determined: $m(\gamma_1|\gamma_2)$, $m(\gamma_2|\gamma_1)$, $\sigma(\gamma_1|\gamma_2)$, $\sigma(\gamma_2|\gamma_1)$, r of density of distribution of continuous system of random variables (X_1, X_2), that satisfy lognormal distributions.

The value of random variable X_2 is determined by conditional law of distribution with parameters $m(\gamma_2|\gamma_1)$, $\sigma(\gamma_2|\gamma_1)$:

$$f_{simulated}(\gamma_2) = \frac{\xi}{\sigma(\gamma_2|\gamma_1)\sqrt{2\pi}\gamma_2} \times \times exp\left\{-\frac{\left(10\, log_{10}\,\gamma_2 - m\cdot(\gamma_2|\gamma_1)\right)^2}{2\sigma^2(\gamma_2|\gamma_1)}\right\}. \quad (9)$$

Let us illustrate the presented approach by an example. We simulate the joint law of distribution of two-dimensional system of random variables (X_1, X_2), that satisfy lognormal distributions. Analysis of statistical data on annual maximal amplitudes of average monthly temperatures at hydroschemes of the Dnieper cascade, and also determination of parameters of their distribution functions is performed in investigation [12]. It is presented in Table 1. Selection of function of distribution has been performed by comparison of deviations of probabilities σp and maximal amplitude of monthly average temperatures $\sigma\Delta t$ of actual values from analytical distribution. It is presented in Table 2.

Table 1. Parameters of distribution functions of probability of annual maximal amplitude of monthly average temperatures at geographical places of location of hydroschemes Dnieper cascade.

Item observation	Logarithmic-normal distribution	
	mathematical expectation	standard deviation
t. Vyshhorod	25.16	1.16
t. Kaniv	24.59	1.16
t. Kremenchuk	25.77	1.17
t. Kamyanske	27.43	1.16
t. Zaporizhzhia	27.00	1.16
t. Nova Kakhovka	26.72	1.16

Table 2. Results of assessment of accuracy of calculations of probability of annual maximal amplitude of monthly average temperatures at geographical places of location of hydroschemes of Dnieper cascade.

Item observation	Logarithmic-normal distribution	
	deviations of probabilities σp, %	deviations of maximal amplitude of monthly average temperatures σΔt, %
t. Vyshhorod	2.8	0.4
t. Kaniv	3.7	0.6
t. Kremenchuk	4.2	0.8
t. Kamyanske	2.8	0.5
t. Zaporizhzhia	6.9	0.9
t. Nova Kakhovka	2.9	0.5

It is found that probabilities of annual maximal amplitudes of average monthly temperatures in t. Kaniv, t. Kremenchuk can be presented by lognormal distribution. Parameters of the distributions for t. Kaniv: mathematical expectation $m_{\Delta t1}$ = 24.59 °C, standard deviation $\sigma_{\Delta t1}$ = 1.16 °C; for t. Kremenchuk: mathematical expectation $m_{\Delta t2}$ = 25.77 °C, standard deviation $\sigma_{\Delta t2}$ = 1.17 °C.

Investigation of correlation connections between annual maximal amplitudes of average monthly temperatures by statistical data of observations at t. Kaniv and t. Kremenchuk, carried out in investigation [13], indicates close correlation dependence between annual maximal amplitudes of average monthly temperatures in dam sites of hydroschemes of the Dnieper cascade.

By results of correlation analysis of statistical samples of maximal amplitude of average monthly temperatures of outdoor air, °C, correlation coefficient of two samples at t. Kaniv and t. Kremenchuk is r = 0.871. It is presented in Fig. 1.

The linear regression equation is taken as

$$y(x) = b_0 + b_1 \times x, \quad (10)$$

where $y(x)$ – regression of pairs of statistical series of annual maximum amplitudes of average monthly temperatures in the alignments in the geographical locations of hydropower plants of the Dnieper cascade;
x – statistical series of the annual maximum amplitude of average monthly temperatures along the X axis;
b_0, b_1 – empirical coefficients.

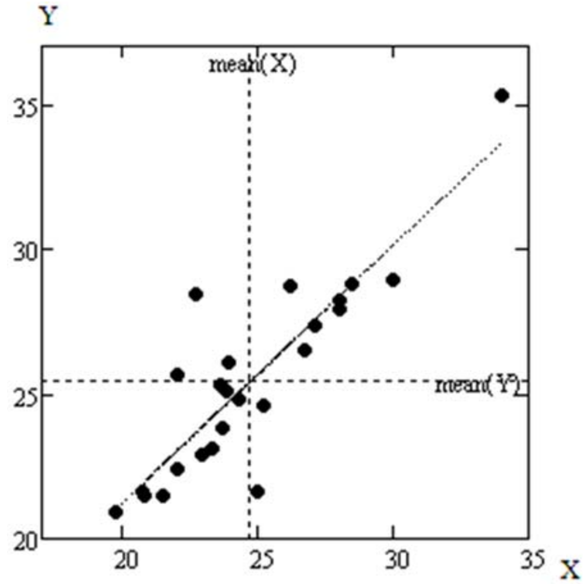

Fig. 1. Graph of the linear regression function of the statistical series of the annual maximum amplitude of the average monthly outdoor air temperatures, °C, observed in t. Kaniv (X axis), for the statistical series of the annual maximum amplitude of the average monthly outdoor air temperatures, °C, observed in t. Kremenchuk (Y axis): - - - – graph of the linear regression function; • • • – statistical series.

Sample correlation coefficients, sample covariance, standard errors are calculated. It is presented in Tables 3, 4, 5.

Using expression (1), we can construct joint density of distribution $f(\gamma_1(\Delta t_1), \gamma_2(\Delta t_2))$ of two-dimensional system of random variables ($X_1 = \Delta t_1$, $X_2 = \Delta t_2$), that satisfy lognormal distributions with parameters for t. Kaniv: $m_{\Delta t1}$ = 24.59 °C, $\sigma_{\Delta t1}$ = 1.16 °C; and t. Kremenchuk: $m_{\Delta t2}$ = 25.77 °C, $\sigma_{\Delta t2}$ = 1.17 °C. It is presented in Fig. 2.

Conditions (11–12), those function of joint density of distribution $f(\gamma_1(\Delta t_1), \gamma_2(\Delta t_2))$ of system of two correlated random variables [14] Δt_1, Δt_2 must obey, – are satisfied

$$f(\gamma_1(\Delta t_1), \gamma_1(\Delta t_1)) \geq 0, \quad (11)$$

$$\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(\gamma_1(\Delta t_1), \gamma_2(\Delta t_2)) d\gamma_1(\Delta t_1) d\gamma_2(\Delta t_2) = 1 . \quad (12)$$

Table 3. The results of statistical processing of the annual maximum amplitude of the average monthly outdoor air temperatures, °C in the geographical locations of hydropower plants of the Dnieper cascade for the period of observations from 1966 to 1977 and from 1979 to 2008.

Item observation (reservoir)	Selective average, °C	The standard deviation	Selective dispersion
Kyiv Reservoir	25.7	2.7	7.3
Kaniv Reservoir	24.7	3.3	11.2
Kremenchuk Reservoir	25.5	3.4	11.5
Middle Dnieper Reservoir	26.2	3.6	12.9
Dnieper Reservoir	26.0	3.4	11.6
Kakhovka Reservoir	25.0	3.1	9.3

Table 4. The empirical coefficients of linear regression equation (10) of statistical series of the annual maximum amplitude of the average monthly outdoor air temperatures, °C in the geographical locations of hydropower plants of the Dnieper cascade for the period of observations from 1966 to 1977 and from 1979 to 2008.

Item observation (reservoir)	Coefficients	
	b_0	b_1
Kyiv Reservoir – Kaniv Reservoir	0.412	0.946
Kaniv Reservoir – Kremenchuk Reservoir	3.583	0.884
Kremenchuk Reservoir – Middle Dnieper Reservoir	1.026	0.989
Middle Dnieper Reservoir – Dnieper Reservoir	2.034	0.914
Dnieper Reservoir – Kakhovka Reservoir	2.897	0.853

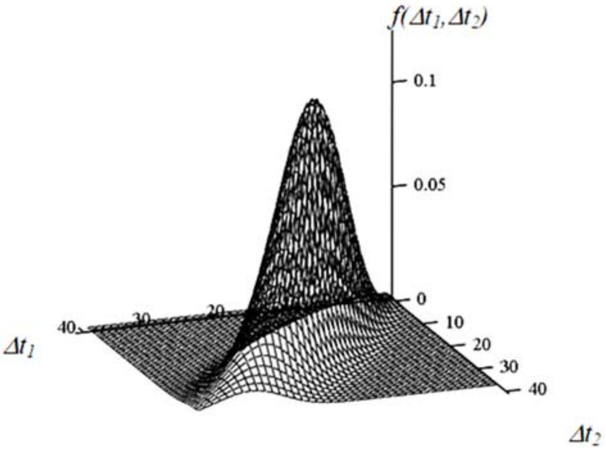

Fig. 2. Function of density of distribution $f(\gamma_1(\Delta t_1), \gamma_2(\Delta t_2))$ of system of two correlated variables Δt_1, Δt_2, that satisfy lognormal distributions.

Table 5. The results of correlation analysis of statistical series of the annual maximum amplitude of the average monthly outdoor air temperatures, °C in the geographical locations of hydropower plants of the Dnieper cascade for the period of observations from 1966 to 1977 and from 1979 to 2008.

Item observation (reservoir)	Correlation coefficient of two statistical series	Covariance of two statistical series	Standard error
Kyiv Reservoir – Kaniv Reservoir	0.761	6.6	2.2
Kaniv Reservoir – Kremenchuk Reservoir	0.871	9.5	1.7
Kremenchuk Reservoir – Middle Dnieper Reservoir	0.936	10.9	1.3
Middle Dnieper Reservoir – Dnieper Reservoir	0.964	11.3	0.9
Dnieper Reservoir – Kakhovka Reservoir	0.950	9.4	1.0

We obtain conditional law of distribution $f(\gamma_2(\Delta t_2)|\gamma_1(\Delta t_1))$ of random variable Δt_2 at fixed value of Δt_1 in analytical form by expressions (4–5).

Conditional mathematical expectation $m(\gamma_2(\Delta t_2)|\gamma_1(\Delta t_1))$ of random variable Δt_2 at fixed value of Δt_1 is obtained in analytical form by expression (6). Its numerical value is $m(\gamma_2(\Delta t_2)|\gamma_1(\Delta t_1))$ = 25.65299 °C. Conditional dispersion $D(\gamma_2(\Delta t_2)|\gamma_1(\Delta t_1))$ and standard deviation $\sigma(\gamma_2(\Delta t_2)|\gamma_1(\Delta t_1))$ of random variable Δt_2 at fixed value of Δt_1 is obtained in analytical form by expressions (7–8). Their numerical values equal $D(\gamma_2(\Delta t_2)|\gamma_1(\Delta t_1))$ = 1.36911 °C^2, $\sigma(\gamma_2(\Delta t_2)|\gamma_1(\Delta t_1))$ = =1.17009 °C.

Random probability of annual maximal amplitudes of average monthly temperatures $p(\Delta t_1) = p(\Delta t_2)$, distributed from 0 to 1 is specified. By known probability of amplitude of average monthly temperatures $p(\Delta t_2)$, using conditional distribution law (9) with parameters $m(\gamma_2(\Delta t_2)|\gamma_1(\Delta t_1))$, $\sigma(\gamma_2(\Delta t_2)|\gamma_1(\Delta t_1))$, we determine the quantile – the value of amplitude of average monthly temperatures $\Delta t_{2\ simulated}$.

The value of random variable Δt_2 is determined by conditional distribution law (9) with parameters $m(\gamma_2(\Delta t_2)|\gamma_1(\Delta t_1))$, $\sigma(\gamma_2(\Delta t_2)|\gamma_1(\Delta t_1))$. It is presented in Fig. 3.

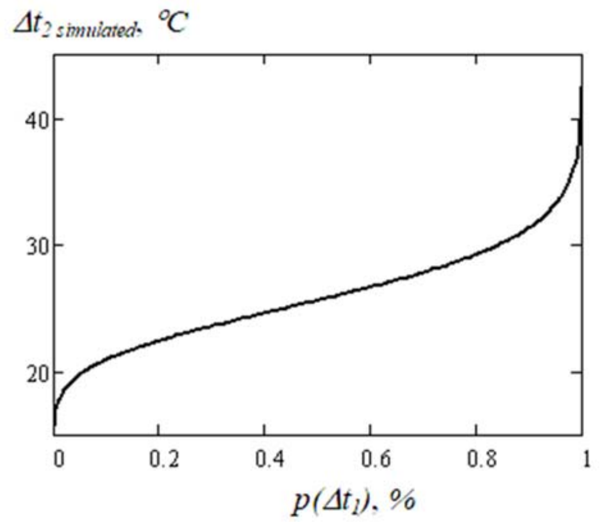

Fig. 3. Probability curve for annual maximal amplitude of average monthly temperatures at dam site of Kremenchuk hydroscheme (t. Kremenchuk) on the coordinates $\Delta t_{2\ simulated}$, °C – annual maximal amplitude of average monthly temperatures, $p(\Delta t_1)$, % – probability.

In investigations [11], substitution of

$$\Delta t_{cond,i} = a \times mean(\Delta t) \left(\frac{\Delta t_i}{mean(\Delta t)}\right)^b, \quad (13)$$

$i = 1 \dots n$, into output statistical series was used to transform laws of distribution of statistical data of annual maximal amplitudes of average monthly temperatures at hydroschemes of the Dnieper cascade into normal distributions, where Δt_i – corresponding members of the output statistical series, $\Delta t_{cond,i}$ – corresponding members of the transformed statistical series; $mean(\Delta t)$ – the average value of annual maximal amplitude of average monthly temperatures of the output statistical series; *a, b* – empirical coefficients. It is presented in Table 6.

Table 6. Parameters of transformation (13) of distribution laws of annual maximal amplitude of monthly average temperatures Δt, °C at geographical sites of location of hydro schemes of Dnieper cascade.

Item observation (reservoir)	*mean*(*Δt*), °C	Coefficients	
		a	*b*
Kaniv Reservoir (t. Kaniv)	24,733	1,05	0,15
Kremenchuk Reservoir (t. Kremenchuk)	25,458	1,01	0,25
Dnieper Reservoir (t. Zaporizhzhia)	25,975	1,04	0,24

Conditional distribution laws of lowest monthly average temperatures and of maximal amplitudes of monthly average temperatures according to [40] correspond to normal law if values of expression (14) are within the confidence interval:

$$\frac{max(\Delta t_{\mathrm{cond,i}}) - min(\Delta t_{\mathrm{cond,i}})}{\sigma(\Delta t_{\mathrm{cond,i}})}, \quad (14)$$

where $max(\Delta t_{cond,i})$ – maximal values of maximal amplitudes of monthly average temperatures of transformed normal distribution; $min(\Delta t_{cond,i})$ – minimal values of maximal amplitudes of monthly average temperatures of transformed normal distribution; $\sigma(\Delta t_{cond,i})$ – standard deviations of values of maximal amplitudes of monthly average temperatures of transformed normal distribution.

When the number of members of statistical series n = 24 and significance level p = 10%, the lower boundary of the interval is 3.41, the upper boundary of the interval is 4.52. It is presented in Table 7.

Table 7. Confidence intervals (14) of transformation of distribution laws of annual maximal amplitude of monthly average temperatures Δt, °C at geographical sites of location of hydro schemes of Dnieper cascade.

Item observation (reservoir)	**(*max*(*Δt*cond, *i*) – *min*(*Δt*cond, *i*)) / *σ*(*Δt*cond, *i*)**
Kaniv Reservoir (t. Kaniv)	3,41 < **4,20** < 4,52
Kremenchuk Reservoir (t. Kremenchuk)	3,41 < **4,40** < 4,52
Dnieper Reservoir (t. Zaporizhzhia)	3,41 < **4,21** < 4,52

For annual maximal amplitudes of average monthly temperatures $\Delta t_{1\ cond}$ and $\Delta t_{2\ cond}$ at dam sites of two hydroschemes, that are specified by normal distribution law as random correlated variables with the corresponding parameters: mathematical expectations $m_{\Delta t,1\ cond}$, $m_{\Delta t,2\ cond}$, standard deviations $\sigma_{\Delta t,1\ cond}$, $\sigma_{\Delta t,2\ cond}$, correlation coefficient $r_{\Delta t,1\ cond,\Delta t,2\ cond}$, correlation moment $K_{\Delta t,1\ cond,\Delta t,2\ cond}$, variation coefficient C_v; random probability of annual maximal amplitudes of average monthly temperatures $p(\Delta t_{1\ cond})$, distributed from 0 to 1 is specified. By normal distribution law with parameters presented above $m_{\Delta t,1\ cond}$, $\sigma_{\Delta t,1\ cond}$, quantile – the value of annual maximal amplitudes of average monthly temperatures $\Delta t_{1\ cond}$ - is determined by formulas:

$$m_{\Delta t1\ \mathrm{cond},\Delta t2\ \mathrm{cond}} = m_{\Delta t2\ \mathrm{cond}} + r_{\Delta t1\ \mathrm{cond},\Delta t2\ \mathrm{cond}} \times \times \frac{\sigma_{\Delta t2\ \mathrm{cond}}}{\sigma_{\Delta t1\ \mathrm{cond}}} \cdot (\Delta t_{1\ \mathrm{cond}} - m_{\Delta t1\ \mathrm{cond}}), \quad (15)$$

$$\sigma_{\Delta t1\ \mathrm{cond},\Delta t2\ \mathrm{cond}} = \sigma_{\Delta t2\ \mathrm{cond}} \sqrt{1 - r^2_{\Delta t1\ \mathrm{cond},\Delta t2\ \mathrm{cond}}}. \quad (16)$$

Parameters of conditional distribution law $m_{\Delta t1\ cond,\Delta t2\ cond}$, $\sigma_{\Delta t1\ cond,\Delta t2\ cond}$ are being determined. By known probability of the value of annual maximal amplitudes of average monthly temperatures $p(\Delta t_{2\ cond})$, using conditional distribution law, quantile – the value of quantity of annual maximal amplitudes of average monthly temperatures $\Delta t_{2\ cond}$ – is being determined. Recalculation of the value of annual maximal amplitudes of average monthly temperatures $\Delta t_{1\ cond}$, $\Delta t_{2\ cond}$, presented by conditional distribution law with substitution of formula (13), into real annual maximal amplitudes of average monthly temperatures $\Delta t_{1\ real}$, $\Delta t_{2\ real}$ at dam sites of hydroschemes is being performed. It is presented in Fig. 4.

Deviations of the values of amplitudes of average monthly temperatures, obtained by different procedures, from the observed data were assessed by comparison of their standard deviations. It was found that deviation of amplitudes of average monthly temperatures $\Delta t_{2\ real}$, °C, calculated by transformation into conditional normal distribution law [11], from the observed points of annual maximal amplitude of average monthly temperatures is $\sigma(\Delta t_{2\ real})$ = 2.227 °C. Deviation of amplitudes of average monthly temperatures $\Delta t_{2\ simulated}$, °C, calculated by two-dimensional lognormal distribution law, from observed points of annual maximal amplitude of average monthly temperatures is $\sigma(\Delta t_{2\ simulated})$ = 1.682 °C. Difference between $\sigma(\Delta t_{2\ real})$ = 2.227 °C and $\sigma(\Delta t_{2\ simulated})$ = = 1.682 °C is 24.5%.

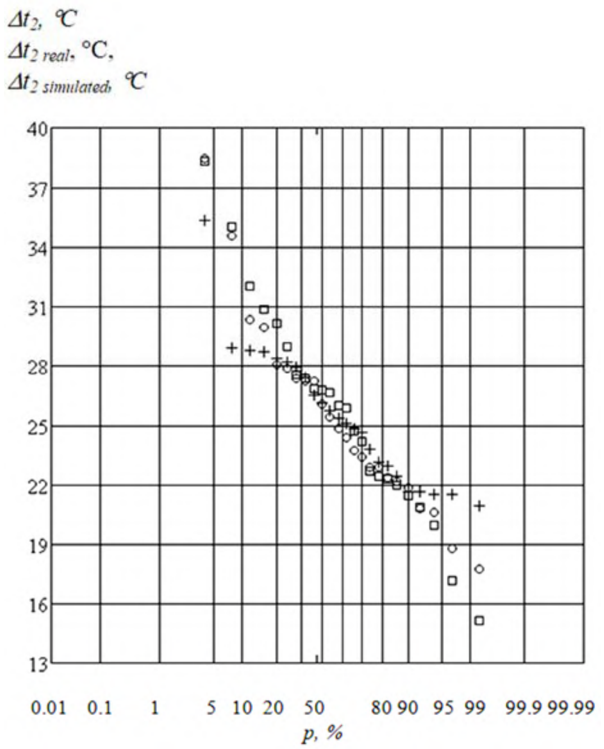

Fig. 4. Points of the probability curve of annual maximal amplitude of average monthly temperatures at dam site of the Kremenchuk hydroscheme (t. Kremenchuk) on the coordinates Δt_2, °C – annual maximal amplitude of average monthly temperatures, p, % – probability: + – observed amplitude of average monthly temperatures Δt_2, °C; – amplitude of average monthly temperatures $\Delta t_{2\ real}$, °C, calculated by transformation into conditional normal distribution law [11]; o – amplitude of average monthly temperatures $\Delta t_{2\ simulated}$, °C, calculated by two-dimensional lognormal distribution law.

Deviation of amplitudes of average monthly temperatures $\Delta t_{2\ simulated}$, °C, calculated by two-dimensional lognormal distribution law, from amplitudes of average monthly temperatures $\Delta t_{2\ real}$, °C, calculated by transformation into conditional normal distribution law, is σ = 2.11 °C.

4 Conclusions

Taking into account the great diversity of distribution laws of random variables of natural-climatic factors connected by correlation dependencies, and mathematical complexity of construction of joint distribution laws, method which is based on transformation of distribution laws into normal form has advantage in the further use. Assessment of accuracy of the results obtained by different procedures is performed. The results can be used in probabilistic calculations of reliability of hydraulic structures and cascades of hydroschemes.

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Methods for developing an indoor navigation system

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Abstract. The report offers methods for developing an indoor navigation system. For this purpose, popular navigation applications have been analysed. We have been strongly motivated by the fact that no universal methods have been established that are applicable with this kind of projects. Very often the case is that new methods are formed in view of a specific process and they are based on a particular technology and on the related organisation, design and other considerations. This is also confirmed by a conducted experiment with a commercial product for indoor navigation. The methods offered include map digitising, determining a user's location, and selecting the shortest path. This is achieved by applying elements of graph theory, databases, XML and QR code. The methods offered are universal and could be applied to any type of building. The methods have been approbated in the building of a mobile application for the needs of the University of Mining and Geology, Sofia.

1 Introduction

With the ever increasing human mobility, the various navigation systems are become more widespread and gain significance. Modern navigation systems (positioning technologies, of location determination technologies) are expected to offer optimised routes taking into consideration the peculiarities of our environment and also, to have a user-friendly, easy, informative and intelligible interface.

The Global Positioning System (GPS) is the most common navigation system used. When localising an object or route indoor, this system does not function well because the signal emitted by its satellites is lost. When navigating indoors, the multitude of objects that reflect signals should be taken into account. These could be the pieces of equipment, the walls, or people [1].

In order to overcome the malfunctions in GPS positioning and to perform accurate positioning in a sophisticated indoor environment, systems called Indoor Positioning Systems (IPSs) are introduced. Some of the most popular technologies of this type are the infrared connection, WI-FI and above all Wi-Fi fingerprinting, which is often employed in the development of smart phone applications [2, 3, 4], Bluetooth, ZigBee, ultrasound, radio frequency identification (RFID), and ultra-wideband (UWB) [5, 6], which offers higher accuracy.

Very generally, the above can be categorised into active and passive. Indoor positioning technologies via radio signal or WI-FI fall into the category of "active" technologies, since their requirement is for the object to move and to be equipped with some sort of a connecting device. In addition, the devices should be able to collect and process the transmitted information. With "passive" systems, a physical device attached to the moving object is not necessary. The concept with this category of technology is to use an available wireless network for data exchange, to detect changes in the environment, and to track the location of objects passively without requiring additional equipment. Only the UWB technology can be used as a passive system as well. The practice of combining several technologies in order to build systems of increased stability and accuracy in location determining has become increasingly popular [7, 8].

The criteria in terms of which wireless technologies can be compared are given in [9].

The areas where such developments are being applied are customer tracking, health and patients' monitoring [10, 11], finding objects, robotics, to name but a few [12].

2 Commercial solutions for indoor positioning

According to IndustryARC [13], the market for applications for indoor positioning and navigation will grow from $ 6.92 billion in 2020 to $ 23.6 billion in 2023.

Various commercial solutions for indoor positioning exist. Among the most popular are: Ekahau RTLS, SpotON – those work on the principle of the radio signal; AT&T Cambridge – it uses UWB; Microsoft Radar, Cisco Prime Infrastructure – these locate objects via WI-FI; SmartSpace – this is a modular, open source location tracking software platform. The commissioning of such a system requires large financial and expert resources.

Mobile applications for indoor positioning exist as well (Navizon, HERE Indoor Radio Mapper,

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MapsIndoors, etc.). All of them require a usage fee. They employ different standards to describe the maps used. Some of them (HERE Indoor Radio Mapper) have specific requirements for installation and use. There is no information about the employed methodologies and approaches in the creation of such applications.

In February 2020 with the assistance of *Dundee Precious Metals*, *Chelopech*, a simulation was performed in the Cisco Prime Infrastructure environment in order to determine the location of guests and students in the Laboratory Unit at the University of Mining and Geology.

These are the simulation stages:

To perform the tests, six Cisco Access Points (APs) model 1242 are used; those are positioned in two rooms, each with three APs. The range of one AP of this model is between 60 and 70 m. Each triple AP isconnected to a 12-port switch and the necessary set-ups are made to obtain the IP addresses of APs.

The APs are connected to the Wireless controller (WLC) via the Dynamic Host Configuration Protocol (DHCP). Checks are then made for possible attacks on the transmitted data, called bit-flip attacks, using a Cisco certificate - self-signed certificates (SSC) to the controller. When everything is checked and there is no risk of external interference, the controller returns a request to connect the access point to it. The result is the so-called tunnel between the AP and the WLC. The data is transmitted using the CAPWAP protocol (Control and Provisioning of Wireless Access Points Protocol) for access.

Having performed the required configuration, we proceed to the construction of a map, a building and floors within a system. An approximate location of the building is indicated. The system allows a 2D projection of the map of the building under consideration. It is possible to apply it in any format. For the purposes of the simulation, an evacuation map of the 1st and 2nd floors in the Laboratory Unit at the University of Mining and Geology was used. Three access points (APs) were placed on each floor, equidistant in one direction for both floors.

After applying a map and placing access points, customers are connected to them and their location can be determined. The deviation given by the system is about 2 meters. Access points serve as reference points (or: landmarks). Determining the location of customers across the network is calculated using the RSSI and TDoA methods. For buildings overground, the triangulation method is applied, whereas for underground premises, the trilateration method is applicable.

The tags employed to carry out the simulation are AeroScout T2, and Cisco Prime provides detailed information about the data transfer between the tag and the access point (Fig. 1). A time difference of 2-3 seconds may occur.

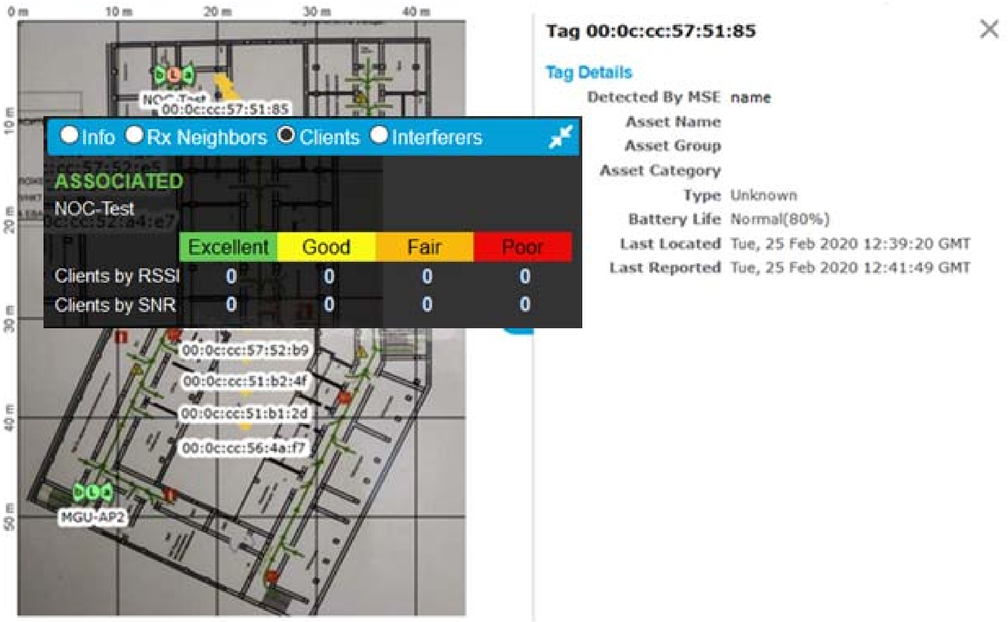

Fig. 1. Detailed information about the clients connected to the map of the building.

After connecting the APs to the wireless controller, a virtual engine (Mobility Services Engine) calculates the location of the objects using mathematical algorithms. The Cisco CEX algorithm is applied for the connection between client and MSE, and the Cisco CMX or DNA spaces algorithms monitor the data over the network. The necessary configuration is required, after which various analyses can be performed. In our case, an analysis of the signal strength between the access points and the RFID tags was performed. At the beginning of the test, no signal interruption was reported. An RSSI analysis was also performed on the day of the tests because the switch used for the simulation was fully configured for the purposes of the simulation and it was not possible to compare the signal strength over a longer period of time. In case signal interference is detected, the Kalman filter algorithm can be applied to determine the cause of the received interference.

The simulation performed with the help of the Cisco's corporate solution has made it possible to visually track objects using the WI-FI wireless technology. The advantage of the system is the provision of a general solution for localising, secure maintenance, and a complete set of tools and the description to it. The disadvantages of this type of systems include the inability to combine various company hardware and software components other than those of the manufacturing company, as well as the lack of ability to use three-dimensional maps. This makes the application too expensive. Additional disadvantages include the lack of a mobile version of the application, as well as the fact that it allows only for localising but not for navigating.

3 Proposing methods and testing them for approval

It is clear, from all that we have stated so far, that the choice of appropriate methods is of particular importance for the construction of NIS. Various computer developments exist that are employed for indoor localising, are commercial solutions, yet the methods wherewith they have been developed are not specified. Universal methods suitable for all types of projects have not been developed yet. As is often the case, new methods are formed for a particular process and they are based on a specific technology and the related organisational, design and other considerations.

Creating an indoor computer application is an elaborate process. Depending on the building, the appropriate navigation technology has to be selected. Then, in relation to this technology, the methods used for calculating the distance and the algorithms for determining the path must be taken into account. However, research has shown that, in the building of a software solution for navigating people indoors where there is no access to a GPS signal, the steps performed can be integrated and presented as methods that are founded on known methods and algorithms.

The structure of the proposed methods for creating computer applications for indoor navigation is presented in Fig. 2.

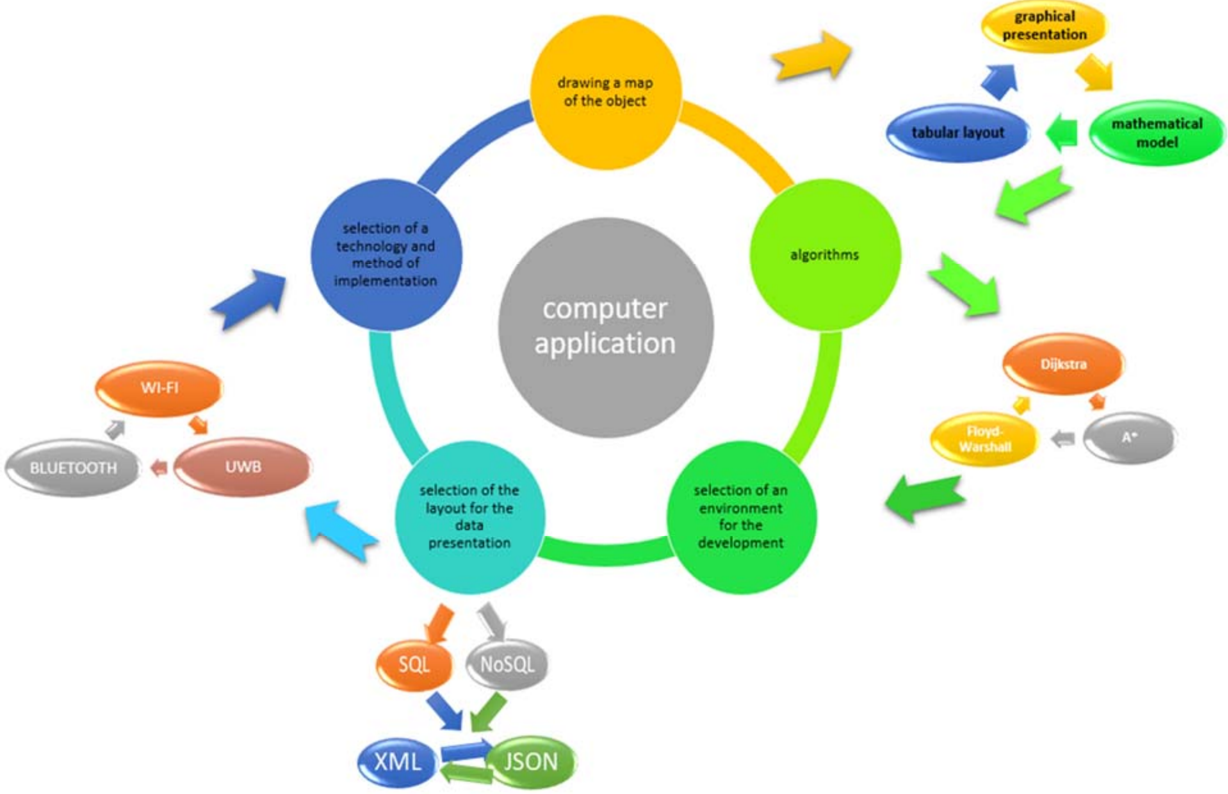

Fig. 2. Structure of the methods for designing computer applications for indoor navigation.

In order to localise an object/site, it is necessary to find its position relative to the surrounding objects. As a rule, when positioning outdoors, cartographic maps of the area in which the object is located are used, whereas a possible solution with indoor objects is maps similar to the Fire Evacuation Plans.

For the implementation of the algorithms in a particular development environment, the appropriate layout for the data presentation needs to be selected. Among the other ways to represent the graph describing the building are the use of such formats as the XML and JSON. These variants are suitable for embedding in systems that use the BigData or NoSQL databases with which the natural evolution of the considered system is associated.

3.1 Digitisation of the map of the building

The object of the current study are the 1st and 2nd floors of the Laboratory Unit at the University of Mining and Geology “St. Ivan Rilski”. The available fire evacuation map has been used as a basis which has been updated with the current hall numeration and the refurbishment of some halls. For a clearer view, the height between the floors on the scheme is extended. Such a map could be applied to any type of building.

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The map of the building in question can be presented by an undirected graph. The graph considered has 83 nodes and 3403 edges. By properly traversing the graph, a path can be found between each of its two nodes.

In order to determine the shortest path between two vertices of a graph, the algorithms of Dijkstra, A* and Floyd-Warshall were considered. In the long run, Dijkstra's algorithm was chosen due to its popularity, easy implementation, the presence of only positive edge weights, and its speed.

The proposed graph is spatial. It comprises two sub-graphs for each of the floors in the building (Fig. 3). What is checked initially is where the “start” and “end” nodes of the searched route are located; then the search is confined within one of the sub-graphs. But even if the route includes elements from both sub-graphs, the basic search is within each sub-graph separately. Thus, the fast response time of the algorithm increases, since it is not necessary to constantly traverse the entire graph.

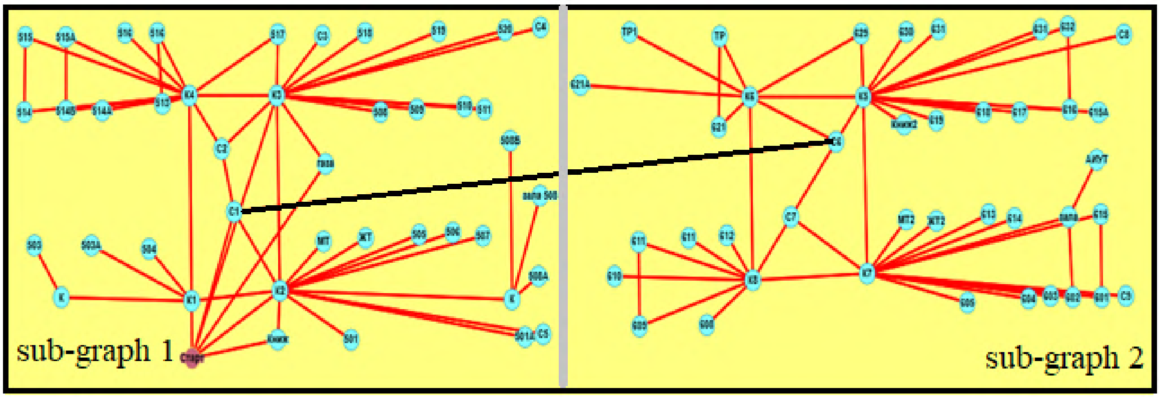

Fig. 3. A map of the 1st and 2nd floors of the Laboratory Unit presented by an undirected graph.

In the application implemented, the structure of the graph is represented by an adjacency matrix. This is one of the most common ways to represent graphs This matrix sets the weight of the edges of the graph

3.2 Mobile application

Using the methods offered, a mobile application for indoor navigation has been implemented.

The developed mobile application is based on the relational data model. The reasons are as follows:

- the rather the static nature of the object described – redistribution of the inner space in order to establish new separate classrooms and offices is rarely done;
- well-developed and accessible means for data import and export from other formats (mostly XML and JSON) are available in the contemporary DBMS - this would facilitate the transition to NoSQL in future addition of information to the database
- intelligible data presentation in the tables;
- a high degree of physical and logical data independence;
- sufficiently rich experience in various relational database management systems (RDBMS).

The mobile application has been developed for the Android operating system. It can be used by registered users and guests. The registered users are allowed to add their own map of a desired building, the information wherewith is included in the database. Guests, in turn, can make use of the services of the application by having only access to the current data – available maps, scanning a QR codes, and entering a hall number. The diagram of the mobile application developed is shown in Fig. 4.

By means of the proposed mobile application, guests and newly-admitted students can easily navigate within the buildings of the university campus without the need for additional guidance and loss of time. The application is offered with a pleasant and lightweight user interface that will eliminate unnecessary “clicks” on the part of its users on their way to the desired goal.

The identification of the starting point is performed by scanning a QR code. For this purpose, a free-of-charge QR code must be generated for each hall (vertex on the graph). It must be positioned at a spot which is convenient for scanning, at the door or in the immediate proximity to it. The choice of QR code scanning was prompted by the fact that more and more cameras on mobile devices support the function of automatic QR code recognition. For devices that lack such an option, an additional installation of an application that reads QR codes is required.

The end point identification can be done in two ways:

1. By entering the number (name) of the required hall. For the user’s convenience, as well as to ensure the selection of a really existing hall, the end point determining is performed through a selection from a menu (Fig. 6).
2. By entering search criteria – the name of the department, laboratory or hall. The end point is selected by clicking on an element (hall) from the result returned.

The mobile application contains one major panel (Figure 5) with the following elements :

1. *Navigation bar* – along with the name of the application, it contains a button with a hidden menu. In order to make it possible to use the application for different buildings and not only for the one under consideration, the feature for adding a new map has been supplemented in the menu as an option. Accordingly, the layout of the map should be in the format proposed by the methods considered. A button for clearing a previous search has also been provided.
2. *Information field (text box)* - it automatically displays the information from the QR code scan.

3. *Scan button* - the application offers its users to scan a QR code as the starting point for determining their location. For this purpose, all halls in the building under consideration have been equipped with additional signs with generated QR codes. The scan information is loaded into the information field.

4. *Editing field (search engine)* – offers the user a possibility to enter the end point of their route. The user can to manually enter the particular hall number they want to reach or search for in the offered list box.

5. *List box* - all of the existing halls, offices and laboratories in the respective building in question are extracted from a database. A filter to the list box has been addedl, whereby, upon entering part of a hall number, the list box shows only the halls containing those numbers.

6. *Floating button* - after scanning the QR code and selecting the final destination, the button visualises the map of the building, calculates the algorithm entered (in this case, Dijkstra's algorithm for find the shortest path), and draws up the route which the user should follow.

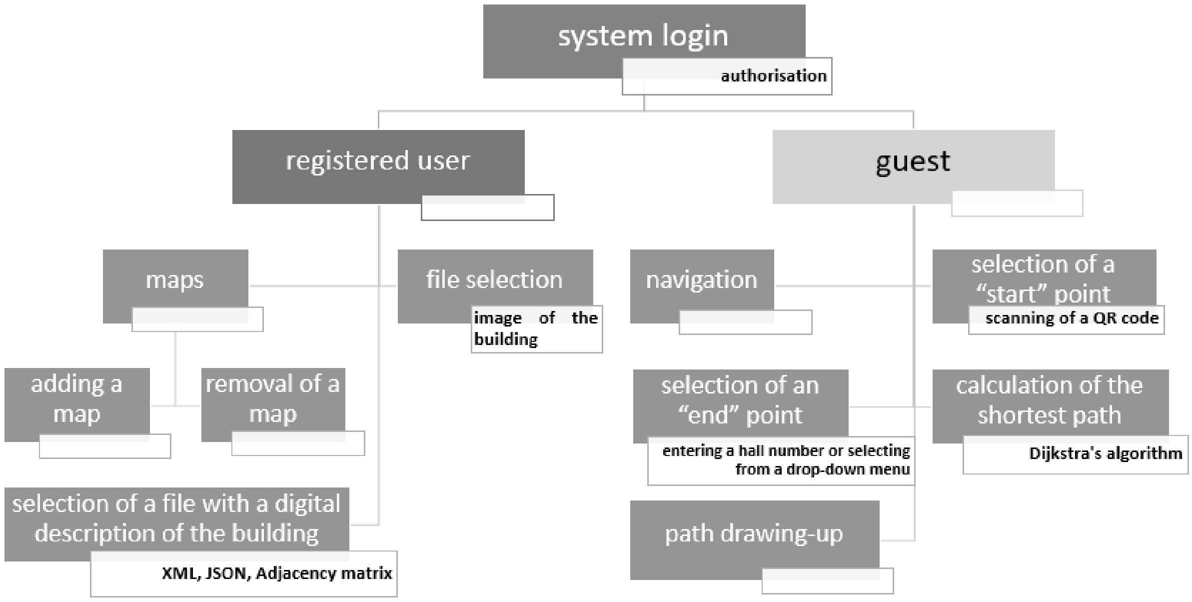

Fig. 4. Diagram of the mobile application.

Fig. 5. Home screen of the mobile application.

Upon pressing the button on the floating bar, the path is visualised in real meters. The result is visualised using a standard Java graphics library for Android (Figure 6)

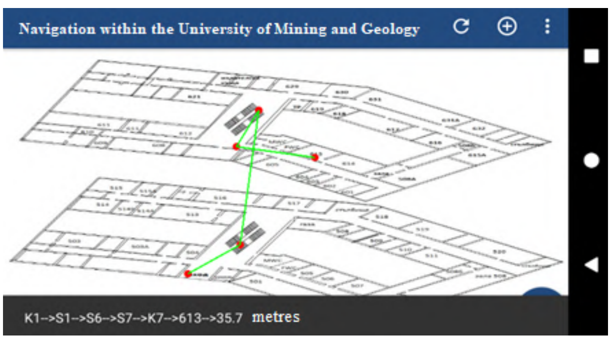

Fig. 6. Visualisation of the shortest route.

4 Conclusion

Systems exist for indoor or outdoor object localising. Globally, indoor positioning systems are currently undergoing a process of active development. This is a relatively new subject matter for professionals. Besides, the information on it is limited. The analysis of existing indoor positioning systems has shown the scarcity of the information available in this area. An even more serious challenge is how to track the position of a moving object, shifting from an outdoor to an indoor environment and/or vice versa.

To date, there is no universal system for indoor navigation, nor is there an approach (methods) for developing such a system.

This report proposes methods for creating an indoor navigation system. For this purpose, a thorough analysis has been performed of existing methods, technologies and algorithms which can be combined in such a manner that the process of navigating an object from one point to another be optimised.

In the methods described, the location of the site is determined by creating a digital map of a building and a graph that describes the connections between the internal sites. The selection of the shortest path is performed by applying Dijkstra's algorithm. In the case of more buildings or multi-floor buildings, separate subgraphs are formed within the overall graph so as to optimise the Dijkstra method. In order to test the methods for approval, a mobile navigation system has been developed. This choice is prompted by the fact that today mobile devices are more popular, affordable and portable than conventional computers. The system is still being developed, and some of the major issues that need to be solved in the near future are the following:

- Enabling users of various operating systems to use the mobile application;
- Ability to navigate in different buildings - outdoors and indoors concurrently;
- Additional modules to the application, according to the specifics of the building;
- Unified representation of a map of the building (e.g. through an XML document validated with a specific XML Schema and transformed into an SVG file);
- Creating Fingerprints based on the object position established via Wi-Fi and comparing those with the results of the current scan by the users for the purposes of neural network training;
- Calculating the approximate duration of movement;
- Navigating handicapped people;
- In order to automate the process of tracking the user's movement from the start to the final point, it would be useful to conduct experiments combining a variety of navigation technologies, such as infrared connection, WI-FI, Bluetooth, ZigBee, ultrasound, radio frequency identification (RFID), and ultra-wideband (UWB).

The evolution of information technologies also requires constant monitoring of new trends in the field, as well as the implementation of new technologies in order to improve the current development.

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The participative budget of making a city sustainable: quintuple helix approach

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Abstract. For transition economies, urban management processes are also in transition, which also means a situational opportunity to apply an integrated approach to the implementation of innovative projects, in which economic and political, as well as social, socio-cultural and environmental directions of development can receive a positive stimulus. Purpose of the study is to analyze the structure of participatory budgeting projects on the continuum "science and education – environment", in accordance with the methodological approach to justify the innovative development of the city (based on helix-modeling). The paper has outlined an approach to activation the principles of sustainable and inclusive development at the local level, on the example of the participatory budget of Kyiv city in Ukraine. At the methodological level, the stages of the evolution of helix-modeling to the quintuple level have been analyzed in detail, the results of which are proposed to be implemented in accelerating the transformation of the projects structure aimed at the development of economic, social and environmental aspects of citizens life, namely in the fields of education, science, culture, sports, ecology, etc. Analysis of the change in the structure of participatory budgeting in Kyiv for the period 2017-2019 allows us to talk about the optimistic transition scenario of the city and the country in whole to the real pace of achievement the Sustainable Development Goals 2030. Strengthening the current positive changes with the help of state support, as well as ensuring a sufficient responsible investment, allows at a project level to succeed in improving the sustainability of the city.

1 Introduction

Urban sustainability is one of the current areas of research within the concept of sustainable development [1–3]. In the conditions of transformation [4], the specificity of the situation lays not so much in the smart city – the global trend of urban planning and urban ecology of the last decade, but in the constant maintenance of sustainable and innovative urban development.

Contrary to the fact, that scientific sphere in Ukraine as of 2020 is in the situation of waiting for reforms; innovation activity begins exactly in this sphere. And then from here innovations gradually spread to other spheres of society life and development of the country and its cities. From education and science begins all-encompassing progress, in which business and industry, the public and activities related to the environment are involving. It is clear that without state support it is impossible to stabilize the sustainable development of cities and achieve the Global Goals at the international [5] and national [6] levels (especially Goal 11 "Sustainable cities and communities"), given the possible threats and impact of crisis factors.

Along with direct investment, an important tool for provision of sustainable urban development is a participatory budgeting. Since this process is relatively new for Ukraine, it is advisable to theoretically substantiate it on the basis of approaches to innovation modeling, which complement the approaches to modeling the relevant investment processes [7; 8].

It is also advisable to make extensive use of foreign experience in participatory budgeting. At the beginning of the 21st century, Europe adopted this sustainable mechanism from Latin America and, as of 2010, applied it in dozens of cities. The participatory budgeting gained the greatest development in Italy, Portugal, Spain, France, Germany, and the United Kingdom. The most common models of the participatory budgeting development in Western Europe are as follows: participatory democracy (clearly defined rules, good quality deliberation; combining strong participation with social justice), proximity democracy (informal rules, deliberative quality weak or average; combining participation with formal decision-making process) and participatory modernization (rules may be clear, weak deliberative quality; broad political consensus) [9]. In Germany, for almost two decades, participatory budgeting has evolved from a symbolic political instrument to improve communication between citizens and administration [10] to a mechanism for democratic innovation and municipal modernization [11].

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2 Methodology

The conceptual basis of the study is an evolutionary approach to innovation development modeling – the helix-modeling (Fig. 1), which includes six types of models (three prototype models and three helix models), as well as five gradual stages of transition from one model to another: from a linear model to a quintuple helix model, which summarizes the following elements of innovation development: science and education, business and industry, government and state support, the civil society, the environment and the social environment.

The proposed approach was used to analyze the dynamics of structural changes in the short term (2017–2019) on the example of the formation and use of participatory budget at the municipal level, namely the example of Kyiv city.

The information base is the online platform [18], on which project data is constantly updated.

The evolutionary approach in the context of changing the forms of descriptive helix-model, when it is transferred to the plane of formation of the participatory budget of the city, allows to identify features of its innovative development and to substantiate expediency of acceleration of transformation of projects structure.

3 Results

The logic of the study consists of, firstly, on the actualization of a set interrelated factors of sustainable development, including reflection in indicators that characterize the social and environmental components of sustainability and inclusiveness, at the level of the economic region of Ukraine, the center of which is Kyiv city; and also, secondly, on the implementation of the analysis of the structure of project directions within the participatory budget of Kyiv city on the basis of an evolutionary approach to helix-modeling of innovation activity.

3.1 Rating analysis of sustainable and inclusive development indicators of the territory

When conducting analysis of sustainable and inclusive development indicators of the Central economic region of Ukraine, their comparison with similar indicators of other economic regions of Ukraine were carried out and, accordingly, the results of the rating assessment were obtained (Table 1). The results (above all, the first place by level of higher education, as well as the second place by level of Internet access) prove the existence of preconditions, and therefore the expediency of innovative modeling of participatory budgeting in Kyiv. Also the composition of the main problems can be seen preliminarily (for example, VII place – overcrowding housing or VI place – the inability to satisfy recreational services), which, on the one hand, reflect the situation in the country, and, on the other hand, indicate bottlenecks in urban development and therefore it should affect the structure of the participatory budget of Kyiv.

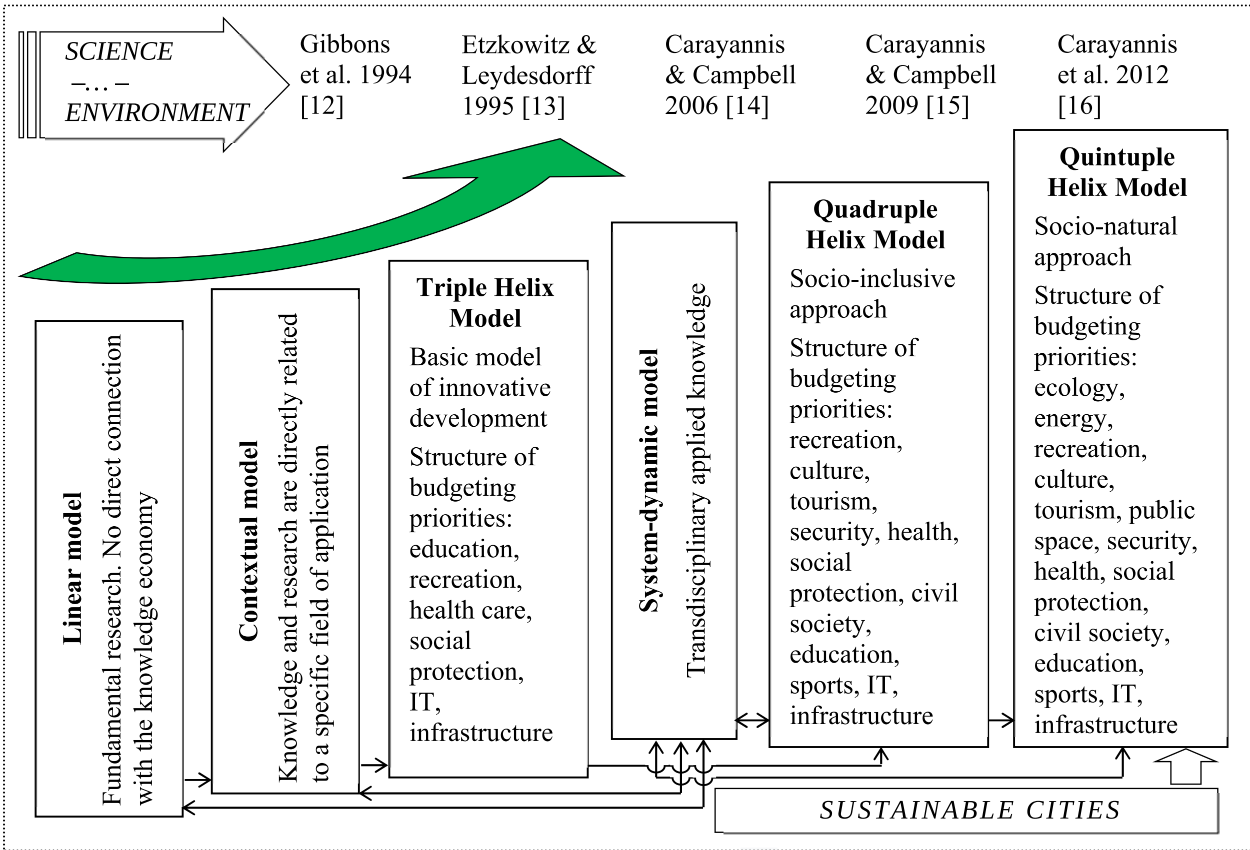

Fig. 1. The evolution of helix-models and its sustainable context (based on [16; 17]).

Table 1. Comparative analysis of sustainable and inclusive development indicators of the Central economic region of Ukraine, 2019 (according to [19; 20]).

Indicators	Value	Ranking
Number of household members who rated their health as good, thousand	3112,25	II
Number of household members who rated their health as bad, thousand	424,49	III
Households whose members constantly denied themselves the most necessary, in addition to food, thousand	654,30	III
Share of persons suffering from 4 or more signs of material deprivation of 9 signs, %	14,90	II
Share of population living in overcrowded housing, %	54,50	VII
Share of households that are (very) dissatisfied with housing conditions, %	13,10	II
Share of households that are (very) satisfied with housing conditions, %	60,60	I
Number of persons who can allow minimum recreational services, thousand	2298,80	VI
Number of persons who reported that they used Internet services at least once a day, thousand	2952,60	II
Number of households with Internet access at home, thousand	1553,00	II
Share of population with complete higher education, %	33,80	I
Number of persons living in households who could not afford unexpected necessary expenses, thousand	2861,50	VI
The average indicator of ecological status	10,00	III
Total	–	I

3.2 Evolution of helix-modeling and its projection into the plane of formation of innovative ecologically oriented, educational and other socially significant projects

That, how helix-modeling evolved is shown in Figures 2-6: from a linear model that reflects the activities of educational and research institutions (Fig. 2, upper left corner) to a model that includes five interconnected components, integrated in the joint innovation process – quintuple helix model (Fig. 6).

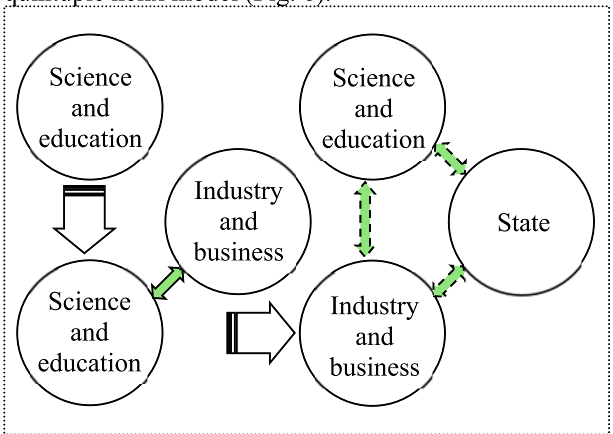

Fig. 2. Triple helix-modeling scheme for innovation activity in emerging countries (based on [21]).

The structure of participatory budgeting in Kyiv is presented in Table 2.

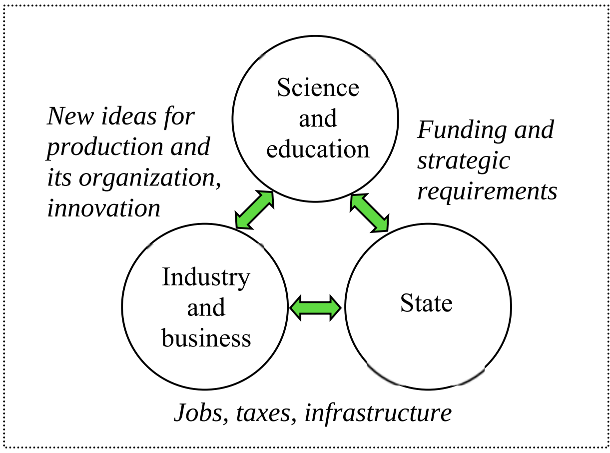

Fig. 3. Triple Helix-modeling scheme for innovation activity in countries with economies in transition (based on [21]).

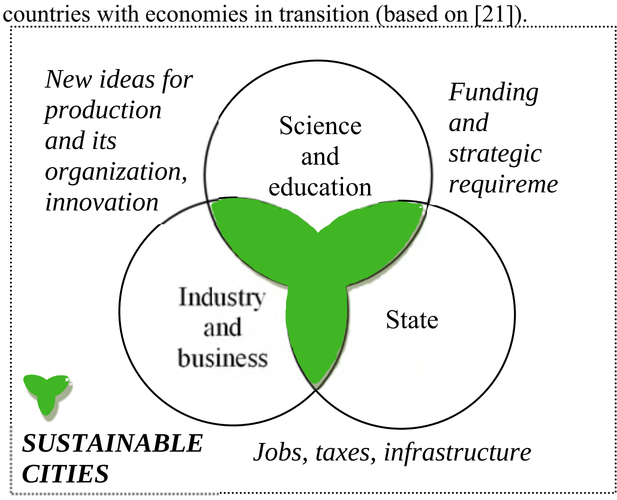

Fig. 4. Triple helix-modeling scheme for innovation activity in developed countries (based on [21]).

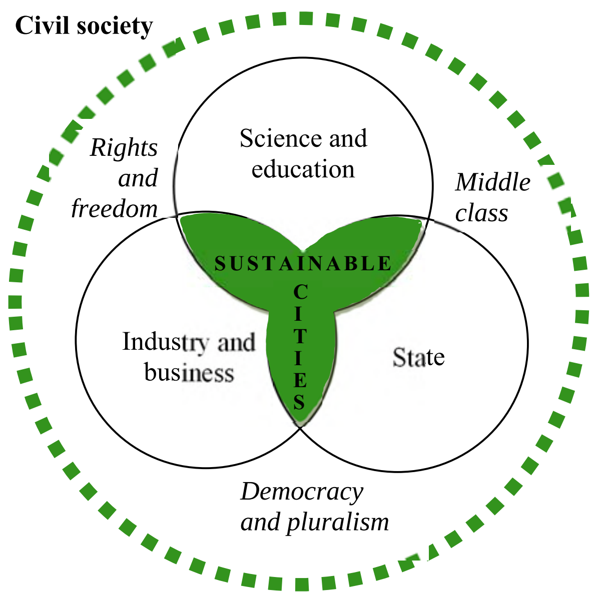

Fig. 5. Quadruple Helix-modeling scheme for innovation activity (based on [15]).

The analysis results of the changeability of the structure of innovative projects directions within the participative budgeting of Kyiv (Table 2) allow to speak about the optimistic scenario of transition of the capital of Ukraine to real rates of achievement of Sustainable

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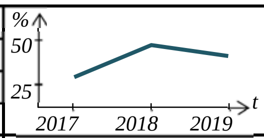
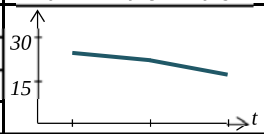
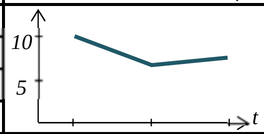
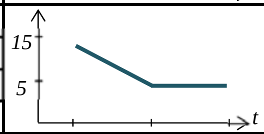
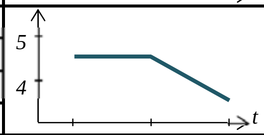
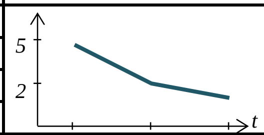
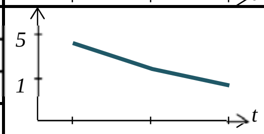
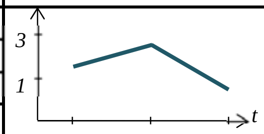
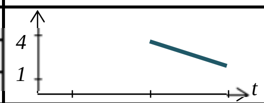
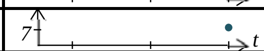
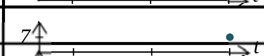
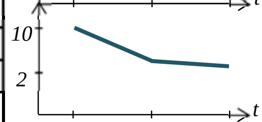
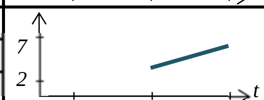
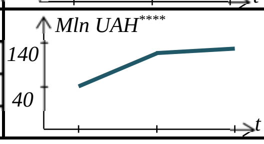
Development Goals by 2030 (by overcoming the coronavirus pandemic and its consequences in the short or medium term perspective 2021–2023) under the condition of accelerating the transformation of the project structure towards the balance of economic, social and environmental factors, and at the same time increase funding by rising the volume of responsible investment.

Table 2. Projects of the participatory budget of Kyiv, 2017-2019 (project cost in 2019: UAH 50,000 – 3 million) (according to [18]).

Categories of projects	Period	Number of projects: all, winning, %			Number of votes cast, % per year, trend			Cost of projects: all, winning, %		
Education	2017*	76	18	23.7	28020	28,3		54355309	15026066	10.7
	2018**	75	28	37.3	31739	45,2		25838568	10377291	40.2
	2018***	165	29	17.6	172732	49,8		285349395	57909982	20.3
	2019	295	135	45.8	192596	39,5		219802938	58345294	26.6
Sports	2017	89	12	13.5	22260	22,5		58286296	10848183	18.6
	2018	42	14	33.3	12704	18,1		14789451	5162387	34.9
	2018	116	17	14.7	79027	22,8		198933838	31331915	15.8
	2019	138	38	27.6	79239	16,3		126088215	20356399	16.1
Culture, tourism	2017	65	3	4.6	9912	10,0		44221186	1918735	4.3
	2018	21	5	23.8	4657	6,6		7526261	1742731	23.2
	2018	34	4	11.8	24325	7,0		57255287	6925000	12.1
	2019	78	15	19.2	37609	7,7		66066332	14563595	22.0
Health	2017	38	5	13.2	14078	14,2		21855650	4166000	19.1
	2018	6	2	33.3	2077	3,0		1989936	800000	40.2
	2018	28	3	10.7	23360	6,7		47476184	5960893	12.6
	2019	26	11	42.3	23388	4,8		37274699	8039884	21.6
Social protection	2017	30	2	6.7	4476	4,5		19781017	1293100	6.5
	2018	21	7	33.3	5601	8,0		7320170	2750042	37.6
	2018	22	1	4.6	4325	1,2		35773962	1850000	5.2
	2019	32	15	46.9	16578	3,4		15263694	4191334	27.5
Infra-structure	2017	28	3	10.7	4843	4,9		18212164	2992549	16.4
	2018	11	2	18.2	2593	3,7		2733409	799980	29.3
	2018	12	0	0	2244	0,6		20476000	0	0
	2019	17	3	17.7	6942	1,4		14717256	1042600	7.1
Security	2017	26	2	7.7	4103	4,1		16411352	1980719	12.1
	2018	10	2	20.0	1175	1,7		3642675	769895	21.1
	2018	10	2	20.0	7320	2,1		17709851	3780000	21.3
	2019	16	4	25.0	3298	0,7		13691455	1201973	8.8
IT	2017	19	0	0	1267	1,3		12263997	0	0
	2018	7	2	28.6	2180	3,1		2391115	785519	32.9
	2018	15	1	6.7	8577	2,5		28383907	2000000	7.0
	2019	17	1	5.9	3528	0,7		21415954	741054	3.5
Others	2018	8	2	25.0	2572	3,7		2115105	503000	23.8
	2018	10	0	0	2074	0,6		16632020	0	0
	2019	22	6	27.3	8081	1,7		17586941	2251781	12.8
Energy	2019	76	19	0.25	36505	7,5		48684801	7465896	15.3
Public space	2019	55	18	32.7	34110	7,0		49858463	11550493	23.2
Ecology	2017	40	7	17.5	10130	10,2		26317569	4218339	16.0
	2018	17	1	5.9	3652	5,2		6182506	400000	6.5
	2018	31	0	0	8768	2,5		56476009	0	0
	2019	35	9	25.7	11848	2,4		20965023	3302023	15.8
Civil society	2018	13	2	10,9	1299	1,8		4452347	799948	18.0
	2018	30	1	3.3	14331	4,1		53802254	2000000	3.7
	2019	330	44	13.3	33618	6,9		83361237	7862000	9.4
Total	2017	411	52	12.7	99089	100		271704540	42443691	15.6
	2018	231	67	29.0	70249	100		78981543	24890793	31.5
	2018	473	58	12.3	347083	100		818268707	111757790	13.7
	2019	1137	318	28.0	487340	100		734777008	140914326	19.2

*Cost of projects (UAH): 1 thous. – 1 mln, **1 thous. – 400 thous., ***401 thous. – 2 mln, **** Trend of total project cost

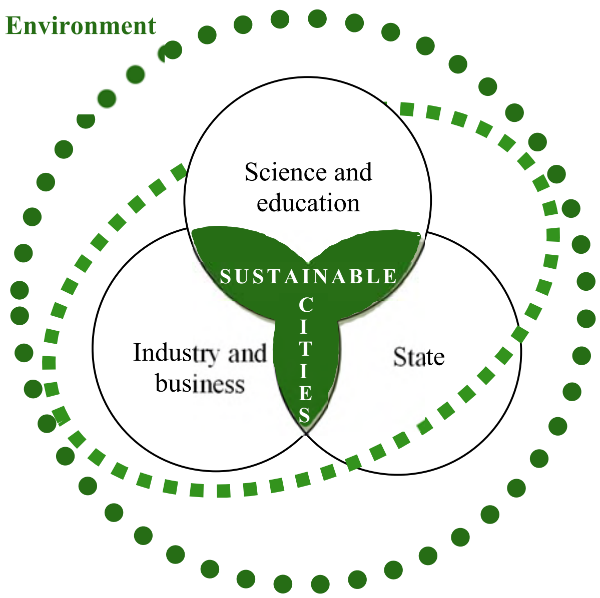


Fig. 6. Quintuple Helix-modeling scheme for innovation activity (based on [16]).

Based on these results and taking into account the experience of Germany [22; 23], as well as recommendations for ecologically oriented recreational development [24; 25] and the introduction of international standards to strengthen the resistance to the coronavirus pandemic [26], an indicative structure as a benchmark for the sustainability of Kyiv city in the medium term is proposed in the paper (Fig. 7).

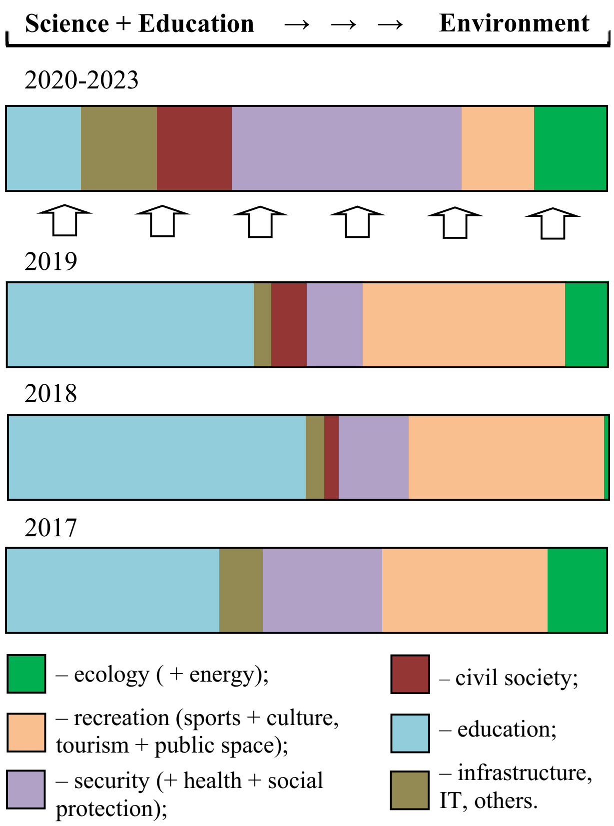


Fig. 7. Structure of project directions (according to the total cost of winning projects) within the participatory budget of Kyiv.

The main share (it is proposed to triple its weight in order to accelerate the response to the pandemic) in the structure belongs to security. Other shares have an approximately equal weight, which corresponds to the principle of balance: the weight of ecology, infrastructure and civil society increases, but the weight of recreation, and education decreases, which is possible in the conditions of distance learning.

4 Discussion

Trends and prospects for the development of educational sector and its support in the side of the state and international organizations, in particular in Germany, which has one of the most progressive and effective systems of education and science [27–33] within participatory budgeting requires a balanced approach to attracting investment. It is necessary to strengthen the role of public-private partnership, which will ensure the guarantee of completion the projects in full of planned costs, as well as control over the quality of their implementation, including in the period after the completion of projects. This provision is principal: the sustainability of cities and, in particular, of educational sector means ensuring the support of realization innovative, especially inclusive, projects over a long period of time, now, as a rule, till 2030. For countries with economies in transition responsible investment is extremely important, especially aimed at the development of inclusive education.

5 Conclusion

The study of the participatory budgeting contribution to the sustainability of the city, on the example of Kyiv in Ukraine, based on the methodological approach of innovative helix-modeling is conducted in the paper. The evolution of helix-models, ranging from the basic model (triple helix model) to the ecologically integrated model (quintuple helix model) demonstrates the importance of not just taking into account the additive principle, but the integration of five components (science and education, business, government, public, environment) in the plane of innovative projects implementation formed on the principles of sustainability and inclusiveness. The analysis of the participatory budgeting structure, aimed at increasing the sustainability of Kyiv city, confirms the positive dynamics relevant to the evolutionary approach of helix-modeling. Given the pandemic crisis, as well as the peculiarities of the Sustainable Development Goals implementation in Ukraine, a benchmark of this structure in the medium term 2021-2023 is proposed in a study, which is based on a balance of six components: ecology, recreation, security, civil society, infrastructure projects and education. Taking into account the specifics of the current situation, security has the largest share, the share of education and recreation should decrease, but the share of the environment, including the recreational environment increases due to the expansion of "green" public space. An increment of the share of civil society to accelerate the development of democracy in the country is also important.

Prospects for further research are related to the analysis of the possibilities of applying the participatory budgeting mechanism within the European Green Deal, in particular such strategies as “A zero pollution ambition for a toxic free environment”, “Accelerating the shift to sustainable and smart mobility”, and “Supplying clean, affordable and secure energy” at the municipal level.

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The transformation of the engineering and planning organization of the territory of the Luhansk region in the conditions of the functions changing of the regional typology

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Abstract. The conditions of the origin, development and transformation of the Donetsk and Luhansk regions of Ukraine are considered. There is an irreversible tendency to reduce the industrial potential of the coal and metallurgical industry, the collapse of the urban base. The nature and scale of the impact of the armed conflict in eastern Ukraine on the state of engineering and planning organization in the territory of Luhansk region is studied. Trends of development, circumstances and preconditions of formation of agglomerations of the region are determined. The correspondence of regional typologies on the basis of function in modern conditions of armed conflict is analyzed. The analysis allows us to identify the following important aspects. A gradual but irreversible process of deindustrialization is recorded. The transformation of the engineering and planning organization of the territory of the Luhansk region in the conditions of the armed conflict in the East of Ukraine is a fait accompli. A new political and economic reality is being formed. The Luhansk and Donetsk regions are artificially divided. The internal status of the region has led to the formation of a large number of urban agglomerations, a dense transport network. The analysis of a demographic condition, a territorial, town-planning complex testifies to discrepancy of typological signs of the area in the modern conditions. The Luhansk region is becoming a cross-border region with a dense border. It is expedient to expand the existing classification of regions by introducing certain special functions of the regional typology. In modern conditions in the Luhansk and Donetsk regions the border region is formed. Along this line, the function of cross-border cooperation is complemented by the function of border control. This function aims to limit a certain type – the fixation of the border, the mode of its crossing, strict compliance with statutory procedures. The addition of the functions of the regional typology should be taken into account in the tasks of improving the territorial – planning organization of Luhansk region.

1 Problem statement

The Donetsk and Luhansk regions form the Donbass region, which is characterized by the highest level of urbanization in Ukraine. It is an old industrial region based on the coal and metallurgical complex. The phase of extensive development based on the active exploitation of minerals, primarily coal, has passed. The need for a continuous increase in coal production no longer exists. An irreversible tendency towards a decrease in the industrial potential of the coal and metallurgical industry is forming. Due to a decrease in industrial potential, a reduction of the urban planning base is recorded. In 2014, an armed conflict broke out in the East of Ukraine, inspired from the outside, which significantly worsened the situation, and introduced unforeseen circumstances in the form of alienation of the part of the territories. The strategic directions and tasks of the territorial development of the Luhansk region require updating and adjustment.

The territories of the Luhansk and Donetsk regions are highly urbanized. As of 2014, the percentage of the urban population of the regions reached 80-90%.

The population of the Donetsk region amounted to 4,356,000 people, Lugansk region – 2,256 million people, together more than 6,600,000 people, which in aggregate more than in some small European countries. Of the 47 European states, 27 have a population of less than 6 ml. people. [1] The artificial division of the territories of the two regions radically changed the engineering and planning organization of the region. The task of urban development, territorial planning should take into account the circumstances caused by the armed conflict. Research and analysis of the problems of territorial development of the region are relevant.

2 Purpose, idea and research methodology

The goal of the research – to study the nature and extent of the impact of the armed conflict in the east of Ukraine on the state of the engineering and planning organization of the territory of the Luhansk region. Determine development trends, circumstances and prerequisites for the formation of the agglomerations in the Luhansk region. To investigate the place and role of the Lisichansk-Severodonetsk agglomeration in the system of regional settlement and the Luhansk region, to establish the peculiarities of the formation of the functional spatial structure of the agglomeration, its development trends, the evolution of the regional settlement system, the state and problems of urban development. Analyze the correspondence of the regional typologies on the basis of function in modern conditions of the armed conflict.

The idea. Ukrainian Donbass has unique historical features. In fact, this industrial region instantly emerged and developed. However, the focus on the coal and metallurgical complex, the outdated industrial structure led to a gradual decline in the region. The complex of socio-economic problems has multiplied the complexity of the armed conflict. All development strategies, territorial planning tasks, territorial development management tasks have lost their relevance. The need arose to improve the methodological prerequisites for managing the development of territories.

Methodology. Research is based on systematic analysis, analytical comparison, historical methodology. The paper investigates external and internal factors influencing the functional and planning organization of the region. The information base consists of literary and archival sources, cartographic materials.

3 The research results

In the theory and practice of regional planning, the classification of regions according to the features of function and form is used. By functional purpose, there are the metropolitan, transport and cross-border regions. According to special natural conditions, there are coastal, riverside and regions with minerals. [2] In the Luhansk and Donetsk regions, a border region is formed, which arose and functions in the context of an armed conflict. The border control function aims at a certain type of restriction – fixing the border, the mode of crossing it, strict adherence to legally established procedures. The addition of the functions of the regional typology should be taken into account in the tasks of improving the territorial planning organization of the Luhansk region.

7 agglomerations were formed on the territory of the Luhansk and Donetsk regions of Ukraine (Fig. 1). [1]

The Luhansk region is located in the east of Ukraine and since 2015 is located in the zone of the joint forces operation (JFO), part of the region's territory is not controlled by state authorities. The regional center, Lugansk, was seized by illegal armed groups and lost its administrative and economic significance. The administrative functions of the regional level were transferred to the city of oblast subordination, Severodonetsk.

The region is characterized by a high level of urbanization. By the number of cities, it ranks second in Ukraine. On the territory of the region, it is possible to distinguish the agrarian north, the industrial center, the coal mining south. According to the type of settlement, the following agglomerations can be distinguished: Central-Lugansk (Alchevsk – Kadievka), Severo-Lugansk (Lugansk), Yugo-Lugansk (Khrustalny), Severodonetsk – Lisichansk agglomeration. (Fig. 1). [1]

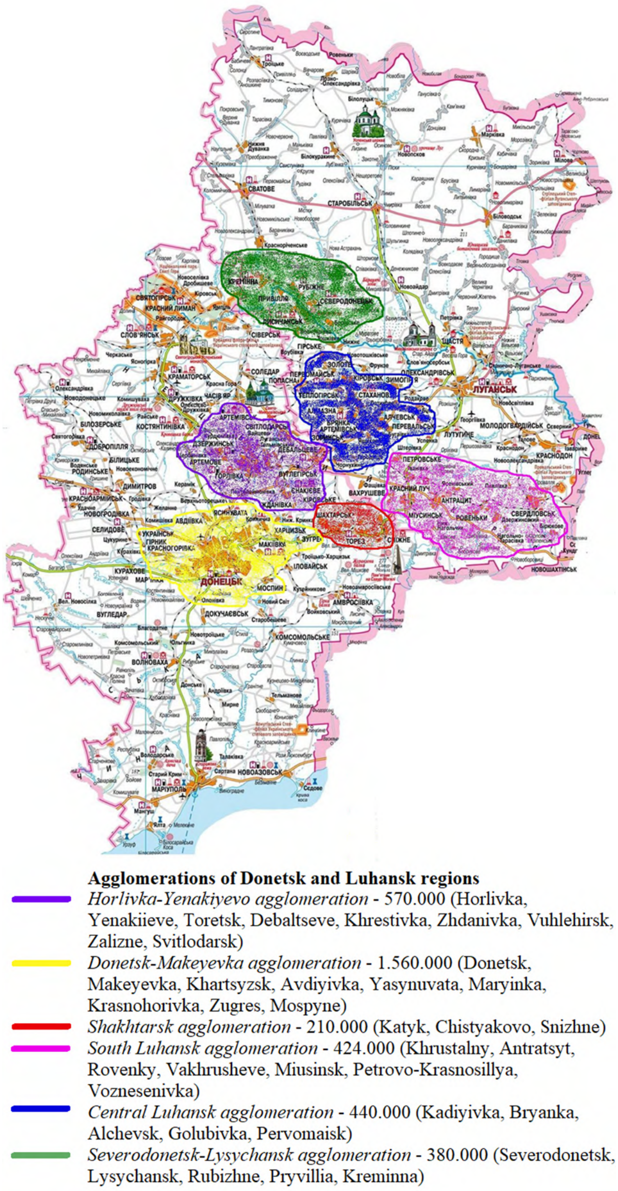

Fig. 1. The agglomerations of the Donbass region.

Donbass arose and developed instantly, by historical standards (Fig. 2, 3). History has not known such cases [3, 4].

Rapid growth of the extensive type threatens the decline of developmental factors. In an industrial economy, excessive urbanization overloads the territory. In conditions of limited natural resources, the maintenance of the vast majority of the working population causes structural distortions of the development. The city's own exports should prevail, then the city has the opportunity to develop. This statement is also true for agglomerations [5]. In the archaic agrarian period, this region is better known as the Wild Field. The Donbass region belongs to the zone of risky farming, when only 2 out of 10 years are usually productive. Thus, from 1799 to 1856, for a period of 57 years, there were 28 non-productive years [3].

There were 1.1% of skilled agricultural workers at the beginning of the twentieth century in the Donetsk region, and correspondingly in the Luhansk region. – 1.3% of the population. Such low indicators show, firstly, an insufficient level of provision of the region with its own food, secondly, the resource of further urbanization is almost exhausted, and thirdly, the lack of agricultural land, however the possibilities of intensifying agricultural production are clearly demonstrated by such states as the Netherlands and Israel.

Fig. 2. The scheme of the main industrial regions of Europe during the Industrial Revolution.

It should be noted – Donbass has always been an internal region. It had transport and geographical advantages and contributed to its development as a powerful industrial hub.

The rapid development of Donbass begins in the 70-80s. of the 19th century, when the action of the several key factors of the industrial revolution coincided:

- The aggression of the Russian Empire in the direction of the Balkans and the Black Sea, which required a large number of weapons, hence metal;
- The emergence and spread of steam engines and steam locomotives – consumers of coal;
- Ukrainian chernozems became safe agricultural economic territories after a series of Crimean and Turkish wars, the partition of Poland.

In 1895–1900 the production of iron and steel in the Donbass equaled the volume of production in the Urals, that is, from this period Donbass can be considered a new industrial center of the Russian Empire. [3]

The events of the XX century, IWW and IIWW affected the territorial development of the region.

Donbass experienced a decline in 1918-1924, which was caused by the civil war and the absence of a central government. In fact, adjusted for the era, the problems were / are of the same nature, and the consequences are generally similar – reduced production, migration of people and workers, widespread gardening to avoid famine, hunger, impoverishment and natural exchange. [6]

For the second time, Donbass was destroyed during the German occupation during World War II. The consequences of the occupation were also exacerbated by the "scorched earth" policy used by the Soviet authorities.

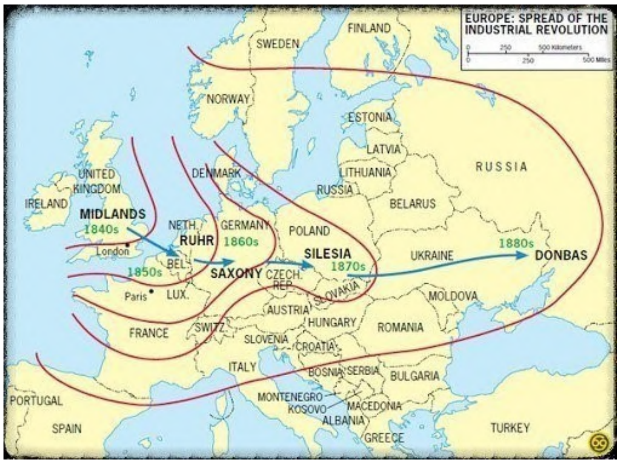

Fig. 3. The speed of the spread of the industrial revolution in Europe [4].

The status of the inland region allowed to quickly restore industrial potential.

After the Second World War, the USSR implemented a large-scale plan to revive Donbass. Metal, energy, and fuel were needed to rebuild the state. However, at that time there were distortions associated with the dominance of the needs of the defense industry. Many companies were focused on the production of military products. [7]

For the period 1950-1980, a strategy for the development of Donbass was laid and partially implemented, which provided for the accelerated urbanization of the region. It is clear that the population growth was mainly due to labor migration, including the use of tough administrative measures.

During the days of independent Ukraine, the coal and metallurgical industry stabilized after the creation of vertically integrated corporations, concentrated in the hands of large oligarchic capital.

Geography does not always take into account state boundaries. Part of the coal deposits are located on the territory of the Russian Federation – in the Rostov region. The Russian part of Donbass still looks ugly, with the only prospect – accelerated degradation, social and demographic. The coal industry practically does not exist in the region. Economic factors, logistics conditions have made the region's coal unprofitable. The mining and metallurgical complex of Russia is concentrated in the Urals. It is necessary to take into account the fact that in this direction the development of the situation in the Russian part of Donbass is ahead of two decades, which means that it indicates the similar consequences in Ukraine for coal-mining cities.

Analysis of the prerequisites for the formation of the Donbass phenomenon, the study of trends that are laid down by statistical data, allows us to determine the following important aspects.

The development of the region was uneven, based on a resource economy. When a natural resource is exhausted, a gradual but irreversible process of de-industrialization begins.

We note once again – the coal has not run out – the need for coal has decreased. As historians testify, J. Hughes, the founder of Yuzovka – Donetsk, counted on the life of his industrial empire for 50-60 years.

Large multidisciplinary cities have developed in an advantageous location, gradually increasing and pulling into their orbit nearby territories and settlements.

History knows cases when majestic capitals disappeared from the map of the world, and cities that had a strategic status and influence have now turned into second-class provincial cities (Carthage, Genoa, Venice).

The Agglomerations of Donbass were formed from settlements at industrial enterprises. Enterprises were grouped near mineral deposits. Socialist cities have their own history, which begins with workers' barracks next to factories.

It can be assumed that the exploitation of the natural resources of Donbass was of a colonial nature. After all, the first investors were foreign capital – the Scots, Belgians, etc. The Soviet government was also more willing to take as much resource as possible from Donbass in a short time. It is impossible to speak seriously about the priority of the development of the urban environment and the quality of life. Among the arguments in favor, opponents give examples of regional development programs for Donbass, but the results of the implementation of these programs speak for themselves:

- The urban development planning proceeded from the needs of the industry in workers. The primary bias is due to the narrow profile orientation of heavy industry. So, during the Soviet era, the question arose of a shortage of jobs for women – after all, mining is a predominantly male profession. Again, they tried to solve the problem in a directive way – they built enterprises focused on women's work. The results have not always been successful;
- the priority for the maximum indicators of industrial production has led to environmental pollution of the territory, which is partly irreversible;
- cases and threats of man-made disasters caused by overexploitation;
- catastrophic pollution of water resources. This fact alone may be enough to make the area uninhabitable;
- unfavorable demographic situation and depopulation, which is actually becoming a fact;
- deindustrialization – and, as a possible consequence, degradation of industrial potential; an excessive number of places of detention, which is typical for the Soviet economy with the use of prison labor.

The deterioration of the ecological situation, the instability of the economic complex, the high proportion of industrial and communal storage areas in the structure of the city have led to the fact that at the present time these "tired" cities are large industrial areas, a significant proportion of the population of which lives in sanitary protection zones. [7]

The consequence of all these distortions, multiplied by the political turbulence of the post-Soviet period, was a significant deterioration in the quality of life of the overwhelming majority of the population. The social, political, economic, and financial crises have deprived the resources necessary for decisive progressive changes. A somewhat deformed structure of employment has taken shape. At the beginning of the 21st century approximately 10% of the population of Donbass was involved in management, 30% of highly skilled workers for non-physical labor, 40% of skilled manual labor, 13% of unskilled professions. [8]

For the first time, Donbass faced a situation when, instead of a recipient of labor resources, it turned into a donor. Objectively, this is a completely natural process. Industrial degradation is causing job losses. The wage arrears crisis is making local jobs unattractive. First of all, young people and highly qualified personnel leave. The deterioration of the situation enters a new circle.

Quote: "The number of workers in the Yekaterinoslav region in 1913 compared to 1861-1870 increased 41 times." In modern conditions, such an increase looks like something extraordinary. [8]

In the society of the region, paternalistic expectations are widespread, the essence of which is briefly described by the thesis "Donbass feeds everyone", "the center is robbing us". The Donetsk and Luhansk regions took the last and penultimate places in terms of the aggregate level of human development in the region. The factors that led to the low rating are due to unsatisfactory indicators of the demographic state, living conditions of the population, the level of education, a very difficult ecological situation, and an inappropriate level of development of the social environment. However, Donetsk region took the third place in terms of material well-being out of 27 regions of Ukraine.

Statistics, however, show that this public belief contradicts economic indicators. The share of GDP of the Donetsk region in 2010 was 12%, and the total share of subsidies and transfers reached 20.9%, and 27% in 2011. The Luhansk region contributed 4% of GDP, while subsidies and transfers in 2010 and 2011 were 7.8% and 11%, respectively. That is, Donbass received 2 – 2.5 times more than it gave. At the same time, the

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regions recorded the largest volume of wage arrears. [8]

Let us add one more aspect – the economic crisis has entailed humanitarian complications. The number of scientific workers, has decreased. But since the scientific staff had a narrow industry focus, this makes it impossible to use them in other areas.

Deindustrialization, social and humanitarian crises lead to the reproduction of an archaic type of survival – so-called "Copanks" (small illegal coalmine) and the collection of scrap metal. It is becoming the norm and no one is surprised when the trolley wire or cables are stolen.

But a crisis can turn into a disaster. All of the above are prerequisites for the current situation. The armed conflict was inspired, among other things, due to the deformed social and national structure of the region, regional proximity to the border, the lumpenization of the population makes the consequences in the region catastrophic.

At the beginning of the XXI century, the industrial cities of the Lugansk region faced a number of problems caused by the collapse of the industrial base. Such as: ecological overload of territories; outdated technology of the industrial era; curtailment of the urban planning base; decrease in the number of working-age population.

In 2014 this situation was aggravated by the armed conflict. There is a situation of artificial division of the territorial and economic complex, which has been going on for more than 6 years, the time period is comparable to the stage of implementation and planning of the general plan decisions. [9]

Fig. 4. The JFO demarcation line.

The JFO demarcation line separates the two regions of Donbass, blocks a number of highways and a national railway. The north and most of the agricultural land of the Luhansk region are under the control of Ukraine. The south and center are not controlled by the government. The front line runs along the boundaries of the main agglomeration formations and along natural barriers. (Fig. 4). [10]

The situation has certainly negative consequences, the issues of territorial development, improvement of urban planning and planning organization are generally removed from the agenda.

The uniqueness of the situation is that the place of conflict is an urban area. (Fig. 5). [11].

Despite the localization of the front line, the area of the conflict can be compared to a small European state. Ukraine does not control 407 km. state border, 47 000 km^2 or 12% of its territory (including the Crimea), the demarcation line reaches 427 km. (Fig. 6). [10, 12] 1.4 million people are registered as temporarily displaced, and almost 4 million remain in the uncontrolled territory. External military intervention has a hidden hybrid nature. Foreign policy factors dominate in resolving the armed conflict.

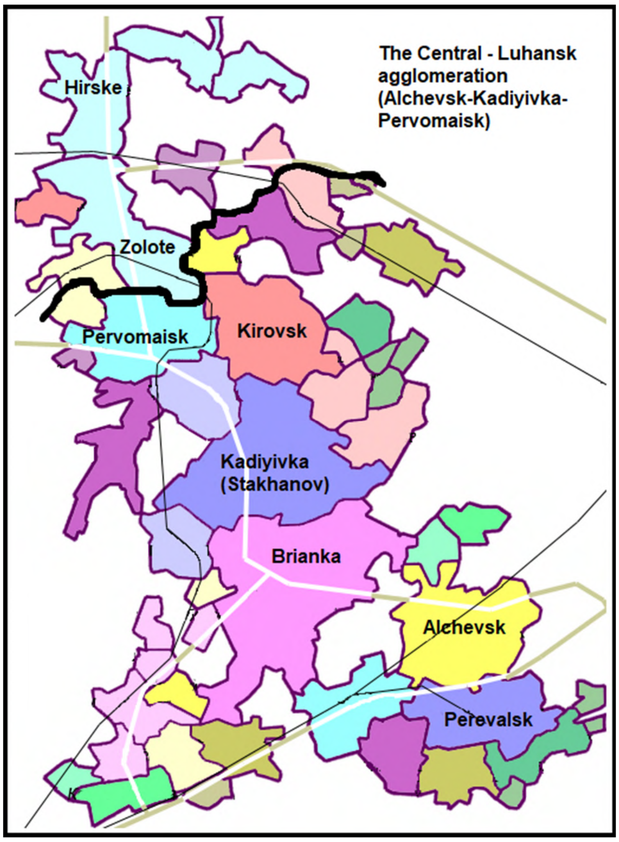

Fig. 5. The scheme of the Central – Luhansk agglomeration. The administrative boundaries of settlements.

Unfortunately, there is still no reason to assert that there is a well-developed, effective and resource-secured scenario for overcoming the crisis.

The political component dominates and makes economic forecasts insignificant.

There may be several basic scenarios:

- Return of control over the temporarily occupied territories in the near future;
- Return of the temporarily occupied territories in the distant perspective.

We will not consider the first scenario in our article, as it will probably involve a number of political agreements that create burdens.

The second scenario makes the territory of the Luhansk region controlled by Ukraine, with the only

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large agglomeration – Severodonetsk-Rubezhnoe – Kremennaya, the object of research.

Yu. M. Belokon provides a classification of regions based on function and form. The regions of the first group are divided according to their functional purpose: metropolitan; transport; cross-border.

Regions of the second group, according to special natural conditions, are divided into coastal, riverside and regions with minerals. [7] The author notes that industrial regions with minerals have the same tasks of modernizing the coal industry, providing employment for the population, improving the environment, looking for new incentives for development. Separately, it was noted that cross-border regions should become an actual object of the urban planning. [7]

Fig. 6. The territories of Ukraine occupied by illegal armed group (the temporarily uncontrolled territories of Ukraine).

At the level of scientific discussion, the question arises of an extensive interpretation of the list of individual special functions of the regional typology. Along the demarcation line, along the existing border, which is temporarily uncontrolled by Ukraine, a de facto border region is being formed, within which the concept of "cross-border cooperation" can acquire another function – "border control" – when the state border plays a protective role.

It is advisable to direct further research to drawing up a balance of the available resources of the region. [13, 14] The list of balance groups under consideration should contain: population and its demographic structure; territory including agricultural land; industrial production volumes; available resources of minerals; level of provision (self-sufficiency) with water resources; level of security (self-sufficiency) with energy resources; transport development of the territory; the level of social development of cities and territories; the level of environmental pollution. It is also advisable to perform zoning of the region's territory in modern conditions.

4 Conclusions

The transformation of the engineering and planning organization of the territory of the Luhansk region in the conditions of the armed conflict in the East of Ukraine is a fait accompli. A new political and economic reality is being formed, which cannot be ignored. The Luhansk and Donetsk regions are artificially separated. The industrial region developed as a coal and metallurgical industrial complex. Its status as an inland region has led to the formation of a large number of urban agglomerations and a dense transport network. The analysis of the demographic state, territorial, town-planning complex testifies to the discrepancy between the typological features of the region in modern conditions. The Luhansk region is turning into a cross-border region. The existing classification of regions provides for two groups – by typological features of function and form. There is a need to expand the list of individual special functions of regional typology. In modern conditions, in the Luhansk and Donetsk regions, a border region is formed, consisting of sections of the state border and the JFO demarcation line. On this line, the function of cross-border cooperation, where the dominant is the exchange of goods, services, cultural contacts, is supplemented by the function of border control. This function aims at limiting a certain type – fixing the border, the mode of crossing it, strict adherence to legally established procedures. The addition of the functions of the regional typology should be taken into account in the tasks of improving the territorial planning organization of the Luhansk region.

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Positive psychology as a counterweight to youth economic deprivation

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Abstract. The article deals with the topical problem of economic deprivation of young women and men and alternatives for overcoming it through the introduction of the psycho-correctional practices of positive psychology. The subject of the study is to find out the gender symmetry or its violation in the position of the subjectivity of genders in the choice of life activity strategy. The conceptual model of positive psychology and its components as the indicators of the psychological state of young women and men in personal and professional self-determination are presented. The social and psychological factors that determine the satisfaction of the youth with the choice of a job and its content, the ability to direct and adjust the requests and motivations of young women and men in searching for a more successful professional and social status have been substantiated. It has been found out that overcoming gender inequality in social and economic gender expectations, and a sense of economic deprivation of the youth is possible by internalizing the basic principles of personality self-determination through learning, and involvement in positive psychology. Egalitarian orientations concerning the importance of receiving professional education and developing adequate personality qualities are important for youth but especially for young women's internal subjective well-being experience. Satisfaction with social environment and confidence in the coming day the most common international concepts of economic happiness for group youth psychology.

1 Introduction

COVID-19 affected all layers of the population economically and deepened the level of youth "relative deprivation" as the perception of oneself (family or one's own reference group) as less economically prosperous. Self-esteem, being an indicator of a socially less successful economic personal or group compared to others, has always been much higher for the students and working youth. It is young people entering adulthood who have to face such socio-economic challenges as the need to find the desired professional activity and opportunities to achieve it, pay for vocational education or living separate from the family, look for a job without the necessary level of professional qualifications and work experience, support their own financial needs related to the age interests of the youth and more. Eric Erickson by no coincidence found an all-embracing psychological definition of this age stage in the periodization of personality development: identification versus isolation. The process of creating identity occurs during adolescence, but primarily takes place in early adulthood,in soudens years. Reaching adulthood in modern society is not always a linear or clean transition. As generations continue to adapt new adult markers are created that add different social expectations to what it means to be an adult.

2 Problem statement

Experiencing relative economic deprivation as a psychological source of personal unhappiness due to the un fulfillment of many social and basic needs, ways to correct toxic thoughts and find positive meanings in overcoming internal conflicts is one of the areas of positive psychology, which explores the factors of personal subjective well-being (SWB) [1].

Positive psychology explains why the level of youth aggression (various types of crime), when many young people with their inability to accept socio-economic challenges and implement ways of overcoming them, is higher in authoritarian countries, where the share of the middle economic class is low and there is a significant economic difference in the incomes of the upper, middle and lower classes.

Why do the very youth need special psychological support? Because the youth without a proper professional and educational level create a vicious circle of poverty reflection when young people start families that, due to low economic levels, do not have a sufficient level to meet the material and spiritual needs of their own children who, like their parents, are not able to achieve a sufficient level of education, as well as professional in the near future, which poverty again reproduces a new circle of poverty,

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so called vicious circle [2, 3, 4, 5]. The results of the researches testify the difference of value attitudes towards material enrichment of the student youth, which underwent socialization within the framework of market and planned socialist economy [6, 7, 8].

Gender-specific problems in young adulthood are observed in double employment of women, their lower economic status, the level of payment. Even in democratic egalitarian societies dominate the ideas of exploiting one-sex responsibility (man is the main breadwinner and the dominative social and personality expectations from women-to stay at the role of mother, children and caregiver for elderly members of the family) [9, 10, 11, 12, 13]. So the main spheres of her subjective well-being in self-realization, working activity and developing personality habits, skills and knowledge is in family settings. Every new generation continues to adapt new adult markers and create that add different social gender expectations to what it means to be a professional and economically sufficient adult.

The experience of European countries is considered to be the most effective regarding implementation of the positive actions on achieving gender equality. Council of Europe Gender Equality Strategy (2018–2023) focus on six strategic areas: 1) to prevent and combat gender stereotypes and sexism; 2) to prevent and combat violence against women and domestic violence; 3) to ensure the equal access of women to justice; 4) to achieve a balanced participation of women and men in political and public decision-making; 5) to protect the rights of migrant, refugee, and asylum-seeking women and girls; 6) to achieve gender mainstreaming in all policies and measures [14].

If the concept of economic culture in the past was mainly characterized in the financial categories such as expenditures, profits, income, etc., today the economic categories are inseparable from the civilizational principles of providing them with certain legal and moral principles. That is why a set of internal and external factors that have caused the frustration of certain social needs is always considered in the process of analyzing the various causes of protest youth economic movements.

Among them, the degree of satisfaction or dissatisfaction with their social and economic status due to the frustration of a ging demands in the psychological theory of economic deprivation [15]. The relative economic deprivation as a source of the frustration occurs in comparison with others, such as the average income of women with average income of men. At the same time, the greater the level of "relative deprivation" is the greater the mass of protest, often aggressive, angry behavior.

Without stopping on the consequences of gender economic deprivation, which are widely presented in the scientific literature [16, 17, 18], we want to draw attention to the ways of overcoming it through the application of the principles of positive psychology, which is capable of activating personal potential of an individual in overcoming traditional gender stereotypes [12, 13, 19, 20, 21, 22]. After all, if the position of women is assessed according to their economic status, both in relatively economically prosperous societies and in those that are just getting on the rails of a market economy, it will occupy the lowest level.

Since the subjective sense of well-being mediates any sphere of human activity, a lot of research in positive psychology is devoted to the problem of the relationship between professional work and a sense of satisfaction with it, including the research of the factors for happiness. Although mindfulness is integrated in many positive psychology manuals as a "positive" technique, they have hardly developed the implications of their use or have investigated the relationship between mindfulness and human well-being [23, 24, 25, 26, 27, 28].

The opinion of the co-founder of the principles of positive psychology M. Seligman referring to the understanding of the significance of the doctrine of roles in young adulthood states that "The positive emotions of confidence hope and trust, for example, serve us best not when life is easy, but when life is difficult. In times of trouble, understanding and building the strengths and virtues like valor, perspective, integrity, equality, loyalty – may become more urgent than in good times" [1, p. 322].

The study aim~~s~~ is to find out the gender symmetry or its violation in the psychological background personality position of the genders SWB in the choice of professional, working life activity strategies.

3 Conceptual models

Progress in psychological measuring of happiness has been made in understanding the components of SWB: there is no gender correlation between estimation material prosperity and possibility to get perfect professional education and happiness of youth the adaptation, goals and meanings, the cultural influences national indicators of happiness [29].

The favor to the gender division of personal self-realization spheres into male (subject-instrumental) and female (guardian-expressive), is inherent in young men and women with traditional orientations, often as an example of parental imitation. The adherents of egalitarian equality have constructed an androgynous, multidimensional concept of building not only a professional career but also a family one on the basis of the interchangeability of family roles and ignoring the role in their construction of gender. Such universalization of family and professional roles of the genders was motivated, among other things, by the factor of the possibility of achieving the fullness of happiness and life satisfaction in equal partnership.

It is important to note that a happy partnership and personal self-realization at work, as an indicator of internal satisfaction of the position of positive psychology, as indicators of a happy life, is the openness to the new experiences and at the same time self-reliance, actualization of self-aspirations, self-sufficiency, self-perception without protective mechanisms, stereotyped expectations, the position of subjectivity in life.

4 Goals and objectives of the research

The object of the study was socio-psychological factors that determine the SWB of the university students as the strivings for the necessity of developing basic professional skills and opportunities future job activities and accepting its demands and personality expectations. The discovering subjective gender differences in meanings, strivings and abilities concerning the requests and motivations for future economic status.

The subject of the study was to find out the gender symmetry or its violation in the position of the students subjectivity in the choice of life activity strategy.

The main hypothesis at the initial stage of the study was the assumption that young people's individual acceptance of patriarchal gender culture which may be observed difference in personality internalized descriptive, indicative or directive-prohibitive sex stereotypes may reduce and limit the level of desirable work positions in developing subjectivity as reflection of professional abilities, career aspirations, demonstration of individual self-presentation. Traditional gender orientations motivate manifestations of polarization of life spheres and self-realization as among female as well as among male students.

The methods of the research included a complex of complementary techniques (theoretical analysis of the achievements of positive psychology; conducting gender-homogeneous, gender-mixed focus groups, content analysis of finishing sentences as short students answers to opened questions connected with the topic: "It's me in 10-15 years" standardized A. Matchak psycho diagnostic test [30].

Gender differences have been noted and compared in the construction of individual scenarios of future socio-economic life in the time perspective in 10-15 years with the dominative content of individual oral narratives fixed in focus groups discussions. The standardized individual interviews have been conducted was with those young women striving for success in professional non-traditional careers, such as police, military, or IT spheres as well for women and males with strict traditional gender orientations. Egalitarian orientations concerning the importance of receiving professional education and developing adequate personality qualities are important for all young people, but especially for young women's internal subjective-being experience. Different kinds of external or internal factors of students function can determine their subjective well-being in chosen professional education or in starting point of practice searching for the desirable economic status. But the quest for youth meaning is a key part of what makes males and females self-assertive in everyday activities coming toward the desirable financially sufficient constant not temporary status.

Satisfaction with social environment and confidence in the coming day are the most common international concepts of happiness on the individual and group youth psychology including gender.

In total, 298 students (180 female students and 118 male students) participated in the research.

5 The results of research

The data obtained in the research study confirm the results of our previous studies, namely the fact of more purposeful development of the image of economic "I" in male students due to higher coherence of affective, cognitive and behavioral components with internalized traditional gender stereotypes concerning the importance for male persons SWB reaching material and financial status and for the women's SBW to have such husband [21, 22, 31, 32]. Female youth more accept emotions connected with subjective working experience with such emotions as fear, sadness, or anxiety as indicators of unhappiness. Male youth are more likely to overcome them.

Female students show a higher level of intimate competence as an important component of social competence (the method "Questionnaire of three types of competence", A. Matchak [30]) (Fig. 1).

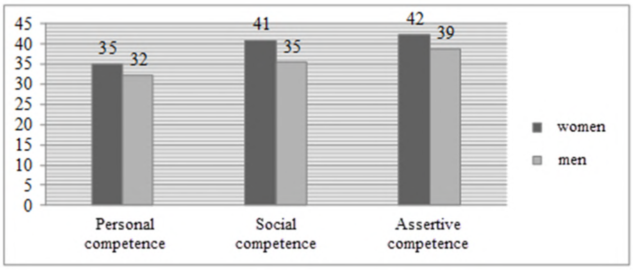

Fig. 1. An average values by "Three types of competence questionnaire" methodology.
Annex to figure1– steins raw results to women and men in**:**
personal competence: females 35–37=3, males 29–33=2;
social competence: females 39–41=5, males 33–35 =3;
assertive competence: females 42–45=5, males, 39–41=4,5.

They are also able to successful presentation their skills and qualities in the social exposition situation compared with the lower men's indicators, which reflecting the ability to be guided by certain standards of presentation of their own professional ability in situations where the person is at the center of attention. Young women are more focused on social interaction than young men; they are characterized through more communicative persistence in the process of doing professional duties. Comparison of the self-determination scale indicators in values of life demonstrates higher results of male selection, reflects their unconditional acceptance of their own life activities, higher self-confidence in successful professional self-actualization.

According to the assessment economic position and "happy human being" turned out to be a significant factor determinates gender difference in economic strivings and professional expectations (Table 1).

The content analysis of the student`s narratives as well as discourses of focus groups discussions (Questions for discussion like "What social environment influence make you more happy?", "What kind of your educational activity make you happier?" etc.) demonstrated the manifestation of gender stereotypes in economic and financial spheres (in youth the design of the concepts of femininity as economic objectivity; masculinity as economic subjectivity and androgynous as gender neutral).

Table 1. The degree of assimilated traditional stereotypes by students (in %).

Varieties (character) of gender prescriptive stereotypes	Percentage of egalitarian stereotypes in the form of women and men *Self*	Percentage of patriarchal stereotypes in the form of women and men *Self*	Varieties (character) of gender prescriptive stereotypes
Descriptive (orienting)	25%	75%	**Descriptive** (orienting)
Prescriptive (evaluating)	10%	90%	**Prescriptive** (evaluating)
Proscriptive	2%	98%	**Proscriptive**

Young women in evaluating SWB in themselves demonstrated a higher level of self-satisfaction in such aspect of it as moral acceptance, coherence of moral views with real behavior, their own ability to manage people than their male counterparts. At the same time, women show a much higher level on the scale of “protective strengthening of self-esteem”, which indicates, on the one hand, a certain degree of acceptance of one’s Self and, on the other, a fear of possible rejection of oneself, rejection of significant others, desire to show oneself in a better way.

In our view, such a gender disparity of results testifies to the greater subordination of a woman's life scenarios, her goal setting and self-realization to the effects of traditional gender stereotypes, which increase a woman's anxiety before expecting to have children, motherhood, a combination of professional and home responsibilities, which affects the corresponding anxious reflection of woman's own meanings of being.

Thus, the dilemma of self-determination in the choice of professional and family roles in the young adulthood demonstrates the negative power of the psychological impact of stereotypes, compliance with which does not allow young people to meet the need for individual choice. On the contrary, the adoption of egalitarian culture, which give~~s~~ them a feeling of happiness through the strengthening of self-confidence, performs an energy-saving function in building family relationships, educational, professional and career growth. It should be noted that the modern female students are more psychologically adapted to functioning in the future “male world”, more successful in mastering political, managerial roles, unusual professions than males, who find it difficult to be involved in the household guardianship and parental roles, teaching professions, family circle~~,~~ etc. However, those women, who are ready to play on the “male field”, still taste androcentric behavior: in the role of leaders they are going to adapt men’s management styles, evaluate economy and career aspirations through the prism of “male” needs and demands, ready take on additional household responsibilities, exacerbating, exasperate the phenomenon of double employment. Nevertheless male financial happiness was related more to being a taker rather than a giver, whereas meaning of women’s economic aspirations were related more to being a giver than a taker.

One of the objectives of the study was to identify alternatives to economic deprivation, including its gender aspect, by applying the psycho correctional personality (individual) approaches.

Positive psychology considers the personality achievement in any kind of self-realization through the prism of adherence to happiness as the intersection between pleasure and meaning. Among set of meanings are the principles of rationality as consciousness and using in practice thought full ways to achieve prosperity, understanding the necessary educational and professional means to achieve it, the consistency of different kinds of economic activity on the legal principles adopted in the nearest social environment. This refers not only to the standards that correspond to the release of some educational product, but also the development of personality features of economic behavior (e.g., frugality, self-assertiveness).

The prestige is the principle of economic activity, which deals not only with the place of work, shopping, but also, above all, with the self: the social status of the profession, working skills and abilities, career economic opportunities, holding a position and career perspectives, the uniqueness of possibility to realize the main meanings of the own Self. The prestige forecast of the chosen profession is an important indicator of the students economic culture, which sometimes have been motivated by “fashionable” professions, such as law or IT, and does not take into account their connection with personality inclinations~~.~~ However, many young people started to notice, that the profession should be in need in far future on the contrary to choosing in soviet times a foreign language translator, which lost its prestige in terms of globalization and open borders.

Altruism is a positive psychology principle that testifies to the extent of the sacrifice for the material support of others: families, elderly parents, orphans, people with special needs. It is not only about charitable activities for the benefit of those who need help, but also about conscious self-sacrifice, self-denial for the economic benefit of others, which brings satisfaction, raises self-esteem. Thus, the key principles of positive psychology of getting satisfaction from economic activity, its pleasure allows not only to be financially supported, but also to have positive emotions to work. Their implementation requires proper psychological counseling of the youth, professional diagnostics and professional selection, which predicts the possibility of satisfaction with the chosen activity as a basic motive for its economic success.

Disclosure of the psychology of gender differences in the economic behavior of the student youth, the ability to be guided by economic principles at different levels of material functioning has a hidden psychological basis such as a positive objective attitude to their personal economic potential and prospects for its application (self-reflection). It is this basis that dictates the different economic behavior of men and women in terms of limited material resources and expanding the range of personal needs. Thus, in addition to the internality of the locuscontrol, the principles that ensure positive thinking play an important role in achieving the desired status of economic well-being and overcoming the psychological pressure of gender stereotypes.

It is known that in positive psychology the feeling of satisfaction, happiness, well-being is divided into two types: hedonistic as situational pleasure, which is usually short-term, sensory according to the external source of pleasure and value, intra-personal. The latter is achieved when a person manages to achieve meaningful goals, objectives, sense of life. That is why this kind of positive experiences is called the result of value-semantic well-being, realization of personal potential.

Discussions about which satisfaction brings more comfort and pleasure hedonistic, situational or value-semantic, show that the latter is the most preferable, because it is able to shift deep emotions, raise self-esteem, prolong the feeling of happiness. The example of one of the student groups, which instead of celebrating the prom, decided to donate the saved money to the orphanage for the needs of local children deprived of parental attention, can be illustrative in this respect. At the same time, proms were quickly erased from the memory of other student groups, but those who organized a holiday for children remembered this for many years and celebrated the memorable event.

Although positive psychology considers both sources of satisfaction equally important and denies personal self-realization as a higher level of satisfaction, its basic postulates are based on the importance of experiencing a state of passion for activity, absorption by its essence, fascination with their achievements. The culture of human economic existence is precisely to maximize the long-term achievements of material support for the realization of vital goals and to minimize situations of the lack of funds. It is no coincidence that poverty is considered the greatest human defect, and material prosperity is a necessary condition for the personal freedom.

If we apply the model of the founder of positive psychology M. Seligman [1, 29] to the economic well-being of a person, then personal achievements according to his theory of well-being depend on the implementation of basic conditions, such as: inclusion in the activity, passion for it, satisfaction with interpersonal relations with people, realization of the sense of their activity and its achievements. Such conditions of the personalized activity can be realized both at the level of microeconomics (household, smallholding, etc.) and at the macro level.

If the proposed conceptual model of life satisfaction of positive psychology is compared with the social situation of student youth development, then its structural components can act as a prognosis and at the same time a diagnosis of psychological states of a young person (well-being or dissatisfaction with life), who masters the basics of their profession, determine their future material status. Indicators of their present and most importantly future psychological well-being can be indicators of the wheel of fortune by M. Seligman, namely confidence in the right choice of professional self-determination and its personal significance, consistency of the chosen path with their own life values, belief in their own ability to fully realize their potential with maximum dedication and in harmonious relationships with others.

The results of research of emotions nature, their impact on a person suggests that the strength of positive and negative emotions are different, that is the well-being of the individual depends on their proportion, the share of both, their ratio in life. According to the research done by representatives of positive psychology, the negative emotions reduce the life satisfaction much more than the same amount of positive ones. The ratio of negative to positive is 3:1, that is bad is much stronger in terms of influence than good.

Theoretical principles of positive psychology prompted us to find the adequate to its conceptual provisions focus groups and training programs with emphasis on the development of the youth ability, regardless of gender, to establish social relations with other people, involve in professional activities in the present and in the future, to realize their views on life, meaningful life orientations, to achieve success.

6 Discussion

According to positive psychology the more people felt their activities were consistent with the core of themselves, the desirable values of their self, the greater meaning they report in their dream about and real professional choice.

According to some male opinion (youth with egalitarian gender orientations in focus-group discussions) scarcity of money in performing some desirable for them “female” professions (teacher, medical nurses, preschool educator, library worker etc.) reduced possibility for self-realization, when possibility for happiness less possible in comparison to meaning. Desirable for youth social-economic status, professional male`s and female`s self-image is formed depending on gender orientations.

Students with egalitarian gender attitudes of both sexes perceive satisfaction with the chosen educational profession as a source of economic activity, which is connected with internal work satisfaction-positive personality traits: the capacity to love chosen vocation, feelings to be proud of it (“we are future teachers”, “psychologists”, “journalists”), independence and creativity in individual performance of working duties, effective interpersonal skills, talent of personality growth in everyday practice and experience.

Prioritize in economic well-being of students with traditional gender orientations are connected mostly with external work satisfaction factors: less strongly with subjective activity, personality determination, mostly with objective circumstances of working duties, the salary level, relations with the colleagues.

The collected empirical data suggest that the social roles of men and women are still largely mediated by gender stereotypes, which serve as a guide in differentiating the areas of their economic self-expression, determining the life scenarios declared by students and views on material obligations. However, the realities of the economic functioning of genders have formed a greater personal potential of women in the development of traditionally male economic space, the trigger for which will be the dominant over patriarchal egalitarian ideas of personal professional self-presentation.

7 Conclusions

Overcoming gender inequality in social and economic status, in particular a sense of economic deprivation is possible by internalizing the basic principles of economic culture through learning, development, involvement in positive psychology.

Pilot testing of a number of questionnaires allowed us to identify the most adequate structural research methods for the identifying feeling of economic youth economic well-being and economic self-deprivation such as the degree of self-reflection and satisfaction by chosen kind of the professional education, as well in the self-analyzing the obtained working experience as skills, abilities and habits which will are in needs for the future professional activities.

Gender difference in the level of self-reflective estimation by students the necessary social and professional abilities have been investigated by the complex methods including A. Matchak psychological test for study the social competences as abilities to perform and be successful in close interpersonal contacts, in actualizing the self in wide social communication and exposition and in social environment demanding assertive behavior. The measurement of such working abilities and skills considered the psychological background of SWB in successful performance any professional job activities and usually considered more often by male population.

The study results exposed higher development of social competences in female students especially among those who are adhered to egalitarian gender culture. Female and male students with traditional attitudes to profession division and household duties, social activities for men's and women's are less optimistic in the individual subjective wellness in reaching the desirable economic status relationships with others, absorption, realization of the Self in a personally significant social activity, its conformity to own system of views, life values.

The realities of gender economic functioning especially among young women oriented on egalitarian sex relationships have shaped their greater personal professional potential and readiness of in intromission to the traditionally masculine economic professions-spheres. The trigger mechanism in striving SWB in economic status is in overcoming patriarchal ideas of bipolar personal professional self-presentation among youth.

Egalitarian attitudes and behavior are more likely help youth to open ourselves up to positive psychology in financial success on the way of their professional education. Gender differences in expected economic well-being and real strivings are best predicted by difference in gender orientations, personal vision on goal attainment and high self-esteem or self-efficacy, but not sex belonging. It is important for youth to feel belongingness in a society and it social care and psychological guardian ship, so they can develop their full working potential and achieve self actualization.

Internalizing egalitarian gender culture can enhance the individual economic activity, increase the motivation for self-development in professional education.

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Regional development of enterprises: concept of sustainable development and data mining

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Abstract. Ukrainian enterprises are having a goal of get on with the concept of sustainable development. However, in the different regions of Ukraine there are various challenges, which needed to be considered in management of enterprises and organizations. Therefore important question is discovered about the main directions of developing enterprises, which will be relevant for a particular region. This study is highlighting statistic indicators, which characterizing the economic, social and environmental components of sustainable development of Ukrainian enterprises. On the basis of data about 1990-2019 years (2020 isn't used due to the impact of the pandemic, which significantly affected these parameters) cluster analysis of sustainable development enterprises of Ukraine by region is made. In the result of clustering regions were separated in three groups (clusters). Detailed analysis of the features of indicators of each cluster (group of regions) is made. On the basis of results of clustering recommendations about priority directions of increasing the level of sustainable development of Ukraine are discovered. Results of the study can be used in management of local enterprises and organizations in the certain regions to improve the level of achievement of sustainable development goals.

1 Introduction

In modern business conditions, enterprises face the processes of globalization, intensive changes that lead to uneven market development, uncertainty of the environment, inconsistencies in the implementation of the needs and interests of different market participants. It becomes obvious that achieving economic growth alone, even constant, is insufficient, as high rates of production can coexist with low efficiency of economic and social processes, become a threat to the environment. Therefore, it is important to ensure sustainable development of enterprises in the conditions of constant changes [1].

An important role in achieving sustainable development of enterprises is played by the evaluation of its indicators. This allows faster effective decision-making through the choice of appropriate criteria, methods, technologies, models, response mechanisms, interaction [2].

The formation of a system for assessing the sustainable development of Ukrainian enterprises is carried out taking into account the most problematic aspects of management, related to the functioning of ecosystems, ensuring environmental, economic and social needs of society. It should perform not only informational and control functions, but also reflect the desired changes and trends and timely direct efforts to achieve the goal.

Sustainable development has many dimensions, such as improving the social living conditions of the population, improvement of production infrastructure and other. Research in these areas has been carried out in many scientific works [3-4].

However, it is important to improve the economic efficiency of enterprises in the region subject to the concept of sustainable development. The scientific works of many scientists were devoted to this task [4-7]. These studies help to consider important factors of statistics of key indicators regional development of enterprises.

Modeling of the dynamics of indicators regional development of enterprises can be produced by new methods of Data mining. There are many works dedicated to use these methods to improve quality of management of enterprises on different levels: local, region, country and other [8-10].

Despite the broad theoretical and applied elaboration of sustainable development management in different socio-economic systems and at the level of the country's economy, it should be noted that there is no methodology for integrated management of sustainable development from the standpoint of a holistic approach to modeling the dynamics of such development.

The relevance of the study is based on the questions of sustainable development of enterprises, the analysis of statistic indicators of enterprises in different regions, data mining methods in researching of sustainable development enterprises of Ukraine by region. The purpose, tasks and directions of the research are determined by the insufficient development of the management level of local enterprises and organizations in sustainable development goals reaching.

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The purpose of this article is to obtain recommendations for justification for the choice of strategies development of regional enterprises, based on results of data mining with taking into account the concept of sustainable development.

2 Materials and methods

The concept of sustainable development is a new approach that defines new guidelines for the world order. However, significant changes in connection with the transition to sustainable development in all spheres of public life, including political, involve the definition of new complex goals and objectives that require some transformation of this system.

If we consider sustainable development from the point of view of the social component, the agenda of social institutions includes problems related to establishing a balance between the needs of modern generations (namely, the need for global governance, finding effective ways to address pressing issues), on the one hand, and , on the other hand an efficient economic system.

Sustainable development is the process of building a state based on the coordination and harmonization of social, economic and environmental components in order to meet the needs of present and future generations. Harmony in the development of three components of the modern world: man – economy – nature is the basis of sustainable development.

On the way to sustainable development of a country or region, research of indicators that determine this development are important: social (life expectancy, level of education, sanitation, involvement of the working population); ecological (preservation of biodiversity and natural landscapes, waters, atmospheric air, use of household waste); economic (capital investment, remodeling of production, GDP per capita, development of science and technology); institutional (access to information, environmental education, public participation in addressing issues of local and national importance).

The main goal of sustainable development of Ukraine is to ensure dynamic socio-economic growth, preserve the quality of the environment and rational use of natural resource potential, meet the needs of present and future generations by building a highly efficient economic system that stimulates environmental sustainability, productive work, scientific and technological progress. and also has a social orientation.

More and more attention is paid to the practical implementation of the concept of sustainable development in the world. The aggravation of the economic, environmental and social situation requires each state to take measures so that the activities carried out on its territory are not the cause of environmental degradation, which leads to changes in the functions of the state. Hence the modern responsibilities of states:

- to preserve and to use the environment and natural resources in the interests of present and future generations;
- to support the ecosystem and ecological processes necessary for the functioning of the biosphere, to protect biological diversity and to adhere to the principles of maintaining maximum sustainability of productivity during the use of living natural resources and ecosystems;
- to establish appropriate norms of environmental protection, monitor changes in environmental quality, as well as publish all data in this regard.

Thus, the struggle for the preservation of the natural foundations of life should be included among the important state tasks. It is natural that the priority of the environmental function in a global crisis should be quite high – it needs to take place immediately after the economic, to the greatest extent to influence government decision-making.

Since the formation of the system of assessment of sustainable development of enterprises on the basis of criteria and indicators is carried out taking into account the most problematic aspects of management related to the functioning of ecosystems, environmental, economic and social needs of society, it must perform not only informational and control functions. reflect the desired changes and trends and timely direct efforts to achieve the goal.

At the international level, criteria and indicators are a tool to help:

- creation of a single database relating to the state of the economic sector of the world, their ability to perform environmental, economic and socio-cultural functions in order to solve global environmental problems that threaten the existence of mankind, as well as providing basic needs of present and future generations;
- improvement of international cooperation in order to develop common provisions, recommendations and define long-term strategies and, accordingly, to form common approaches and requirements to the system of evaluation of the country's progress towards sustainable enterprise development, including clear and uniform interpretation of terms, methods of collecting, processing, disseminating information, etc. ;
- harmonization of important aspects of international trade related to ensuring compliance with the principles of sustainable development, environmental and socio-economic requirements for the management process.

At the national level, the application of a system of criteria and indicators will be useful for:

- control over the implementation of Ukraine's international obligations related to the decisions of the UN conventions on environment and development, as well as the provisions set out in the Concept of Sustainable Development of Ukraine and other state regulations;
- improvement of national economic, legal framework to take into account the basic requirements for sustainable use of natural resources, national priorities and environmental and economic characteristics of nature, as well as adjusting existing programs, various measures in line with economic trends;
- improvement of the decision-making process regarding the conservation, protection, reproduction and use of natural resource potential.

At the operational level of management include evaluation of the effectiveness of business, which coordinates the management at the operational level, as well as the formation of information base not only for management purposes and objectives, but also to improve all environmental practices in accordance with existing environmental and economic conditions, potential and new capabilities achievements in scientific and technical sphere.

Definitely, using only the system of assessment can`t provide sustainable development without new methods and models. So, to improve the achievement of goals of sustainable development its necessary use data mining.

To solve this problem is recommended to use classification and cluster analyses. Unlike classification tasks, cluster analysis does not require a priori assumptions about the data set, does not impose restrictions on the display of the studied objects, allows you to analyze indicators of different types of data (interval data, frequencies, binary data). Also, chosen variables must be measured on comparable scales.

Cluster analysis allows to reduce the dimensionality of data, to make them clear. Cluster analysis can be applied to sets of time series, here periods of similarity of some indicators can be distinguished and groups of time series with similar dynamics can be determined.

Let's define variables for cluster analysis.

To choose variables for clustering lets analyze indicators of entrepreneurship development (Fig. 1).

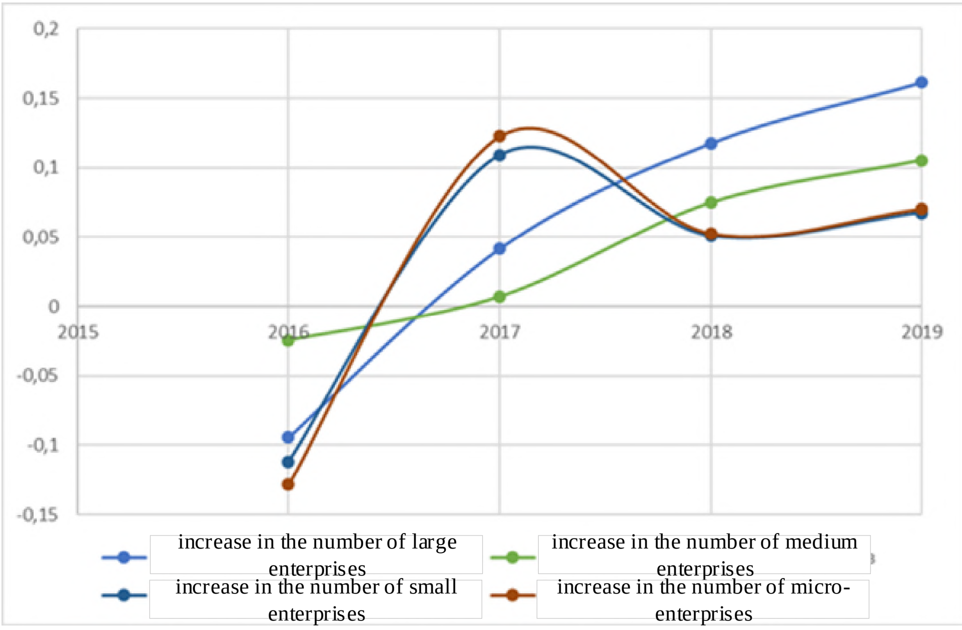

Fig. 1. Increases in the number of enterprises by type in the period from 2015 to 2019 [11].

One of the important indicators of business development, which determines the favorable business environment in particular and the state of the economy as a whole, is the number of small and micro enterprises. A feature of the development of domestic entrepreneurship is a significant jump in the number of small and micro enterprises, caused by the adoption in 2016 of the "Strategy for the development of small and medium enterprises in Ukraine until 2020."

There are 380597 enterprises in Ukraine with net profit about 523778 UAH million according to state statistics service of Ukraine [11]. Due to the analysis of enterprises development, seven variables were chosen for clustering from the full number of 62, which can fully characterize directions of the sustainable development.

In the analysis we will consider the following objects: Vinnytsia, Volyn, Dnipropetrovsk, Zhytomyr, Zakarpattia, Zaporizhzhia, Ivano-Frankivsk, Kyiv, Kirovohrad, Lviv, Mykolaiv, Odessa, Poltava, Rivne, Sumy, Ternopil, Kharkiv, Khmelnytsky, Cherkasy, Chernivtsi, Chernihiv regions.

As variables for clustering we will use the parameters that characterize directions of the sustainable development of the region:

1 – economic direction:
- quantity of sold products by regions;
- the number of employees in business entities by region;

2 – social direction:
- staff costs of enterprises by region;
- capital investments in environmental protection by regions;

3 – ecological direction:
- current costs of environmental protection by region;
- carbon dioxide emissions by region;
- emissions of pollutants into the atmosphere from stationary sources of pollution by region.

The process of ensuring the sustainable development of the enterprise involves the solution of a significant number of complex tasks, among which a lot of space is occupied by the processes of evaluation and implementation. The main task in the study of development is to identify for a particular enterprise all the opportunities that can be used.

To analyze the sustainable development of Ukraine by region, we will use statistics for 2015-2019 (2020 will not be used due to the significant impact of the pandemic, which significantly affected these parameters) [11].

Among the indicators of the dynamics of these parameters we will use the following.

Average time series value:

$$X_{cp} = \frac{\sum_i^n x_i}{n} \quad (1)$$

where X_i is the value of the indicator at period i, n is the total number of periods.

Standard deviation (RMS):

$$X_{CKO} = \sqrt{\frac{\sum_i^n (X_i - \bar{X})}{n}} \quad (2)$$

where $\bar{X}$ is the average value of the indicator.

The value of time series growth for 2015-2019:

$$X_{\text{p}} = X_{2019} - X_{2015} \quad (3)$$

where X_{2019}, X_{2015} values of indicators in the specified periods.

The main point of the study is the choice of distance, this distance depends on the options for the final partition. The most common are two procedures: the method of "nearest neighbor" and the method of "far neighbor".

The criterion for determining the similarities and differences of clusters is the distance between the points on the scattering diagram. This similarity can be "measured", it is equal to the distance between the points on the graph. There are few ways to determine the degree of distance between clusters, which is also called the degree of proximity. The most common way is to calculate the Euclidean distance between two points i and j on a plane when their X and Y coordinates are known. Therefore, in paper there is used Euclidean distance for cluster analysis.

If we need to find the distance between two points in the space of a larger number of measurements, the formula changes to the number of specified measurements.

To perform cluster analysis, we use the MS Excel toolkit add-on Data Mining.

3 Results

We use the tools to search for categories of Analysis Services by the above indicators (Table 1). To search for categories, use the value of the searched categories – 3.

Table 1. The total number of objects in the clusters.

Category name	Row counter
Cluster 1	12
Cluster 2	5
Cluster 3	5

Thus, we obtain three clusters. Cluster 1 has the largest number of facilities, including Volyn, Zhytomyr, Zakarpattia, Kirovohrad, Mykolaiv, Rivne, Sumy, Ternopil, Kherson, Khmelnytsky, Chernivtsi and Chernihiv regions. This cluster is characterized by the following characteristics (Table 2).

According to this analysis, the following conclusions can be drawn: the first category includes regions with low levels of harmful emissions and personnel costs. These are regions without developed industry with moderate costs of enterprises to support workers. Significant changes in the number of employees involved in the enterprise are constantly increasing.

Let's analyze cluster 2. This cluster includes such regions as Dnipropetrovsk, Zaporizhzhia, Kyiv, Poltava, Kharkiv regions.

The second cluster is characterized by the following characteristics (Table 3). According to the results of the cluster analysis, this group includes regions with a moderate level of emissions of toxic substances and an increase in current expenditures on environmental protection. However, the environmental costs themselves in this cluster are higher than in other clusters. This cluster is represented by regions with developed industry.

It can be concluded that with a significant increase in emissions of substances High level of growth of carbon emissions: 11118,3964094464 – 35759,6843737088, the cost of improving the environmental situation is not significant.

Table 2. Characteristics of the cluster 1.

Column	Value	The importance (%)
Standard deviation of carbon emissions	Low:< 652,3916407808	100
Average values of staff	Low:< 8850140,26319299	96
Average values of products	Very low:< 99659768,2879332	82
Average values of emissions of substances	Low:< 59,2431839616	81
Standard deviation of values of staff	Low:< 3912059,98129316	79
Average values of carbon emissions	Low :< 3486,4703696896	62
Growth of investment	Low:< 118108,007038976	61

Table 3. Characteristics of the cluster 2.

Column	Value	The importance (%)
Standard deviation of emissions of substances	Average:33,502394944 – 163,1016636416	35
Growth of environmental costs	Average:739425,918124032 – 1987735,51220654	33
Standard deviation of investment	Average:90005,5426793472 – 676550,476719718	28
Standard deviation of environmental costs	High:>= 516068,619426202	27
Average values of environmental costs	High:636797,562493338 – 2291954,27998597	27
Average values of investment	Average:184307,307380736 – 714445,43874007	27

Let's analyze cluster 3. This cluster includes such regions as Vinnytsia, Ivano-Frankivsk, Lviv, Odessa, Cherkasy regions.

The second cluster is characterized by the following characteristics (table 4).

Table 4. Characteristics of the cluster 3

Column	Value	The importance (%)
Standard deviation of carbon emissions	Average:652,3916407808 – 6697,0645192704	100
Growth of emissions of substances	Very High:>= -4,4394651672	55
Average values of products	Low:99659768,2879332 – 210243602,310234	49
Average values of emissions of substances	Average:59,2431839616 – 629,3593749504	32
Average values of values of staff	Average:8850140,26319299 – 19665719,2475034	31
Growth of values of staff	Average:16272684,5190504 – 26496168,0780296	26

According to clustering data, this class includes regions with average values of harmful emissions and low growth of environmental costs. Unlike other clusters, the objects of this show a very high level of pollution growth with a low value of the products produced by enterprises. These areas are mainly aimed at the recreational sector and tourism without significant industrial facilities. The growth of emissions is largely due to the development of the economy and the emergence of new enterprises during the period under review.

The results of the analysis can be seen in Fig. 2, which shows the ratio of low, medium, high and very high levels of growth in emissions, environmental costs and production by category.

Thus, we can conclude that the regions with developed industry (cluster 2) show the largest increase in the cost of improving the quality of the environment. Also, cluster 3 is characterized by a significant increase in the number of manufactured products and an increase in harmful emissions with a consistently small contribution to the maintenance of the environment.

According to the results of the cluster analysis, three groups of regions have been identified for which it is advisable to apply different types of strategies to implement the concept of sustainable development.

There is no doubt that due to a number of differences in the sustainable development of enterprises in different regions, it is necessary to apply different strategies for the integration of the concept.

In general, based on the resolution of the Verkhovna Rada of Ukraine on the Concept of Sustainable Development in Settlements, it is planned to improve the current state of development in the following areas: coordination of social, economic, urban and environmental aspects of development of settlements and surrounding areas. , creating appropriate conditions for the development of enterprises of all forms of ownership for productive employment, restoration of human and scientific potential, a sufficient number of jobs and others.

To do this, a number of measures are planned to:

- ensuring the rational use of natural resources;
- improving the social living conditions of the population;
- providing the population with housing;
- improvement of production infrastructure;
- development of transport infrastructure;
- development of engineering infrastructure;
- formation of a full-fledged living environment in settlements;
- improvement of sanitary and hygienic conditions;
- protection from adverse natural phenomena;
- prevention of man-made accidents.

However, the funds of local enterprises and organizations of all forms of ownership, capital investments of the state and local budgets are used for the implementation of the measures [12]. Therefore, it is necessary to identify those measures that will bring the greatest benefit within the concept of sustainable development for the region.

Based on the cluster analysis, we offer recommendations for the selection of priority measures by region (Table 5).

These recommendations identify priority actions for areas that need more attention. The application of the stated priorities will allow to carry out actions to achieve the concept of sustainable development more effectively.

The application of the recommendations will allow on the basis of a more efficient allocation of resources to enable the following tasks, which were established in [13]:

– to ensure the annual growth of gross domestic product;

– to promote a change in the structure of exports towards the growth of products and services with a high share of value added;

– to achieve productivity growth in the economy through diversification, technical modernization, creating incentives, including tax incentives, for innovation and increasing the number of jobs.

4 Conclusion

The peculiarity of the functioning of enterprises in the current conditions of a long crisis is their constant dependence on the whole set of industrial and non-industrial entities, which is characterized by increased fierce competition. As a result, it negatively affects the competitiveness and sustainability of domestic enterprises. Therefore, the main task of the enterprise in modern economic conditions is to solve the problem of sustainable development and the ability to withstand adverse situations.

The using of the main socio-economic indicators to get sustainable development in the international, the national and the operational levels was analyzed.

The sustainable development of Ukrainian enterprises is analyzed, on the basis of which the main factors of restoration of the main socio-economic indicators of Ukrainian enterprises are chosen.

A cluster analysis of the dynamics of sustainable development of Ukrainian enterprises by regions is constructed. Based on clustering, the regions were divided into three groups. A detailed analysis of each of the groups of regions was conducted.

On the basis of cluster analysis, recommendations are proposed on priority measures to increase the level of sustainable development of Ukraine, which allows improve quality of citizens' life and reach economic development.

The obtained results can be used in the development of funds of local enterprises and organizations to improve the efficiency of the allocation of resources, which will increase the quality of achieving sustainable development goals.

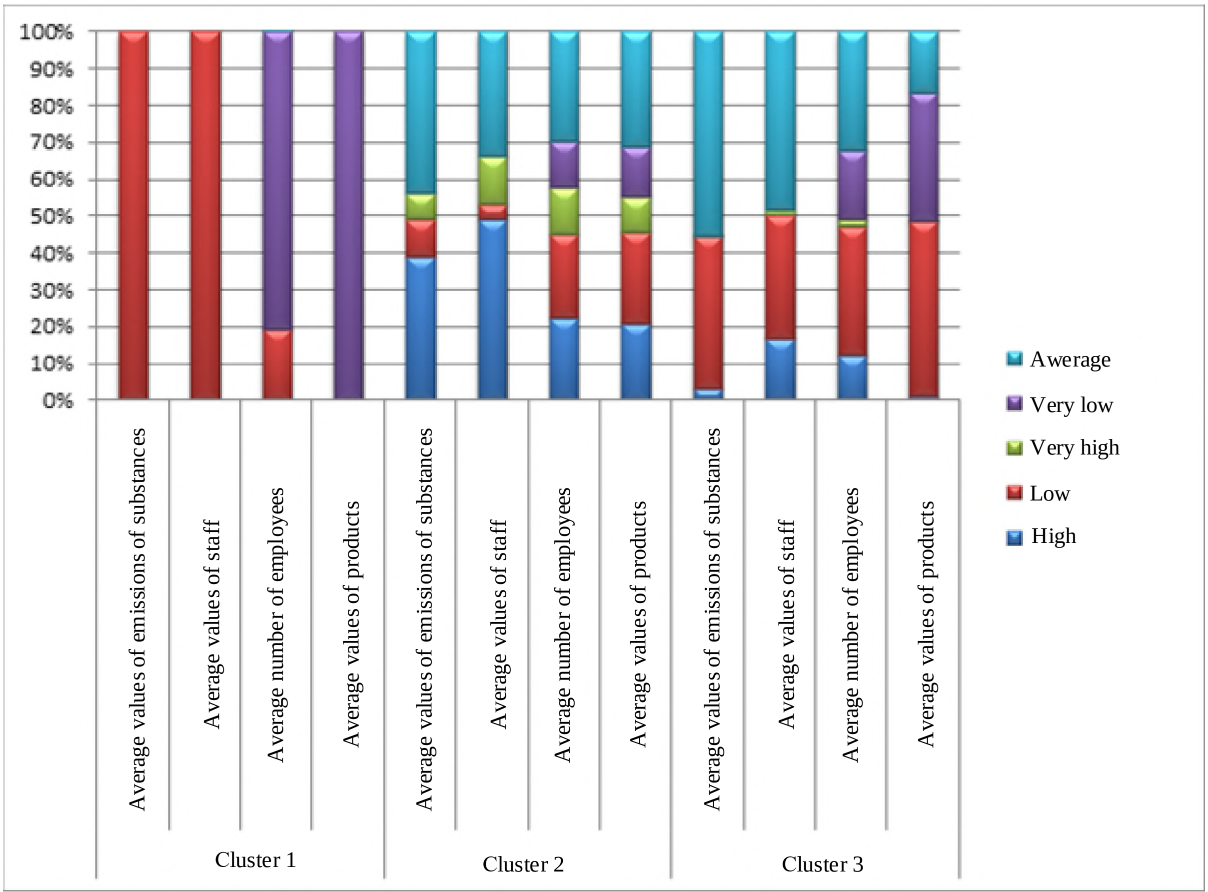

Fig. 2. The results of cluster analysis.

Table 5. Recommendations for measures to achieve the concept of sustainable development by region.

Cluster	Regions included in the cluster	Recommended measures
1	Volyn, Zhytomyr, Zakarpattia, Kirovohrad, Mykolaiv, Rivne, Sumy, Ternopil, Kherson, Khmelnytsky, Chernivtsi and Chernihiv regions	a) ensuring the rational use of natural resources; b) improvement of production infrastructure; c) improving the social living conditions of the population.
2	Dnipropetrovsk, Donetsk, Zaporizhzhia, Kyiv, Luhansk, Poltava, Kharkiv regions	a) improving the social living conditions of the population; b) improvement of sanitary and hygienic conditions; c) prevention of man-made accidents.
3	Vinnytsia, Ivano-Frankivsk, Lviv, Odessa, Cherkasy regions	a) protection against adverse natural phenomena; b) improvement of production infrastructure; c) the formation of a full-fledged living environment in settlements.

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Modern development trend of normative monetary valuation of non-agricultural land plots in Ukraine

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Abstract. The article identifies the main types of land valuation – expert monetary valuation for individual evaluation of particular plots and normative monetary valuation for systematic valuation of land for tax purposes. To conduct the last one, a mass assessment of land plots considering geoinformation technologies is used. It is established that at the present stage of normative monetary valuation of non-agricultural land plots in Ukraine two methodologies are used: within the settlement and outside it. The project of the unified methodology of normative monetary valuation of land plots by combining the existing methods submitted for discussion by the Ministry of Economy, Trade and Agriculture of Ukraine is considered. The values of land plots according to the existing and unified methodologies are studied on the example of four land plots under gas stations, which are located in the city of Kharkiv and outside it. It is established that the values of land plots, determined by existing and unified methods, differ both in the direction of increase and decrease, the difference varies from 9 % to 97 %. It is necessary to conduct additional analysis of initial data and indicators, which are the basis for calculating and improve the offer unified methodology.

1 Introduction

Land valuation has recently become a mandatory component in land transactions [1], such as taxation, sale, withdrawal, consolidation [2], as well as in the field of land management, management of land resources [3] and State Land Cadastre management [4]. The value of land depends on physical, economic, social, environmental and legal factors [5]. As in other countries, there are two main concepts of land value - market (expert monetary valuation) and for taxation (regulatory monetary valuation) in Ukraine [6].

Expert monetary valuation of land is performed by an expert appraiser in the case of alienation and insurance, pledge, reorganization, bankruptcy or liquidation of the enterprise that owns the land, it is done by court decision [7]. The following methodological approaches are used [8]:

- capitalization of net operating or rental income (direct and indirect);
- comparison of sale prices of similar land plots;
- taking into account the cost of land improvements.

The expert appraiser uses a methodical approach, which is provided with complete information about the object of evaluation. But determining the exact and optimal approach is a difficult task due to the variation of factors that affect the assessment, so the value of the land is often perceived as contradictory and biased. In addition, there is a human factor that leads to an overestimation or decrease in the real value of the evaluated object. Despite these shortcomings, such a model for determining the value of land may be acceptable for individual assessment of particular plots.

Systematic assessment of all land plots included in the State Land Cadaster [4] is performed for taxation, determination of the amount of rent, alienation, land management and cadaster by conducting an assessment for taxation (in Ukraine analogue to the normative monetary assessment). It requires up-to-date data, clear consistency and transparency [9-11]. Therefore, in most countries of the world mass valuation of land using geoinformation technologies [12-19] is performed, which allows to automate the collection of factors influencing the assessment, to analyze them and the necessary calculations. The use of automatic estimation models has been popular for more than ten years in developed countries such as Sweden, Canada and the United States, and is becoming popular around the world [20].

There is also a tendency to form such automated land valuation systems in Ukraine, but it is only at the stage of creating a regulatory framework and improving the methodology of regulatory monetary valuation of land [21]. Therefore, it is important to study changes in the regulatory monetary valuation of land in Ukraine.

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2 Changes in the regulatory framework for conducting regulatory monetary valuation of land

Nowadays the assessment of agricultural land and non-agricultural land is carried out separately in accordance with the relevant Procedures and Methods [22-27] in Ukraine. At the same time, appraisal works were allocated separately within the settlement [26, 27] and outside it [24, 25] for non-agricultural land plots. The focus will be on non-agricultural land in the future, as they are the most common and their value (especially land for industrial, transport, communications, energy, defense and other) is quite high.

The normative monetary valuation for non-agricultural land plots within a settlement is based on the capitalization of the rent income of the settlement. The main stages of determining the value of non-agricultural land within the settlement are shown in Figure 1 according to the procedure [26].

The cost of one square meter of land of a certain functional use (Cn) is determined taking into account the territorial planning, engineering-geological, historical-cultural, natural-landscape, sanitary-hygienic and engineering-infrastructural features of its location within the economic-planning zone according to the formula (1) [26]:

$$Cn = Cnz \cdot Kf \cdot Km3. \qquad (1)$$

The value of the coefficient Km3 is determined for an individual land plot on the basis of determining the share of the area occupied by the factor on the land plot. The share of the area is established mainly through the use of GIS technologies and electronic digital maps.

Normative monetary valuation of non-agricultural lands within the settlement

↓

The average base cost of one square meter of land of the settlement depending on regional factors of a location (Cnm)

↓

The cost of one square meter of land in settlements by economic planning zones (Cnz)

↓

Local coefficient (Kmz)

↓

The cost of one square meter of land of a certain functional use (Cn)

↓

The cost of land (Czd)

Fig. 1. Stages of determining the value of non-agricultural land within the settlement.

Normative monetary valuation of non-agricultural land outside the settlement is based on the norm of rental income and is determined by formula (2) [24]:

$$Cn = Pd \cdot Rd \cdot Sc \cdot Km \cdot Kv \cdot Kmc \cdot Ki, \qquad (2)$$

where Pd – area of the land plot accepted according to the data of the State Land Cadaster or land management documentation, m^2;

Rd – rental income per m2 of area for the relevant category of land, determined by the standards of rental income for the relevant category of land, UAH / year;

Sc – term of capitalization, years;

Km – coefficient that takes into account the location of the land;

Kv – coefficient that takes into account the type of land use;

Kmc – coefficient that takes into account the affiliation of the land to the lands of environmental, health, recreational, historical and cultural purposes;

Ki – indexation coefficient of the normative monetary valuation of lands.

According to the project of Normative monetary valuation methodology of land plots [21], it is offered to create a single valuation procedure for all land plots, regardless of their purpose and location relative to the settlement. But this takes into account the boundaries of the territorial community.

Normative monetary valuation of land (Cn) is determined by formula (3):

$$Cn = Pd \cdot Nrd \cdot Km1 \cdot Km2 \cdot m3 \cdot Km4 \cdot Kcp \cdot Kmc \cdot Kni, \qquad (3)$$

where Pd – land area, m^2;

Nrd – the rate of capitalized rental income per unit area;

Km1 – coefficient that takes into account the location of the community within the zone of influence of large cities;

Km2 – coefficient that takes into account the resort and recreational value of settlements;

Km3 – coefficient that takes into account the location of the community within the zones of radiation pollution;

Km4 – coefficient that characterizes the zonal factors of the location of the land;

Kcp – coefficient that takes into account the purpose of the land in accordance with the State Land Cadastre;

Kmc – coefficient that takes into account the peculiarities of land use within the category of land for the main purpose;

Kni – the product of the indexation coefficients of the normative monetary valuation of land for the period from the approval of the standard of capitalized rental income to the date of the valuation.

The application of the project Methodology [21] will unify the cadastral information exchange file (XML-file), which is used to enter information in the State Land Cadaster [4], and apply automated methods of calculating the value of land using data from the State Land Cadaster.

3 Investigation of changes in the value of non-agricultural land plots using a unified methodology

To study the change in the value of non-agricultural land plots using a unified method of calculating the normative monetary valuation, land plots with gas stations are selected and information about which is freely available on the Public Cadastral Map of Ukraine [28] (Fig. 2).

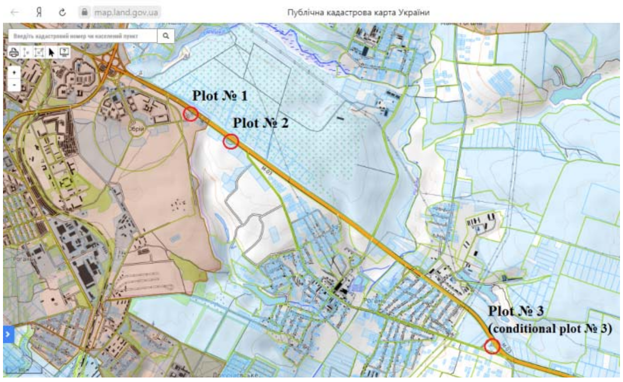

Fig. 2. Layout of land plots (according to the State Land Cadastre) [28].

Land plot № 1 (cadastral number 6310138200:10:015:0003) is located on the outskirts of the regional center – the city of Kharkiv (Fig. 2). The plot has a total area of 2 682 m^2 (0.2682 ha) and is privately owned. It is located along the highway of state importance M-03 Kyiv – Kharkiv – Dovzhansky (to the city of Rostov-on-Don) (Kharkiv – Rostov-on-Don (M19)) at a distance of 250 m from the eastern border of Kharkiv (Fig. 3).

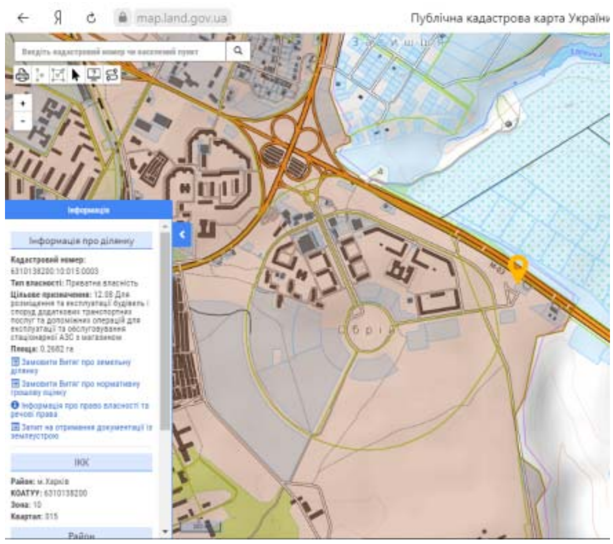

Fig. 3. Information on the land plot № 1 (materials of the State Land Cadaster – data of the Public Cadastral Map of Ukraine) [28].

Land plot № 2 (cadastral number 6325182500:02:005:0005) is located near the border of the regional center – the city of Kharkiv on the territory of Vilkhiv united territorial community within Maloroganska village council, Kharkiv district, Kharkiv region (Fig. 4). The plot with a total area of 10 000 m^2 (1.0000 ha) is state-owned. It is located along the state highway M-03 Kyiv – Kharkiv – Dovzhansky (to the city of Rostov-on-Don) (Kharkiv – Rostov-on-Don (M19)) at a distance of 350 m from the eastern border of Kharkiv. The distance between sections № 1 and № 2 is 560 m on the highway, between sections № 2 and № 3 – 4 600 m on the highway (Fig. 2).

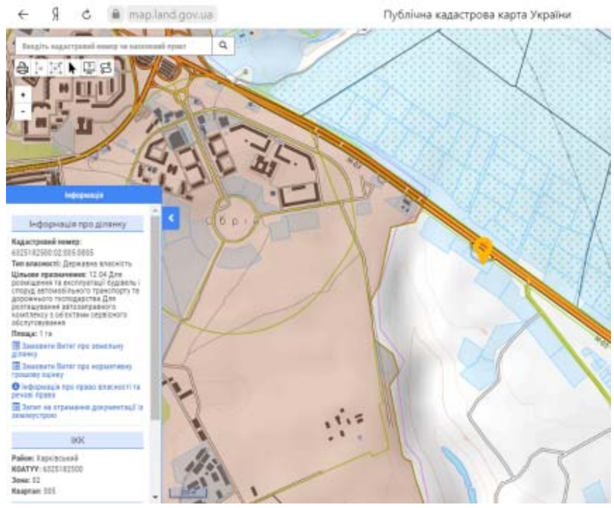

Fig. 4. Information on the land plot № 2 (materials of the State Land Cadaster - data of the Public Cadastral Map of Ukraine) [28].

Land plot № 3 (cadastral number 6325158500:01:041:0005) is located at a distance of km from the eastern border of the regional center – the city of Kharkiv on the territory of Rogan united territorial community within Rogan village council, Kharkiv district, Kharkiv region (Fig. 2). The plot with a total area of 5 270 m^2 (0.5270 ha) is state-owned. Located outside the village of Rogan near its eastern border (in the direction of Chuguev), along the highway of state importance M-03 Kyiv – Kharkiv – Dovzhansky (to the city of Rostov-on-Don) (Kharkiv – Rostov-on-Don) (M19)) (Fig. 5).

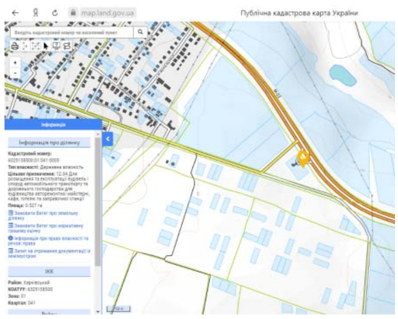

Fig. 5. Information on the land plot № 3 (materials of the tate Land Cadastre – data of the Public Cadastral Map of Ukraine) [20]

For investigation the conditional plot № 3 will be taken, which has the same characteristics as the land plot № 3, but is located within the settlement of Rohan village with the conditional cadastral number 6325158500:00:005:0000 (Fig. 2).

According to the existing regulatory framework and Figure 1, the calculations of the normative monetary valuation of land plots № 1 and № 3 are conditional, as plots are located within the settlements (Table 1). Indicators of the base value of 1 m^2 of land of the respective settlements are taken according to the data posted on the official website of the State Service of Ukraine for Geodesy, Cartography and Cadaster (State Geocadaster of Ukraine) [29]. According to the purpose of further analysis and comparison of indicators of estimation of data reduction we will carry out with base cost of 1 m^2 of land plots of the settlement for 01.01.2020, that's why the indexing factor (Ki) is applied.

According to the calculations of the normative monetary valuation of land plots of same definite purpose, which are located along one highway of state importance on the outskirts of settlements at a distance of about 5 km, the cost of 1 m^2 of land located within the regional center – Kharkiv almost five times more than the cost of 1 m^2 of land located within the neighboring village of Rogan (Table 1).

Land plots № 2 and № 3 are located outside the settlements along one highway of state importance, but on the territory of the neighboring united territorial communities (Vilkhivska and Rohanska). According to formula 2 the normative monetary valuation of land plots № 2 and № 3, which are located outside the settlements (Table 2) can be calculated.

According to the calculations of the normative monetary valuation of land plots of one purpose, which are located along one highway of state importance outside the settlements, the cost of 1 m^2 of land № 2 located closer to the regional center – the city of Kharkiv is almost 13 % higher than the cost of 1 m^2 of land plots № 3, due to the coefficient, which takes into account the location of lands.

The next step is to calculate the normative monetary valuation of four land plots of the same purpose, which are located along one highway of state importance within and outside the settlements according to the draft methodology of normative monetary valuation of land plots [21] (formula 3). In order not to distort the results of the assessment, the coefficient that characterizes the zonal factors of the location of the land plot (Km4) is taken equal to 1 for all land plots. The results of the calculation of the normative monetary valuation of four non-agricultural land plots within and outside the settlements (under the gas station) according to the Project Methodology 2020 [21] are shown in Table 3.

Table 1. Normative monetary valuation of land plots within settlements (under the gas stations).

Indicator	Characteristics	Value	
		plot № 1	Conditional plot № 3
Pd	Land area, m^2	2 682	5 270
Cnm	Base coat 1 m^2, UAH (for 01.01.2020)	639,78	131,63
Km1	Regional location ratio	3	1,5
Kf	Functional utilization coefficient	2,5	2,5
Km2	Coefficient, which concerns the degree of urban value	1	1
Km3	Local coefficients for the location of land	0,87	0,87
Cn	**Monetary value 1 m^2 of land, UAH**	**1 391,52**	**286,30**
Czd	**Monetary value of land plot, UAH**	**3 732 056,64**	**1 508 801,00**

Table 2. Calculation of the normative monetary valuation of non-agricultural land outside settlements (under the gas stations).

Indicator	Characteristics	Value	
		plot № 2	plot № 3
Pd	Land area, m^2	10 000	5 270
Rd	Rent income per 1 m^2 area of relevant land category, UAH/year	0,6637	0,6637
Sk	Capitalization period, years	33	33
Km	Coefficient of land location	5,1708	4,5679
Kv	Coefficient of land usage	2,9750	2,9750
Kmc	Coefficient of land belonging to natural security, recreational, historical, health or cultural objects	1	1
Ki	Indexation coefficient of normative monetary valuation of land	1,8972	1,8972
Cn_1	**Normative monetary value of 1м^2 of land, UAH/m^2**	**639,21**	**564,68**
Cn	**Normative monetary value of land plot, UAH**	**6 392 100,00**	**2 975 863,60**

According to the results of calculations of the normative monetary valuation of four non-agricultural land plots within and outside settlements (under gas stations) according to the Project Methodology 2020 [21], the cost of 1 m^2 of land plot located within the regional center Kharkiv is the highest. The cost of 1 m2 of land № 2, which is located closest to the regional center – the city of Kharkiv (350 m) and at a distance from the site № 1 – 560 m is 4.75 times less than the cost of 1 m^2 of land № 1, and 1,53 times less than the value of 1 m^2 of land № 3 and 1.68 times less than the value of 1 m^2 of conditional plot № 3. The results of comparing the calculations of the normative monetary valuation of four non-agricultural land plots within and outside settlements (under gas stations) according to the current methods [25, 27] and the project Methodology 2020 [21] are shown in Figure 5. According to the results of calculations the regulatory monetary value of land № 1 will increase in 2021 by 15 %.

However, the regulatory monetary value of land № 2 will decrease in 2021 by almost half (47 %). This is due to the value of the capitalized rental income ratio, which is determined depending on the population in the settlement, which is the administrative center of the community. A slight decrease in the regulatory monetary value in 2021 is projected for land plot № 3 – by 9 %. And for the conditional land plot № 3 it is possible to increase the normative monetary assessment in 2021 almost twice (by 97 %), which is partly due to the use when calculating the base value of 1 m^2 of land of the settlement (Rogan village) according to the land valuation settlements held in 2009.

Table 3. Calculation of the normative monetary valuation of non-agricultural land outside settlements (under the gas stations) according to the Project Methodology 2020 [21].

Indicator	Characteristics	Value			
		plot № 1	**plot № 2**	**plot № 3**	**conditional plot № 3**
Pd	Land area, m^2	2 682	10 000	5 270	5 270
Nrd	Rate of capitalized rental income per unit of area	639	87	133	133
Km1	Location coefficient of the community within the area of influence of large cities	1	1,3	1,3	1,3
Km2	Resort and recreational value coefficient of settlements	1	1	1	1
Km3	Location of the community within the areas of radiation pollution coefficient	1	1	1	1
Km4	Zonal factors coefficient of the land location	1,000	1,000	1,000	1,000
Kcp	Land purpose coefficient	2,5	2,5	2,5	2,5
Kmc	Peculiarities of land use coefficient within the category of land for the main purpose	1,001	1,19	1,19	1,304
Kni	Product of coefficients' indexation of normative monetary valuation of lands	1,000	1,000	1,000	1,000
Cn$_1$	Normative monetary value of 1 m^2 of land	**1 599,10**	**336,47**	**514,38**	**563,65**
Cn	Normative monetary value of land	**4 288 786,20**	**3 364 700,00**	**2 710 782,60**	**2 970 435,50**

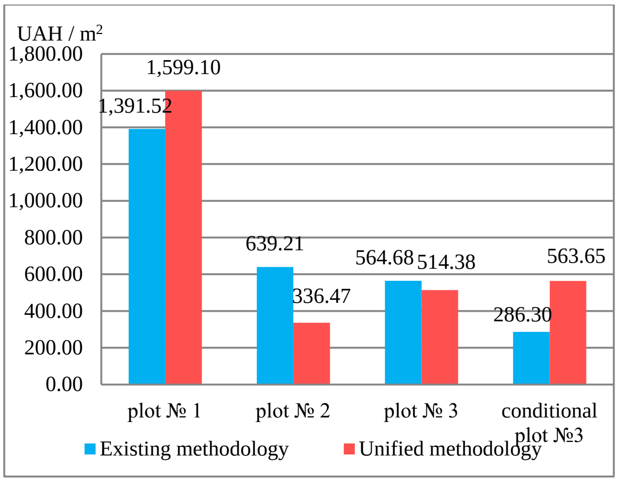

Fig. 5. The results of comparing the calculations of the normative monetary valuation according to the current methods [25, 27] and the project Methodology 2020 [21].

4 Conclusions

1. Works on land valuation do not lose relevance.
2. The use of geographic information technologies in the implementation of land valuation works create preconditions for the development and improvement of both land valuation works and the convenience of using its results by various entities.
3. The unified approach to the normative monetary valuation of land, offered by The Ministry of Economic Development, Trade and Agriculture of Ukraine, increases the convenience and improves the quality of land valuation work as a source of filling the State Land Cadaster with reliable data.
4. These calculations prove the need to analyze the initial data and indicators that underlie the calculations of the normative monetary valuation of land and further improvement of the proposed approach, in order to establish the fair value of all land.

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Substantiation of the advanced training program “Social work with military personnel and military-social work in the context of sustainable development goals”

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Abstract. The article is devoted to the implementation of sustainable development goals in the training of social employees and military personnel engaged in military and social work. The purpose of the research is to develop a training program “Social work with military staff and military-social work”. There were used such research methods as comparative analysis, theoretical analysis, generalization, survey, modeling, synthesis. The result of the article is the developed program that consist of three modules. Among them there are such modules as “Digital tools for teaching social work”, “Theoretical foundations of social work with servicemen and their families”, and “Practice of social work with servicemen and their families in the community”. The program features are following: a training form and a set of approaches to its content. There are the program prerequisites for the study result implementation such as the mastering by teachers of the tools of media education, the distance technologies and their methods of use, and interaction of community specialists with military component in training. The prospects for further research are the development of specialization disciplines in the higher education institutions on the research issue. The scientific novelty consists of a set of scientific approaches in the program content developing, clarifying the essence of the “military and social work” concept and others.

1 Introduction

We associate the relevance of our research with the fact that:

1. Sustainable development means improving conditions for maintaining health, peace and harmony in countries and communities, ensuring gender equality, overcoming poverty and hunger, reducing inequality, ensuring openness, love of peace, security, resilience and sustainability of cities and towns, high level of education as well as providing decent work and ensuring economic growth, and etc. All these are the social aspects of sustainable development within the competence of social policy. One of the approaches for ensuring sustainable development is social policy, and it solves the social problems of various categories of the population, expresses the interests of various categories of the population, and promotes the realization of human rights. In the context of sustainable development, it is a social policy to preserve humanity and its resources to meet the necessary needs. The social policy is implemented through the social welfare but the social work is implemented through the provision of standardized social services for those in need. Today, the social policy in Ukraine is participatory, and it’s unlike the EU countries. Its resources are not enough to solve the problems of those who has suffered from the military conflict, pandemic, migration and etc. Therefore, there are significant resources in the field of sustainable development policy and social work. The sustainable development policy comprehensively solves the social problems of the population and provides goals as criteria for solving problems. Social work is aimed at solving the[*] people situations with socialization, adaptation, rehabilitation, as well as the people who are in difficult circumstances because of life crises, trauma, and other various external circumstances. So, the sustainable development policy can be implemented through social work with servicemen with particular social problems (socialization, adaptation, rehabilitation, integration, etc.) as a result of the military conflict in Ukraine, the pandemic, or the transformation of society.

At the same time, social work with military personnel in the context of sustainable development of society was not considered in the higher educational institutions educational programs. Although it has significant opportunities for this. The training matters for work with military personnel are included into the program of entrance examinations for a master degree in social work of various institutions of higher education. [1, 2]. In the curriculum of individual higher educational institutions is

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included such topic as “Social work with representatives of problem groups, military personnel” [3, 4]. At the same time, the practice reflects that the problems of servicemen and members of their families have increased with their involving into the military conflict in the East of Ukraine and the pandemic. That is why the trained social workers are required today both in the conflict zone and in peaceful communities.

2. The Ukraine's sustainable development strategy should be assessed through the prism of the theory of central places. It has been proven that the theory of central places should be applied in practice not only in relation to the certain settlements, but to the countries. A prime example is the process of human resources formation and development. Conducting statistical analyzing of the initial data of the mentioned process in Ukraine (the dynamics of the population size, its natural movement and the level of unemployment) we have come to the conclusion that real conditions do not correspond to sufficient socio-economic conditions for the formation of the necessary competencies and improvements in people who are suitable for certain activities, as well as the use of the acquired potential of human resources in the process of creating benefits, taking into account the constant changes in the operating conditions. This leads to the migration, which is associated with certain risks to sustainable development [5]. Within the constant changes, in particular, with the emergence of an armed conflict in the East of Ukraine, the spread of COVID-19, we should review the content of training specialists according to the specialty 231 “Social work”, with the stages of implementation of John P. Cotter’s changes [6, 7]. Despite the fact that more than one hundred of Ukraine higher educational institutions are providing such specialists training, more specialists are required according to the listed changes. The solution to this problem is the organization of advanced training for specialists in the field of social work. Considerable emphasis in the content of the relevant program should be paid to social work with such categories as military personnel, of their families’ members, former servicemen, and in particular with those who has become disabled as a result of hostilities. Such advanced training is also advisable for the specialists in the moral and psychological support of military units (deputy commanders in personnel welfare), as they perform social work activities with military personnel within their units. Recently, the discussions regarding the transition from moral and psychological support [8] to psychological support with a method of comparative analysis, focusing on the NATO countries military formations have been taking place in military formations. In our opinion, this is not correct approach [9]. Even before the beginning of the conflict in the East of Ukraine, the sufficient socio-economic conditions for guaranteed recruitment of military posts in the Ukrainian military units were not created [10]. As a result, there is a lack of proper candidates for military service selection. Thus there is a necessity for socio-pedagogical prevention of maladaptation of servicemen [11] and other measures of social work.

3. The social work is necessary for the military personnel, members of their families, and military units in general the at are located on the territory of Ukraine in specific local communities and interact with them and are not isolated from the society. Therefore, a sustainable development in a society or community is an integral part of sustainable development in military units. The communities and the military units’ social services interaction was not traditionally carried out due to the closed nature of military formations. Today, these resources need to be combined, especially in the context of military conflict and pandemic, for their economy and rational use, as well as to achieve the goals 1, 2, 3, 4, 5, 8, 10, 16 in the field of sustainable development. The training of specialists for such interaction has not been conducted before in the interests of servicemen and members of their families.

4. There is a discrete issue of military and social work in military units with servicemen and their families’ members, as they are involved in the military conflict in Eastern Ukraine. There are dead and wounded combatants, received psychological trauma by servicemen family members as well as social and material problems. Ya. Spodar says that today “one of the priorities of the National Guard Command of Ukraine is the implementation of military and social work aimed primarily at ensuring social protection of wounded servicemen, their family members and killed combatants at combat missions [12]. Officers were not trained for military and social work before the military conflict in Eastern Ukraine. Although some issues of military and social work were included in some academic lectures and textbooks of higher military education establishments in Ukraine [13]. The National Academy of the National Guard of Ukraine and the National University of Defense of Ukraine delivers a discipline on military-social work with military personnel and members of their families. There is also a module at the bachelor degree training in this discipline, but the essence of such work is not clearly defined today. The concept of sustainable development as a guideline for such work has not been applied as well as there is no currently advanced training on this issue.

5. Since the 90s of the 20th century, there have been social services consulting centers for young people in Ukraine at the military commissariats, military units and at assembly points. However, these points do not take into account the specifics of our time - the military conflict in the East of Ukraine, its consequences, as well as new social, political and economic realities in Ukraine, and of course the pandemic. Thus, we need to update the content of advanced training of social workers of Ukraine to work with the military personnel and their families in the modern context.

6. Today the State social policy and social work as a direction of its realization through rendering of social services guarantee quality of life of all citizens at the level of the state standards (according to the legislation of Ukraine to all people who are in difficult life circumstances) [14, 15].To-day military personnel and their family members have a number of different problems of socialization, social adaptation and social rehabilitation, associated with military professional activities and its consequences (restriction of certain

human rights, problems with the employment of wives, high-quality education of children in small towns, problems of disability, adaptation of military veterans in civil society, lack of their own housing due to displacement in the country, etc.).The problems of the servicemen necessitated the attention of the leaders of the uniformed services of Ukraine. Their attention is focused on military-social work with their subordinates and members of their families as complementary social assistance and support from the capabilities of their departments. That strengthens the morale of the military. And the servicemen believe that they and their families will not be left without help in the performance of their official duty. These problems are related to health, quality education, decent working conditions, overcoming poverty and poverty in a pandemic and unemployment for family members, gender equality, countering violence, creating conditions for peaceful coexistence in communities, and etc. For example, there are international programs and projects for the Armed Forces of Ukraine personnel social adaptation [15]. In the future, these programs will be implemented only by Ukrainian specialists, who need to be already prepared for this activities. The orientation of Ukraine to the NATO, its social standards for the military today are far from the reality in Ukraine, and if there is no social welfare at this level, there should be, respectively, opportunities for moral and psychological support, military professional activity, that includes military social work.

7. Today we need modern social services of adaptation and rehabilitation in social work with servicemen in the community [17, 18]. A feature of modern social problems of servicemen is the impact of their participation in the military conflict on their future lives and the lives of their families. Among others there are such matters as problems of rehabilitation of combatants in conflicts in Ukraine and peacekeeping forces, psychological trauma due to tasks in the military conflict zone, which affect members of their families, further life of the families of fallen servicemen, peaceful and successful adaptation of the military in civilian life after demobilization due to injury, discharge from military service, etc. These situations are solved by the social services. Solving such new problems is at the same time solving the problems of sustainable development policy of society, and it is necessary to train specialists for this type of job.

8. Legislation on social services that solve social problems of the population and are implemented through social work defines them as “actions aimed at preventing difficult life circumstances, overcoming such circumstances or minimizing their negative consequences for individuals / families in them. Individuals / families can be provided with one or several social services at the same time”[15]. Difficult life circumstances are “circumstances that negatively affect the life, health and development of a person, the functioning of the family, which the person / family cannot overcome on their own. Factors that can cause difficult life circumstances are: a) old age; b) partial or complete loss of motor activity, memory; c) incurable diseases, diseases that require long-term treatment; d) mental and behavioral disorders, including due to the use of psychoactive substances; e) disability; f) unemployment; g) homelessness; h) person poverty; i) behavioral disorders in children due to parental divorce; j) evasion by parents or guardians of their responsibilities for the upbringing of the child; k) loss of social ties, including while in prison; l) child abuse; m) gender-based violence; n) domestic violence, o) getting into a situation of human trafficking; p) damage caused by fire, natural disaster, catastrophe, hostilities, terrorist act, armed conflict, temporary occupation” [15]. This enumeration allows to clarify the list of users of social services. These can be both veterans and active servicemen and their family members, but unfortunately, the resources of the military-social work of military units are not enough to solve most of these problems, and specialists who are to carry out this work have not received appropriate training. In the field of view of specialists who carry out military-social work, is their social and legal protection and socio-economic support in the Armed Forces of Ukraine [13] and social protection in the National Guard of Ukraine [19]. Other existing problems for military personnel and their families require interaction with social workers in the community. So, the training in identifying such problems and overcoming them in cooperation with attracted specialists is needed, as well as a separate management for advanced training, for which we also need to train specialists, both civilian and military.

9. Many social problems arise when people return from the zone of military conflict to peaceful service, families and peaceful cities. This is no longer their own military unit and it may be a different community. And a social employee needs to be able to offer a person necessary social services. This is a difficult to communicate category of people who are not used to being weak and asking for help, they held weapons in their hands, survived the war. Therefore, peaceful people need to be able to talk and work with them, especially women, who are most of all among social workers. There is no theoretical and practical training for future social workers with servicemen in civilian higher education institutions.

10. It should be noted that certain topics of training in higher education institutions still exist, but advanced training still does not exist. This is due to the fact that for social workers for the military it is differ because of different subordination to the Ministry of Social Policy and to Ministry of Defense. Interaction in the interests of servicemen and their family members is absent in the professional development programs, and servicemen today are not subject of the State social standards of social work. Therefore, there is no advanced training on the problem.

Thus, it is necessary to update the advance training for social work with servicemen of different categories and members of their families as the implementation of the state social policy of Ukraine in the context of the policy of sustainable development of the society. Such training should be provided by both civilian and military higher education institutions. This issue requires separate joint programs of disciplines, and not a separate topic in the discipline or an isolated discipline of only a civilian or only a military institution of higher education. Because they need to work in cooperation. Training today should be in a collaborative group for networking and understanding at the community level through the specific people who implement it. The common content is to solve the social problems of servicemen and their families in the context of sustainable development goals, which transfers social work with this category of clients from only social protection, payments, benefits to socialization and social problems through a wider range of social services in interaction with social community workers based on community interaction.

We interviewed thirty-four social workers of social services centers for families, children and youth and non-governmental organizations in Ternopil and Ivano-Frankivsk. They all answered that they did not have enough advanced training in higher educational establishment for such work, and modern approaches and methods of work are needed. Various tried and tested methods of working with servicemen and members of their families are needed too.

We interviewed fifty-six students of the six-year courses of the specialty "Social work" of higher educational establishments in these cities. We asked whether they would be ready to carry out such field of work. Everyone answered that not at all. The reasons for doubting the success of the work were called a young age, lack of experience (professional and life), the complexity of social problems and amount of such problems among servicemen and their families. Although no one said they would refuse to provide social services to this category of clients. This means that the strengthening of such advanced training is obligatory, taking into account gaps and sustainable development ideas. The question arises about the development of such an advanced training program, taking into account the specifics of professional responsibilities and opportunities, state social standards for the providing social services, departmental opportunities, pooling of resources in the community and cooperation in the maintenance of social services, etc. The development of such a program is the purpose of the article.

2 Research methods and methodology

Materials for the study are:

1. Legislation of Ukraine on higher education, military education, social work, social services, sustainable development, social policy of the state. The methodological significance is in the orientation of the program, that we will develop, on the best world models of building the educational process, solving social problems and problems of socialization of servicemen and their families, based on the competence approach in education, ideas of sustainable development in social work and military social work.

2. Regulatory framework for military social work in various law enforcement agencies [19, 20]. Today, the solution to the problem of improving the quality of officers of the security forces of Ukraine service depends on the human factor, moral and psychological support of the service, the microclimate within the military unit and the creation of various conditions for service, including social, economic, material, psychological, medical, etc. The unit commander is unable to solve all the social problems of his subordinates both of an individual and the entire unit. To help them, the positions of deputy commanders in welfare have been implemented. So they are responsible for such areas of work as military social work with personnel. He also carries out morale and welfare work with personnel. There is no definition of the essence of military social work in the legislation today. Therefore, the training of specialists for military social work should be carried out taking into account the regulations of military structures, as well as basic education, science, theory, technology, methodology. Note that the regulations are already based on the idea of sustainable development for goals 1,2,3,4,5,8,10,16. But their implementation at the level of practical social work is absent.

3. Characteristics and list of both general and special social needs and problems of servicemen and members of their families [16, 17, 21-27]. Older people, children with disabilities and others in need of outer support and assistance are particularly vulnerable in pandemics and military conflict, and need more support and assistance in their everyday lives. Thus, goal 10 in the field of sustainable development suggests that, in a pandemic, "Refugees and migrants, as well as the older people, people with disabilities and children, are particularly at risk to be neglected. In addition, hate speech against vulnerable groups is growing" [28]. These are essentially tasks of military social work and social protection, which coincide with the goals of sustainable development. The military conflict in Ukraine has significantly increased the number of social services users. The military themselves have already understood the necessity of social work with their colleagues and members of their families (assessing by modern regulations on the problem of military formations. The list of these problems) [21-27]. Also the military conflict made it possible to determine the current tasks and content of military social work and social work with servicemen and their families such as social adaptation, social prevention, social rehabilitation, social support, management of social services implemented through complexes of social services;

4. Social work with servicemen theoretical and methodological principles developed in the world and in Ukraine to solve their social problems. Thus, Joel F. Handler [29] says about British model of integrated complex family services at the local community level as a rigid set of social services. We believe that they still need some alternative, choice, taking into account the characteristics of customers and their families. But it is valuable to combine the diagnostic model of social work with social policy and management of social services in the community. This combination is not established in Ukraine. The social services are centralized according to standards and categories of clients. In the UK, all social services must comply not only with public social policy, but also be scientifically proved, useful in a particular community. Communication within the community is especially important [30]. The UK uses different approaches to social work, including intervention,

medical social work, group theory and work with them, the idea of group development (which coincides with our idea of family development and organizational development), problem-oriented and environmental approaches to social work [31], and that provides for individualization and differentiation in the provision of social services. But the client cannot determine and choose the set of services. It is the object of services. Since 2001, Ukraine has been working with clients as subjects of social services, only in certain identified crisis cases - as an object ("self-help" and "crisis intervention") [32]. Valuable in the UK is the methodology of working with the families of servicemen who have been involved in military conflicts "FOCUS". This methodology reduces military personnel and their family members' anxiety and depression and provides a long-term positive result. A family-centric approach to socio-pedagogical work with the family is useful for working with servicemen' families. It considers socio-pedagogical services as a subsystem of social services, as the main for learning a new positive model of behavior of family members, and as creating conditions for implementation family rights in society and community and family member rights in the family [32]. This requires considering working with a serviceman, taking into account the integrity and rights. We also relied on Carl Castro and Sanela Dursun's book "Reintegration of the Military Veteran" [33], which reveals the views of experts from all over the world on the problem, offers a methodology for assessing the veteran's needs, and a roadmap for achieving the best social services in the future. Also the description of the program of transition from military service to civilian life, the role of the family, the public, medical institutions in this process is valuable in this study. In the United States, the need for a program-targeted approach to the reintegration and provision of social services has been proven [34]. This is also confirmed by our work as a consultant in the Ukraine central state authority on social work in 2000-2015. We worked on the following state comprehensive and targeted programs for social support of the family: "Social support of the family"; "Social support for disadvantaged families"; "Social support of orphanages and foster families"[32], and implemented them. But there are no separate programs of social work to support servicemen and members of their families in Ukraine. We also relied on approaches to the social services for servicemen and their families in different countries. Among them there are social services and social programs in a peaceful life and in a conflict of Ukraine, the Great Britain, the USA, France and Germany, which use integrated, comprehensive, problem-oriented approaches, the theory of strengths, "self-help" and "crisis intervention"), took into account the results of the analysis of theories of social work in Ukraine [32, 35].

5. World and local experience on the problem. Thus, the goal of the "social service of the Swiss Armed Forces is to reduce social disparities. Assistance takes the form of personal advice on family, financial or legal matters. Topics include labor law (protection against dismissal, continued payment of partial wages), income replacement, health insurance contributions, debt collection and others…. assistance is provided through information, consulting, support, mediation and financial support"[36]. At the same time, the Swiss Armed Forces social service is a specialized agency of the armed forces that provides advice on social issues. It is a military function, not civilian work [38]. In the USA, Canada there are Centers and departments in the Ministries of Defense for work with personnel and veterans, researches of their social rehabilitation, social work with families of combatants are carried out, new approaches and strategies on their social adaptation to civilian life are developed, developed federal programs for the disabled and veterans, conducted research on the psychological and social characteristics of peaceful service and during hostilities [35]. Institutional forms of providing social services to servicemen and members of their families in the world and in Ukraine today are service hubs, integrated support centers, social services and their specialized formations, rehabilitation centers, personnel departments, etc. [39, 32]. Social service centers for families, children and young people have some experience in adapting servicemen to the conditions of service, for example, their psychological boarding on a Ukrainian Navy vessels. The Veterans of Military Conflict Department exists in the Ministry of Internal Affairs of Ukraine. It provides practical social assistance to veterans and members of their families. At the National Guard of Ukraine units, the military social work is carried out essentially as social welfare [19]. All participants in hostilities in Ukraine are provided with social welfare in accordance with the law [40]. It should be noted that military and social work in military units today can be carried out according to normative documents not only by deputy commanders in welfare. The legal acts allows to conduct such type of work with families, children and youth by specialists, such as the authorized bodies engaged in social work with families, children and youth; social work specialists; associations of citizens, charitable, religious organizations; legal entities and individuals that provide social services to families, children and youth; volunteers in the field of social work with families, children and youth (law on social work). Therefore, their experience and resources are appropriate for social work with servicemen. Military and social work is the sphere of activity of the military, but they can interact with other subjects of social work in the interests of solving social problems of the militaries and members of their families, the community in which the military unit is located.

6. Scientific sources on social and military social work, which clarify its essence, purpose, scientific basis. According to the legislation of Ukraine [14], social work is understood as "professional activity aimed at preventing, minimizing negative consequences and overcoming difficult life circumstances of families, children and youth, strengthening their ability to realize their own life potential". This totally applies to officers and their families and is in line with the sustainable development goals 1,2,3,4,5,8,10,16. Savitsky [41] considers that military social work, as well as social work in general, should be considered from such several points of view as: a) it is a kind of human activity - it concerns a person whose life in some way affects the army; b) it is the science of the laws of military social work, its

methods, principles, technologies; c) it is a science that sheds light on practical and transformative charitable practice in the plane of military society; d) it is an academic discipline that, based on the points of the theory of social work, its content shows the peculiarities of the practice of social services in the military social environment.

We agree with this meaning of social work, and it allows us to apply to military and social work all the theoretical principles and methodological developments of social work, to take into account the problems of servicemen and their families as well as methods of training social workers to train officers who practice military and social work. The same researcher defines that "military social work is the science of formation, development, charity in the army, the organization of social services and the providing of appropriate social assistance to servicemen, as well as all those who have or had some relationship to the defense of the Motherland" [41]. Thus, this definition emphasizes the purpose of military and social work, as well as the criteria for defining its objects. They are the active servicemen and those who were involved in military service. There are other points of view on this concept.

Military and social work today is understood in the Russian Federation as "a system of conceptual-theoretical, political-legal and organizational-practical measures of the state and non-state institutions and authorities to meet the needs, interests and benefits of servicemen discharged from military service and their families in the social sphere of life. It serves, on the one hand, as an instrument and conductor of the state's social policy in the military field, and on the other hand, as a concretization and addition of social policy to the activities of civil society institutions to realize specific social needs and interests, rights and freedoms, guarantees and benefits of military society [42]. We do not agree that military and social work is limited to those servicemen who are discharged to the reserve.

Today a number of acting servicemen also need social support and assistance due to the circumstances described above. But the idea of combining in the system the measures of different levels and spheres of activity that implements a systematic and multidisciplinary approach in social work is useful. Today, the Armed Forces of Ukraine interprets social work as "socio-legal, informational and organizational measures regarding promotion of the implementation of the rights, benefits, social assistance and appropriate compensations for servicemen and employees of the Armed Forces and other military formations of Ukraine, for the members of their families, by creating social conditions and guarantees in military and labor collectives which would provide their normal vital activity, conscientious and high-quality performance by servicemen and civilian personnel of the functional and service duties assigned to them" which is established by the legislation of Ukraine and other legal acts, thus military social work is divided into social and material maintenance and socio-legal protection [43].

Sharing the opinion of the authors on the need for social work to create social conditions and guarantees in military social work, we note that social services in Ukraine according to the legal acts are broader than both social welfare and legal protection and social and material security. Moreover, prevention measures are the part of military social work that includes not only educational but also social, psychological, legal content, and so on. Today the spectrum of social problems of servicemen and members of their families is bigger than 7 years ago. Therefore, the content of military social work requires improvement. There is an opinion that in Ukraine "military social work is an integral type of social work and military management, specifically military education, work on humanitarian issues" [41]. And it is true in terms of working with personnel. However, we believe that it should include issues of social management and management of social services, interaction in the community in the interests of servicemen and members of their families. Therefore, it is the way of sustainable development ideas implementation. Families of servicemen also have economic problems today. The Coronavirus pandemic, which has caused many family members of military personnel to lose their jobs, is already a challenge in military camps, where wives often work unprofessionally or are underemployed. Also, there is not much work for young people. A serviceman becomes the only working person in the family, not having the right under the legislation of Ukraine to work part-time anywhere except the scientific and teaching spheres. Therefore, we need to work to support and help family members to prevent impoverishment and create decent living conditions for ourselves and our children. These are goals 1, 2, 3, 4, 8, 10 in the field of sustainable development.

7. The philosophy and sociology studies of war and peace [44-52] determined the socio-philosophical foundations of military and professional activity and the purpose of military service during war and peace, which affects the problems of users of social services, features of their provision, content, technology and methods of social work and military social work in subdivisions and units. The philosophy of war and peace influences the peculiarities of training servicemen for peaceful service and in combat, the peculiarities of social management in military units and social work itself. The philosophy says about number of issues to be solved such as a need to solve a set of problems of servicemen in different conditions, the problems solution, a human factor as the basis of victories and defeats and social conditions for this, a problem-oriented approach in social work in combat, a need to form reliability and resilience of servicemen through competency and activity approaches as well as special training of social workers to provide social services in different conditions to the different categories of servicemen and their families [53, 54].

8. Educational programs of civilian institutions of higher education that train specialists in social work [1-4]. Today these programs almost don't take into account the problems of servicemen and members of their families as subjects and objects of social work. But they provide theoretical and practical foundations for working with different categories of the population, form professional competencies for this purpose.

9. Educational programs of higher military

educational institutions of Ukraine (the National University of Defense of Ukraine (NUDU), the National Academy of the National Guard of Ukraine (NANGU)) and of the world. The analysis of these programs shows the implementation of a competency-based approach in higher military educational establishment. However, there is no interaction with community social workers, sustainable development goals, modern social problems of servicemen and technologies and methods of solving them, world experience on the problem in programs of disciplines related to military social work. In the discipline "Information and propaganda support of military missions and operations", there is a module on military social work, but it does not take into account the issues of interaction with social services of the community and sustainable development. We believe that social work is a separate area of the officer's work, as it includes a range of social services and types of work aimed at solving social problems, of which educational and pedagogical problems are only a small part of the whole range of social problems of servicemen and these problems require a solution with the help of a complex of social services. That is, not educational work should include social work, and military social work can have an educational approach. The reasons for this are that the concept of socialization of the personality in pedagogy is broader than education, and includes it as a purposeful factor in the development of personality, as one of many factors that affect the development of personality and determine it. The Swiss experience of training social workers for the military forces is interesting. It is carried out as advanced training on the basis of education in social work, social sphere and military training (conscript schools). The training course for a military social worker is a fascinating three-week training course (technical course) that prepares for the specifics of social work in the army, as well as for the tasks and activities in favor of social service in the army. After the course an officer is appointed as a specialist. The course is conducted in conjunction with the army pastoral care and the army psychological and pedagogical service" [38]. But this course also did not provide preparation for interaction in the community and there is no focus on the goals of sustainable development. But the Swiss army has great social achievements in terms of social protection of servicemen and at the same time takes care of professional social work in terms of morale and psychological condition of the servicemen. In Germany, the servicemen emerging problems are solved by the social workers from the reserve officers who received the second higher profile education after dismissal at the expense of the Ministry of Defense [55, p. 218].

10. Basics of gender theory in military units. [56] 10% of women took part in hostilities in Eastern Ukraine. Since 2012 there have been female cadet sat higher military educational institutions. There are women who take up military posts. Therefore, it is necessary to take into account their points of view in decisions making concerning of creating social conditions for successful service. In addition, gender-based social work will help prevent family violence, sexual harassment at service, and gender education for men and women. Goal #5 of Sustainable Development states that today, "The coronavirus outbreak exacerbates existing inequalities for women and girls in all areas, from health and economy to security and social protection", "the data show that since the moment of pandemic outbreak beginning violence against women and girls, especially family violence, intensified." Women's economic freedom is the basis of social prevention of family violence. Therefore, a gender approach should be included in the program for the provision of social services.

The methods of our study are following: comparative analysis, theoretical analysis of sources, generalization, survey, observation, modeling and synthesis.

3 Results

In order to develop advanced training programs for working specialists of social services and the servicemen we had to solve several tasks. Among them there are: 1) to clarify the essence of the concept of "military social work"; 2) to determine the users of military social and social work services with servicemen and members of their families; 3) to substantiate and determine the theoretical foundations of such social work and the construction of such programs (in the context of sustainable development); 4) to develop advanced training joint program for social workers of the community and the servicemen who are responsible for this type of job in their units. As there is no legislative definition of this term in Ukraine as well as its unique understanding, we applied to native and international experience in solving the problem. In the United States, military social work has its own organizational structure, regulations, service delivery standards. It provides educational and qualification requirements for military social workers, specific professional training and following certain ethical principles [35, 57]. The military social workers positions were introduced at the United States Department of Defense. At the Department of Veterans' Affairs the positions were established to work with veterans. That is, in the United States, they work both with those servicemen who serve, and with those servicemen who are already retired [57]. At the same time, a profile approach is also interesting. It combines United States civilian social workers and servicemen and defines military social work as "continuous activities, political and administrative measures, and advocacy, including prevention, treatment and rehabilitation services for social clients, veterans, their families and the communities in which they live" [35]. This approach is multilevel and partnership-based to provide services to the military and their families. At the same time, it singles out military social work as a separate area of social work with servicemen. But it does not fully take into account the Ukraine realities and its current problems because it is permanent, and in Ukraine there is an acceptable concept of "help for self-help" in social work [32], which is limited in time and provides a gradual transition from crisis to development. Therefore, we agree with this approach in combination with other approaches that are appropriate in our country.

Today in Ukraine, "the purpose of social work in the context of military service is to restore the physical and mental strength of those who are assisted, to adjust the personal attitudes of clients, teaching them to properly perceive the coercive aspects of their lives; to introduce elements of social justice into the framework of subordinate attitudes which are typical of military service" [58, p. 149-156]. This focuses to social rehabilitation (recovery), social prevention, which are the types of social work, psychological and ethical approaches. But social work is needed by those who are in the conflict zone, veterans and the disabled, their families, and those who are currently serving in peaceful areas. The conflict in Eastern Ukraine leads to the social problems: deaths of servicemen, their injuries, family distance, psychological trauma and mental and behavioral disorders, right up to alcoholism, drug addiction, smoking, etc. At the same time, family members themselves take upon the father burden who performs tasks for a long time in a military conflict zone. This is a long-term stress for the family and each of its members. In addition, the coronavirus pandemic leads to problems with psychological state, anxiety, even suicide, alcoholism and drug addiction. This is a double burden on the family, which requires special psychological and social support and assistance to officers and their families, the promotion of a healthy lifestyle, and so on.

Therefore, Goal #3 in the field of sustainable development says about a need to help maintain the mental health of people during a pandemic and coincides with the goal of social prevention of negative phenomena as a sphere of the social work content. Preventive and rehabilitation approaches are thus important for social work with servicemen and their families. This coincides with the opinion of Yu. V. Brindikov [17], who was engaged in social rehabilitation of ATO soldiers. N. S. Oleksiuk [18] has proved a need for a socio-pedagogical approach in work with the servicemen families. This approach combines social assistance and support along with showing positive patterns of behavior in the family.

The military conflict itself is a threat to sustainable development and requires the social support of those who are affected and involved. "The best form of response will be to neutralize direct threats by actions which are commensurate with those threats, while protecting human rights and the rule of law", the UN Secretary-General claimed [60]. At the same time, human rights must be also ensured in this situation because they preserve human dignity [60]. This means relying on the theory of human rights and a human rights-based approach in social work and makes military social work necessary on this basis to focus on working with those military who are involved in the conflict in Eastern Ukraine. We have proved that socio-pedagogical work as a component of social work is essentially human rights-based like creating conditions for the realization of human rights, showing a new positive model of behavior [32]. In addition, "in relation to a serviceman of service for a fixed period, military social work helps to discharge his/her duty with dignity, for an officer it contributes to family well-being, for a military retiree it provides a dignified existence, etc." [41] This means the differentiation of military social work and targeted provision of social services with different content and methods, technologies. How to implement it in the conditions of a conflict and pandemics, what criteria for providing social services should be guided, how to choose the priority problems to solve in the conflict zone, to find resources and other issues are the problems for many social workers and commanders. They need to be taught this on the basis of a problem-oriented approach and human rights theory. Note that officers often change their place of service, and this requires both their adaptation to new conditions of service and life, and adaptation in the community and micro-environment of their families.

This process is always difficult and long, painful and can be resolved more calmly if you use the services of social workers. Goal #8 of sustainable development says about the necessary socio-economic measures for sustainable development in the conditions of a pandemic: "… helping people to overcome trials through social protection and basic services; promoting social cohesion and investing in community-based resilience and response systems." These are multidisciplinary, organizational and resource-based approaches in social work with the servicemen. Since our advanced training program is designed for adults, not students, it should be developed taking into account an androgynous approach which requires learning from the experience of students, taking into account their views in learning; today a competence approach is the basis of education, and an activity and student-oriented approach and a personality-oriented approach are the basis of all learning, they take into account the views and wishes of learners, learning in activities. All this requires a training form of adult education, the features of which we have explored and taken into account in developing the program. In addition, a digital approach for learning the program material is required, as the presentation of information for learning is the basis of a conscious activity, and the digital form of its presentation better contributes to the implementation of learning principles (clarity, science, connection with life, etc.), accelerates learning.

On the basis of the stated information, we can make such generalizations on the 1st, 2nd and 3rd tasks of the article as a basis for performance of the last task. Military social work is the direction of implementation of social policy with servicemen and the members of their families, which is carried out through the provision of social services on counseling, information, support, assistance, self-help, advocacy, organizational measures, social protection in various types of social work (social prevention, social rehabilitation, social support, social services, social management) and benefits, social guarantees of the state. It should be noted that state standards for the provision of social services in Ukraine also belong to the state social guarantees. Social work is subordinated to social management in the military team, solves social problems of servicemen and is carried out by a unit deputy commander on work with personnel. Its purpose is to create social conditions in the military unit to perform military and professional tasks at the highest level by servicemen, to realize their rights and legitimate interests in everyday life and service, to meet the specific needs of servicemen and their benefits and to solve their special social problems (socialization), adaptation, integration, etc.). Social work with servicemen is a social work, the object of which is the servicemen and the members of their families, it solves their problems of socialization and adaptation, rehabilitation. It is carried out as the provision of social services to people in difficult life circumstances.

The objects of military social work are: servicemen on active service and the members of their families; in reserve servicemen, retired, lost their ability to work; the family members of lost servicemen; all members of military units. The subjects of military social work are: military personnel commanders and military personnel deputy commanders of military units, as well as servicemen and the members of their families. In social work, these are the same objects as in military social work, but only those that are in difficult life circumstances. We consider the objects of both types of social work at the same time as its subjects, except the cases of family violence, child abuse, threats to life and health of family members and children.

Based on the theoretical foundations of the social work in military aspects and the social work with the military, we have identified the following scientific approaches:

1) Philosophical approaches: the persistent development of society, ethical area, philosophy of war and peace, human development;

2) General scientific approaches: the theory of human rights, resources, optimization, multidisciplinary; organizational, systemic, political, comparative and axiological approaches;

3) Specific scientific approaches: the human rights-based approach, social policy, socio-pedagogical (environmental, family-centered, personal), program-target approach, pedagogical (the theory of activation, theory of team, the dialogue of cultures, theory of participation, personality-oriented education, pedagogical support, facilitation);

4) Approaches of social work: the problem-oriented and psychological oriented approaches (humanistic, functional, behavioral and cognitive theories, catalytic and client-centric models of social work), approach of sociological focus (the systemic theory of social work, theory of social roles, theory of stigmatization), complex oriented method (intervention (crisis intervention), a model which is oriented on a task or a problem, a self-help aid); the preventive, rehabilitative, profile and integrated approaches, theory of strong points. Its content is a variety of social services, which are realized in a comprehensive manner at the social prevention, social support, social management, social protection, social services and social rehabilitation.

Of great importance is the consideration of scientific approaches and theoretical foundations: the theory of persistent development; student-centered, informational, digital, competence, androgynous and personality-oriented approaches, theories of educational content, activation of education process. It presents during the development and realization of a professional development program for social workers who help servicemen and members of their families, and the military who work in military units in the context of the military social work.

In view of the foregoing and exploring the professional development programs for social workers and servicemen [1-4,60 and others], we can formulate the purpose and tasks of the professional development programs for social workers to work with the military in the context of persistent development ideas. The purpose is to develop the professional competencies of social workers and officers in military units to occupy the social work with servicemen in coordination in the community. The tasks are to develop the professional competences of social workers and military officers who deliver the social work (the ability to analyze mental properties, states and processes, processes of military personnel socialization, prevention of social risks, difficult life circumstances, prevention and resolving of social conflicts in the military staff, serviceman's family, divorce prevention, ability to understand the organization and functioning of the social protection system and social services in the community and at the military formations, ability to study the social problem of the military and their families, to appreciate their problems, requirements, specifics and resources, ability to develop effective methods and ways to solve problems, ability to give efficient social services to the military, capability to cooperate with community members, capability to adhere to ethical principles of social work, ability to justify, to make professional decisions as regards clients of social work and to take responsibility for their consequences) and general competencies (ability to use the information and communication technologies, ability to be critical and self-critical, ability to work as a team and alone, ability to communicate with members of other professional groups).

Features of the program are the simultaneous training of social workers and the military of the community; focus on social services in the context of persistent development: goals 1,2,3,4,5,8,10,16; focus on the human factor and cooperation, the subjectivity of the individual, human rights and the improving communications in the community, exchange of resources and social services; the theory of social work with the military is combined with exercises, the experience of specialists (ideally as training forms of its realization), the using of media education tools and distance learning technologies, a work in microgroups. This program is developed for professionals of the higher education in social work and military support. The program is designed for 30 hours of classes and 60 hours of individual practice, in total of three credits. It highlights the content of the professional development program for social workers and the military "Social work with the military and the social work in military aspects in the context of the persistent development of society" (See table 1).This development program was discussed at the Departments of Pedagogy and Pedagogical Management; Social work, Special education and socio-cultural management and after approbations it was posted in the website of Ternopil Volodymyr Hnatiuk National Pedagogical University. It was socially advertised among social workers in the region, in the military units. Its content and methodological materials were developed before its implementation and people were interested in. Nowadays there are methodological and organizational studies to introduce the realization of the program using the distance learning tools. Professors (who will realize it) have graduated the distance studding courses of the media education and mastered digital tools of interactive teaching. They have learnt methods of their application during the distance education. The first lessons will be hold after January 14, 2021. It will be based on Ternopil Volodymyr Hnatiuk National Pedagogical in the Ternopil region. The addition of media competence elements as a part of the development course to master tools and the real training by students (use to divide to small groups for discussion, to assume by everyone, to do tasks and etc.) is another successful condition during the pandemic. The curriculum of the program is given in the Table 1 [61].

Table 1. The curriculum of the development program “Social work with the military and the social work in military aspects in the context of the sustainable development of society”.

№	Name and content of training modules	Hours	For		Teacher
			Classes	Independent work	
Module 1 “Digital tools for teaching of social work”					
1	Media education tools and distance technology tools in the educational process	3	1	2	Petryshyn L.Y., Medvid M.M., Trubavina I.M., Meshko H.M.
Module 2 “Theoretical foundations of social work with the military and members of their families”					
2	The military and members of their familiesas subjects and objects of the social work and the social work in military aspects.	3	1	2	Petryshyn L.Y., Medvid M.M., Trubavina I.M., Meshko H.M.
3	The sustainable development policy and social policy towards the military and members of their families in Ukraine	3	1	2	Petryshyn L.Y., Medvid M.M., Trubavina I.M., Meshko H.M.
4	Theories of social work in relation to the military and members of their families	3	1	2	Petryshyn L.Y., Medvid M.M., Trubavina I.M., Meshko H.M.
Module 3. “Practice of social work with the military and members of their families in the community”					
5	The world and internal experience of social work in the community with the military and members of their families	6	2	4	Petryshyn L.Y., Medvid M.M., Trubavina I.M., Meshko H.M.
6	The cooperation in the community as a base for solving social problems of the military and their families.	3	1	2	Petryshyn L.Y., Medvid M.M., Trubavina I.M., Meshko H.M.
7	Project presentations, program results	9	3	6	Petryshyn L.Y., Medvid M.M., Trubavina I.M., Meshko H.M.

4 Discussion

Our development program takes into account the purposes of the sustainable development, the main modern problems of the military from the different structures of Ukraine, the foreign and internal experience of social work with them, based on the theoretical foundations of such work. The foundations are determined taking into account the mentality of Ukrainians, the best international experience of the education and the valid legislation about the social work and education in this area, pay attention to thoughts of main stakeholders in this way of educational activities, the experience in developing and realizing such programs in civil and military higher educational establishments in Ukraine.

It should be noted that there is not any social work with the military or the social work in military aspects in the Republic of Poland. But there are the NATO social standards for the military. Seminars for advanced training of the military personnel are conducted in Ukraine by international organizations (UN-women and their partners to introduce a gender approach in the educational process of higher educational establishments). But this is only a separate aspect of our program content. The European University Continuing Education Network held a scientific-practical conference with the simultaneous short-term professional development “Actual Problems of Psychology, Sociology, Social Work and Professional Training of Specialists” [62] in Slovakia. The same event was about the topic “Status and prospects of reforming the security and defense sector of Ukraine”, also the topic “Optimization of training in the context of national and international security” was studied [62].But the issue of training specialists for the social work with servicemen and the social work in military aspects was not considered there. Accordingly, there are not any training programs for the social work with servicemen. According to scientific researches, in the Russian Federation there is a necessity to increase the military and social work, requirements for military and social workers, their education and training in the social work, the studding to improve the cooperation with non-governmental organizations (Committee of Soldiers' Mothers), [63, p. 221]. But our advanced training development program is unique.

Conclusions

The study identifies the possibility of orientation and realization of the social work for the military and members of their families, and the social work in military aspects as a part of the sustainable development ideas and as a direction of realization of sustainable development policy and the governmental social policy. This social development program is topicality, it should be common and simultaneous for all parties. The single program should pay attention to the problems of the military and their families, sustainable development ideas and the social policy, the necessity in the community using the set of scientific approaches for such social work. The program consists of three modules: “Digital tools for teaching of social work”, “Theoretical foundations of social work with the military and members of their families” and “Practice of social work with the military and members of their families in the community”. It is required 30 hours of classwork and 15 hours of independent work. It is based on a set of scientific approaches to professional development of social workers and the military in the social aspects who already have a higher education and a work experience. The conditions for its implementation during a pandemic are the teachers’ development in the area of media tools for education and distance technologies for interactive learning. In this situation they should also accomplish another using method, cooperation in the development community some social services; the social advertising of the program among potential listeners. For students, it is a condition for the successful professional development during the studying of the course about media education tools which will be needed in the developing. Further research into the chosen problems looks promising as the development and implementation of specialization disciplines in higher educational establishments as a choice of studying the social work with the military and members of their families, the social work in military aspects for cadets and students.

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Modeling the assessment of investment projects for territorial communities in compliance with the concept of sustainable development

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Abstract. The article is devoted to the problem of evaluation and selection of investment projects aimed at the development of territorial communities (TC) and take into account the need to pursue the goals of sustainable development at the local level. In the context of decentralization reform, attracting investment funds is the leading activity of local self-government. And to ensure the transparency of management and presentation of its results to the governing bodies of TC need new scientific methods to justify the choice of one or more projects from a variety of alternative solutions. Decision-making taking into account the concept of sustainable development determines the evaluation of investment projects in terms of their effectiveness in finding a balance between social, economic and environmental components. The peculiarity of comparative analysis is taking into account the qualitative assessment, so to make optimal investment management decisions, a model is proposed, developed on the basis of fuzzy logic and implemented using tools Fuzzy Logic Toolbox. The article builds and substantiates an improved fuzzy model for evaluating investment projects for TC development. The improved model is based on a system of 15 quantitative and qualitative indicators of achieving goals in the social, economic and environmental components of the concept and allows for a "soft" assessment of the investment project. This model is used to substantiate the decisions of the TC of Zaporizhzhia region and can be used in the development of decision support systems at the level of TC for quantitative justification of decisions, conducting variant calculation.

1 Introduction

In the current conditions of economic development of the territorial communities (TC) in view of the processes of globalization and intensification of competition, the issue of financial security of economic entities of certain regions becomes relevant. Now there is an urgent need for a mechanism of mobilization and optimal management of financial resources of economic entities to protect their investment activities from the consequences of the unstable economic situation in Ukraine and inefficient management.

Ensuring the balanced development of the regions is one of the priority areas of Ukraine's regional policy at the present stage of its transformations. In general, sustainable development is no longer a national or, even more so, a local problem, but encompasses global goals. Significant is the merit of the UN, whose activities are mediated by world summits, declarations, resolutions, final documents of conferences and others. Among the latter are the announced global goals of sustainable development by 2030 [1]. The report presents the results of adaptation of 17 global SDGs taking into account the specifics of national development, 86 national development objectives and 172 indicators for their monitoring, as well as benchmarking benchmarks to be achieved by 2030. This should be considered as a basis for further planning of Ukraine's development and monitoring the state of achievement of SDGs. Therefore, the urgency of the issue of finding ways to achieve the goals of sustainable development is beyond doubt. This also applies to TC in Ukraine.

Among the general approaches to interpreting the essence of the category of sustainable development, we follow the definition proposed by the World Commission on Environment and UN Development in 1987, according to which sustainable development is development that meets the needs of the present, but does not jeopardize the ability of future generations own needs [3].

This concept provides an opportunity to provide comprehensive management of territorial socioeconomic systems, integrates the agreed aspects of economic, environmental and social development of society, creates conditions under which from one generation to the next the quality and safety of human life will not diminish, the environment will not deteriorate and socio – economic progress will be ensured [3]. Each territorial community is tasked with identifying areas and means that will enable sustainable development, both in the long term and at every step of government.

The problem of choosing from possible alternative solutions is usually not easy for decision makers and requires qualified justification. This is especially important in the context of Ukraine's progress towards openness of society, increasing demands for transparency of government actions and their results.

The scientific works of both domestic and foreign scientists [4-8] are devoted to the study of socioecological and economic development of the region, in particular those related to the development of models for assessing its level.

Problems associated with SDGs have been investigated in sources [9, 10]. Methods for determining the degree of achievement of SDGs are considered in the works of Joanna Marszałek-Kawa, Piotr Siemiątkowski [11], Jonathan D. Moyer, Steve Hedden [12]. Foreign direct investment related to SDGs has been considered in the work of Juri Suehrer [13].

However, studies on the quality of investment projects at the regional level [14-17] take into account only certain aspects (environmental, social or economic), indicators of achievement of SDGs are not taken into account. The article [18] proposes a multi-criteria approach to the selection of investment projects. However, there is no analysis of the development of regional systems and integrated territorial communities, especially those that fully take into account the goals and objectives of the concept of sustainable development.

The work [19] of the authors is devoted to solving the problem of evaluation and selection of investment projects aimed at the development of local communities, taking into account the concept of sustainable development. The constructed fuzzy model of evaluation of the investment project gives the chance of "soft" – qualitative estimation of the considered investment project. However, the constructed model is based on selective quantitative and qualitative assessments of the social, economic and environmental components of the concept, but does not take into account the detail of SDGs.

The purpose of this work is to improve and apply a fuzzy model for assessing the quality of investment projects for local communities to take into account the goals and objectives of the concept of sustainable development, recommendations for its application in the strategic decision-making process for the community.

2 Materials and methods

The essence of the problem to which this work is devoted, is the evaluation and comparative analysis of investment projects. These projects are presented to the territorial community (TC) management for selection and influence its further development in the context of the implementation of the sustainable development strategy.

To take into account the concept of sustainable development when choosing investment projects for territorial communities, it is necessary to address two issues:

1) what indicators to take into account when evaluating them;
2) how to take into account the selected indicators.

The last question is equivalent to the choice of a relevant mathematical model, which should be used to build an integrated assessment of the project and develop recommendations for choosing the best project available. The solution of the first question should be based on the use of a system of national indicators of achievement of SDGs, which are used to monitor the degree of implementation of the Concept of Sustainable Development [20].

Sustainable development of territories is ensured by a combination of environmental, economic and social components (spheres), each of which can be assessed by a whole set of relevant indicators. For further modeling of estimation of the level of development of TC as a result of realization of the investment project for each component we will select one measurable indicator, which in the further researches can be replaced by, for example, an integral indicator for a certain area. Each of these marks (indicators) characterizes the effectiveness of an investment project for TC in terms of a specific area. It should be noted that the choice of a measured indicator faces the problem of choosing a measurement scale and methods of its measurement / calculation. If a quantitative indicator can be chosen to estimate the level of economic development, for example, the rate of increase / decrease in community budget revenues resulting from the project implementation, and to estimate the social impact, the number of jobs that will be created during the project implementation, then the environmental component is not always suitable for formal quantitative measurement procedure. Therefore, it is often only expert evaluation that can be used to measure it. However, confidence in such estimates may be different. Thus, the rating system, which characterizes the effectiveness of the implementation of the investment project, can contain both quantitative and qualitative indicators.

With this in mind, we come to the conclusion that in order to solve the problem of evaluating investment projects in the context of the concept of sustainable development and to make management decisions on the development of TC, it is advisable to use data mining tools, namely fuzzy modeling. Its founders – L. Zade [21], D. Dubois and H. Prade [22] devoted their research to problems of the use of a fuzzy logic for the analysis of economic systems. The works of A. Matviychuk [23], A. Nedosekin [24], N. Maksyshko, V. Shapovalova [25], E. Kanaeva [26] and others are devoted to the improvement of decision-making methods in the economy based on the use of a fuzzy modeling methods.

The methodology for constructing a fuzzy model, including to obtain a qualitative assessment of an investment project for the development of TC, taking into account the concept of sustainable development, consists of the following stages:

- formation of a base of a fuzzy model input variables;
- fuzzification of input variables;
- formation of a base of rules of a fuzzy logic;
- accumulation of conclusions based on a fuzzy rules;
- defuzzification of the output variable (see Fig. 1).

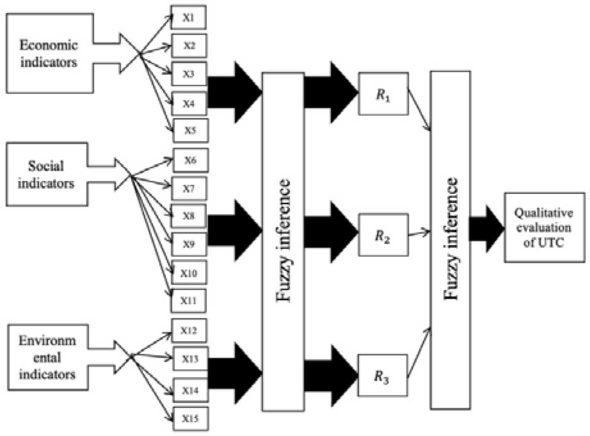


Fig. 1. The general scheme of construction of a fuzzy model of investment project evaluation for the development of TC.

A fuzzy model for evaluating the attractiveness of investment projects will be used to benchmark them on the development of TC in line with the sustainable development concept. The general scheme of the decision-making method for choosing an investment project is presented in Fig. 2.

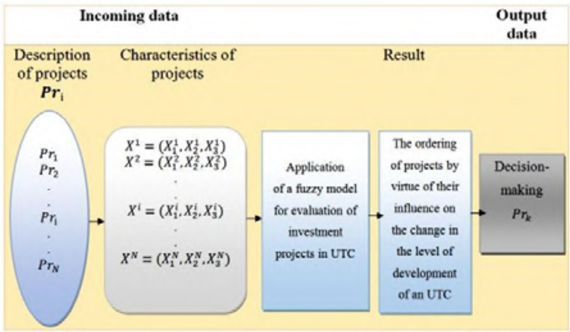


Fig. 2. The general scheme of the method of deciding on the choice of investment project for the development of TC.

To implement the fuzzy TC project evaluation model, the editor uses the Fuzzy Logic Toolbox, which is built into the Mathworks application package.

3 Results

3.1 Assessment of the attractiveness of the project in three areas: economic, social and environmental

The assessment of the investment attractiveness of projects for TC will consist of two parts: first we evaluate each of the three areas, and then we combine the obtained estimates in a generalized model. This approach will allow you to determine the advantages and disadvantages of projects in each area, and choose the best project that will take into account the requirements of all components of sustainable development.

We build a model for assessing the attractiveness of investment projects based on the use of fuzzy logic. Taking into account the three areas of sustainable development for which the assessment and general assessment will be carried out, we are building four models.

To assess the attractiveness of investment projects, taking into account the concept of sustainable development, we will define three assessments R_1 assessment of economic attractiveness of the project, R_2- assessment of social impact, R_3- assessment of environmental impact. The generalized estimate obtained as a result of applying the integrated model is denoted by R.

3.2 Assessment of the economic attractiveness of the project

The first two stages of construction of the fuzzy model (formation of the base of input variables of the fuzzy model and fuzzification of input variables) will be performed in parallel. At the first stage we determine the content of variables, sets of their linguistic evaluations (terms), and at the second stage – fuzzification – we determine the sets of terms of variables and the type of membership functions. To construct a fuzzy model, three types of membership functions are used: triangular, trapezoidal, and Gaussian. The first two of them express a linear relationship between the parameters and the value of its correspondence to the linguistic variable. Moreover, when full correspondence is achieved only with one value of the parameter (for example, 0 with the linguistic variable "neutral influence"), then a triangular function is used, if several values then trapezoidal function is used. The Gaussian membership function expresses a nonlinear dependence that corresponds to the normal distribution and is closest to natural processes. The Gaussian function is used for parameters that contain a significant share of uncertainty or are estimated by experts.

The output variable R_1 means economic impact, and includes 4 input variables:

X_1 – the rate of increase / decrease in community budget revenues;

X_2 – assessment of the impact on productivity growth;

X_3 – the volume of net inflow of direct investment;

X_4 – assessment of the impact of the project implementation on the optimal level of agricultural land use.

Consider each variable in more detail.

Variable X_1 reflects the rate of increase / decrease in community budget revenues. This indicator characterizes relative velocity (%) of changes in budget revenues resulting from project implementation.

The indicator X_1 will be calculated by the formula:

$$X_1 = \frac{F_i}{F_{i-1}} \times 100\%, \tag{1}$$

where X_1 – Economic growth (%);

F_i – the amount of budget receipts after project implementation (at time i);

F_{i-1} – the amount of budget revenues before the implementation of the project (during i-1).

Based on the analysis of existing investment business projects for the set of values of variable X_1 we will select the segment [70; 150] ($X_1 \in [70; 150]$). The 70% limit is explained by the fact that, despite the potential environmental and social benefits of the investment, the project will not be considered if its losses can exceed 30% of the community budget. The upper limit is set at 50% of all budget revenues and is 150 [20].

The next variable X_2 – assessment of the impact on productivity growth, which means comparing output per unit of working time with the previous similar period. X_2 is in the range [-10; 10] and is determined by three Gaussian membership functions.

Variable X_3 means the volume of net inflow of direct investment in total community income, and is measured in percent.

It should be noted that direct investment can have a positive impact on the host, not only through direct cash flows, but also the transfer of technology and management resources, which, in the absence of investment, would be unavailable. Such a transfer of resources can stimulate the economic growth of the local community. The value of the variable X_3 is within $X_3 \in$ [0; 25]. The limit of 25% is explained by the fact that all investments with 25% of income and more are considered absolutely important (membership function $\mu = 1$).

Variable X_4 – assessment of the impact of the project implementation on the optimal level of agricultural land use. According to the Law of Ukraine "On the circulation of agricultural land" [27] the basic principles of state policy in the field of circulation of agricultural land purpose is: rational use of land; priority of land use for its intended purpose; establishment of a special legal regime for the purchase and sale of land; prevention of land monopolization; prevention of speculative transactions. X_4 is in the range [-10; 10] and is determined by three Gaussian membership functions.

Using four input variables that characterize the economic impact, it is necessary to obtain an overall assessment of the economic attractiveness of the project – the output variable R_1, which indicates the level of attractiveness of the investment project to TC (measured in points). R_1 is defined on the interval [0; 100].

The parameters of fuzzification of input and output variables are given in the Table 1.

Stage 3 – building a fuzzy knowledge base and decision-making rules

Decisive rules are based on the following considerations. The leading indicator is X_1, which reflects the level of income generated by the project.

Therefore, if X_1 is increasing and X_2- X_4 are not negative, then the economic effect is considered significant. If X_1 decrease and X_2- X_4 also do not show positive indicators, then the economic effect is slight.

Table 1. Parameters of fuzzification of input variables X_1, X_2, X_3, X_4 and output variable R_1**.**

Linguistic assessment	**View membership function**	**Function options**
	X_1	
Decrease	Trapezoidal	[70;70; 90; 100]
Permanence	Triangular	[93; 100; 107]
Increase	Trapezoidal	[100; 120; 150; 150]
	X_2	
Negative	Gaussian	[3.739; -10]
Neutral	Gaussian	[1; 1.665e-016]
Positive	Gaussian	[3.738; 10]
	X_3	
Low	Triangular	[0; 0; 5]
Middle	Triangular	[2; 10; 15]
High	Trapezoidal	[10; 20; 25; 25]
	X_4	
Negative	Gaussian	[3.539; -10]
Neutral	Gaussian	[1.123; 0]
Positive	Gaussian	[3.538; 10]
	R_1	
Slight	triangular	[0 0 35]
Medium	triangular	[25 50 75]
Significant	triangular	[65 100 100]

For other combinations of input indicators the corresponding rules are developed, in total the model includes 29 rules.

3.3 Assessment of the social attractiveness of the project

Rating R_2 means social impact, and includes 6 input variables:

X_5 – assessment of the degree of compliance of the TC development strategy and the region and action plans for their implementation;

X_6 – the impact of the project on the unemployment rate in the community;

X_7 – assessment of the impact of the project on the state of public health;

X_8 – assessment of the impact of the project implementation on the development of education for the population;

X_9 – assessment of the impact of the project implementation on infrastructure development;

X_{10} – assessment of the impact of the project implementation on the level of public service provision.

Consider each variable in more detail.

Variable X_5 – assessment of the degree of compliance of the TC development strategy and the region and action plans for their implementation. Projects financed from the State Budget of Ukraine must meet the priorities of regional development strategies and action plans for their implementation. In 2015, the order of the Ministry of Regional Development, Construction and Housing of Ukraine on the selection of investment programs and regional development projects for further implementation at the expense of the State Fund for Rural Development was adopted. The order, in particular, states that the project should be aimed at development, and to this end, project applicants are required to determine the problem to be solved, justify the expected quantitative and 11 qualitative results of project implementation and innovation. In turn, the regional commissions that evaluate the project are responsible, among other things, for determining the relevance of the project, as well as the social and economic effect of its implementation [28].

Variable X_6 characterizes the impact of the project on the unemployment rate in the community (calculated as the ratio of the number of jobs created during the implementation of the project to total number of unemployed communities):

$$X_6 = \frac{W}{U} \times 100\%, \quad (2)$$

where X_6 – reduction in the unemployment rate in the community (%);

W – number of new jobs created during the project implementation;

U is total number of unemployed communities [20].

The value of variable X_6 is within $X_6 \in [0; 100]$. Thus, if no new jobs are created during the investment, then X_6=0, if the number of jobs created is equal to the number of unemployed communities, then X_6 = 100 (%). Cases where the number of jobs exceeds the number of unemployed persons should be considered separately and are not the subject of this study, as they cover the issue of changing the social policy of the community regarding labor attraction.

The next variable X_7 is the assessment of the impact of the project on the state of public health. Population health is one of the greatest values, a necessary condition for the socio-economic development of the country. Creating optimal conditions for the realization of the potential of each person throughout life, achieving European standards of quality of life and well-being is one of the main tasks set by the Sustainable Development Strategy "Ukraine – 2020", approved by Presidential Decree of 12 January 2015 № 5, and part of the obligations under the Association Agreement between Ukraine, on the one hand, and the European Union, the European Atomic Energy Community and their Member States, on the other hand [29].

Variable X_8 – assessment of the impact of the project implementation on the development of education for the population. In the field of education, the work is primarily aimed at ensuring the right of all citizens to education, improving the functioning and innovative development of education at the level of all its components, improving quality and competitiveness, creating the necessary conditions for a good modern European education.

Input variable X_9 – assessment of the impact of the project implementation on infrastructure development. Ukraine lags far behind the level of development and efficiency of infrastructure in comparison with developed countries. The main reason for the current state of infrastructure is chronic underfunding from the state budget and inefficient state property management system.

The next variable X_{10} – assessment of the impact of the project implementation on the level of public service provision. Building an efficient and competitive national economy involves a systemic reform of public financial management as part of the public administration system in general, the problems and inconsistencies of which pose a serious risk to the resumption of economic growth. An effective public financial management system is the basis for the implementation of public policy and the achievement of strategic development goals by ensuring compliance with general budget discipline, strategic allocation of budget funds and effective provision of public services.

Using six input variables that characterize the social impact, it is necessary to obtain an integrated assessment – the output variable R_2, which indicates the level of attractiveness of the investment project to TC (measured in points). R_2 is defined on the interval [0; 100].

Table 2. Parameters of fuzzification of input variables X_5, X_6, X_7, X_8, X_9, X_{10} and output variable R_2**.**

Linguistic assessment	View membership function	Function options
X_5		
Slight	Gaussian	[17; 0]
Medium	Gaussian	[10; 50]
Significant	Gaussian	[17; 100]
X_6		
Slight	Triangular	[0; 0; 20]
Medium	Triangular	[10; 30 ;50]
Significant	Trapezoidal	[30; 60; 100; 100]
X_7		
Slight	Gaussian	[17; 0]
Medium	Gaussian	[10; 50]
Significant	Gaussian	[17; 100]
X_8		
Slight	Gaussian	[17; 0]
Medium	Gaussian	[10; 50]
Significant	Gaussian	[17; 100]
X_9		
Slight	Gaussian	[17; 0]
Medium	Gaussian	[10; 50]
Significant	Gaussian	[17; 100]
X_{10}		
Slight	Gaussian	[17; 0]
Medium	Gaussian	[10; 50]
Significant	Gaussian	[17; 100]
R_2		
Slight	triangular	[0 0 30]
Medium	triangular	[8 50 90]
Significant	triangular	[50 100 100]

Given that the variables X_5, X_7, X_8, X_9, X_{10} have a similar nature (determined by experts, are in the same ranges), the same parameters of fuzzification are applied to them (three terms expressed by Gaussian membership functions). The input variable X6 is determined by calculation by formula (2), so for its fuzzing applied triangular and trapezoidal membership function. The main parameters of fuzzification for input and output variable model of social impact assessment of the project R2 are given in the Table 2.

The base of the decision rules of this model consists of only three rules:

1. If at least one of the input variables of the project is Significant – that is, one that significantly affects the improvement of social conditions of the community, the project is important from a social point of view.
2. If the social impact of all six input variables of the project is assessed as weak, then the social impact of the project will also be Slight.
3. In other cases, the social impact of the project is assessed as Medium.

This is due to the fact that the project may not cover all areas of social life of the community, but if it gives a positive result in at least one area, it is considered a socially effective project.

3.4 Assessment of the attractiveness of the project, in terms of the environmental component

Rating R_3 means social impact, and includes 5 input variables:

X_{11} – environmental protection;

X_{12} – assessment of the impact of the project implementation on access to safe drinking water;

X_{13} – assessment of the impact of the project on the management of household and non-household waste;

X_{14} – assessment of the project impact on the increase / decrease of electricity production.

Indicator X_{11} describes the environmental impact of the investment project. The value of X_{11} is determined on the basis of expert judgment, measured in points and is in the range $X_{11} \in [-100; 100]$. That is, at the most destructive value of environmental impact $X_{11} = -100$, at neutral impact $X_{11} = 0$, and at maximum positive 100. The basis for determining the indicator X_{11} can be the results of the report on the environmental impact assessment based on the Law of Ukraine № 2059 -VIII [3] or calculations, for example, by the method [15].

The next variable – X_{12} characterizes the assessment of the impact of the project implementation on access to safe drinking water. The existing inequalities between urban and rural populations in access to quality drinking water and sanitation in Ukraine remain quite significant. According to the National Report on Drinking Water Quality and the Status of Drinking Water Supply, centralized water supply covers more than 99 percent of cities and only 30 percent of villages. Therefore, access to sustainable and safe water supply remains problematic for many Ukrainians.

Variable X_{13} – assessment of the impact of the project on the management of household and non-household waste. The value of X_{13} is determined on the basis of expert judgment, measured in points.

The next variable X_{14} means the assessment of the project impact on the increase / decrease of electricity production. The value of X_{14} is determined on the basis of expert judgment, measured in points.

Using four input variables that characterize the environmental impact, it is necessary to obtain an integrated assessment – the output variable R_3, which indicates the level of attractiveness of the investment project to TC (measured in points). R_3 is defined on the interval [0; 100].

The output variable R_3 means environmental impact, it includes 4 input variables (table 3).

Table 3. Fuzzing of X_{11}, X_{12}, X_{13}, X_{14} variable**.**

Linguistic assessment	View membership function	Function options
X_{11}		
Negative	Gaussian	[38; -100]
Neutral	Gaussian	[10; 10]
Positive	Gaussian	[30; 100]
X_{12}		
Negative	Gaussian	[37; -100]
Neutral	Gaussian	[7; 0]
Positive	Gaussian	[37; 100]
X_{13}		
Negative	Gaussian	[37; -100]
Neutral	Gaussian	[7; 0]
Positive	Gaussian	[37; 100]
X_{14}		
Negative	Gaussian	[37; -100]
Neutral	Gaussian	[7; 0]
Positive	Gaussian	[37; 100]
R_3		
Slight	triangular	[0 0 35]
Medium	triangular	[25 50 75]
Significant	triangular	[65 100 100]

To form a database, we define that the leading (generalizing) indicator is the indicator X_{11}. Indicators X_{12}- X_{14} are ancillary, showing the degree of coverage of environmental problems. And even with one significantly bad indicator X_{12}- X_{14}, the indicator X_{11} can not be good. Therefore, with a negative X_{11}, the project is considered bad from an environmental point of view; when X_{11} is positive, the project is considered good. At neutral values of X_{11}, we turn to the consideration of differentiated indicators for water (X_{12}), waste (X_{13}) and electricity (X_{14}). For such cases the base of rules including 24 rules is formed.

3.5 Integral assessment of the attractiveness of the project in three areas: economic, social and environmental

Thus, we obtain three assessments that characterize the projects in three areas: economic, social and economic. In order to obtain an integrated assessment based on the concept of sustainable development, we will build a generalized model. Its input variables will be R_1, R_2 and R_3. Output: integral estimate R. All input variables have the same interval [0 100] and are given by three Gaussian membership functions. Initial – three triangular functions (Table 4).

The rules of the fuzzy knowledge database will be presented in the form of Table 5.

Table 4. Parameters of fuzzification of input variables R_1, R_2, R_3 and output variable R.

Linguistic assessment	View membership function	Function options
	R_1	
Slight	Gaussian	[17 0]
Medium	Gaussian	[10 50]
Significant	Gaussian	[17 100]
	R_2	
Slight	Gaussian	[17 0]
Medium	Gaussian	[10 50]
Significant	Gaussian	[17 100]
	R_3	
Slight	Gaussian	[17 0]
Medium	Gaussian	[10 50]
Significant	Gaussian	[17 100]
	R	
Slight	Triangular	[0 0 35]
Medium	Triangular	[25 50 75]
Significant	Triangular	[65 100 135.3]

Table 5. Knowledge base for R-evaluation of the investment attractiveness.

Variables		R3 (Negative)	R3 (Neutral)	R3 (Positive)
R1	**R2**	***R***	***R***	***R***
Decrease	Slight	Slight	Slight	Slight
Decrease	Medium	Slight	Slight	Medium
Decrease	Significant	Slight	Slight	Medium
Permanence	Slight	Slight	Slight	Medium
Permanence	Medium	Slight	Medium	Significant
Permanence	Significant	Slight	Significant	Significant
Increase	Slight	Slight	Significant	Significant
Increase	Medium	Medium	Significant	Significant
Increase	Significant	Medium	Significant	Significant

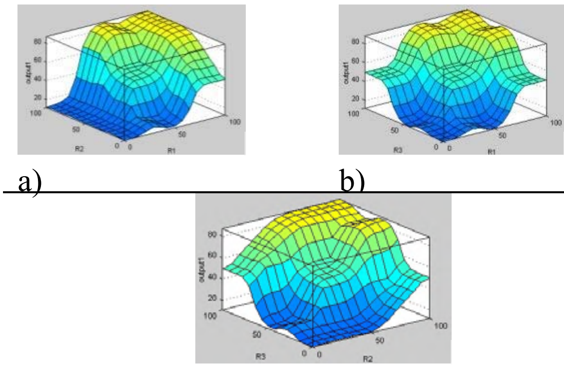
The absence of a statistical sample of quantifiable estimates of the indicators under study and the qualitative nature of the input variables and the output indicator R (investment project estimate), determine the choice of a logical inference using the Mamdani fuzzy inference system mechanism.

As a result of the built model, it is possible to build a surface that gives a graphical idea of the project estimates depending on the values of the input indicators (Fig. 3).

The constructed model can be applied to support decision-making in the development and justification of a strategic plan for the development of Veselivska territorial community [30].

According to the data provided by Veselivska TC, the population (excluding preschool and school age children) is 10,640 people, and the amount of income (according to estimates) of the territorial community is 12.679 million UAH. According to the State Statistics Service of Ukraine, the average unemployment rate in Zaporizhia region is 9.9% among the population aged 15-70 years [31]. Then the number of unemployed Veselovskaya TC is about 1053 people.

Consider two alternative investment projects for the development of the territorial community: the traditional activity for Ukrainian farmers is sunflower cultivation and the construction of a solar power plant.



c)

Fig. 3. The output surface for the variables: a) R1 and R2; b) R1 and R3; c) R2 and R3.

Let's look at project characteristics in more detail.

Project 1 – Sunflower cultivation.

Sunflower growing is a profitable business, it is the most profitable oilseed crop in our country. The basic data for the calculation were obtained from the source [32], in particular, the results of sunflower cultivation of LLC «Dokuchaevsky Chernozem», Karlovsky district of Poltava region.

It is known that the territorial community is considering the use of 20 hectares of land owned by it.

The costs of growing and harvesting in this case amount to 280 thousand UAH, the increase in cash flow from the project is also 280 thousand UAH.

It has been expertly determined that the implementation of the project will not affect labor productivity, and there is no need to attract investment. Since agricultural work does not require a change of purpose or land monopolization, the indicator X_4 is also zero.

Support and development of agricultural production is one of the main strategic directions of the community, but the implementation of the project does not involve significant changes and improvements, so the degree of compliance of the TC development strategy with experts is set at 10 points. The number of jobs created is 10, which is 1% of the unemployment rate. Due to the fact that the implementation of the project does not affect the level of health care, education, infrastructure or public services, the X_7- X_{10}, respectively, will be zero.

The cultivation of sunflower is associated with such negative effects as the depletion and drying of the soil, increased water and wind erosion [33]. Considering that the problem of soil depletion and erosion is solved, and the problem of drying is smoothed by the correct cultivation of land, the expert assessment of environmental impact is -10 points. The impact of the project on access to safe drinking water, on the management of household and non-household waste and on the increase / decrease in electricity production is zero.

So the input variables of the sunflower cultivation project are:

- For R_1: X_1 = 102.2%; X_2 = 0 points; X_3 = 0%; X_4 = 0 points.
- For R_2: X_5 = 10 points; X_6 = 1%; X_7= 0 points; X_8 = 0 points; X_9 = 0 points; X_{10} = 0 points.
- For R_3: X_{11} = -10 points; X_{12} = 0 points; X_{13} = 0 points; X_{14} = 0 points.

As a result of application of the developed models project estimations on three directions of sustainable development were received:

- - economic impact R_1 = 50 points; – - social R_2 = 9.9 points; – - ecological R_3 = 46 points.

This means that Project 1 has average economic and environmental impacts on the development of a TC and low social impact.

Let's calculate the value of the generalized evaluation of the project R.

The result of the evaluation of the project 1 in the defuzzing step is 14.3 points out of 100 possible, which is quite low.

Let's make similar calculations for Project 2 – construction of a solar power plant.

A solar grid power plant is used to sell electricity to the grid at a «green» rate.

Suppose that solar power plant want to build on a plot of 20 ha.

The cost of its construction is $8 million, the profitability of the project will be 25.3%, the payback period of the project – 5 years. As a result, we receive $2.078 million revenues, 25 jobs, and a positive environmental impact assessment at 50 points (used for calculations [34]).

However, it should be noted that the TC doesn't have the financial resources to implement such a large-scale, in terms of initial investment, project, so the implementation of this project is possible only with the participation of the investor. If the community finds an investor and receives only land and taxes, the annual income will be 250,000 UAH. This will increase the community's income to 101.9%.

Increasing labor productivity (X_2) by attracting labor at a solar power plant is estimated by experts at 2 out of 10 possible.

The project will attract $8 million, which is more than 63% of the annual income of the community. Since the maximum value of the input variable is 25, and the value of X3 at which the membership function reaches one is 20% (i.e., all investments greater than 20% of income are considered the most useful), we assume that X_3 is 25%.

Since the implementation of the project involves a change in the purpose of the land, X_4 is estimated at -2.

The assessment of the degree of compliance of the TC development strategy with the region and the action plans for their implementation (X_5) is 40 points. Project 2 does not affect the level of development of health care, education, infrastructure or public services.

The construction of the power plant is associated with waste generation, so the indicator X_{13} is estimated at -10. One effect on the energy component is the most positive X_{14} = 100 points.

Thus, the input variables of a project involving an investor to build a solar power plant are:

- For R_1: X_1 = 101.9%; X_2 = 2 points; X_3 = 25%; X_4 = -2 points.
- For R_2: X_5 = 40 points;X_6 = 2.4%; X_7, X_8, X_9, X_{10} = 0 points;
- For R_3: X_{11} = 50 points; X_{12} = 0 points; X_{13} = -10 points; X_{14} = 100 points.

As a result of the project evaluation by areas, the following were obtained:

- economic impact R_1 = 60.4 points; – social R_2 = 17.4 points; – ecological R_3 = 84.7 points.

That is, Project 2 also has a weak social impact, albeit a larger one than Project 1. The economic impact is above average and the environmental component is high.

The generalizing result of the evaluation of project 2 in the defuzzing step is 62.6 points out of 100, which is better than the project for growing sunflower.

Comparing the two projects, it can be noted that the "weak spot" of both projects is low social impact; project 2 is better than project 1 in all areas, and if the difference is not large for the economic and social component, the environmental positive impact of project 2 is almost twice that of project 1.

As a result of application of the developed two-stage model to two alternative investment projects of the community, the numerical characteristic of projects on separate directions of sustainable development (economic, social and ecological), and the general estimation taking into account all structural components is received.

Thus, when making decisions, it is possible not only to establish which project is more reasonable, but also to identify "weaknesses" and the advantages of each of them.

4 Conclusion

The development of TC is aimed at coordinated and balanced management of its resources, taking into account the concept of sustainable development to ensure social, economic and environmental development of TC, expanding its economic opportunities, creating a full living environment for present and future generations. To achieve this goal, it is necessary to form an effective system of state power, which is facilitated by decentralization reform. The transfer of competencies to TC increases the economic activity of local governments, encourages them to rationally and skillfully use available resources, to make effective decisions when choosing alternatives to increase the competitiveness of TC.

Finding a balance between economic, social and environmental components is one of the main tasks in managing the development of TC, taking into account the concept of sustainable development. To solve these problems, it is necessary to use new digital technologies to optimize and automate decision-making processes, transparency in the activities of local governments and improve connection with community members.

This article develops and describes a fuzzy evaluation model of an investment project for TC development, consisting of two stages. At the first stage, three fuzzy models were created that allow evaluating an investment project in three areas of sustainable development: economic (R1), social (R2) and environmental (R3) impact. For the assessment of the economic in the project, the four most important, according to the authors, input indicators were emphasized: X_1 – the rate of increase / decrease in community budget revenues; X_2 – assessment of the impact on productivity growth; X_3 – the volume of net inflow of direct investment; X_4 – assessment of the impact of the project implementation on the optimal level of agricultural land use. To assess the social impact, the input parameters are X_5 – assessment of the degree of compliance of the TC development strategy and the region and action plans for their implementation; X_6 – the impact of the project on the unemployment rate in the community; X_7 – assessment of the impact of the project on the state of public health; X_8 – assessment of the impact of the project implementation on the development of education for the population; X_9 – assessment of the impact of the project implementation on infrastructure development; X_{10} – assessment of the impact of the project implementation on the level of public service provision. The impact of the project on the environment is determined by the 5 input variables: X_{11} – environmental protection; X_{12} – assessment of the impact of the project implementation on access to safe drinking water; X_{13} – assessment of the impact of the project on the management of household and non-household waste; X_{14} – assessment of the project impact on the increase / decrease of electricity production.

As a result, three diverse indicators that characterize the project were obtained. In addition, using the developed integrated fuzzy model, we obtain an integrated indicator of investment attractiveness of the project, which includes all areas of sustainable development.

The developed models were tested on the data of the Veselivska Territorial Community of Veselivsky District of Zaporizhzhia Region. A comparative analysis was conducted for two investment projects – Sunflower Growing and Solar Power Plant Construction. As a result, the attractiveness assessments were obtained in different areas of each project, weaknesses and strengths were identified, as well as integrated indicators were obtained, which allowed to select the most attractive project for the territorial community.

Application of the proposed models creates opportunities for the formation and development of territorial decision support systems for quantifying decisions, carrying out variant calculations to select the best investment options. The development and improvement of a decision support system is extremely important for TC, as it will help to accumulate and model a database that solves management problems.

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Sustainable development and tolerance in the socializing and resocializing of the architectural environment of cities

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Abstract. The article considers the sustainable development of the city public spaces and the penitentiary complexes problems from the Synergetics and Socionics standpoint. These approaches provide consideration of the opposite processes of public spaces socialization and correctional complexes resocialization, sustainability, and dynamism its organization, and self-organization. The regularities of sustainable development are present in the cyclical nature of historical changes in public spaces and the penitentiary system. Cycles unfold in the alternation order of pairwise polarized processes, on the one hand, dispersion and concentration, and, on the other, – self-organization and adaptation. We have found that the interaction of universal processes and the natural change of cycles stimulates, on the one hand, growth and stabilization, and, on the other, – transformation and metamorphosis, which lead to the emergence of new forms and structures of public spaces and penitentiary complexes. We have proposed to use Socionical methods for increasing tolerance and democracy in the architectural environment of settlements. We have described the methodological tools to achieve the harmonization of the architectural environment of settlements.

1 Introduction

Sustainable development problems, which have become especially relevant and highlighted in international documents, have gradually gained a proper place in architecture and urban planning [1, 2]. The global nature of these problems required large-scale methodological tools for their positive solution. A synergistic approach is one of them. It aims at tolerant Socionic cooperation and self-organization of all participants of the urban environment sustainable development. It involves the study of complex systems, the development of which has signs of sustainability and dynamism.

Sustainable development of architectural and urban planning systems is subject to self-organization laws. They operate in a wide range and determine the formation of diametrically opposite types of architectural environment – socializing (public spaces) and resocializing (penitentiary complexes).

Some scientists have studied the problems of urban self-organization. New areas of research – Urban Synergetics and Architectural Socionics have formed on this basis. The relationship between self-organization and the sustainable development of public spaces and penitentiary complexes, taking into account social relations, has not yet been considered. The solution to these problems is of paramount importance in modern architectural and urban planning theory. The expected results are important for Ukraine, where reforms in urban planning, medicine, education, and other spheres of life continue [3, 4]. New explorations of the features of sustainable development, self-organization and interpersonal relations in urban public spaces, and penitentiary complexes are a direct continuation of our previous research on this topic [5].

Modern cities occupy huge territories and unite various population groups, the interaction between which quite often has polarized and extreme character. This character, on the one hand, testifies to the stability and, on the other, to the dynamism of the urban environment and, in total, determines the boundaries and range of settlements sustainable development. The public spaces are the most actively developing therein that maximally socialize the lives of urban residents. The urban environments of correctional facilities, which aimed at convicts re-socializing and preparing them for regular free life, oppose them. The urgency of the problem lies in the awareness of the need to close the gap between mutually polarized lifestyles.

We need to find ways to organize and self-organize different groups of the population. Then people with different value systems will be able to support each other in a tolerant urban environment. Revealing cyclical order in the historical development of opposite types of architectural environments is the next task. It is associated with the elucidation of differences and similarities in the processes of their self-organization and sustainable development.

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2 Sustainable development ranges of the cities architectural environment

2.1 Features of self-organization of the correctional system and urban penitentiary complexes

The architectural environment of the correctional system requires the introduction of sustainable development ideas. Specialists in various fields of knowledge (criminologists, psychologists, sociologists, architects, and designers) are concerned with the problem of the architectural environments' creation, where humanity, justice, and order are harmoniously coordinated and balanced.

Trends in the development of scientific knowledge over the past 30 years provide an opportunity to say confidently that today synergetic concepts are spreading in many areas of scientific, theoretical, and applied activities. The synergetic approach allows us to consider the problems of the penitentiary system development and the architectural environment of correctional facilities from new positions. It provides new opportunities for its harmonious development, improvement, and sustainability.

D. K. Corten has described the conditions for sustainable development of social institutions [6]. Among them is a guarantee of safety and conditions for self-improvement. Penitentiary complexes belong to such institutions. A harmoniously developing dynamic system must maintain a stable mode of operation, despite external interference [7]. Environmental, economic, and social components determine the sustainability of the systems. The system can develop differently in each of these areas. Social systems are less stable than, for example, ecological and biological. Prison riots and rising suicide cases are among the crisis indicators inherent in penitentiaries.

Opposing trends in the development of systems arise due to internal contradictions and external intervention. They can lead to either the destruction of the system or its improvement. O. M. Knyazeva and S. P. Kurdyumov believes that all existing systems are open, that is, have an exchange of energy and information with the environment [8].

We propose to consider the historical development of the penitentiary system from a synergistic standpoint. The cycle of its development begins from the phase of the punishment and detention conceptions emergence and accumulation in correctional facilities. The system is in a state of dispersion. From the chaotic conceptions of punishment, new individual forms of institutions emerge, such as the Zuchthaus in Amsterdam (1595), the prison for beggars in Britain (1563), and the prison for young men of St. Michael in Rome (1735) (Fig. 1).

At the next stage, the approaches to the legal framework formation change. Views on the problem of criminals correcting transform too. Realistic and utopian conceptions of correctional facilities emerge and strengthen their positions. Among them – the penitentiary in Philadelphia (1776), the Panopticon (1791), the Auburn Detention System (1820), and the Irish Progressive System (1850). Selection of optimal technological and spatial solutions of correctional institutions takes place. The most «progressive» options for retention and correction are becoming more common. At this stage, the self-organization processes of the system are occurring.

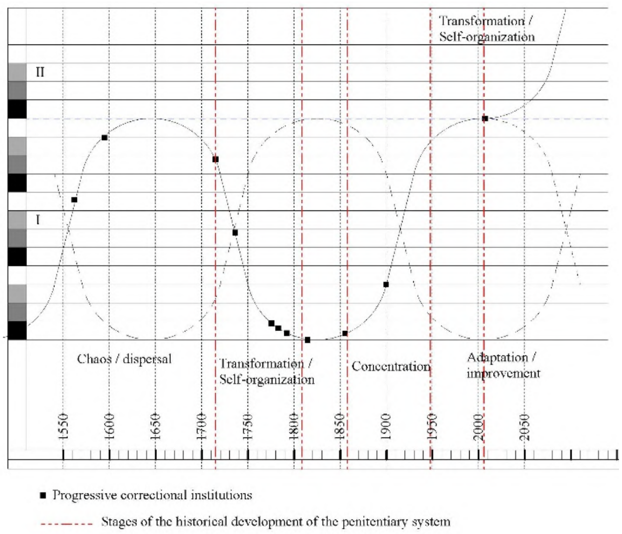

Fig. 1. Scheme of cyclic development of the penitentiary system environment, by Yuliia Tretiak.

Following this, the punishment system is stabilizing. At the stage of concentration, it changes due to the detection of shortcomings. At the same time, awareness of the possibility of returning to past concepts arises. These are the so-called negative feedback loops. For example, the progressive step system of detention of prisoners of the second half of the 19th century acquired the features that operated in the prison of St. Michael in Rome, which functioned since 1735.

For the next almost 100 years, the correctional system was in a stable cumulative state. The Declaration of Human Rights, adopted in 1948, once again changed the socio-humanistic emphasis in the prison sector.

The final phase of the system development cycle is an adaptive one. The results of knowledge accumulation integrate into the paradigm of system modernization at the next hierarchical level. The first period took place in the 1960s and 1970s when the “new wave” penitentiaries appeared in Europe. The second wave followed the prison riots of the 1990s when European countries set out to humanize the correctional environment.

Completely new forms of punishment have rarely emerged in the history of the penitentiary system. The reasons for such system stability were the minimal influence of external factors. The rigid nature of the legislative and regime component of the punishment system restrained this external influence. Thus, the processes of self-organization and adaptation in “closed” systems (prisons, military and labor camps, and towns, psychiatric hospitals) cannot take place fully. Regime restrictions in space and time deprive the process of development of the penitentiary system of extreme conditions. Therefore, completely new forms – architectural complexes and buildings that have no analogs, occur very rarely.

The general cycle of the historical development of the correctional system lasts 120-150 years. Similar processes occur at the level of individual buildings and structures complexes. The life cycle of the building complex of the famous Strangeway prison in Great Britain demonstrates the historical development of its architectural and urban environment for more than 150 years.

A prison for 1,000 men and women opened in 1868 in the park. The plan of the building has the form of a “star” with ten rays. The method of detention and correction in the institution took into account the progressive (Irish) system. The period of “self-organization” of the environment took place until 1963. The transformation into a men's prison took place in 1948 under the influence of the Declaration of Human Rights. From 1964 to 1990, Strangeway experienced a phase of “concentration” when it returned to a harsher detention regime that did not comply with updated and more humane laws.

In April 1990, a series of riots broke out in Strangeway Prison. Damage to the building was one of the reasons for the reconstruction and modernization of the complex. During this adaptive period, the transition to a higher level did not take place in this institution. Reconstruction of the correctional complex could lead to the emergence of new forms. A full-fledged open space could enter the structure of the building. However, the reconstruction of 1994 did not fulfill the corresponding task (Fig. 2). The system returned to the previous stage. To date, regular violations of the detention regime occur in the institution. In 2017, the Independent Oversight Board concluded that Manchester Prison is in urgent need of modernization.

The historical development of penitentiary institutions has shown the pivotal moments of the penitentiary system transformation. It also creates conditions for a rethinking of alternatives.

Synergistic research in economics, sociology, and demography suggests a gradual decline in crime. There are not only objective external but also internal reasons for this. The economic crisis and the stabilization of the population in developed countries are external causes. Tolerance, humanism, and the introduction of alternative means of punishment are internal reasons.

Today, the architectural environment of penitentiary complexes is in a crisis, precarious state. According to the ideas of synergetics, such instability can be a condition for further stabilization and dynamic development of the penitentiary system.

2.2 Architectural Socionics and humanization of the environment of correctional complexes

One of the many possible understandings of the philosophical dilemma of good and evil determines the construction of the penitentiary system in various countries. Each society at each stage of its development chooses the most acceptable ways to achieve a balance between good and evil and appropriate approaches to combating crime. The specific solution to this problem determines the purpose of forcible detention of people who have broken the law.

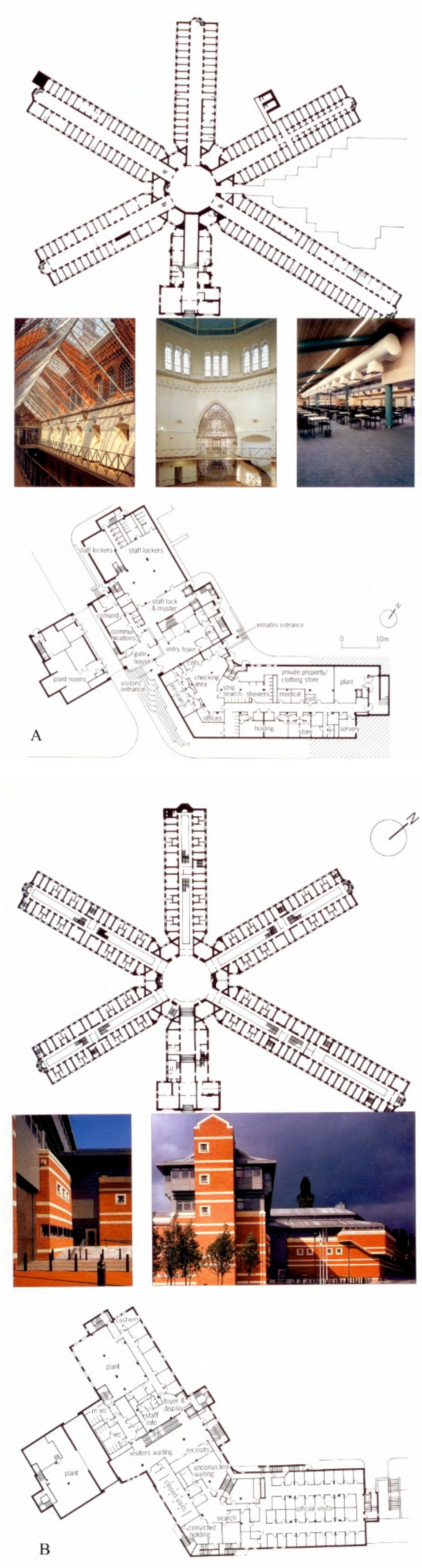

Fig. 2. Strangeway Prison before (A) and after (B) reconstruction. Plan of the building for prisoners (top) and plan of the administrative building (bottom) [9].

Therefore, different penitentiaries solve different and, in essence, opposite problems. Some of them focus on punishing criminals and making it impossible for them to commit atrocities for a certain period. Others try to re-educate people who have committed some offenses for one reason or another.

The architectural environment of detention places is subject to the primary purpose of freedom restricting of these people. Nowadays, therefore, there are prisons with a polar attitude to detainees in different developed countries. Conditions of stay in some of them are intolerable, and in others – similar to sanatoriums. For example, Japan's prison conditions are very harsh (Fig. 3) [10]. Instead, new prisons in Denmark or Norway impress with their humane treatment of detainees (Fig. 4) [11].

Fig. 2. Prohibition of communication even between convicts, Japan, https://novate.ru/blogs/140920/56010/.

Fig. 3. The little play garden for communication of convicts with families in Halden Correctional Facility, Norway https://www.bbc.com/news/stories-48885846

Ironically, both situations do not contradict elementary logic. The first approach appeals to the instinct of self-preservation because the strict order should arouse the desire never to return to prison. In this case, fear should deter criminals from re-offending. The second approach appeals to everyone's innate desire to be better than he is now. The support a person receives during imprisonment will help them achieve what they want. As a result, the former convict will not return deliberately to the wrong path.

Naturally, the question arises – if there are no violations of logic in both cases, why none of both approaches can solve the problem of crime finally. Likely, the matter is not in the architectural and planning solution of the detention places and not in the rules of organizing this process. It may be wrong to use inappropriate methods of influencing different types of people. We believe that a unified attitude towards people is the root cause of many problems occurring in various spheres of social relations. In particular, severe punishment will oppress one person and anger another, encourage one to be cautious, and strengthen the desire for revenge in another. Similarly, the humane treatment of one detainee will encourage spiritual growth, and of the other will allow self-improvement in the criminal craft.

In our opinion, an attentive attitude to each psychological type will significantly alleviate the crime problem, if not solve it. In this way, architects aim at creating the most diverse physical and spatial conditions in buildings and complexes designed for imprisonment. However, it would be good that specialists in Psychology and Socionics work in the penitentiary system. They would be able to determine the type of energy-informational metabolism of each person, committed the offense. Positive experience to the application of Socionics in Pedagogy, Psychology, Business, Politics, artificial intelligence technologies development, and the intelligent systems' formation confirms this hypothesis [12].

Understanding the values system of the appropriate psychological type would allow choosing the optimal detention conditions, both for those who can re-educate and those who have made a life choice quite consciously and are not going to change it. Socionics specialists would provide an invaluable service to convicts if they were involved in the micro collectives` formation in correctional institutions. After all, the compelled long-term stay of people with opposite value systems in the same room causes unnecessary suffering to all participants in such relationships and in no way contributes to the re-education process.

Based on the development of architectural Socionics [13], we propose to supplement the architectural typology of penitentiary institutions by allocating within it at least four types of correctional buildings and complexes. The penitentiary institutions' architectural environment of each proposed types should take into account the value priorities of the relevant Socionic quadra, in other words, – a category of people with a similar worldview, whose psychological types complement each other in pairs. This step will allow architects to offer optimal architectural and planning solutions for correctional buildings and complexes of four types. The first type is for the temporary detention of persons with extraordinary creative abilities (quadra α). The second type is for the temporary detention of persons who support centralized, hierarchical systems, which respect the authorities, focused, primarily, on the strength (quadra β). The third type is for convicts seeking personal self-realization (quadra γ). The fourth type is for individuals who are willing to work on personal self-improvement (quadra δ).

The distribution of offenders in correctional facilities, which architectural environment will correspond to the detainees' psychological types, will not only improve their fate but also create the conditions for the time spent behind bars not to turn into years erased from their lives. On the other hand, such an organization of correctional facilities will facilitate the work of penitentiary staff, increase the effectiveness of the impact on the consciousness of detainees, will improve society's attitude to the penitentiary system. The practical implementation of our proposals, ultimately, will lead to the achievement of a synergistic effect – to the humanization of the penitentiary system as a whole.

2.3 The ways to update the open public spaces of the city

Compared to other fragments of the urban environment, public spaces are more sensitive to settlements' transformations. The natural (undistorted) transformation process of urban centers corresponds to the laws of the evolution of complex open, nonlinear systems. It involves the consistent stages of repetition of dispersion, self-organization, concentration, and adaptation.

At the stages of dispersion, various forms of social activity spontaneously occupy new territories. In the phases of self-organization, the selection of the most acceptable ways of interaction between residents takes place. At the stages of concentration, the number of public functions in the respective urban areas increases, and the structural elements of public spaces become more complicated. The use of material and human resources is increasing. Due to this, the territory of public spaces expand, buildings rebuilt, landscaping is improving. During periods of adaptation, community centers are experiencing a stage of prosperity. At this time, the architectural environment of public spaces reaches its maximum diversity. It becomes able to meet the expectations of different categories of the population. Circumstances, most favorable for the transition of public spaces to a qualitatively new structural development level, are forming in such historical periods. If cities fail to make the necessary efforts at the right time, the quality of public life in their centers declines. The oscillating processes of their transformation continue in a monotonous rhythm in anticipation of the next possibility of an evolutionary leap.

A short digression into the development history of the main square of Ukraine capital allows us to illustrate this process with concrete examples. For centuries, the territory of the modern main square of Kyiv has played a leading role in the development of the city. In the 11-13th centuries, one of the main entrances to the Old Town was there. Public life was bustling in this place. However, in 1240 Kyiv fell under the pressure of the invaders. Any activity in the city froze for almost four centuries. The harmonious development of the settlement was interrupted.

From the 17th century, Kyiv began to return to life. The city gates on the road from the Old City to Pechersk resumed work. The water mill began to operate here. Later, the first residential buildings appeared in this area. Since the 19th century, public space began to function here. Pubs and taverns, dens, and brothels actively received visitors. Until 1818, the detention center functioned next to them. That is, the concentration of functions took place in public space.

In the middle of the century, on weekends, the then Khreshchatyk square performed trade, show, and recreational functions (Fig. 5). In 1843, the first fountain appeared in the square, but, at that time, it mainly satisfied economic needs. The public space was actively operating. Thus, this period testifies to the adaptation of the urban environment to the urgent needs of residents.

Over time, stone houses began to displace wooden houses from the square. In the mid-1850s, paving stones first covered the roadway. In 1866, the first public library began to operate on Khreshchatyk Square. The latest technologies had their origin here. For example, in 1864, the first kerosene lanterns appeared here. In 1872, gas lanterns replaced them [14].

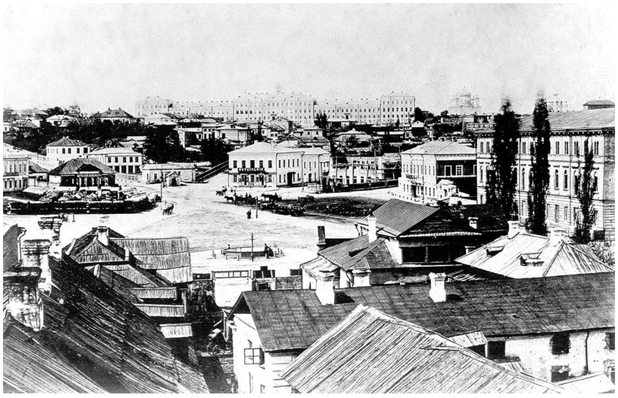

Fig. 5. Panorama of Khreshchatyk Square. Photo of the 1860s, http://archunion.format.com.ua/history/history_004_01.shtml

In 1878, the building of the City Duma appeared on the square. This area has become the administrative center of the city. In 1892, the first trams crossed the then Duma Square. The accumulation of resources to improve the consumer quality of public spaces has reached its maximum at the stage of self-organization.

In 1909, a cozy square with an iron fountain appeared here (Fig. 6). New functions appeared here at the concentration stage – recreation, communication, political meetings, and celebrations.

Fig. 5. Duma Square. Photo of the 1910s, http://archunion.format.com.ua/history/history_004_02.shtml

At the next stage of adaptation, the Second World War interrupted the sustainable development of the main

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square of Kyiv. The historic buildings there have almost completely disappeared.

In the third quarter of the twentieth century, a new cycle of the historical development of the central square of the city began with the stage of concentration of functions in the public space. The new buildings have replaced their predecessors. The square with a fountain continued its operation. In 1946, the Christmas tree began to decorate the then Kalinin Square for the New Year holidays. The entertainment function has returned to the public space.

Fig. 6. Kalinin Square. Photo 1954, http://archunion.format.com.ua/history/history_004_04.shtml

In 1964, the first underpass in Kyiv connected two parts of the square, separated by Khreschatyk Street. In addition to the ground, there was an underground level in the central public space. At the beginning of its existence, it provided the transit of pedestrian flows. However, as early as the 1970s, artists and street musicians began to use this space. Authorities struggled with this phenomenon, but not very successfully.

The “finest hour” of the city center began during the last quarter of the 20th century. In 1976, the subway station opened. In 1981, the main square of Ukraine underwent a large-scale reconstruction. Its open space has become more comfortable and grand (Fig. 7). People started spending much more time there. They gladly took part in numerous mass events, when the square turned into a dance floor or a concert hall. Children's holidays and folk festivals raged on the square. A large of events in the personal life of many city residents took place in this space.

A small museum appeared in the underground space below the western part of the square after the reconstruction in 1981. Visitors could see here the original remains of the foundations of the ancient Russian Lyadsky Gate. Anyone could visit this exhibition space at any time. The underground passage under Khreshchatyk Street at that time turned into a real public space, which was popularly called «Trumpet». There, artists demonstrated their skills, representatives of different subcultures met, restaurants, and shops worked [16].

The independence of Ukraine also affected the functioning of Kyiv's main square. It changed its name in honor of this event and became the main square of the country. The external push has moved the central public space of Maydan Nezalezhnosti to a qualitatively new round of urban evolution.

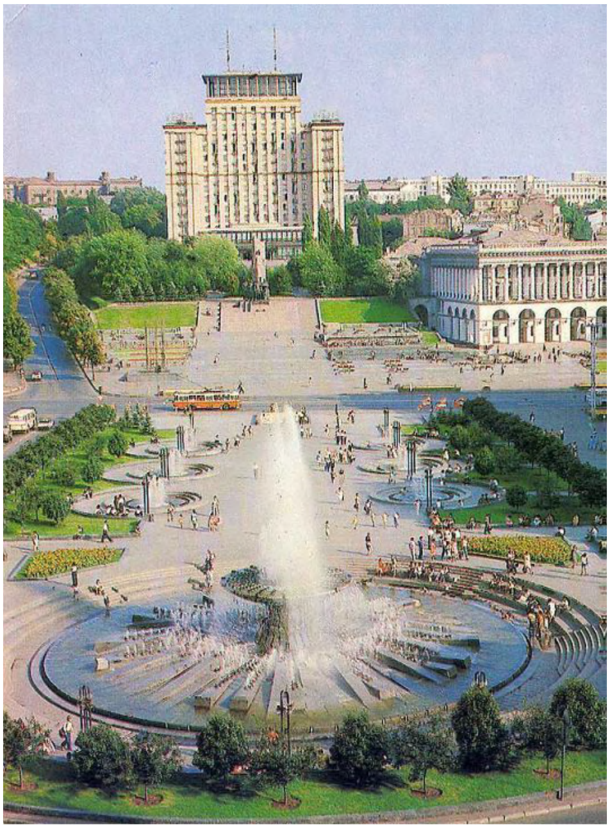

Fig. **7.** October Revolution Square. Photo 1985, http://infoportal.kiev.ua/ploshhad-nezavisimosti-v-kieve-novaya-istoriya-proisxodit-zdes/

The next stage of concentration of public functions has begun in this territory. Reconstruction in 2001 radically changed the area. The underground museum, aboveground recreation areas, and a large fountain have disappeared. Instead, the “Globus” shopping and entertainment complex went under ground level on several floors and rose above its surface (Figs. 8, 9). The main open areas for communication and recreation are at ground level and above ground – in the park near the October Palace and the roof of the third line of the “Globus”. The premises of the shopping and entertainment complex are becoming more popular in the cold season.

Already in the early 1990s, the main square of Kyiv became the primary place of public expression. In 1990, students who made demands to the government lived for a time in a tent camp in the city center. In 2004 and 2013, Independence Square became an arena for political struggle. In 2014, tragic events unfolded there, taking many lives.

The central square of the capital is gradually “healing” the wounds received during the Revolution of Dignity. However, this space will never be the same as before. A memorial was added to the list of his public functions. However, life goes on. A large-scale reconstruction of the underground passage near Khreshchatyk is underway.

The described events testify to the cyclical development of the central public space of Kyiv (Fig. 10).

In this case, the stages of dispersal, self-organization, concentration, and adaptation successively replace one another. Trends in the historical transformations of this space coincide with ideas about the cyclical nature of sustainable development. This opens up prospects for predicting the ways of sustainable and dynamic transformation of public space in the center of Kyiv. They last for about 25 years, which corresponds to the duration of urban activity of one generation.

Fig. 8. Maydan Nezalezhnosti. Foto 2004, http://archunion.format.com.ua/history/history_004_12.shtml

Fig. 9. Shopping and entertainment complex «Globus», http://abcnews.com.ua/ru/markets/pod-svodami-globusa-fotorieportazh

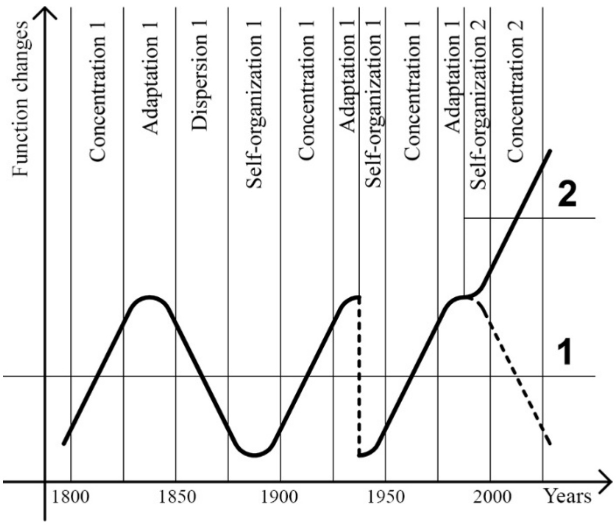

Fig. 10. Dynamics of historical development of the central public space of Kyiv: 1, 2 – levels of qualitative transformations, by Viktor Timokhin and Nadiia Shebek.

3 Conclusions

The search for new approaches to solving current problems of sustainable development of cities becomes especially important in the current conditions of reforming the architectural and urban planning industry in Ukraine. We found two opposite trends in sustainable development – the desire for stability and dynamism, rigidity of organization and flexibility of self-organization, tolerance, and hostility. Their mutual coordination is a reliable methodological basis for achieving the goal and solving sustainable development problems. We found that the dynamic component of constancy has a regular cyclical nature that manifested in a kind of genetic code of the alternation of pairwise polarized processes of dispersion and concentration, self-organization, and adaptation. On this basis, we have developed a new method of polarized cyclicity, which differs from existing methods in its dialectical content. It allows identifying important moments when minimal efforts stimulate a new round of sustainable development processes.

Their composition and order of deployment have signs of universality and are distinctive for all types of architectural environments in the city. Therefore, we used Synergetic and Socionic approaches to address sustainable development. Its cyclical nature is in the historical transformations of mutually polarized components of the city – the socializing public space and the resocializing environment of penitentiary complexes. Their diametric opposite outlines the range of tasks for diagnosing the stages of sustainable development and allows them to involve in their solving Socionic methods that contribute to the urban environment humanization.

The revealed patterns of historical and sustainable development and the usage of synergetic and Socionic approaches open new perspectives in architectural studies of transformations and metamorphoses of public spaces and the penitentiary environment. The list of methodological tools includes diagnosing these complex environments, finding out the reasons for their arrhythmic development, coordinating the phases of transformation, and efforts to maintain trends of sustainability and dynamism. They will contribute to achieving the goals, solving the problems of sustainable development of cities, and the humanization of the architectural environment of their various parts.

We propose to use this methodological approach in the architectural and urban planning practice to solve some problems. Among them: tasks of detailed planning of the territory, forecasting the stages of reconstruction and renovation of public spaces, penitentiary complexes, and other types of the urban environment.

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The response strategy of social work with displaced families and the receiving community (within the context of sustainable development)

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Abstract. The article deals with the issues of overcoming poverty, inequality, nutrition improvement, ensuring a healthy way of life, raising education quality, enhancing well-being, and building up a peaceful and open society for internally displaced persons (IDP) and the receiving community by means of the social response strategy. The goal of the research: theoretic substantiation of the response strategy in social work with IDP and the community in the context of the perspective of ensuring their sustainable development. The presented response strategy is for the first time theoretically substantiated and adapted to the Ukrainian realities in the conflict zone and takes into account the peculiarities of the DP and social work in the receiving borderline community and includes standard actions to react to extraordinary situations, activity directions – psychology-and-pedagogic, socio-medical, humanitarian, information-and-cultural assistance. The strategy is based on the principles of integration, multi-sidedness, multidisciplinary connection, resource-orientation, green-aware social work, the advantages theory, partnership, assistance for self-assistance, family-centrism, innovation, synergy, etc.; it takes into account the perspective ensuring of sustainable future for both the displaced families and the receiving community in general. The methods of the research: theoretical analysis, synthesis, systemizing, generalizing, comparison, documentation study, estimation of needs, and mathematic statistics methods. The obtained results of applying the mentioned theory under conditions of the military conflict in the Luhansk oblast (area) of Ukraine confirm its efficiency in qualitative and numerical terms and are supported by mathematic statistics methods.

1 Introduction

Overcoming poverty and hunger, reducing inequality, nutrition improvement, ensuring a healthy way of life, raising education quality, enhancing well-being for various age-groups of population, formation of a peaceful and open society as the goals of sustainable development, proclaimed in the UN General Assembly Resolution for the period till 2030 [1] and adopted by Ukraine [2], are the principal landmarks for working out social projects and programs for improvement of medical, social, and educational services for vulnerable strata of population in the context of securing their sustainable future [3; 4]. Attaining these goals is of special urgency in the east of Ukraine, where the military conflict has affected the population's well-being level, led to the arising of the new for the country vulnerable social group, internally displaced persons (IDP), the number of whom as of 13.04.2020 was 1,446,881 according to the Unified information database on internally displaced persons of the Ministry of Social Policies of Ukraine. These people need support and assistance, including social work concerning a decrease in the conflict's consequences influences on their lives, securing their sustainable development, adaptation to the new communities, and integrating into new conditions of life. On the other hand, the arrival of IDP to new communities has led to the growth of tension therein, due to the need in sharing the existing resources among all the community members, thus making the receiving party poorer as a result of IDP' arrival. It is the border regions of Ukraine where this situation has formed along the demarcation line, where, for instance, in the city of Berdyansk there was registered the ratio of 1:5 between IDP and the local inhabitants which makes 20% of the population. An EU 1.3 mln euros project solved the issue of diminishing social problems, easing tensions between IDP and the receiving community of this city [6], but not all towns in the borderline zone get such financing. Other ways of solving the problems of IDP and local community are needed, like, among other things, activation of people themselves to render self-assistance, granting targeted assistance, and so on. The concepts of social work acting in Ukraine ("assistance for self-assistance", "crisis intervening") are characterized as rendering assistance for adults in the time of peace [7], while the conditions of a military conflict

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attest to peculiar problems of socialization and activities of children, families, and adults [8; 9]. The existing concepts of social work [10–12] insufficiently account for the peculiarities of IDP and the receiving community. Attention should be paid to strengthening and encouragement of communities, to satisfying the needs of all vulnerable families of IDP and local people from the receiving community, which is attained in practice by integrating resources and interdepartmental and multidisciplinary cooperation in rendering social services [6; 13–17]. Nevertheless, the mentioned measures overall do not facilitate the development of IDP and local people or communities. Other approaches are needed, targeted at sustainable development of every person, family, community under conditions of a humanitarian crisis and military conflict.

As to conception and formation of the ideas of sustainable development in social work, it should be noted that accentuation on individual sustainability (a personality sustainability) has existed in social work for a long time and has evolved as a concept, but it was not applied to IDP, particularly to children and their families that prevail among IDP [18]. In its turn, the interconnected vectors of social work and sustainable development of communities, society, of interaction between the personality, the family, and the community are a new direction that has become the reason for activation of research in this sphere to find ways of mobilizing resources of all IDP and the community, for development of strategies which will facilitate ensuring sustainable future [6; 19–24]. Such strategies have not been yet applied to IDP in Ukraine.

Among the researches by foreign scientists devoted to this topic, there are studies representing the theory and practices of social work with vulnerable strata of population, including IDP under conditions of a military conflict. Social work with them is based on eco-social foundations. Military actions are viewed as cause and effect of environment degradation (Aniche Alexander [25], J. Lambert [26], T. John Pardeck [27]; K. van Wormer et al. [28], and others). The impact of a military conflict on internally displaced children and families with the accentuation on their mental health, considering the displacements as a social ecology problem that determines deprivation, poverty, and social rejection, is presented in the works by K. Lai [29], K. Miller [30]. L. Dominelli within the concept of the green social work focuses on the problems of social injustice, social rejection, and segregation of people [31]. Historic development and dilemmas of social work with displaced population are represented in the work by P. Boccagni and E. Righard [32]. The issue of different consequences of internal displacements and IDP integration into receiving communities is elucidated by A. Carrillo [33]. These researches are related to the authors' studies of the IDP's problems [8], their life in the places of compact residence of IDP and social services for them in the receiving community [6] in the context of special problems of socialization and integration of internally displaced children and adults, the need in comprehensive solving their problems. The ecologic perspective in social work with the IDP and the community, according to the world studies, is based on support of a personality and their environment, satisfying their needs, search for and integration of resources for solving personal problems [34; 35]. Currently, social work in the global context of sustainable future is of multidisciplinary character and requires that a social worker perform the role of a coordinator of individual and social sustainability development [31] and is directed at overcoming of poverty, fair distribution of resources, decrease in the risks of negative consequences on the level of an individual, a family, a group, a community and society in general, integration of a personality into a community and accepting them by local people. This highlights the topicality of theoretic substantiation of the new theory of social work with IDP and community with taking into account the country's specifics, its particular region, and practical implementation of the principal guidelines in the activities of various social institutions in the context of the perspective of securing a sustainable future for the mentioned social group and the community.

In the international practice, social work with vulnerable strata of population that suffered as a result of a military conflict began developing after the World War II; it was non-existent in Ukraine. Nowadays, the Ukrainian system of social services appears to be unprepared for timely response to the new social problem, the arrival of IDP. That is why a portion of the work concerning rendering assistance to them was undertaken by international public organizations and volunteers [36]. One of such organizations is the International charity organization "SOS Children's Villages", whose general activity strategy for the period till 2030 is targeted at ensuring the best care of children, innovations introduction, uniting larger numbers of partners to solve the problems of children from the families that found themselves in difficult life situations, as well as to react to changeable needs of communities [37]. Its goals are closely related to the sustainable development goals in such spheres as poverty, inequality, education, healthcare, social protection, decent work, and fostering their achievement with the accentuation on the target group – children and families. This supposes the work of the organization concerning improvement of national social protection systems, combating social inequality, promoting access to quality education, broadening opportunities for youths' employment, eliminating violation to children [38]. These aspects of the organization's activities are of global character because "SOS Children's Villages" operates in 136 countries and territories of the world [39]. They do not reflect the specifics of each state, but lay foundations for working out new theories of social work with children and their families taking into account the circumstances in a particular country, or in a particular region, which determines the expediency in utilizing their experience when developing new theories. This organization applies the responsive strategy of social work which is targeted at working with individuals, groups, and communities that have suffered from extraordinary situations (natural disasters, technogenic catastrophes, wars, etc.), restoring their activities, and access to resources [40]. But this strategy has not been theoretically substantiated and adapted to the realities of Ukraine.

Therefore, there is a need in solving the problems of IDP and community in socially unstable regions. Formation of new communities in such regions and securing for them a perspective of sustainable development is becoming even more acute and calls for substantiation of the new social work theory which the authors have determined to be the response strategy. Therefore, the goal of this article is theoretical substantiation of the response strategy in social work with internally displaced families and the community within the context of the perspective of ensuring their sustainable development.

Attaining the goal supposes solving the following tasks: 1) determining the peculiarities of social work with IDP and the community in Luhansk oblast; 2) substantiation and disclosing the essence of the response strategy in social work with IDP and communities at the areas bordering with the conflict zone in Luhansk oblast; 3) to estimate the efficiency of the response strategy's application on the mentioned theoretical foundations in Luhansk oblast.

2 Methodology

The main methods that ensured attaining the goal and the tasks of this research were theoretical analysis of sources on the studied problem, synthesis, systemizing, generalization, comparison, documentation study, needs estimation, mathematic statistics methods for comparing, evaluation and estimation of the obtained results. The base for the research was the work of the Luhansk area branch of the international charity organization "SOS Children's Villages" in the military conflict zone and the border regions.

The research was conducted within the partnership between the Science-and-research Center of Social Pedagogy Problems and Social Work at the National Academy of Pedagogic Sciences (hereinafter the Center) established on the base of State Institution "Luhansk Taras Shevchenko National University" on the one part, and the Luhansk area branch of the international charity organization "SOS Children's Villages" on the other part. The research was financed from the State budget of Ukraine as part of the fundamental research "Socializing of the school and student youth of the East of Ukraine under the hybrid was in Donbas" (2018–2020) [41] and in the course of participating in the international project on "Strengthening Communities for Ensuring the Children's and Families' Needs in the North of Luhansk Oblast" supported by the UNICEF and Luhansk oblast branch of the international charity organization "SOS Children's Villages International") [41; 42].

In the towns of Starobilsk and Severodonetsk, experimental sites were established to work with IDP, the community, and internally displaced children's villages. The materials of the conducted work have been generalized in this article.

3 The results of the research

3.1 Peculiarities of social work in the conflict border regions

The specifics of the operation of the Center and Luhansk oblast branch of "SOS Children's Villages" is that that the employed specialists' staff is composed of both local specialists and those who are IDP. For this reason, they like no other feel the problems and needs of internally displaced families in a new community. Another peculiarity in the Center's activities is that it takes place in Luhansk region, part of which is temporally occupied. On the territory which is controlled by Ukrainian government, the power is exercised by military-and-civil administrations for securing safety and normalizing population's activity, law order, taking part in counteracting aggression acts, subversive activity and terrorist acts, preventing humanitarian catastrophe [43]. This means the need in coordinating social work, its events with military-and-civil administrations for safety of social workers and the clients. Luhansk oblast is the second in Ukraine after Donetsk oblast by the number of IDP, which amounts to 280,437 people [44] and aggravates the situation considering that the area itself has suffered and is still experiences the consequences of the active conflict. Therefore, the peculiarity of rendering social services is the need in resources in the receiving community and the lack of these resources. At present, an aggravation of conflicts in all spheres of group interaction between IDP and representatives of receiving communities is observed, which is mostly determined by the absence of real public dialogue, ignoring the interests of all parties, taking unjustified decisions concerning socially significant issues [45]. That is why social management is important considering the problem of redistribution of the available resources. In Luhansk and Donetsk oblasts has formed the worst situation in Ukraine as to the state of satisfying the basic needs of people, which is determined by high unemployment level in these areas. In the areas, there is no support of IDP by local authorities who do not develop programs for IDP integration and do not provide for financing their social needs from local budgets. The reason is that IDP have no right to vote at local elections, not being permanent residents. Therefore, the peculiarity of social work is its orientation at those state programs that are limited in an area with military-and-civil administration, as well as at public organizations and citizens' self-assistance.

In the Center's activity and that of "SOS Children's Villages", *resilience* is actively applied, the approach that orientates social work at client's advantages that facilitates avoiding deep traumatizing of children and families that found themselves in dangerous or extreme conditions. Resilience is different from resistance to stress, which changes a person under the impact of outside events and influences. This notion supposes an individual's resistance to such influences, the absence of the result of influencing people. In the context of the research, the authors attempted to compare some peculiarities of social work in terms of applying standard approaches and that of resilience (Table 1).

Table 1. Comparing resilience with standard approaches to understanding a difficult life situation in social work*.

Standard approach – when focusing on deprivation, disorders, a trauma	**Resilience – when orientated at a person's advantages**
Considering a person's problem as a typical case	Orientation at the personality's uniqueness
Focusing attention on the client's problem	Focusing attention at potential opportunities
Needs are determined by social worker	An individual determines their needs independently (or with social worker's assistance)
Difficult life situation is perceived as a risk of negative consequences	Difficult life situation is perceived as activation of a personality's powerful inner resources which had been used before
Inability to resist an extraordinary situation	Ability to overcome difficulties caused by an extraordinary situation, to preserve the balance and stability

* Compiled by the authors as an example based on the exercise "Advantages theory in social work" [46].

Therefore, it is possible to determine the peculiarities of social work in Luhansk oblast: a larger number of clients' social problems compared with other regions, the majority of the clients are IDP, there exist specific problems of IDP and the receiving community, dependence of social work on military-and-civil administrations and the territory status, the need in social management under limited resources, involvement of IDP in social work as specialists, the absence of local assistance programs for IDS, orientation of state social services at state assistance programs for IDP that act on the territory of Ukraine and do not take into account the specifics of the territories in the conflict zone, involvement of public organizations in rendering social services to IDP and the community, orientation at resilience (focusing on the clients' advantages).

3.2 Substantiation of the essence of the response strategy in social work in the military conflict zone

The strategy of social work with clients of different age groups and categories is defined as part of a social worker's skills, which include its basic components connected with his/her ability to select for each presented task the optimal social technologies, methodologies, and tactics that would ensure its successful accomplishment [11]. A strategy's peculiarity is that if the strategy is chosen correctly and is of high quality, it does not need alterations regardless of the changes in environment, for it is in itself a precondition for survival in a constantly changing environment. Only the plan of measures is to be adjusted depending on the chosen strategy. At the same time, the measures should be integrated and mutually connected [47].

The response strategy in social work is meant for work with individuals, groups, and communities who have suffered from extraordinary situations (natural disasters, technogenic catastrophes, wars, etc.), for restoration of their activities and access to resources [40]. It is directed at overcoming the dependency on humanitarian aid, recuperation of work potential, socio-cultural and social relations, efficient self-management and self-assistance [36]. This strategy is maintained on the basis of observing both the legal norms (General Declaration of Human Rights [48], the UN Convention on Children's Rights [49], the UN Guidelines concerning Alternative Childcare [50], the UN Goals of Sustainable Development till 2030 [1] and others) and the developed inner standards in social services provision. Correspondently, the measures of the "SOS Children's Villages" organization and the Center on the issues of readiness for and reacting to extraordinary situations, planning for unforeseen circumstances, joint estimation and development of standards and guidelines, fulfilling of corresponding programs of rendering assistance in extraordinary situations, reacting to consequences of military actions, providing assistance for vulnerable strata of population, particularly to internally displaced children and families reflect the main priorities of the UN activities in this sphere. That is, the measures are oriented at observing the human rights, preserving the integrity of family, safety, and other basic needs of people.

It is stated in the UN Manual on Extraordinary Situations, that "any extraordinary situation is unique, that is why there is no single comprehensive plan to control it. Nevertheless, extraordinary situations usually develop on scenarios that have some common features, which enables specify standard actions in response" [51]. Analysis of the content of the response to extraordinary situations concerning the work with refugees in the UN documents, and in the practices of the "SOS Children's Villages" organization's operation has made it possible to establish the list and the main content of such actions (table 2).

The measures on rendering assistance to IDS as a new category of social services' clients for Ukraine are in many cases similar to those for refugees, although IDP, unlike refugees, remain on the territory of their country, therefore their protection and rights are regulated not so much by particular international legal acts as by national legislation [51]. That is why forming various conditions for their rights implementation and protecting them as the goal of social work enables using scientific approaches of human rights protection, a family-centered approach (of protecting the family, family members and their rights). The peculiarity of the response strategy in social work with IDP and community under conditions of the military conflict and social crisis in Luhansk oblast is that the safety issues are accentuated on, including those of evaluating the family and community's needs for creating a safe life, considering the project initiatives in local development in the context of vision of the perspectives of their sustainable future [52]. This means the need in utilizing all the benefits of the risk-orientated and the project-orientated approaches, of diagnostic social work. They enable solving locally the problems of community, decreasing danger and risks for people's life, and finding additional financing for problems solving.

Table 2. Standard actions within the response strategy to extraordinary situations

Standard actions	Contents of the actions
Estimate the problem, the needs and resources	Initial estimation of the problem and people's needs
Mobilizing resources	Activation and use of potential resources in order to eliminate the threat for people's life and health
Regulating the relations with the donors and the media	Ensuring communication between family members and relatives
Planning operations	Additional estimation of the client's needs, development of the actions plan, determining current tasks and long-term goals and measures to achieve them
Carrying out operations and coordinating the actions	Tasks distribution, making coordination mechanisms of fulfilling individual tasks
Monitoring and estimating the situation constantly	Estimation of the dynamics in changes in the course of solving the problem, comparing the initial, the intermediate, and the final results of social work with the client
Going on to the actions following the termination of an extraordinary situation	Completion of work, defining the perspectives of renewing the work with the client if needed

It should be noted that the response strategy in social work in the "SOS Children's Villages" activity is aimed at work with children and families that found themselves in difficult life situations, at renewal of their viability, access to resources, and integration into the receiving communities [53]. In essence, this strategy relies on the integration and the eco-social approaches, which are based on the foundations of partnership, viability, innovations, and synergy, and can include crisis intervening when a person or a family needs support in difficult and extraordinary situations, which is broader than the social work in difficult life situations conducted by the rest of social workers of Ukraine [not involved in work with IDP]. Due to the fact that such social work can be made by IDP themselves, the participation theory is important for the work with IDP and the community. Partnership in this sense of social work supposes conducting various consultations aimed at well-grounded expectations of the community from power bodies. All the interested parties – representatives of power bodies, scientific and educational institutions, enterprises, and other institutes of civil society – are invited to take part in passing decisions and development of strategic goals. This is the democratic approach in social work. Innovation acts as a kind of indicator of the response strategy projects and for the larger part relates to efficient use of available resources. The synergy approach supposes considering individuals, families, groups, and communities as self-organizing systems, especially in unstable, crisis states.

The idea of application of the integration approach is that social response to the clients' needs supposes not only their adapting to the community, but also the community's adapting to them, community's creating favorable conditions for the utmost implementation of its members' potential, strengthening inter-sectoral cooperation between different social institutions on partnership terms, provision of comprehensive social services [3]. This means the use of the resource approach in a community. An important role in this work is allotted to interdepartmental interaction, which supposes mutually coordinated activity of structural units of the local executive power body and the offices subordinated to them with involvement of other institutions and administrations representatives vested in authorities provided for by legislation if necessary for the best ensuring of the rights of children who reside or stay on their departmental territory, solving their families' problems, forming conditions for children's upbringing by their responsible parents or legal representatives. Interdepartmental interaction on the issues of assistance, support, and guiding a child and their family in the "SOS Children's Villages" operation supposes close cooperation between state organizations, healthcare system institutions, social protection of population, education, non-governmental organizations and institutions. Organizing such interaction in present conditions of development and improvement of social services for families should become the mechanism which facilitates attaining high standards in the sphere of rendering social services [54]. The interdepartmental approach supposes multidisciplinary operation, organizing and coordination of social services provision, systemacy in rendering them, which means integration and cooperation of all structures and specialists, the basis of which may comprise, according to the human rights theory, of the family-centered approach, human rights, and family rights.

The eco-social approach departs from the idea of interconnection and interaction between an individual and the environment. A social worker's actions are directed at assisting a person to overcome a number of problems that are a consequence of this interaction. Social problems are viewed as ecological problems, and corresponding work is aimed at ensuring decent environmental conditions, ecological justice and equal access to natural resources, environment preservation, assistance to population in extraordinary situations [40]. It is access to water, medicines, food, and other essential things that matters most in the so-called "grey zones", in the conflict-bordering areas. That is why socio-economic services are the foundation of satisfying people's basic needs and solving their daily problems. A task-oriented model of social work is needed. In eco-social approach, resilience requires "assistance for self-assistance", as well as training to perform resistance to outer negative influences and circumstances with relying on the positive in the situation and the person.

Thus, the theoretical foundations of the response strategy in the Center's social work with IDP and community in Luhansk oblast are scientific approaches of various levels, namely:

Philosophic approaches: the human rights theory, the sustainable development theory, the pragmatic the democratic, the multidisciplinary approaches, and the participation theory;

General science approaches: the integrated, the innovational, and the synergy approaches;

Specific science approaches: the family-centered, the risk-orientated, the project, and the resource approaches;

Social work approaches: the advantages theory, assistance for self-assistance, crisis intervening, eco-social, diagnostic social work, and task-oriented model.

The principles of social work based on the response strategy in Luhansk oblast are: observing human and family rights, orientation at sustainable development of a person and the community, subjectivity, viability, synergy, integration, cooperation, solving urgent problems, orientation at result, directedness at self-assistance and resilience, innovations introduction in problem solving, removing risks and dangers, their minimization, relying on local projects, joining resources, considering clients as subjects and in case of a crisis as objects of social work, work with environment and in community, problems and needs estimation, responding to problems and needs.

The content of the response measures on this basis should be determined departing from the problems, goals, and principles of work. Thus, the main problems of IDP in the East of Ukraine are the problems of obtaining temporal housing, residence registration, medical examination and treatment, education, food, clothes and hygiene products supply, coordination of procedures to get social assistance, the issues of work and employment, etc., which if not timely attended to will cause instability and loss of control over the situation and one's own life, abrupt decrease in material well-being, fear of being rejected by society, feeling of insecurity, and being unable to foresee one's future [8; 55; 56; 57; 58]. Also, as has been proved, outreach and socio-cultural work is needed [6]. That is why, the main directions in implementation of the response strategy in the Center's social work with IDP and the community are psychology-and-pedagogic, socio-medical, information-and-cultural, and humanitarian assistance. Each of these kinds of work can be performed at different levels of a case: from servicing to rehabilitation, support and intervening. It is these kinds of work that help gradually bring a person out of crisis and lead them to development without negative consequences for their life and health. The chief methods are the following: social, socio-psychological, socio-pedagogical, socio-economic, organization, and diagnostic ones.

Within the authors' experimental research, each of the mentioned kinds of social work became a criterion in evaluating the efficiency of the response strategy application in the "SOS Children's Villages" organization and the Center in Luhansk oblast, and the chief methods of social work mentioned in this connection were indicators of these criteria.

The experiment involved 250 families that found themselves in difficult life situations and were entitled to social support at "SOS Children's Villages" (towns Starobilsk and Severodonetsk) through the response strategy in social work. 80% of these families had the IDP status, while 20% of the families were locals. The answers to the questions concerning the need in these or other kinds of services were given by women as representatives of these families. The experiment supposed comparing the results obtained prior and following the social response actions, i.e. women's independent estimation of needs in obtaining different kinds of services before and after social support. The research was based on the standards of observing ethical principles of conducting research with humans as subjects. The families participated in the interviews on their free will.

At the initial stage of the experiment (October 2018) in the psychology-pedagogic assistance direction, the urgency in satisfying the needs of internally displaced families in logopedist services were estimated and amounted to 12% of the total number of families that agreed to participate in experimental actions concerning the response strategy application in the course of their social support. The needs in psychologist services were 84.4%, in those of a social worker – 81.6%, improvement of their knowledge of English – 25.6%, catching up with the school program – 15.2%. By the socio-medical assistance direction, the needs in covering families' expenditures on medical treatment of children were 31.6%, recovery – 69.2%, By the direction of information-and-cultural assistance, 64.4% of families needed information services, and 89.6% needed help in organization of daily activities and leisure. The families' needs in humanitarian aid were 88.4%. The obtained data match the results of the research concerning the estimation of IDP's needs and employment possibilities in Ukraine (n=2000) conducted in October 2014 – December 2015 by the International Labor Organization, which estimated the unemployment percentage among the IDP due to looking after ill family members and young children to be 31.5% [59] and the research on estimation of IDP and services for them in Ukraine (n=471) conducted by the international NGO "Social Initiatives in Labor Protection and Healthcare" in January 2015, which reported that the number of IDP who had no access to medicines or could not afford them was 27.3%. This research also revealed that the urgent need in humanitarian aid (food and clothes only) was 65.7%, in social assistance – 86.5%, in psychological – 89%, in cultural – 92.7% [60]. It should be noted that the data obtained as to the needs in humanitarian aid differ considerably due to the fact that in the authors' [of this article] research the humanitarian aid services related not only to satisfying the basic needs in food and clothes, but encompassed a somewhat broader range – stationery, hygiene goods, preparing for winter season, etc.

At the main stage of the experiment (November 2018 – October 2019), the response strategy in social work with IDP and the receiving community was applied by the mentioned kinds of social work. By the psychology-and-pedagogic assistance direction, the Center jointly with the "SOS the Children's Villages" cooperated actively with education institutions in order to form a modern, most comfortable for children education environment to assist teachers to cope with the tasks of adaptation of children from vulnerable families to school, to give them an opportunity of overcoming difficulties and develop their abilities to the fullest extent. The following methods and measures were suggested: individual consultations by a psychologist; consultations by a social work specialist; sessions with a logopedist; group classes in art-therapy; group classes in parental potential development; mutual assistance groups; individual psycho-therapeutic sessions for children who experienced a trauma; charity initiatives (for instance “A backpack of kindness” – assistance to children in getting ready for school), additional classes in school subjects, etc. The socio-medical assistance was connected with such aspects as recovery (health improvement) that supposes organizing resting holidays for children from the region that suffered from the conflict, covering a certain sum of expenditures on buying medicines for children if prescribed by a doctor, giving out medicines and vitamins, training children and families in a healthy way of life. The information-and-cultural support supposed organization of joint leisure for parents and children, information support as to a family’s renewal of their social status, family and social ties (information support in paperwork (restoring documents), various kinds of social payments, etc.), development and propagation of information materials for parents and children. Jointly with the “SOS Children’s Villages” the Center provided humanitarian aid in the form of food parcels, hygiene sets, baby-boxes, medicines and vitamins, seasonal clothes and footwear according to the detected needs. It should be noted, that the main programs fulfilled by the Center jointly with the “SOS Children’s Villages” are family forms of upbringing, strengthening families, programs within the projects of responses to extraordinary situations. For covering expenditures on responses to extraordinary situations, the grant financing mechanisms are involved.

The final stage of the experiment (December 2019 – January 2020) included analyzing the efficiency of applying the response strategy in social work with internally displaced families and the receiving community. In Table 3, the work outcomes are presented. The interpretation of the obtained data was made with the use of φ* indicator of Fisher’s angular criterion. The statistical significance levels of different values of Fisher’s φ* criterion were determined from Hubbler’s table [61].

The obtained results attest to a positive dynamics in solving the problems of IDP families and communities in the East of Ukraine because, owing to the use of the response strategy in the course of their social support, the percentage of families who need further satisfying needs in the mentioned kind of services by all kinds of assistance (psychology-and-pedagogic, socio-medical, information-and-cultural, and humanitarian) decreased, which attests to activation of their own resources in overcoming the consequences of the conflict to their lives, restoring their potential and social relations, raising the level of their integration into the receiving community. These data match the authors’ data on IDP’s rehabilitation, integration, and activation within the EU project in the town of Berdyansk [6], when owing to social work with IDP in the places of their compact residence and the community and activation of IDP and local residents’ subjectivity, tension in the local community decreased. Nevertheless, the program was not oriented at resilience development, which told on further IDP’s migration (at present 10% of residents there are IDP instead of 20% at the beginning).

Table 3. Unified actions in the response strategy for emergency situations.

The necessity in satisfying a need in	% of the total number of families to those who needed support	% of the total number of families to those after social support	φ^*_{emp}	p
Psychology-and-pedagogic assistance				
logopedist services	12,0	2,4	4,43	<0,001
psychologist services	84,4	26,8	13,89	<0,001
a social worker’s services	81,6	23,6	13,86	<0,001
improving their English	25,6	17,2	2,3	0,01
catching up with school program	15,2	5,2	3,81	<0,001
Socio-medical assistance				
covering expenditures on medical treatment of a child	31,6	21,2	2,65	<0,003
recovering (health improvement)	69,2	27,2	9,71	<0,001
Information-and-cultural assistance				
information services	64,4	15,6	11,75	<0,001
organizing of daily activities and leisure	89,6	50,4	10,13	<0,001
Humanitarian aid				
non-financial assistance (school stationery, food, hygienic, winter sets, etc.)	88,4	18,0	17,56	<0,001

Therefore, the use of the response strategy in social work with internally displaced families and the receiving community is efficient and forms favorable conditions for achieving the goals of sustainable development on the road to their stable future.

4 Conclusion

The peculiarities of social work with IDP and the community in Luhansk oblast are that this region is characterized by the dependency of social work on military-and-civil administrations and the territory regime; a large number of IDP; the presence of specific problems and the needs of IDP and the receiving community; IDP’s participation in social work as specialists; orientation of local authorities at state assistance programs for IDP acting in Ukraine and not taking into account the peculiarities in the conflict zone; the need in social management under conditions of limited resources; involvement of public organizations to providing social services for IDP; the need in orienting at resilience.

The response strategy in social work with internally displaced families and community is directed at renewal of their viability, access to resources, and integration of internally displaced families in the receiving communities. Its content is connected with such unified actions as the necessity in estimating the problem and needs, resources mobilizing, actions coordination, and permanent monitoring of the situation. Social response of this type is based on scientific approaches of various levels and principles of human rights protection, sustainable development perspectives, ensuring multidisciplinary approach, integration, resource mobilizing, eco-sociality, advantages theory, assistance for self-assistance, innovativeness, partnership, vitality, synergy, etc. It supposes implementation of the technology of social support of vulnerable children and families, holding events, application of forms and methods by the directions of psychology-and-pedagogic, socio-medical, information-and-cultural, humanitarian aid, that are determined by actual problems and needs of IDP and community.

Application of the response strategy in social work with internally displaced families and community under conditions of difficult socio-political situation that has formed in Luhansk oblast is efficient because it activates their resources in overcoming the consequences of the conflict, restores their potential and social ties, raises stability of both the family and the community in the context of vision of the perspective of achieving the goal of sustainable development.

The authors see the perspective of further scientific research in theoretic substantiation of possible tactics of influence in social work with internally displaced families and the community within the application of the response strategy in the context of the perspective of their sustainable development, the role of communities in forming the market of various social services and their accessibility in the eastern Ukraine regions that are characterized as having a difficult socio-political situation.

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Thermal comfort analysis in the sustainable educational building

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Abstract: In the modern world, a person spends most of his life indoors. That is why it is so important to create optimal conditions for the internal environment. Research on thermal comfort and subjective feeling of people inside the building can help in this. The article discusses two methods that are used in research on thermal sensations. This makes it possible to know the thermal assessment of people and then compare this result with the calculated PMV value, which is calculated using the formula from ISO 7730 standard.

1 Introduction

Today, energy consumption is one of the main problems of the modern world. A solution to this problem is sought in energy-efficient construction, which uses various types of renewable energy sources, such as solar collectors, photovoltaic cells, heat pumps, wind turbines, biofuels or hybrid solutions. Moreover, such buildings belong to sustainable construction, whose main goal, apart from the use of devices for the production of renewable energy, is to reduce waste and pollution generated during the construction of ecological buildings in such a way as to minimize interference with the environment. Another advantage is definitely the cost of maintaining such a building, because the building works on itself, it is self-sufficient. In addition, the idea of sustainable construction is to reduce the consumption of water, electricity, heat losses, create appropriate conditions for the internal environment, including air exchange with the help of well-selected ventilation, use containers for waste segregation and create optimal conditions and thermal comfort for people who spend most of their lives indoors [1-6]. At this point, a lot of research into thermal comfort is carried out. An example of such research is a study by Hwang et al. [7] who analyzed 944 people at universities in Taiwan. The respondents definitely determined that the best temperatures in which they feel are in the range of 21.1ºC to 29.8ºC and 24.2ºC to 29.8ºC. In Australia, Dear and others have attempted to forfeit both primary and secondary school students. During the research, 2,850 questionnaires were received. After analyzing the questionnaires, the results were obtained in which the respondents defined their thermal sensations in the range of 19 -26. Later, these studies were extended to include more results. Kim and Dear [8-9] have further decided to forfeit the school environment. From the obtained results, the authors found out that students prefer cooler temperatures, and more of the received questionnaires, students who had the option of using air conditioning during classes were better adapted to it than children who did not have such an opportunity. Zaki et al [10] analyzed three universities – two in Malaysia and one in Japan, over the summer. 1428 surveys were thoroughly analyzed, which showed that in Japan the best temperature was 25.1ºC, while in Malaysia it was 25.6ºC. In Indonesia, Hamzah et al. [11] perished Hasanuddin University in Gowa. The thermal sensations during the research were described by 118 people, from whom it appears that these guards felt comfortable in selected rooms. Liu et al.[12] analyzed naturally ventilated rooms in northwest China, in the city of Xi'an, to see how the students living in these rooms feel thermal. A total of 992 questionnaires were completed, which showed that the most natural temperature was 20.6ºC, and the range in which the students determined their thermal comfort was the temperature from 19.5ºC to 21.8ºC, and the preferred temperature was 22.7ºC. In Brazil, at the University of Goias, Abreu-Harbich et al. [13] investigated classrooms with three air conditioning methods such as natural ventilation, evaporative cooling, and air conditioning. The authors wanted to get to know the students' thermal feelings, because the discomfort in the classrooms might have compromised their knowledge. 200 people were lost. 69.52% of people definitely did not correspond to the creature conditions by natural ventilation. Less, because only 60.67% were dissatisfied with evaporative cooling and 70.18% of the respondents did not accept the conditions of the internal environment created by air conditioning. Moreover, the neutral temperature was set at 25.9ºC. Buonocore et al. [14] at the University of Sao Luis, Brazil, analyzed the subjects' thermal preferences and the feeling of thermal comfort. The rooms covered by the study were air-conditioned and ventilated in a natural way. The authors of these studies wanted to know the appropriate climatic conditions in the internal environment of the room. Therefore, the city of Sao Luis was chosen for its location in an equatorial climate where it is hot and humid. The problem of local students is overcooling associated with the excessive use of air

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conditioning in the classrooms. From the questionnaires completed by students it was concluded that the best conditions meeting the preferences of the respondents were the temperature range from 23ºC-24ºC. It was in this respect that the students felt thermal comfort. Moreover, they tended to increase the temperature to 26ºC. About 20% of respondents felt discomfort if the temperature was lower than 22, with a clo of 0.3. Guevara et. Al. [15] have taken an analysis of three cities in Ecuador – Quito, Guayaquil, and Tena. From December 2017 to January 2018, the authors of the study received 429 questionnaires completed by volunteers. The aim of this research was to obtain information about the thermal comfort of people living in the tropics, where the weather is very changeable. Neutral temperatures in which the respondents felt best were in turn 21.8ºC, 26.3ºC or 26.9ºC. The respondents from Guayaquil and Tena were directed to cool temperatures because of the hot and humid climate in their areas of residence. In Bangladesh, a study was performed in the summer of 2017 by Talukdar and others [16]. They focused on learning about the thermal preferences of students in naturally ventilated rooms. 579 sheets with respondents' answers were received. The parameters maintained during the test were equal to the temperature – 30.9ºC, humidity – 78.4% and the wind speed – 0.8 m/s. After the analysis, it was found that the best neutral temperature for the feeling of thermal comfort is 27.8ºC. Abdallah [17] conducted research at the Assiut University. The study covered 6 naturally ventilated classrooms. Initially, 331 people participated in the study, but after an in-depth analysis, only 269 questionnaires remained. It was concluded from the responses that the temperature exceeded 28ºC, which was met with discomfort by students in 90%. At the Bahia Federal University in Salvador, Brazil, Costa and others [18] analyzed the students' thermal sensations. Only 53% of the respondents felt thermal comfort. The conclusion of these studies was the incorrect maintenance of the condition of windows and window frames, which prevented the correct flow of air between the external and internal environment. In Thailand, the University tested 3 speeds of the air conditioner – low, medium and high, then the students completed the questionnaires. Puangmalee et al [19] analyzed the results of the surveys which concluded that students would be able to accept a temperature of 28 as long as the air conditioner speed could be regulated. Additionally, the information was obtained that the higher the speed, the higher the neutral temperature.

An educational and laboratory building of Environmental Engineering, Kielce University of Technology, called „Energis" from the year 2012, is such an energy-saving and intelligent building. "Energis" has been designed with sustainable construction in mind. The main and set goal was to monitor the effects of energy saving, the balance of energy gains and losses, maintaining appropriate parameters of the internal environment while using the most modern automation and control solutions for devices such as photovoltaic cells, solar panels, heat pumps, energy storage [20, 21]. Figure 1 presents a photo of the "Energis" building and shows the selected room where the research on thermal comfort of students of Kielce University of Technology was conducted.

Fig. 1. Photo of "Energis" building and selected room where the test was performed.

2 Testing methods

Thermal comfort measurements are divided into two methods, indirect and direct. The indirect method is based on the analysis of completed questionnaires by people in the room covered by the study and direct method aimed at obtaining microclimate parameters using a meter (air temperature, globe temperature probe, air velocity, relative humidity, light intensity). These data, in particular temperature, air velocity and humidity are needed to calculate the PMV (Predicted Mean Vote) from the formula contained in the ISO 7730 standard [22, 23].

The questionnaire included questions about thermal sensations, adequacy of temperature, sensations of humidity, current clothing and physical activity, as assessed by study volunteers. A very important fact when assessing the thermal sensations of test volunteers is to check what physical activity they had before the test. People who did not perform any physical activity, i.e. sat before the test, or walked for no more than 10 minutes, are a reliable source of information about their thermal sensations. If, on the other hand, such people did strength training a moment before the measurement, unfortunately such people may distort the picture of knowing their thermal preferences. Thus, polls must be rejected. Additionally, the actual thermal sensation is also influenced by clothing, otherwise known as the clothing thermal isolation (clo), which for this group was 0,62. Note that if the subject is dressed too warm, he may feel discomfort in the form of heat. Similarly, she will feel bad wearing summer clothes, and the room will be too cold. To measure the internal environment, a Testo 400 meter was used located in the middle of the lecture hall. After 15 minutes, when the values had stabilized, they were collected and recorded. Meanwhile, the volunteers completed the questionnaires. The purpose of using two these methods is to check whether the conditions in the room create thermal comfort for the occupants. Figure 2 and figure 3 below show the meter with a description of the probes collecting the necessary parameters (globe

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temperature probe, light intensity probe, turbulence probe, CO_2 probe, temperature and humidity probe).

Fig. 2. Location of the measuring station in the lecture hall and probes measuring the conditions in the room.

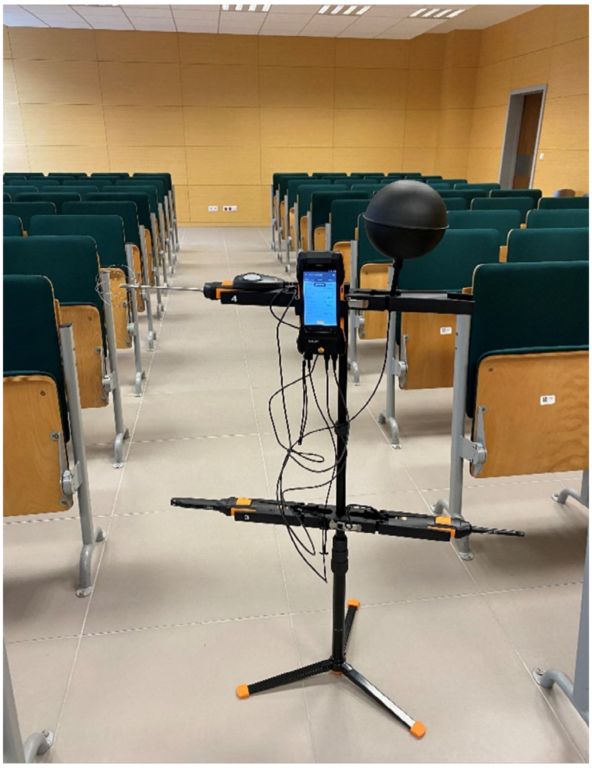

Fig. 3. The meter of Testo 400.

3 Test result

In the selected room where examination was performed, there is mechanical ventilation with adjustable parameters, which was activated during the examination. Table 1 shows the obtained results of the conditions in the tested room with the use of a meter Testo 400.

Table 1. Parameters of the internal environment obtained with the use of the meter.

Air temperature [ºC]	25.7
Black ball temperature [ºC]	25.2
Relative humidity [%]	56,6
Air Velocity [m/s]	0.43

In the study involved 9 people in the age range from 21-24 years. Figure 4 below shows the thermal feelings of the respondents as TSV (thermal sensation votes).

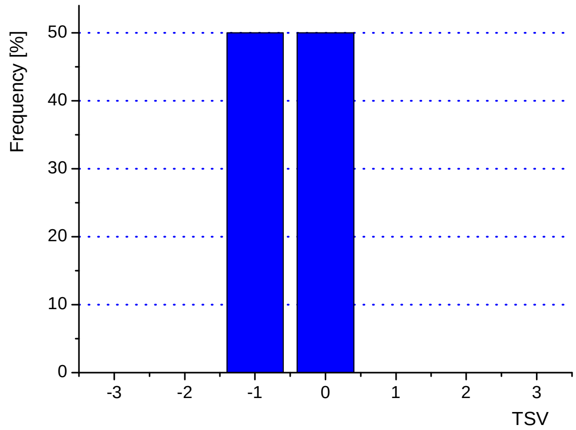

Fig. 4. Voices of the respondents concerning the thermal sensation: -3 – too cold, -2 – too cool, -1 – pleasantly cool, 0 – comfortable, 1 – pleasantly warm, 2 – too warm, 3 – too hot.

50% of respondents consider that the room in pleasantly cool. The other half, i.e. 50% of people described their thermal sensations as comfortable. Figure 5 below shows the group's responses to the feeling of accepting the current temperature in the tested room (TAV – thermal acceptability vote).

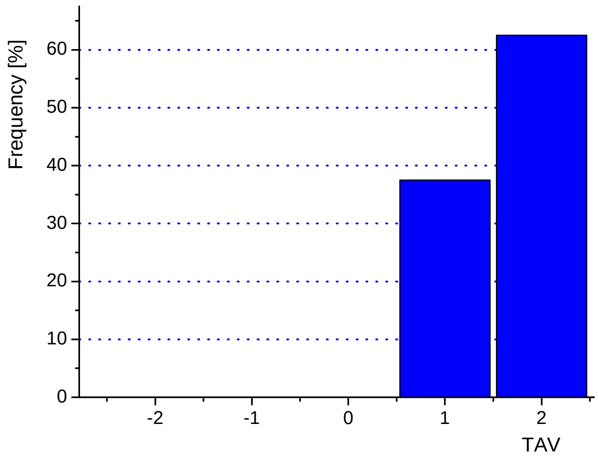

Fig. 5. Acceptance of temperature according to the volunteers: -2 – definitely unpleasant, -1 – unpleasant, 1 – acceptable, 2 – comfortable.

37.5% of people in the study group consider that the temperature is still acceptable, while 62.5% of people described their feelings of temperature as comfortable. Figure 6 shows the responses of individual thermal preferences (TPV – thermal preference vote) in relation to change in air temperature.

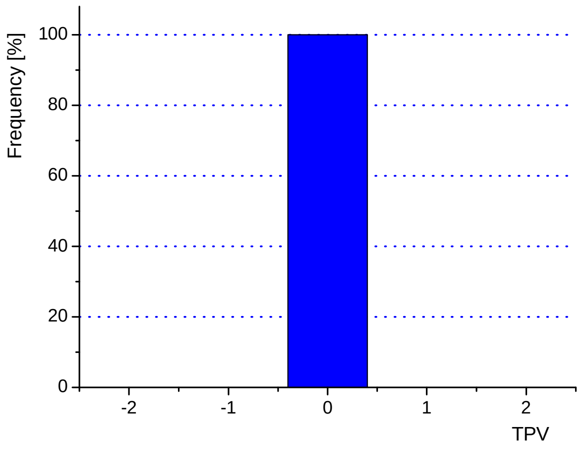

Fig. 6. Thermal preferences vote: -2 – definitely cooler, -1 – cooler, 0 – no change, 1 – warmer, 2-definitely warmer.

100% of people would not want to change the temperature to a cooler or warmer temperature. This proves that the prevailing temperature in the room was so favorable that the whole group of eight felt thermal comfort. Figure 7 below shows the assessment of humidity by the tested group.

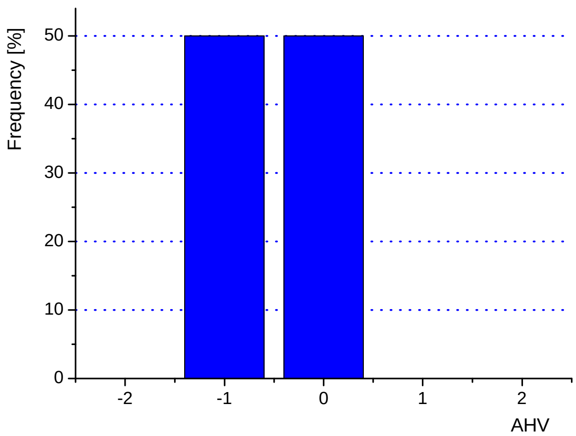

Fig. 7. Assessment of humidity according to the respondents: -2 – too dry, -1 – quite dry, 0 – pleasantly, 1 – quite humid, 2 – too humid

50% of people rated the humidity as pleasant. The other half of the group, i.e. 50% of respondents, think that the room is quite dry. The graph of the humidity preference responses by the volunteers is shown on figure 8.

In the studied group, 75% of people would not like to a change in air humidity, as opposed to 25% of people who would definitely like it to be more humid. Figure 9 shows the relationship between the PMV index and the BMI mass index in order to determine if this parameter had any impact on the obtained results.

According to the figure the higher the BMI index of a person, the warmer they feel. It confirms a generally accepted view and might have a slight impact on the obtained experimental results.

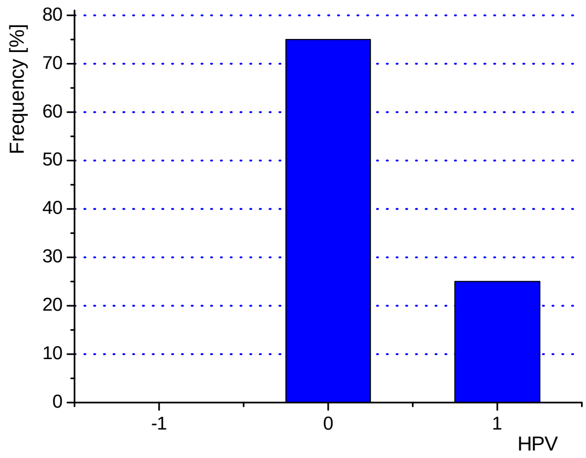

Fig. 8. Frequency of answers humidity preferences vote: -1 – more dry, 0 – no change, 1 – more humid.

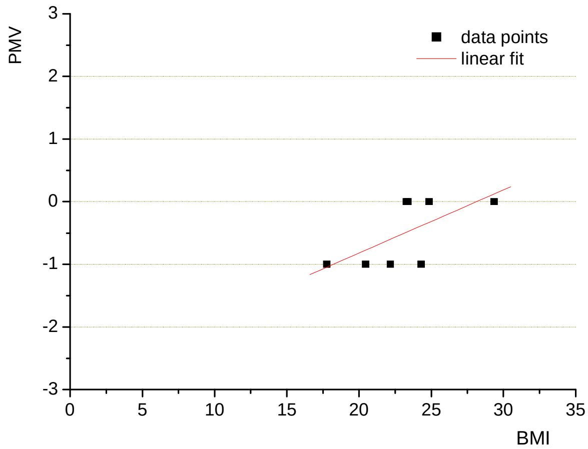

Fig. 9. The relationship between the PMV index and the BMI mass index.

4 Conclusions

To sum up, from the obtained results, it can be concluded that the room meets the expectations of its occupants in the modern “Energis” intelligent building. Thus, such a construction that meets the criteria for the sustainable building is a user – friendly educational building. The temperature there was perceived as comfortable and pleasant, therefore none of the respondents would like to change the prevailing temperature to a warmer or cooler one. Likewise for the humidity where it was found to be pleasant and fairly dry. 75% of the group would not want the humidity settings changed except for the 25% which specified it could be more humid. The conclusion is obvious that the ventilation in this room has well-chosen parameters that ensure well-being in the external environment.

In the future, research on thermal comfort will be carried out in order to better understand the individual thermal preferences of people indoors.

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The problems of forming a system of green areas as an ecological framework of a large city (on the example of Kyiv)

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Abstract. Each large city is characterized by its own unique model of spatial organization of green areas, which form the ecological framework of the city and act as a condition for its balanced ecological development. The article presents results of an analysis of the actual state and preconditions for the formation of a system of green areas of public use of a large city on the example of the city of Kyiv. The model of the ecological framework of Kyiv, in comparison with the models of other European cities, is characterized. The specificity of the spatial organization of the landscaping system is marked by the presence of a powerful water-green diameter in the central part of the city, formed by the valley of the Dnipro River with islands, and a developed peripheral-ring forest park belt. The central and middle densely developed area of the city suffers from a significant lack of green areas for public use. The article formulates urban planning problems completion of the formation of an integrated ecological network of Kyiv, and outlined areas for improving the city's landscaping system.

1 Introduction

Rapid population growth, human economic activity, and land cover change cause an increase in anthropogenic pressure on the planet's ecosystem, including the depletion of natural resources, global warming and climate change [1]. Awareness of the need to take immediate measures to ensure the preservation of the riches and resources of our world is reflected in the formation of the ideology of sustainable development of mankind. One of the key components of such development is the environmental one. In particular, Goal 15 of the 2030 Agenda for Sustainable Development identifies the need to "Protect, restore and promote the sustainable use of terrestrial ecosystems, sustainable forest management, combating desertification and irreversible land degradation and stopping biodiversity loss".

In turn, global urbanization processes lead to excessive concentration of people in limited areas and the constant expansion of territorial boundaries of urban settlements due to the surrounding natural landscapes. This increases the negative impact on the environment, physical and psychological health [2]. The formation of an ecological network at different hierarchical levels as "… a single territorial system that includes areas of natural landscapes, territories and objects of nature reserves" will help to achieve the goal [1].

At the city level a system of green areas and open water of the city – forests, forest parks, parks, squares, other elements of the system of greenery are an ecological network or ecological framework of the city [3]. The most significant interaction of man and the natural environment is felt it is in cities, due to the high concentration of population (in the world – more than half of humanity, in Ukraine – 69.4 %). One of the ways to ensure sustainable development of settlements, reduce the negative impact of urbanization on the environment, stop the destruction of natural landscapes is the formation of cities' own ecological network, prevention of unjustified destruction of greenery and development of urban green area provision [4, 5].

The natural landscape is an important component of human quality of life [6]. The minimum normatively defined level of green area provision of urban areas is expressed in the area of green areas for 1 person. This figure varies significantly from country to country. Regulatory area of public green area (parks of different functional type and hierarchical planning level, squares and boulevards) ranges from 10 sq.m/person (Ukraine, Russia) to 20-25 sq.m/person (Germany, USA) [7], and the actual area can reach 60-70 sq.m/person [8]. Other types of green areas are subject to separate normative regulation: urban landscape and recreational areas (forests, forest parks, meadows), green areas of limited use (in residential areas, other functional facilities) and areas of special purposes [9, 10].

The subjective perception of the city residents of the adequacy of the greenery level is based not only on the normative and actual indicators of the area of green area per capita [11]. Features of landscape-planning and functional-planning organization of the city territory, specifics of relief, climatic area, presence of significant water objects (part of the sea water area, big river or lake)

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within the city are important. City and district parks and squares, which are located within the built-up area of the city, play an extremely important role for residents. Trees, shrubs, water bodies, open green spaces and clean air embody the elements of the natural environment and create a sense of closeness to nature, contribute to the recovery of physical and moral strength [12]. Convenient location and accessibility of green areas are very important for all residents, and especially for the elderly and parents with young children [13]. The formation of the city system of landscaping as close as possible to the person, his place of residence, is one of the main tasks of balanced development of the city.

2 Materials and methods

The formation of a system of green areas in the conditions of a large developing city is under the pressure of various vector tendencies. On the one hand – the growth of diversity of functions, population and level of motorization, and, accordingly, the growing need for normatively defined areas of green areas for various purposes; on the other hand – increasing the intensity of development, building density and reducing vacant plots for new elements of the city's landscaping system.

The purpose of this study was to identify the existing urban issues of the existing green area provision system of a large city (on the example of the city of Kiev) as a basis for developing further proposals to create the most attractive and balanced green area system. The research was based on the analysis of theoretical bases and normative regulation of formation of a system of green areas of general use; materials of factual information on indicators of green area provision in Kyiv. The cartographic basis was the materials of the general plans of Kyiv [14, 15]. Also uses some results of the author's sociological survey of Kyiv residents regarding their attitude to the actual state of green area provision [11].

3 Results

3.1 The current state of green area provision in Kiev

3.1.1 The actual state of green area provision

According to the current Master Plan of Kyiv [14], the model of spatial planning organization of the territory was based on the development of new, free from construction, territories outside the city within the boundaries of 2001. The area of the city was expected to increase from 83.56 thousand hectares to 143.4 thousand hectares (+74 %) with an actually stable population – 2,637 thousand people (2001) to 2,650 thousand people (for the period up to 2020) [14]. The total area of recreational areas of the city was expected to increase from 34.9 thousand hectares to 48.9 thousand hectares, respectively. At the same time, the area of green public areas was expected to increase from 5,289.4 hectares to 7,608.0 hectares for the period up to 2020, and the provision rate, respectively, from 20.3 sq.m/person. up to 28.7 sq.m/person [14] (see Table 1).

Table 1. The main indicators of development of green areas of Kyiv.

indexes	status 2001	Master plan of Kyiv until 2020	current status (2020)	increase (2020/ 2001)
Population, thousand people	2 637	2 650	2 965	+ 328 (+ 12.4 %)
Total area, ha	83 560	143 400	82 640	- 920 (- 1.1 %)
Developed territories, ha	48 660	94 500	37 610	- 11 050 (- 22.7 %)
Public greenery area, ha	5 289	7 608	5 392	+ 103 (+ 1.9 %)
Landscape and recreational area, ha	34 900	48 900	45 030	+ 10 130 (+ 29.0 %)
Population density, people/ha	31.6	18.5	35.9	+ 4.3 (+ 13.6 %)
Population density in the developed territories, people/ha	54.2	18.5	78.9	+ 24.7 (+ 45.6 %)
Public greenery area, sq.m/person	20.1	28.7	18.2	- 1.9 (- 9.5 %)
Landscape and recreational area, sq.m/person	132.3	184.5	151.9	+ 19.6 (+ 14.8 %)
Total level of landscaping, %	41.8	34.1	54.5	+ 12.7 (+ 30.4 %)

However, the actual territorial development of Kyiv has undergone radical changes in relation to the design decisions of the Master Plan of 2002 (see Fig. 1). The actual territory of the city is 82,640 hectares [15], of which green areas and recreational areas cover 45.03 thousand hectares (or 54.5 %), water surfaces – 6.1 thousand hectares (or 7.3 %) [15].

At the same time, the population increased by 12 % compared to the project and reached 2,965 thousand people as of 01.01.2020 [16]. New construction was carried out mainly not in the projected new territories (former suburban areas, which were envisaged to be included in the project boundaries of Kyiv by the current Master Plan), but in the existing urban areas (see Fig. 1). This has led to a significant increase in population density and urban development density (see Table 1).

The area of the territory within Kyiv, which is covered with greenery of all kinds (including garden and country houses) is 45030 hectares or 54.5 % of the city area. A total of 143 parks in Kyiv with a total area of 4,722 hectares, of which 6 objects are specialized and occupy 611.4 hectares (three botanical gardens, Kyiv Zoological Park, National Museum of Folk Architecture and Life, National Complex “Expocenter of Ukraine”).

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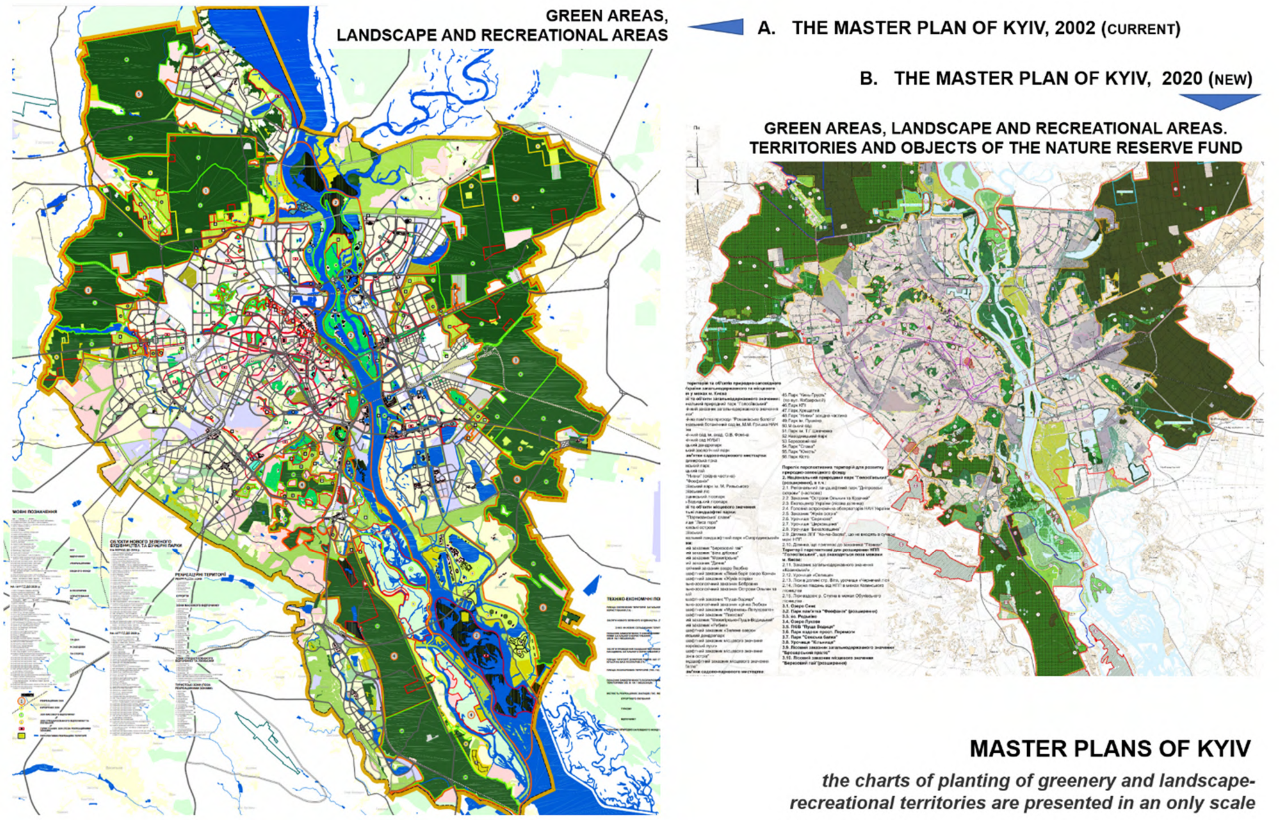

Fig. 1. Schemes of spatial development of green and landscape-recreational territories as a part of general plans of Kyiv. A. General plan of Kyiv, 2002 (current, https://kga.gov.ua/generalnij-plan/genplan2020); B. Master plan of Kyiv, 2020 (draft, https://drive.google.com/drive/folders/1HmqVLp25d4PFL08EuLAQ9O8KEFYbhOo5).

Table 2. Characteristics of the actual state of provision of green areas for public use (by administrative districts of Kyiv).

Administrative districts	Area, ha	Population, persons	Area of public green areas, ha	Level of landscaping, %	Actual landscaping, sq.m/person.
Holosiivsky	15 335	254 331	1069.28	6.88	42.04
Darnytsky	13 160	347 611	473.25	3.60	13.61
Desniansky	14 210	369 155	532.24	3.75	14.42
Dniprovsky	6 170	358 352	1118.35	18.13	31.21
Obolonsky	10 860	318 968	623.41	5.74	19.54
Pechersky	2 555	163 264	367.72	14.51	22.52
Podolsky	3 300	208 449	203.15	5.97	9.75
Svyatoshinsky	10 200	342 544	230.79	2.26	6.74
Solomyansky	4 010	383 387	282.14	7.04	7.36
Shevchenkivsky	2 660	218 952	491.91	18.61	22.47
Kyiv (total)	**82 640**	**2965 013**	**5392.24**	**6.77**	**18.19**

At the same time, 50 % of the park areas are occupied by large parks with an area of over 100 hectares (12 objects). In addition, public recreation areas include squares – 582 objects with a total area of 440.7 hectares and boulevards – 49 objects with a total area of 150.7 hectares [15].

According to the monitoring of the Program of development of the green zone of Kyiv until 2010 and the Concept of formation of green area in the central part of the city [17], within which this study was conducted, as of 01.10.2020 the actual area of green areas is 5 392.24 hectares. The average provision in the city is 18.19 sq.m/person (see Table 2), which meets the regulatory requirements for the city of Kyiv – 16 sq.m/person. However, there is an uneven provision of green public areas in the city districts. The most prosperous are Holosiivskyi and Dniprovskyi, and the least – Sviatoshynskyi, Solomyanskyi, Podilskyi and Darnytskyi districts of the city. The actual state of green area provision in terms of administrative districts of the city of Kyiv is in the Table 2.

3.1.2 Analysis of modern practice of transformation of the green area system of Kyiv

Population growth, the need to increase housing construction, service facilities and places of employment have led to a significant adjustment of the decisions of the current Master plan of Kyiv. Such changes took place by approving of detailed plans of the territory for separate parts of the Master plan. According to the city program of development (updating) of urban planning documentation in Kyiv, approved by the decision of Kyiv City Council dated 13.11.2013 № 518/10006 with changes and additions, 152 drafts of detailed plans of territories, as well as zoning plan of central planning zone and zoning plans of other parts of the territory of Kyiv, are under development now. As of the beginning of 2020, the city has approved 42 detailed plans of territories [18] (see Fig. 2).

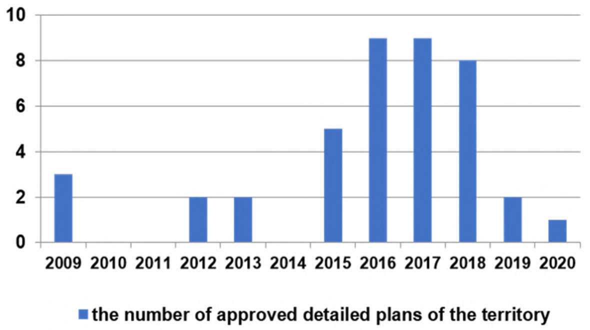

Fig. 2. Dynamics of approval of detailed plans of the territory of Kyiv. Source: data from the Department of Urban Planning and Architecture in Kyiv [18].

There were more than 1,000 changes to the functional purpose of individual land plots taking into account the investment intentions of developers from 2002 to 2011. 1,750 hectares of agricultural land within the city and about 570 hectares of green area have been allocated for construction [15]. Part of the territory really required restructuring due to the suspension of economic activity and degradation of industrial territory and communal warehouses territory. But there is an illegal change of purpose of the land plots of the green area for housing and public building.

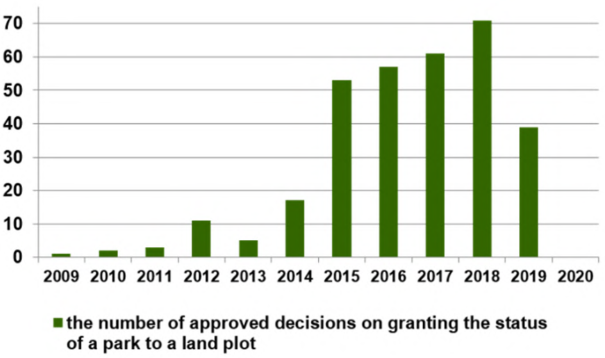

Fig. 3. Dynamics of decision-making on granting the status of a park to a separate green land plot in Kyiv. Source: data of the Kyiv City State Administration [19].

As a compensatory measure and in order to prevent such negative phenomena and excessive compaction of existing housing in the city at the request of deputies of the Kyiv City Council or initiative groups of residents a campaign "to grant the status of a park to land plot" is launched. That is, there is a transfer of green areas of limited use in the category of green areas of public use. There were about 260 such decisions [19] during the period from 2008 to 2020 (see Fig. 3).

However, granting the status of a park to a small land plot within the existing residential building, which is actually part of the adjacent territory of existing residential buildings, leads only to a formal increase in the area of public green areas by reducing the area of adjacent territories and green areas of limited use consequently. In addition, small green areas (0.1-0.5 hectares) do not allow to form an independent element of the system of public greenery - a full-fledged park or square. Such green area remains available only to a limited number of residents of nearby houses.

3.1.3 Assessment by Kyiv residents of the adequacy of the level of landscaping of the city territory

As mentioned above, according to the actual indicators, the level of provision of public green areas in Kyiv is quite sufficient. However, the use of only absolute indicators (area of green area and their share in the total area of the city) or even relative indicators (the level provision of population with green area – sq.m/person.) does not really assess the state of development of landscaping and comfort of the urban environment.

According to the results of a sociological survey conducted by the author [11], the vast majority of respondents in the city (71 %) expressed a lack of green areas, parks and squares. And among the proposed criteria for assessing the attractiveness of the elements of the landscaping system, residents preferred environmental friendliness (over 80 % of respondents) and accessibility of parks (over 67 %) [11].

Dissatisfaction of residents with the level of development of the parks and squares system of Kyiv can be explained by the peculiarities of the spatial organization of the city.

The system of greenery of various functional purposes in Kyiv has been formed for several centuries and has a permanent character. Significant influence on the spatial organization is created by such factors as planning dismemberment into the right-bank and left-bank parts with a large area of the Dnieper River with green islands in the central part. The middle zone of the city is intensively used for residential, public and industrial-warehouse construction and is surrounded by a powerful peripheral forest park belt (see Fig. 1, B). It is the unevenness in the localization of green areas in the planning structure of the city and their proximity to places of concentration of the population (places of residence and places of work) that create the feeling of lack of green areas.

Creating new elements of the system of green areas – parks and squares, which require significant territorial resources, in the conditions of dense urban development and high cost of land in Kyiv is too problematic. Therefore, increasing the attractiveness and level of improvement of existing elements of the city's green area system should be one of the priorities to provide residents with a sense of urban comfort and sufficiency in green areas.

3.2 Specifics of the spatial planning organization of the system of green areas of Kyiv

Spatial planning organization of the system of green areas of any city has its own specific features, due to the peculiarities of the landscape and climate, historical and cultural traditions, the functional orientation of economic activity and regulatory requirements. However, each city, especially a large one, tries to ensure the integrity and continuity of the internal ecological framework, supplementing the existing system of urban green areas with new natural and artificial elements.

Any large city is marked by the unique specificity of the spatial planning organization of the system of green areas. However, the formation of the continuity of the landscaping system with the obligatory connection of individual elements of the landscape into a single network of open spaces (even, including the territories near highways) should be a condition for sustainable ecological development of the city [20]. Consider examples of models of the system of public green areas in some foreign cities [20, 21].

Thus, the municipal project of Milan “Green Rays” in the conditions of dense construction provides for the tracing of pedestrian and bicycle routes, taking into account the available areas of green public areas of different functional types. Complementing them with new planned landscaping – groups of trees along sidewalks, parks - as objects of potential recreation of pedestrians should form a sense of permanence of landscaping in citizens (see Fig. 4, a) [20].

Madrid's ecological system is formed on the basis of suburban natural elements and the restoration of the Manzanares River, forming a continuous connection with large natural areas – the Sierra de Guadarrama, Cuenca Alta del Manzanares, Mount El Pardo, Del Harama Park and Alameda del Tajo. And the main route M30 in some areas was laid underground to open access to the river as the main element of the natural framework of the city [21, 22] (see Fig. 4, b).

The concept of the organization of open spaces in Berlin is to form a system of several groups of green areas. The first – two “green rings” of artificially created in different years elements of urban landscaping: the inner ring around the densely built-up center of Berlin – “Innerer Parkring”; the outer ring is the “Äußere Parkring”, which connects the large residential areas of the 70s and 80s. The second – two “green” diagonals – “Grüne Achsenkreuz”, formed on the basis of the dominant natural elements, green strips about 200 meters wide [23 24] (see Fig. 4, c).

The ecological framework of Krakow includes the most valuable natural areas and cultural landscapes that are subject to protection, and are connected by eco-corridors from individual green areas [25] (see Fig. 4, d). To achieve the goal – the unity of the ecological framework - the Master plan of Krakow provides a change in the purpose of part of the land plots.

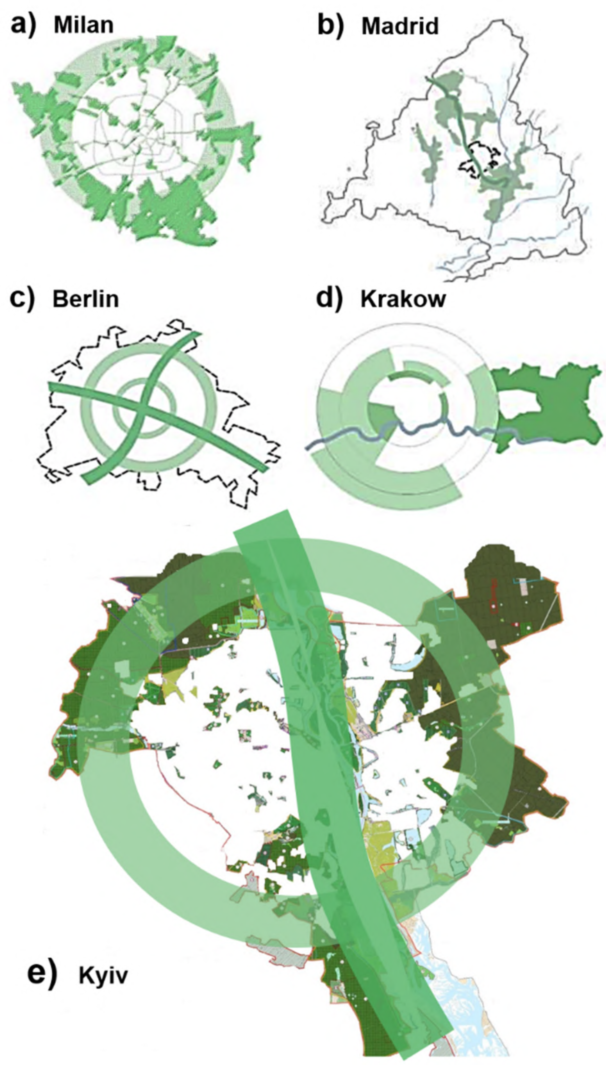

Fig. 4. Examples of ecological framework systems (green and recreational areas) of individual European cities. Sources: a) – [20], b) – [21, 22], c) – [23, 24], d) – [25], e) – own model.

Spatial planning organization of green areas of Kyiv, which has developed over a long period of its development, is also characterized by a unique specificity (see Fig. 4, e). The first characteristic feature is the dismemberment of the city, due to the presence of a powerful water-green diameter in the central part. The Dnieper River with a system of islands and green shores with numerous parks. This diameter runs in the meridional direction from north to south and divides the city into two planning parts – Right Bank and Left Bank.

The second feature is the predominant circular-peripheral model of green areas in the form of a developed system of forests and forest parks around the densely built-up central and middle zones of Kyiv. Within the built-up areas there are a number of separate parks and squares, which creates difficulties in the availability of green spaces for the vast majority of city residents. The modern spatial planning organization of the system of green and recreational areas is shown in Fig. 1, A.

3.3 Urban planning problems of development of the system of green areas of Kyiv

The analysis of the current state of development of the system of green areas of Kyiv allowed to formulate (from the point of view of urban planning) the following main reasons that negatively affect the ecological conditions and the state of green areas:

– anthropogenic congestion of the urban area, which causes the deterioration of the ecological state of the environment and destructive phenomena in the existence of a system of green areas of the city;

– unsatisfactory sanitary and ecological condition of green plantations and insufficient improvement of park territories;

– lack of territorial resources for the creation of additional regulatory areas of public green areas due to the rapid growth of the population of Kyiv (by 328 thousand people or 12.4 % since 2001) in combination with the virtually unchanged area of city territory;

– specificity of spatial planning organization of the city with a clear central-meridional location of a powerful water-green diameter and external ring-peripheral location of the belt of forests, forest parks, meadows and buffer parks, which creates a sense of inadequate landscaping under the conditions of formal normative provision with green areas;

– exceeding the density of the developed (built-up) territory of the city, which occupies only 46 % of the total area of the city, and alternating the location of residential, industrial, utility and transport areas with relatively small interspersed elements of public green areas, which negatively affects the ecological condition of urban areas in general, and green areas in particular;

– uneven distribution of public green areas by administrative districts;

– incorrectness of the practice of increasing the area of green areas of public use due to green areas of limited use by granting the status of parks to certain areas within the adjacent territories of existing buildings;

– improper use of public green areas;

– the need to develop an integrated system of green areas through the creation of new parks and squares in the territories of former industrial and utility facilities to be redeveloped.

4 Conclusions

In conclusion, the strategy of most cities in the world in forming a system of public green areas is to restore, expand and improve the existing network of landscaping, united by creating new elements of green areas into a single ecological framework of the city.

The role of landscape and recreational areas of different origins, nature reserves and green areas of public use in the formation of an integrated system of green areas and the ecological framework of the city differs. If natural objects are the basis of the city's natural planning framework, then objects of artificial origin (parks, squares, boulevards) can complement, optimize or even form the ecological framework of the city.

Completion of the formation of an integral ecological network of Kyiv, general increase of the level of landscaping and comfort, and, accordingly, attractiveness, creation of convenient accessibility of already existing elements of the system of green areas will contribute to the formation of closeness and sufficiency of green areas, providing sustainable environmental development of the city.

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Higher education institutions energy efficient methods of functional planning solution

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Abstract. The article determines that the priority factor of energy efficiency at the design stage is the optimal functional and planning solution of educational buildings; established architectural and planning techniques aimed at improving energy efficiency of higher education institutions, including compaction of educational institutions, clear zoning, implementation of compact architectural and planning solutions for educational buildings and structures, blocking in one or adjacent areas of several free economic cooperation with cooperative use of engineers increasing the number of storeys of buildings, the use of underground space and landscaping in the architectural and planning solution of buildings.

1 Introduction

In the process of long-term development in the leading cities of Ukraine, an extensive network of higher education institutions (HEIs) of various profiles has been formed, which significantly affects urban planning activities, architectural and compositional qualities of buildings, energy efficiency of buildings [1, 2, 7].

The main trends of energy saving are: introduction of fundamentally new types of building structures, use of effective thermal insulation materials, use of solar, wind, earth energy, use of ground heat for heating and cooling of buildings with heat pumps, energy efficient external enclosing structures [12-17]. However, the priority factor of energy efficiency at the design stage is the optimal functional and planning solution of the educational institutions buildings, as well as the appropriate architectural and planning techniques aimed at improving the energy saving of free economic zones.

2 Results

Analysis of the practice of operation of higher education institutions shows that the development of educational facilities is significantly complicated by the lack of territorial resources and significant energy intensity of educational buildings, especially laboratory and educational purposes. Progressive domestic and foreign experience in forming a network of higher education institutions shows that the most realistic direction for optimizing the development of higher education is the consolidation of educational institutions, clear zoning, implementation of compact architectural and planning solutions for educational buildings and structures [3-5, 7, 8].

According to the pedagogical requirements, the territory of the Free Economic Zone should be built up comprehensively. Educational, research, household, residential and other buildings that provide different directions, forms and methods of educational work should be placed on the allocated area. Buildings need to be functionally connected with each other and with other structural elements of the city. The site should provide conditions for the gradual development of free economic zones and provide an opportunity to develop training areas in the future [4,5, 6, 11].

The main scientifically substantiated and tested by project practice principle of planning decisions of higher education institutions is the functional zoning of the territory. Areas of educational zones should be divided into the following main zones: educational, sports, residential, economic. Each of the marked zones, depending on the profile of HEIs and town-planning conditions, has the features. Thus, the training area may include research units and in this case it grows significantly and requires additional areas. In branch educational establishments of technical, agricultural, medical profile and others in the educational zone, as a rule, a large group of research and educational-production subdivisions is created, and in medical educational establishments - a subzone of treatment-and-prophylactic establishments.

The size of the territory for the construction of educational buildings depends on the size and profile of the free economic zone. Theoretical research has identified, and project construction practice has confirmed that the larger the number of university students, the more efficiently the territory is used.

The second direction of improving the construction of higher education institutions is the blocking of several free economic zones in one or adjacent territories under the condition of cooperative use of engineering communications, some buildings of educational and teaching-auxiliary purpose. Cooperation is especially

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expedient at homogeneity of educational and production functions of the establishments forming a complex. In many cases, this allows for the organization of a single public service system, joint research and production and energy centers.

The main functional requirement of the cooperation is the intensive use of premises and territory, increasing the density of buildings at the maximum allowable load. Particularly effective joint operation of energy-intensive and large-sized training and laboratory equipment, experimental equipment, etc. When cooperating, homogeneous zones should be used as intensively as possible, reducing the total size of the territory compared to the normative ones [7].

Fig. 1. University complex in the center of Paris, France.

Fig. 2. University of Compacted Buildings, Tokyo, Japan.

Fig. 3. Ohlone College Academic Core Buildings in Fremont, USA.

Fig. 4. Ryerson University Daphne Cockwell Health Sciences Comple in Toronto, Canada

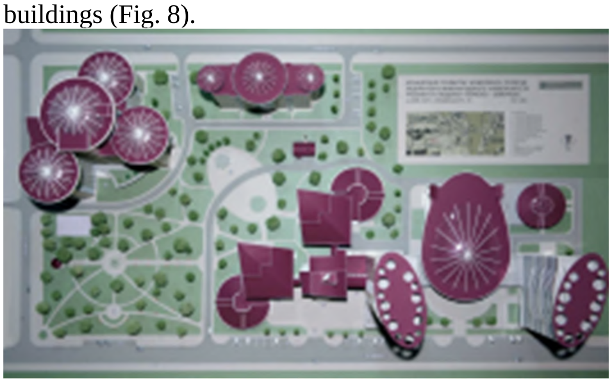
An effective means of compacting the construction of higher education institutions is the use of compact architectural and planning solutions of educational buildings and increasing the number of storeys of buildings, especially student dormitories. In foreign practice, there are many examples of multi-storey buildings of compact structure both in the historical environment (Fig. 1, Fig. 2) and new solutions in developing territories (Fig. 3, Fig. 4) [1, 4, 19, 31, 32].

Fig. 5. 3D model of main buildings of the Kyiv National University of Construction and Architecture, Kyiv, Ukraine.

Fig. 6. Complex of Karazin Kharkiv National University, Kharkiv, Ukraine

In Ukraine, high-rise buildings are built and successfully operate in higher education institutions of Kyiv, Dnipro, Kharkiv, Donetsk, Odessa and other large cities with compacted buildings [1, 2, 21]. Much of the university complexes were built in the second half of the twentieth century, so most of these buildings have a high level of wear, both physical and moral. To increase their comfort and energy efficiency, large-scale reconstruction and renovation works are required (Fig. 5, Fig.6). The main directions of reconstruction should be based on the principles of introduction of resource-saving technologies, ensuring environmental safety. The requirement of compact placement of educational buildings is due not only to the need for rational use of land resources, but also the conditions of effective organization of the educational process, centralized maintenance of teaching aids, more intensive loading of educational premises, reduction of unproductive costs for moving between remote buildings. The total height of educational buildings, the number of floors are accepted depending on the functional requirements and urban conditions. According to the current regulations, educational buildings of higher educational institutions and institutes of advanced training are recommended to provide a height from the ground level, determined at the entrance to the house, to the floor of the top floor within 26.5 m. increasing the number of storeys of buildings [5].

In recent years, the construction and construction of several higher education institutions with high-rise buildings and dormitories have been designed and started. The universities of the new generation include the Open International University of Human Development “Ukraine”, designed in the research and design architectural bureau “LICENZiARCH”. The density of the building led to an increase in the height of educational buildings to 18-21 floors. Increasing the number of storeys did not prevent the creation of all the necessary conditions for effective student learning. This is one of the few higher education institutions in Ukraine that provides comfortable training for professionals with disabilities. Multi-storey educational buildings are blocked with the educational-administrative building and a group of dining room and concert hall. The first floors of the multifunctional volume occupy the premises of general university use. The educational premises of some departments are located on the upper floors. All rooms are connected by stairs and special elevators, which meets the technological needs, fire safety requirements and ensures the movement of people with special needs (Fig. 7). Also, this design bureau made a conceptual proposal for the renovation of the Kyiv National University of Construction and Architecture territory in Kyiv, which provided for the consolidation of the central core and the creation of additional educational and residential buildings (Fig. 8).



a – model of existing complex

b – project proposal

Fig. 7. Open International University of Human Development “Ukraine”, Kyiv, Ukraine.

Fig. 8. Project proposal for Kyiv National University of Construction and Architecture, Kyiv, Ukraine.

The requirement of compact placement of educational buildings is due not only to the need for more rational use of land resources, but also the conditions of effective organization of the educational process, centralized maintenance of technical means of training, intensive loading of educational premises, reducing the length of utilities, heating and electricity. To seal the building, assembly halls, club rooms, libraries, student cafes and canteens are recommended to be blocked on the common territory, thus creating a training and community center. In the conditions of compacted building, if it is impossible to form a public center near educational buildings, part of the club premises, catering establishments, can be located in a residential area [6]. For example, the new campus building at the University of Cincinnati is creating a multi-functional cultural and learning center for collaboration that is not available in older buildings (Fig. 9).

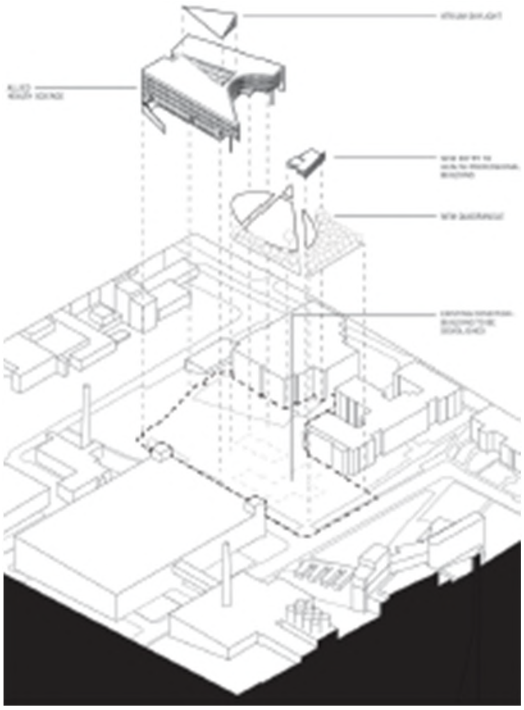


Fig. 9. University of Cincinnati Health Sciences Building, Cincinnati, USA.

Blocks of lecture halls, libraries, assembly halls, dining rooms can be compactly placed in buildings up to 4 floors. In large educational institutions for 5,000 students and more, libraries, club rooms, student canteens should be moved to separate buildings. For a more compact building should also take into account the possibility of using underground space (Fig. 10). In the basement and basement it is allowed to place: TV studios, bookstores, laboratories for the study of individual special projects, part of the premises of catering establishments, warehouses and technical premises. The principle of placement of administrative premises (administration) significantly influences the formation of the educational zone. In educational complexes with a contingent of more than 5,000 students, it is advisable to form a separate administrative and cultural center or block it with a library, assembly hall and other public facilities.

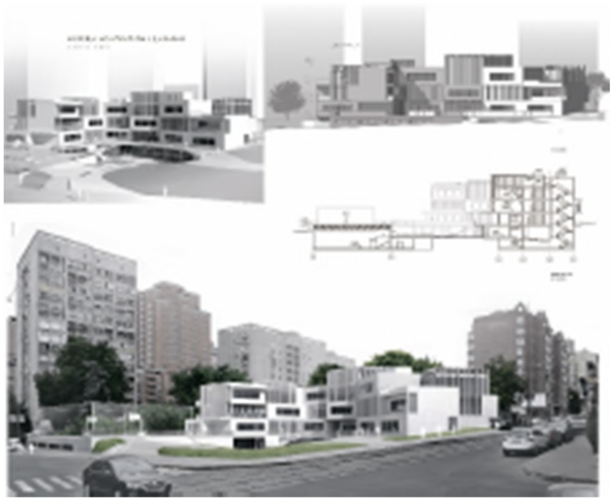


Fig. 10. Bachelor's degree “College of Architecture and Design in Kyiv”, Art. Tolstikov T.O., head – Doctor of Architecture Kovalska G.L.

Energy-efficient methods include the use of landscaping in the architectural and planning solution of buildings. Currently, there are several areas in landscaping of university buildings: landscaping of roofs, landscaping of facades; landscaping due to new ecological materials [22-27]. In this aspect, the interesting building of the non-governmental women's university in Seoul - “Ewha Campus Complex” (Ewha Campus Complex, ECC), arch. Dominic Perrault, 2008 (Fig. 11). The roof of the campus was a garden, which protects the interior from the heat in summer and from the cold in winter. Increases the economy and practical use of rainwater - special tanks have been created for it, from where water is distributed for the operation of bathrooms [10, 12-14, 33]. A similar solution was applied in the design of a social and cultural center in the historic center of Paris (Fig. 12). The building is not only successfully integrated into the existing environment, but also creates an optimal microclimate both inside and outside [34].

Fig. 11. Non-State Women's University (Ewha Campus Complex, ECC) in Seoul, South Korea.

Fig. 12. Modernization of the Lourcine Barracks in the University of Law-Paris I, Paris, France.

The largest area and territory are needed by technical free economic zones due to the need to create auxiliary research units (19-20 square meters per 1 student). When blocking research groups of premises with the relevant departments and faculty blocks, the educational and research process is organized much more efficiently and the energy base is used more rationally. Only specialized research and production units with specific technology are recommended to be allocated and placed in the peripheral areas of the educational institution [2]. Calculations show that due to the compaction of buildings, the introduction of compact architectural and planning solutions can significantly reduce the territory of higher education institutions and reduce energy consumption by 20-30% without deteriorating the conditions of the educational process [8,9].

One of the criteria influencing the energy efficiency of educational complexes is heat loss, which is carried out through the outer walls of the building. Compact architectural solutions, integration of buildings into complexes, blocking of building elements provide reduction of external contours of buildings in comparison with separately placed constructions. As an example, we can calculate the perimeter of the outer walls of two rectangular buildings with sides (a, b) and (c, d), located separately and locked into a single complex (Fig.13). The length of external walls of buildings at a separate arrangement is equal to the sum of their perimeters, namely: 2a + 2b + 2c + 2d. The length of the outer walls of the blocked complex is equal to: 2a + 2c + b + d + (d-b) = 2a + 2c + 2d. These calculations show a reduction in the perimeter of the blocked buildings by 2b and, accordingly, a reduction in heat consumption.

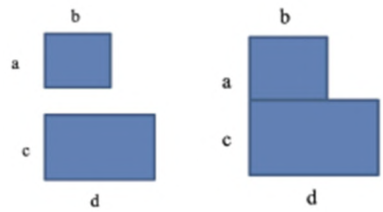


Fig. 13. The scheme of calculation of perimeter at blocking of buildings.

3 Conclusion

Energy efficiency is a necessary measure in the modern architecture of higher education institutions. The architect should think about creating an energy-efficient building at the design stage. The optimal functional and planning solution of buildings, the establishment of appropriate architectural and planning techniques can be called the primary factor in increasing its energy savings.

The article substantiates the importance of a compact architectural and planning solution as one of the important aspects of achieving the overall energy efficiency of the building.

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Is the hospital-park future of the sustainable hospital architecture?

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Abstract. The article deals with important issues of the ecological approach to the health care facilities design within the general world's attention to the problem of sustainable development of the urban environment. Taking as the example the innovative foreign experience of implemented projects of medical institutions, as well as design, competitive and conceptual proposals revealed the latest idea of coexistence and harmonization of natural and man-made worlds within the medical environment that meets the challenges and needs of the XXI century. It is the concept of the hospital-park, that synthetically combines the architectural environment, natural environment, as well as man-made oasis and creates the basis for emergent results both in the medical field and in the need for a neat attitude to our planet. The article reveals the possibilities of designing a hospital-park of different stories and in different initial conditions: in a dense urban environment with a minimum size of the construction site, in suburban and peripheral areas of the city.

1 Introduction

Architecture is gradually changing along with the society development, its changing perceptions of beauty, strength, usefulness, as well as the growing need for comfort, aesthetics, the ideal environment. For a long time, the architecture of health care facilities was perceived and, accordingly, mechanically designed exclusively as a kind of technically necessary shell to ensure the treatment of the depersonalized population. (Fig. 1).

Fig. 1. "Tysiachka" - hospital №2, Kryvyi Rih, Ukraine. Source: https://krmisto.gov.ua/ua/hospitals/2.html.

This approach appeared due to the acute and rapid need in wast amount of medical institutions widely. In particular, this was the case in the last century in the post-Soviet countries. All over this area there were "cloned" typical projects of medical institutions, integrated into the urban environment with huge industrial and panel arrays without regional, cultural and aesthetic connection with "genius loci" and urban context (Fig. 2).

Fig. 2. City Clinical Maternity Hospital №1, Kryvyi Rih, Ukraine. Source: https://info.1kr.ua/place-4367.html

Do we have the right to condemn this large-scale approach that prevailed in the 20th century? No. At that time, this approach allowed to solve the important medical care issues for the majority of the population of the Soviet Union. Thanks to the mass and economic

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industrial design and construction approach, Ukraine has received an extensive urban network of various health care facilities, which continue to perform their functions, accepting the harsh challenges and trials of global pandemics and epidemics.

The main issue is that the acquisition of sovereignty in Ukraine provoked political and oligarchic clan "internecine wars", which for decades froze the attention to improving, modernizing, updating and developing the architecture of health care facilities. Many Ukrainian hospitals are in a condition that not only does not meet sanitary and other requirements, but also threatens the health and lives of patients and staff (Fig. 3, Fig. 4, Fig. 5, Fig. 6).

Fig. 3. The ward in Henichesk Central District Hospital, Henichesk (a resort in the south Ukraine), Ukraine. Source: https://www.umoloda.kiev.ua/number/3190/218/113989/

Fig. 4. The ward in a Mostyska regional hospital, Mostyska, Ukraine.

Fig. 5. Lutsk Infectious Diseases Hospital, Lutsk, Ukraine. Source: https://lutsk.rayon.in.ua/news/29452-v-oblasnii-infektsiinii-likarni-zanepad-i-antisanitariia

Fig. 6. Wards for newborns in surgery of Lviv Okhmatdyt, Lviv, Ukraine. Source: https://lviv.molbuk.ua/picture-of-the-day/283-palaty-dlya-novonarodzhenykh-u-khirurgiyi-lvivskogo-okhmatdytu-urazheni-chornoyu-cvillyu-foto.html

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Despite the fact of the total ignoring of the problems and issues of compliance of domestic medical architecture with world standards for 30 years already, the powerful and somehow the world's best "machine" continued to work, inertially moving down from its pedestal. Nowadays, in 2021, we are frantically approaching the foot of a new "rock" that embodies all the latest advances in health care and which the world's leading countries have gradually, step by step, overcome with a long-term state plan for medical development and carrying out periodic reforms in the medical field.

2 How the hospitals are designed in the world leading countries?

The architecture of health care facilities needs to be upgraded. Hopefully, this is already happening in developed countries. Today hospitals are more likely five-star hotels with all the services rather than ordinary hospitals, for instance in the United States, Germany, France, England, Singapore, Hong Kong, the United Arab Emirates, and others [1]. The attitude towards a patient, who is now a key figure and not a faceless person for calculating statistical indicators of the beds need, that used to be, has changed. The "hotel" hospitals have various ranges of different restaurants, cafes, bank branches, entertainment, shops, and other public functions, which we use in our everyday life (Fig. 7) [2-4]. A sick person can and should live a full life.

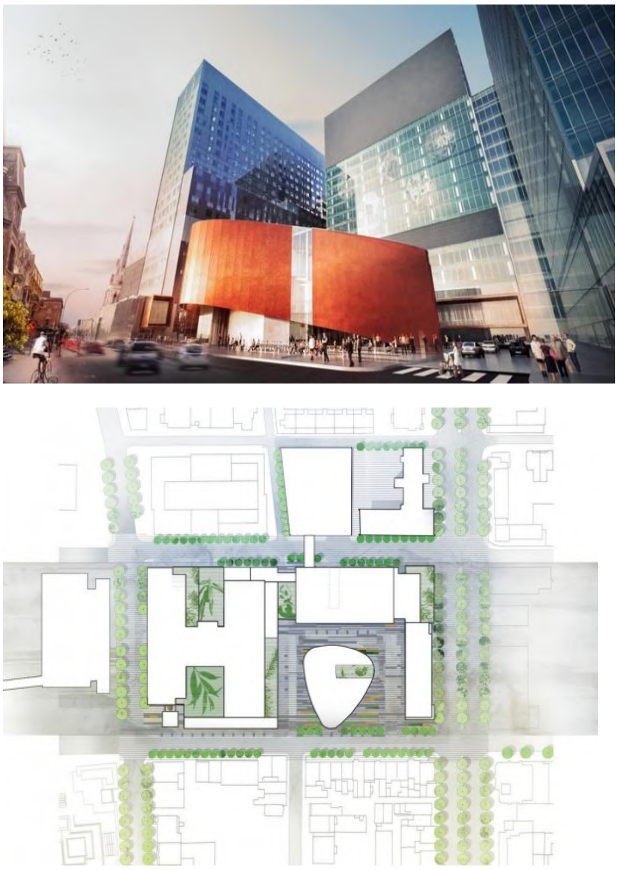

Fig. 7. University of Montreal Hospital Center, Canada. Source: http://healthcare.wsp-pb.com/portfolio/centre-hospitalier-de-luniversite-de-montreal-chum/?portfolioCats=42

Cutting-edge hospitals are megastructural multifunctional medical complexes that have a variety of departments and are usually able to provide all types of medical care services for all age groups of patients. Hospital facilities occupy a large total area, that in some cases can range from 150-300 thousand sq.m. The dense urban environment of megapolises with the lack of free space forces the expansion of existing and historic hospitals significantly in the height dimension. As the result, the new buildings are often difficult to distinguish from the rest of the high-rise public buildings (Fig. 8) [5].

Fig. 8. University Hospital Sant Joan de Reus, Reus, Spain. Source: https://archello.com/project/university-hospital-sant-joan-de-reus

Recently the architectural design of hospital complexes pays significant attention to the organization of public spaces and the interior and adjacent hospital area for the communication between visitors, patients, and staff of the medical institution (Fig. 9) [6]. Architects are actively implementing fascinating multi-story and linear atriums, courtyards, which in addition to public spaces provide natural lighting for the hospital buildings. It should be noted that the patient's ability to independently choose the communication level with society is extremely important. Communicating with others the sick person feels needed, fully-fledged, and not lonely.

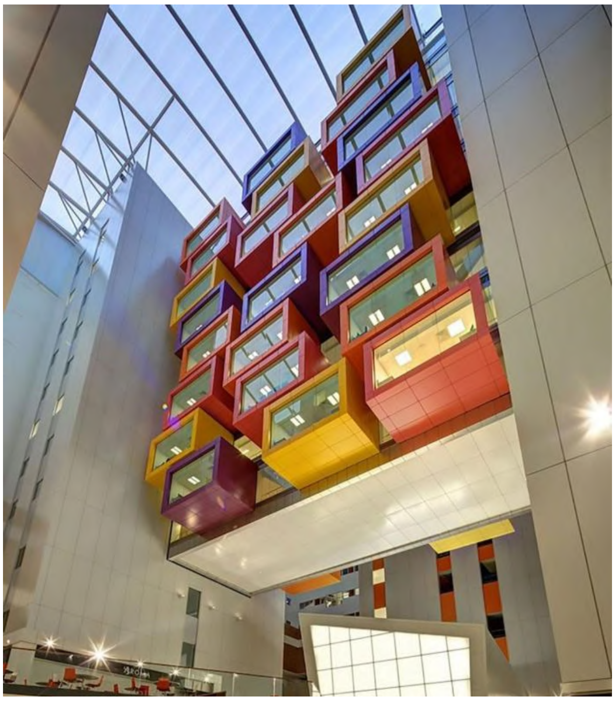

Fig. 9. Queen Elizabeth University Hospital (QEUH), Glasgow, Scotland. Source: http://healthcare.wsp-pb.com/portfolio/queen-elizabeth-university-hospital-glasgow-uk/

3 Future hospitals, which are being developed today

The globe is very contrasting. Simultaneously, many hospitals continue to operate, despite they often do not even have basic living conditions such as sewerage, water supply, and heating. And alongside humanity is working on mega-complex projects of extraterrestrial hospitals. There are many examples of dilapidated buildings with the sign “hospital”. Quite often it’s difficult to name these buildings as “hospitals”. Unfortunately, there are a lot of such destroyed examples all over Ukraine and in rural areas of other post-Soviet states (Fig. 10).

Fig. 10. Rural hospital Voronkiv village, Ukraine.

At the same time, across the planet in the United Arab Emirates a multi-million project and the opening of the world’s first space hospital Emirates Space Hospital, located in Dubai is taking place (Fig. 11, Fig. 12) [7, 8]. The Innovative Hospital of the Future will focus on the UAE Centennial 2071 program and the National Space Program. The hospital will be an example of how telemedicine can be used in the future. Not only in the “Earth” hospitals but also in the space ones. The testing of the first mobile hospital units is planned to be conducted on Mars. The treatment at the Emirates Space Hospital will be carried out using the latest nanorobots, which are able to independently find diseased cells in the astronauts’ bodies and cure them [9].

Fig. 11. Project of Emirates Space Hospital, Dubai, UAE / Mars. Source: https://www.thenationalnews.com/uae/health/space-clinic-being-developed-to-treat-emirati-astronauts-1.700621

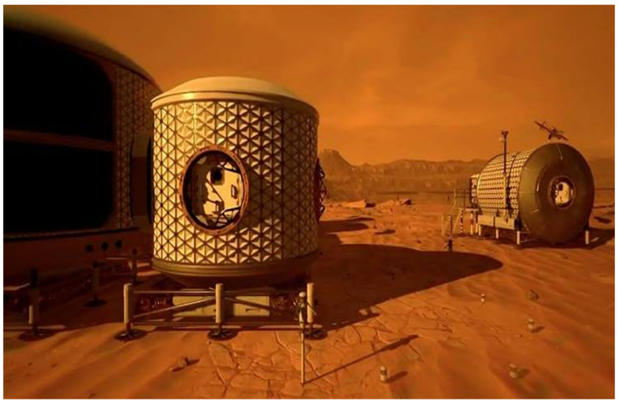

Fig. 11. Medical capsule project to send to Mars, Emirates Space Hospital, Dubai, UAE / Mars. Source: https://dubaiofw.com/mars-science-city-launched/

Besides the project of the future hospital in the UAE, there are already terrestrial and “extraterrestrial” (in terms of architecture and technology) medical facilities that actively use robotization of medical processes, automatic movement of patients and staff, transfer of laboratory materials, and other means by pneumatic pipes, automation of constant control of the main vital signs of patients from mobile devices, etc. (Fig. 12, Fig. 13) [10]. All these and other achievements have allowed bringing the country’s medicine to the world top ten list according to the published rating of the analytical agency Bloomberg [11].

Fig. 12. Cleveland Clinic Abu Dhabi, Abu Dhabi, UAE. Source: https://consultqd.clevelandclinic.org/cleveland-clinic-abu-dhabi-performs-the-uaes-first-full-heart-transplant/

Fig. 13. Robotic operating room. Source: https://www.orlandohealth.com/content-hub/the-wonders-and-benefits-of-robotic-surgery

4 The sustainable development of the health care institutions' architecture

The climate is transforming, and finally, humanity has turned its attention to this issue. At least it's trying to do it. Everyone urges the need for an ecological approach in design, caring attitude to the natural environment, energy-saving, and sustainable development and everywhere [12-23]. In recent decades, the world has held numerous conferences, symposia, international programs, and projects [24]. The problem and the question of the need for sustainable development in architecture affect the whole variety of typological objects of the design activities of architects. Including the segment engaged in the design of health care facilities [25-32].

The current hospitals should not be excluded from the list of energy efficient facilities. They should be designed in accordance with the latest environmental principles and guidelines of sustainable architecture. There are already implemented innovative projects of medical complexes, which should serve as a model for us over the globe. Even in a dense urban environment, on a fairly compact site architects designed and implement a hospital that integrated both the full range of advanced "green" technologies: starting from the full use of regional climate and construction sites (individual aerodynamic spatial and planning structure of the building), ending with the "standard" elements (reuse of rain and used water, solar panels, active and passive insolation, natural ventilation, smart home technology, microclimate through landscaping of roofs and numerous outdoor terraces, as well as many other environmental techniques) (Fig. 14) [33-35].

This design approach has many advantages. Along with the maximum energy autonomy level, compliance with the principles of sustainable development for the future of our planet is achieved by the architects, who managed to create an individual and recognizable artistic icon of the building. This aspect is also very important because the feelings and emotions that the architectural environment evokes significantly affect the process and duration of a sick person's recovery [36]. It should be stated, that the direction of research of the development of their own healing properties of the architectural environment and medical buildings is quite new, but is promising and necessary.

Fig. 14. The hospital complex Ng Teng Fong (NTFGH) & Jurong (JCH) in the urban area, Singapore. Source: https://www.wsp.com/en-MY/projects/ng-teng-fong-general-hospital-singapore

Not fewer than the innovative architectural design approach, which directly affects the development of projects' environmental potential of health care institutions the active integration of the natural environment into the internal and external spaces of medical complexes plays their roles. The latest implemented projects, as well as those that are at the design stage, many competitive and exploratory conceptual developments of hospital buildings allow characterizing this area as the design of the "hospital park".

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5 "Hospital-park" – a proposal for sustainable development of hospital architecture

The hospital-park is a synthesis of a medical building and the natural environment, which involves the active integration of landscaping both in the interior and in the hospital's area improvement. If we talk about the external environment of hospitals, the considerable attention of foreign architects to landscape design over the past decade should be acknowledged. A striking example of the artificial formation of nature in a rather small hospital area is the Lady Cilento Children's Hospital by Conrad Gargett, South Brisbane, Australia (Fig. 15, Fig. 16) [37, 38].

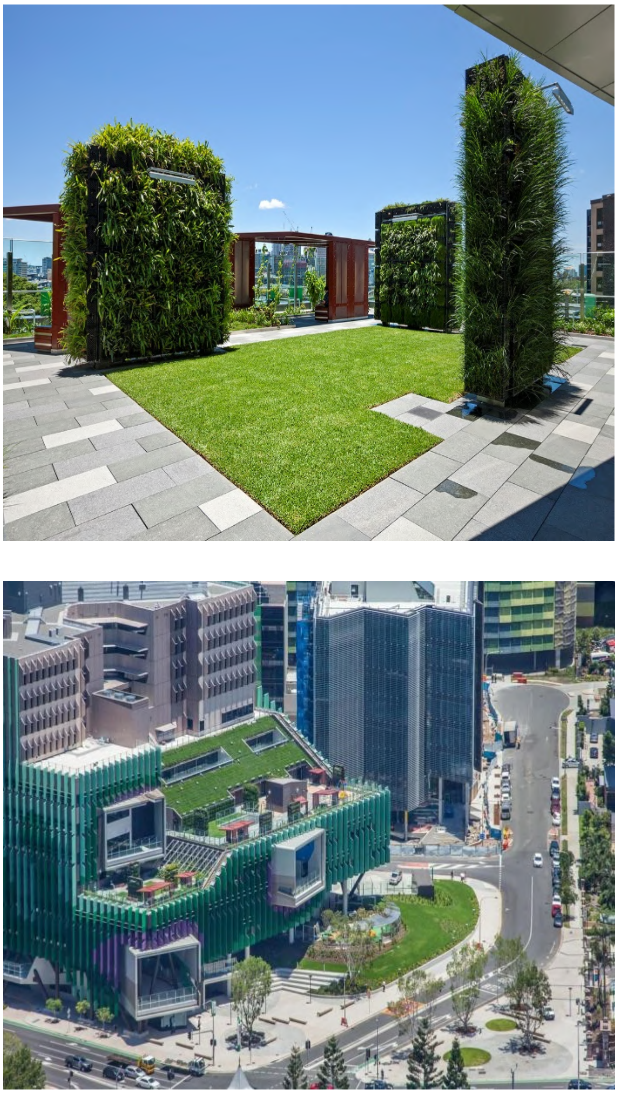

Fig. 15. General view of the Lady Cilento Children's Hospital by Conrad Gargett, South Brisbane, Australia. Source: https://www.archdaily.com/595827/new-lady-cilento-children-s-hospital-lyons-conrad-gargett

In order to maximize the area of the hospital site, the elements of a "man-made nature" were integrated by the architect's decision of plantings and lawns on the terraces, roof, and even used vertical landscaping of the hospital walls. As a result, despite the almost complete absence of its own free territory, the hospital formed a small oasis in the middle of the "stone jungle" of a dense urban environment.

Fig. 16. The Lady Cilento Children's Hospital by Conrad Gargett, South Brisbane, Australia. Source: https://www.archdaily.com/595827/new-lady-cilento-children-s-hospital-lyons-conrad-gargett

Another interesting illustration of the landscape and sustainable design approach of a modern hospital are the finalists of the international competition for the design of the largest hospital in Denmark, namely the architectural offices BIG, Herzog & de Meuron, C. F. Møller submissions. The international competition task was to create a large-scale hospital complex Nyt Hospital Nordsjælland with a total area of about 125,000 sq.m. A picturesque plot of land was proposed for construction, which at the same time served as hunting grounds. Thus, as a context of the environment, the architects received a hilly natural landscape with the largest forest area in the country and many small lakes. Of course, as recognized world-class professionals, each of the finalist teams in their project proposals focused on the integration of nature into the arsenal of the treatment environment.

The team of the Danish office C.F. Møller proposed a project where rather high hospital buildings stand out against the surrounding landscape. The emphasized "functionality" of the project proposal of this variant of the hospital provided the concept according to which the largest hospital of the country should be deployed like the whole city with all necessary functions and structures designed for the needs of patients and staff. The center of the hospital complex is the pubic space with a two round in plan courtyards (Fig. 17, Fig. 18) [39].

Fig. 17. General view of the Nyt Hospital Nordsjælland, C.F. Møller, Denmark. Source: https://www.cfmoller.com/p/-da/Nyt-Hospital-Nordsjaelland-i-Hilleroed-i3067.html

Fig. 18. General view of the Nyt Hospital Nordsjælland, C.F. Møller, Denmark. Source: https://www.e-architect.com/denmark/nyt-hospital-nordsjaelland

The design concept by the BIG architectural office is for the creation of a space capable of "healing"(Fig. 19) [40].

The shape of the hospital complex consists of eight blocks in the form of intersecting rings with courtyards. The architects explained their choice by the fact that it will guarantee a picturesque view from every chamber, the premises will be provided with sunlight, and the opportunity to go for a walk in the public garden will create the conditions for communication. Fresh air, beautiful landscapes, and a positive mood, according to the authors of the project, are true companions of fast and high-quality recovery (Fig. 20, Fig. 21) [40].

Fig. 19. General view of the Nyt Hospital Nordsjælland, BIG, Denmark. Source: https://www.archdaily.com/421002/nyt-hospital-nordsjaelland-shortlisted-proposal-big

Fig. 20. General view of the Nyt Hospital Nordsjælland, BIG, Denmark. Source: https://www.archdaily.com/421002/nyt-hospital-nordsjaelland-shortlisted-proposal-big

Fig. 21. Inner yard view of the Nyt Hospital Nordsjælland, BIG, Denmark. Source: https://www.archdaily.com/421002/nyt-hospital-nordsjaelland-shortlisted-proposal-big

Herzog & de Meuron office offered two- and four-story hospital buildings skillfully integrated into the surrounding natural landscape. The rounded lines of the building plan are more like microorganisms than the traditional shape of a hospital plan. The configuration of the hospital plan is subject to an attempt to provide maximum natural light to the wards. Intersections of hospital buildings with green roofs formed picturesque courtyards. The hospital proposal by the Herzog & de Meuron reflects the close connection between the hospital building and the surrounding landscape, forming an aesthetically pleasing space of a modern hospital park (Fig. 22, Fig. 23) [40-42].

Fig. 22. Inner yard view of the Nyt Hospital Nordsjælland, Herzog & de Meuron, Denmark. Source: https://afasiaarchzine.com/2014/04/herzog-de-meuron_6161/

Fig. 23. Masterplan of the Nyt Hospital Nordsjælland, Herzog & de Meuron, Denmark. Source: https://afasiaarchzine.com/2014/04/herzog-de-meuron_6161/

The idea of a park is obvious in the NTFGH and JCH hospital complex in Singapore. The architects' considerable attention to the integration of sustainable development principles into the architecture of the hospital complex has achieved incredible results. Despite the location of a large hospital in a dense urban environment with almost no free space, the hospital looks like a park with various elements of landscaping. This has significantly improved the views from the windows of hospital rooms and created an atmosphere of psychological peace, relaxation and comfort (Fig. 24, Fig. 25) [33, 34].

The Hughes Medical Institute Hospital in Virginia, USA, designed in 2008 by architect Rafael Vignoli is the best example of how the architecture can reflect the idea of hospital-park using the healing effects of the natural environment, landscape and healing power of water. G. Hughes Medical Complex performs multifunctional tasks, combining state-of-the-art medical laboratory of computational and electrophysiological examinations, robotic and technical research contains conference halls, mini-hotel, spacious public space with registration and recreation area, private offices, medical wards, etc.

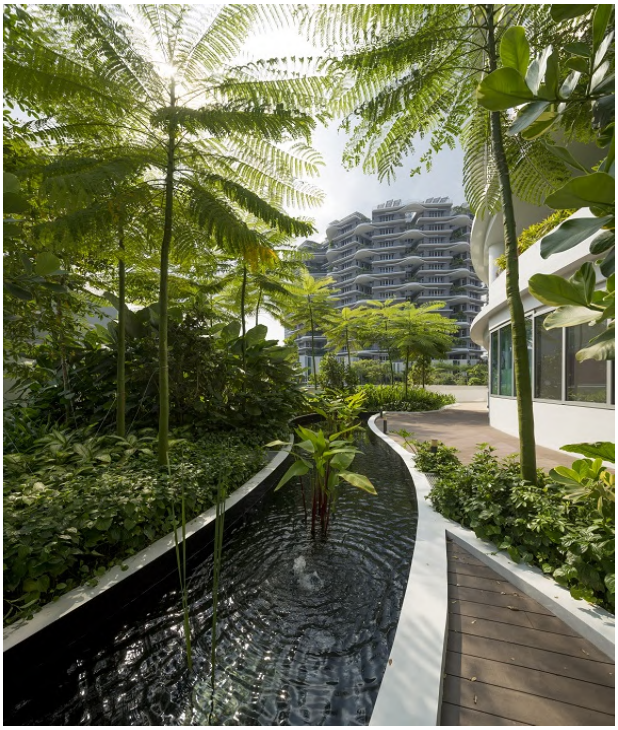

Fig. 24. Exterior and windows from the hospital complex Ng Teng Fong (NTFGH) & Jurong (JCH). Source: https://www.wsp.com/en-MY/projects/ng-teng-fong-general-hospital-singapore

Fig. 25. Active use of landscaping in hospitals Ng Teng Fong (NTFGH) & Jurong (JCH). Source: https://www.wsp.com/en-MY/projects/ng-teng-fong-general-hospital-singapore

The hospital stay provides short-, medium- and long-term medical research courses and programs, so the complex has a hotel for short-term treatment, as well as a building for long-term stay (Fig. 26, Fig. 27) [43-45].

Fig. 26. General view of the Howard Hughes Medical Institute, Virginia, USA. Source: https://www.e-architect.com/america/howard-hughes-medical-institute

Fig. 27. General view of the Howard Hughes Medical Institute, Virginia, USA. Source: https://www.e-architect.com/america/howard-hughes-medical-institute

The next example of the last decade health project, which shows the attention of architects to the integration of the landscape design in medical facilities and thus embodies the ideas and principles of sustainable development, is Seoul National University Hospital Medical Mall, Seoul, South Korea (Fig. 28) [46-48]. The site for the construction of the hospital is located in an urban environment with compacted buildings and has a very limited size. This prompted the bureau of Gresham Smith architects to create an innovative concept, according to which the six-story hospital building was "immersed" in the underground space. Quite a bold idea that does not correspond to the established and traditional architectural approaches to the design of health care facilities! The concept also allowed to develop another unusual tool – the arrangement of a landscape park on the released hospital territory [49].

6 Conclusion

Today in Ukraine there are about 1,793 hospitals with 335,835 hospital beds (78.5 beds per 10,000 inhabitants). Most of these hospitals were built between the 1950s and 1980s. After construction, most of the hospitals received only minimal repairs. And only over the past five years, cosmetic repairs have begun in some hospitals located in large Ukrainian cities. Unfortunately, there is no exact informational data regarding the exact number of hospitals that have already been renovated and those that are currently being renovated.

Fig. 28. General view of the Seoul National University Hospital Medical Mall, Seoul, South Korea.

Nowadays, a number of reforms are undertaken in Ukraine, one of which is to make qualitative and effective changes in the field of health care. From the author's points of view, one of the key issues that need to be addressed immediately is the introduction of ideas and principles of sustainable development in the architecture of medical institutions. From this position, the article analyzes the Ukrainian realities of the state of hospital buildings, as well as advanced foreign design and conceptual experience. Undoubtedly, a huge gap has been identified, which was formed after 30 years of ignoring the needs of modernization and development. But, despite the significant resistance of society against the reformist changes, Ukraine must pass this way. Ukrainian health care facilities must meet world standards of energy-saving and energy efficiency, approaching the zero need for external network engineering systems, making the most of the regional potential of natural properties. It should be noted that it is not possible just to copy the experience of another country. There are always several diverse features (climatic, geographical, relief, hydrological, etc.), which form individual requirements and opportunities. The only invariable potential for the integration of the principles of sustainable development into the architecture of buildings designed for human health, which is appropriate and necessary to implement for all countries of the world, is the active synthesis of the medical and natural environment. One of the possible ways of realization of this idea can be designing a hospital-park, a medical institution that is inserted in a natural environment, and also contains its elements in the internal space. This approach is due to the fact that man is a part of nature, its constituent element and it is natural to assert the harmony of effective and accelerated physical and spiritual renewal in the natural environment.

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Modeling of hydrogen sulfide removal under biomethane production in the concept of renewable energy potential growth of Ukraine

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Abstract. Today, the global trend in the development of renewable energy sources is the implementation of integrated processing of organic waste with the production of biogenic gases such as biomethane. In this case, an essential focus is the study of biogas purification processes to methane. This paper focuses on the process of modeling biochemical purification of biogas from hydrogen sulfide to develop the direction of biomethane production. Simulation of hydrogen sulfide bio-oxidation process with the use of granulated carrier based on phosphogypsum was conducted using experimental data from previous studies to verify the adequacy of the proposed mathematical model. Thus, to implement the process of phosphogypsum utilization in technological systems of biogas purification, it is important to consider the level of bioactivity in the immobilization of bacteria on the loading surface of phosphogypsum and the degree of biotransformation of phosphogypsum components in the oxidation of carbon dioxide and hydrogen sulfide impurities to achieve the highest ecological effect. Also, the use of overlay visualization allowed to form the main clusters of development of research potential in the field of biogas technologies for Ukraine.

1 Introduction

Currently, there is a rapid development of bioenergy worldwide, in particular, the technology of production of biogenic gases for energy purposes [1]. Such countries as Germany and Austria have become the flagships of development in Western Europe, the bioenergy potential is actively developing in the Scandinavian countries (Sweden, Norway) and the United States. Relevant is the problem of the development of renewable energy potential for Ukraine [2, 3] (Fig. 1).

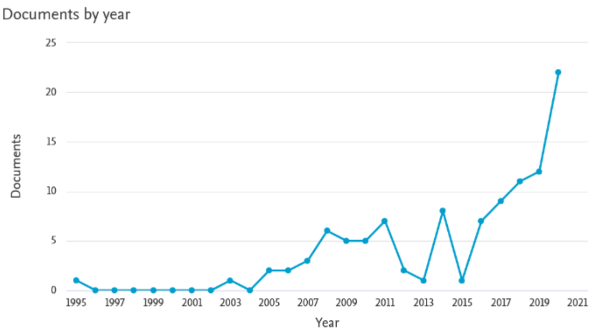

Fig. 1. Publishing trends (number of papers) in the field of biogas technologies research of Ukrainian scientists (using the Scopus database).

When analyzing the publication activity on the query biogas technologies and biomethane production in the Scopus database was highlighted key areas of publications of Ukrainian scientists in highly rated journals, which are associated with bioprocesses of biogas production and waste recycling (Fig. 2 and 3) [4-6]. Thus, the sphere of implementation of scientific research in Ukraine also has significant potential for development and is integrated into the world scientific metrics in the field of bioenergy.

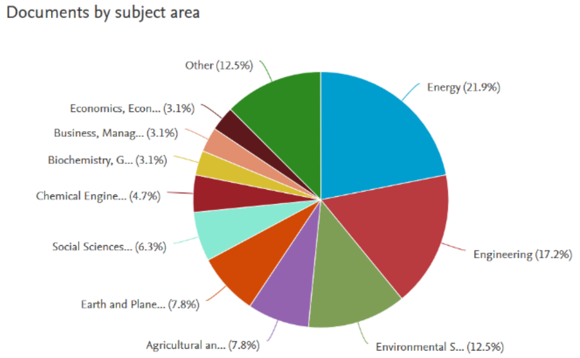

Fig. 2. Directions of publication activity by field of biogas technologies research (using the Scopus database).

The priorities of the new energy strategy of Ukraine until 2035 according to [7] related to bioenergy are as follows:

– promoting the creation of competitive biomass markets;

– support for implementation of cogeneration projects at CHPPs and cogeneration with biofuels;

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– creation of conditions for the creation of logistic system and infrastructure for collection of biomass and its further transportation;

– providing centralized heating systems with energy from renewable sources (bio-pellets, household waste, etc.);

– increasing the share of energy exchange in % of domestic consumption, including other fuels, from 10% in 2015 to 60% in 2035.

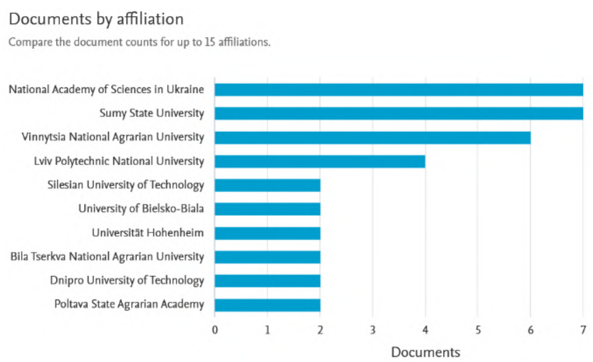

Fig. 3. Affiliation with the leading scientific and educational organizations of Ukraine according to the Scopus database in the field of biogas technology development.

An important direction is also the introduction of integrated processing of organic waste with the production of biogenic gases such as biomethane. In this case, an essential focus is the study of biogas purification processes to methane.

Under our previous studies [8,9] we consider phosphogypsum as an acid-resistant mineral carrier, and besides, it is a source of macro- and microelements for the development of necessary ecological and trophic groups of bacteria. Phosphogypsum entering the environment of life activity of microorganisms becomes a source of nutrition and stimulates metabolic processes of a bacterial cell due to a list of elements necessary for its life activity.

The model of the influence of the main components of phosphogypsum on the vital functions of microorganisms is presented in Fig. 4. For its formation, we used data from previous studies [8,9] and electronic bioinformation databases of the Kyoto Encyclopedia of Genes and Genomes (KEGG) and Metabase of Bacterial Diversity (BacDive).

The annually worldwide production of phosphogypsum is possibly up to 100 million tons [10]. The use of the modified granulated phosphogypsum will make it possible to expand the scope of its use in biochemical purification processes, which is relevant not only for Ukraine, but also throughout the world.

It should be noted, at realization of biogas technologies the special attention is given to quality of biogas and, in particular, to the content of methane, carbon dioxide and other impurities, such as hydrogen sulfide.

Due to the complexity of biochemical reactions, and the presence of inhibitors or hard-to-degrade compounds in the waste, a detailed study of the kinetics is necessary to understand and optimize the process. Vavilov [11] developed mathematical models describing the kinetics of acidogenesis, ethane-degrading acetogenesis, butyrate-degrading acetogenesis, acetoclastic methanogenesis, hydrogenotrophic methanogenesis, bacterial degradation. Gutiérrez Ortiz and Aguilar POllero (2014) provided a methodology for dynamically estimating the total mass transfer coefficient as well as the most appropriate isotherm for a stream containing treated sewage sludge for biogas desulfurization, which requires still evaluating the transition from laboratory studies to industrial applications [12]. The model was verified by comparing the data obtained with experimental data from the literature. Khanongnuch (2019) compared Michaelis-Menten fermentation equations, first- and second-order kinetics of substrate decomposition of cellulose particles of known sizes [13]. The research by Pokorna-Krayzelova et al. (2018) shows that few authors have quantified the kinetics of chemical and biochemical oxidation of sulfides in a single oxygen-limited system. Moreover, the publicly available data are still not consistent, and more specialized measurements are still needed to independently calibrate mathematical models [14].

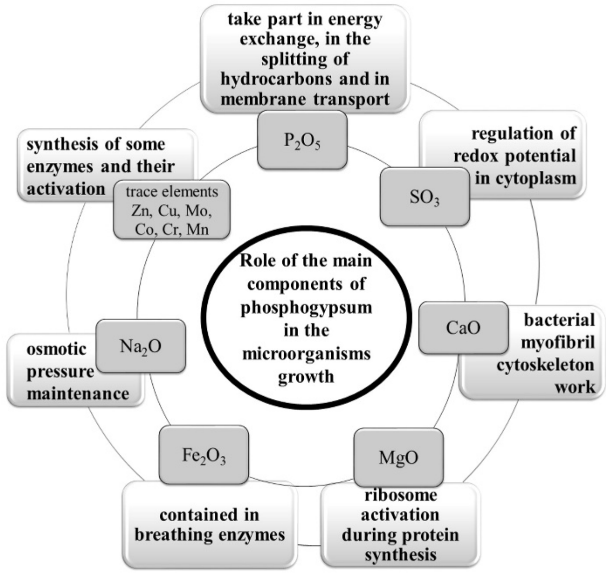

Fig. 4. Role of main phosphogypsum components in microbial activity.

Accordingly, for wide implementation of technologies of biomethane production, it is important to simulate the processes of gas purification with removal of impurities.

However, the growth patterns of bacteria on low-soluble mineral substrate are still practically unstudied. For example, phosphogypsum; in addition, there are practically no data on mathematical modeling and investigation of the biochemical desulfurization process during solid-phase fermentation.Thus, this paper focuses on the process of modeling biochemical purification of biogas from hydrogen sulfide to develop the direction of biomethane production.

This paper focuses on the process of modeling the biochemical purification of biogas from hydrogen sulfide during the biofilm growth on phosphogypsum granules as part of the development of the concept of biomethane production.

2 Materials and methods

Under implementing the mathematical model, we used the values of constants given in Table 1.

Table 1. Constants needed for the software implementation of the mathematical model [15].

Constanta	Value	Unit of measure
$Y_{X/S}$	0.093	mg/mg
μ_m	0.037	d^{-1}
λ	0.031	d^{-1}

Table 2. Symbolic names for program development

Initial designation	Symbolic name	Explanation
F_g	F	input consumption of gas flow containing hydrogen sulfide, dm^3 / min
μ_m	m_max	the specific growth rate of thiobacteria, h^{-1}
V_{gpg}	V	specific layer volume of granulated phosphogypsum, dm^3
C_n	Cn	the minimum value of hydrogen sulfide concentration, ppm
C_k	Ck	the maximum value of hydrogen sulfide concentration, ppm
ΔC	dC	hydrogen sulfide concentration value change, ppm
α_B	*a*	oxidative capacity of biofilm, g / cm^3 h
t	t	contact of the gas flow with the mineral carrier from phosphogypsum, h
ξ_{gph}	L	the biochemical capacity of loading from phosphogypsum, gH_2S / cm^3
C_{H2S}	Chs	the actual concentration of hydrogen sulfide, ppm
λ	l	inactivation rate constant, d^{-1}
e	e	natural constant
$Y_{X/S}$	Y	economic coefficient of thiobacteria biomass yield by substrate - hydrogen sulfide

Fig. 5 shows a simplified algorithm for the simulation process. The computational model was carried out using the C++ programming language in the Borland C++ IDE, which is designed to describe a wide range of tasks and contains mechanisms for controlling the computational process and working with data, optimally suited for the task.

The output data were determined following the biochemical conditions of the biomethane generation process (Table 3).

In this case, the value of C changed in the range, ppm: 250, 400, 550, 700, 850.

Table 3. Initial data for modeling.

Initial condition	Value	Unit of measure
τ	1.5	h.
F_g	0.23	dm^3/min.
V_{gph}	1.8	dm^3

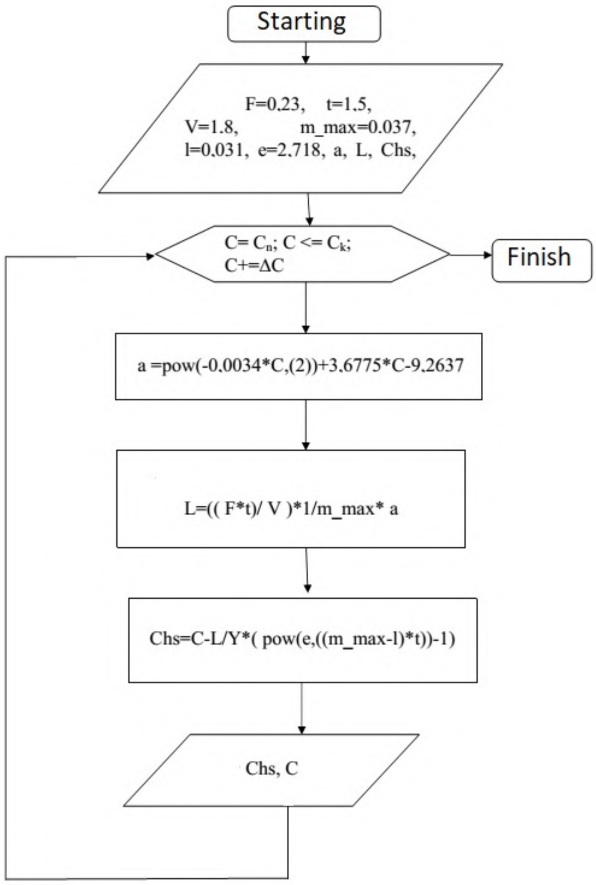

Fig. 5. Simulation algorithm.

To calculate the correlation coefficient between the experimentally determined values of hydrogen sulfide concentration and the values obtained in the simulation, MS Excel program package with the built-in CORREL function was used. Also, special visualization software (VOSViewer v.1.6.15) was used to build a map to visualize the clusters of biogas production in Ukraine.

3 Modeling of hydrogen sulfide removal from biogas for biomethane production

Mathematical modeling of kinetics of hydrogen sulfide conversion by sulfur-oxidizing microorganisms in the process of phosphogypsum utilization assumptions have been put forward: the entire working volume of the biofilter is uniformly filled with phosphogypsum load; concentrations of mineral substrate (phosphogypsum) and biofilm at each point of the biofilter are equal; substrate concentration and the total number of cells are linearly related, the change in hydrogen sulfide concentration (C_{H_2S}) when passing the maximum in the number of viable cells N (at $\mu_m = \frac{1}{N} \cdot \frac{dN}{d\tau}$ = const) gives exponential function and finds dependence on biochemical properties of phosphogypsum load (ξ_{gph}).

The mathematical model of the developed biodesulfurization process using phosphogypsum loading is based on the classical Mono model, widely used in the optimization of biotechnological systems.

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Important for analyzing the efficiency of using phosphogypsum as a mineral carrier for immobilization of microorganisms is to evaluate the biochemical capacity of phosphogypsum loading, taking into account the sorption processes on its surface and the uniform distribution of hydrogen sulfide gas flow. Then the behavior of hydrogen sulfide concentration in time and change in the value of biochemical capacity of phosphogypsum loading can be described by the system of ordinary differential equations:

$$\frac{dC_{H_2S}}{d\tau} = \mathrm{C} - \frac{\xi_{gph}}{Y_{X/S}} \times \left(e^{(\mu_m - \lambda)\tau} - 1\right), \qquad (1)$$

$$\frac{d\xi_{gph}}{d\tau} = \frac{F_g \times \tau}{V_{gph}} \times \frac{1}{\mu_m} \times \alpha_B \qquad (2)$$

where ξ_{gph} is the biochemical capacity of loading from phosphogypsum, gH_2S / dm^3; C is the concentration of H_2S in the biogas stream, g / dm^3; $Y_{X/S}$ is economic thiobacteria biomass yield factor by substrate - hydrogen sulfide; μ_m is the specific thiobacteria growth rate, h^{-1}; λ is inactivation rate constant, failure rate, leading to loss of thiobacteria cells' ability to reproduce, h^{-1}; F_g is input gas flow containing hydrogen sulfide, dm^3 / min; τ is contact time, min.; V_{gph} is a specific layer volume of modified phosphogypsum granules in biofilter or bioscrubber, dm^3; α_B is the oxidative capacity of biofilm, g / dm^3 h.

In the process of metabolic activity of sulfur-oxidizing bacteria, there is consumption as a mineral substrate of phosphogypsum. Therefore, when calculating the value of the reduction of hydrogen sulfide concentration in the gas stream in equation (1) was introduced an indicator characterizing the biochemical capacity of phosphogypsum loading.

In expression (2) when describing the biochemical capacity were taken into account parameters affecting the intensity of sorption on the surface of granules, and biochemical activity, which is characterized by the specific growth rate of bacteria and the oxidative capacity of biofilm, which was determined experimentally.

Thus, expression (2) takes into account the most important conversion parameters, without which it is impossible to predict the biochemical component of purification efficiency, since we consider biochemical removal of impurities from biogas as one of the main direction of research on biomethane production. With further development of complex technical solutions, the model can be expanded and optimized for a number of other parameters.

As can be seen from the graph (Fig. 6) the oxidative capacity of biofilm α_B changes with changes in the concentration of hydrogen sulfide in the gas stream.

A curve was obtained (Fig. 7), which corresponded to the theoretical dynamics of hydrogen sulfide reduction and had a good coincidence with the experimental data.

The greatest decrease in hydrogen sulfide concentration occurred in the second half-period of treatment from 0.5 to 1.0 hour, which corresponded to the stabilization of the development of the bacterial film on the surface of modified phosphogypsum granules after the end of the adaptation period. Thus, to implement the process of phosphogypsum utilization in technological systems of biogas purification, it is important to consider the level of bioactivity in the immobilization of bacteria on the loading surface of phosphogypsum and the degree of biotransformation of dihydrate phosphogypsum in the conversion of carbon dioxide and hydrogen sulfide impurities to achieve the highest ecological effect.

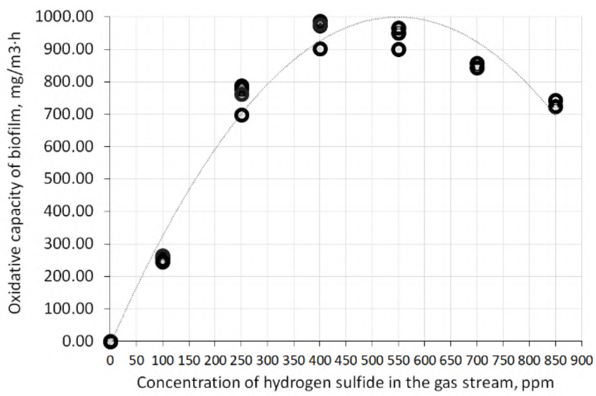

Fig. 6. Biofilm oxidative capacity curve. According to the experimental data from [9].

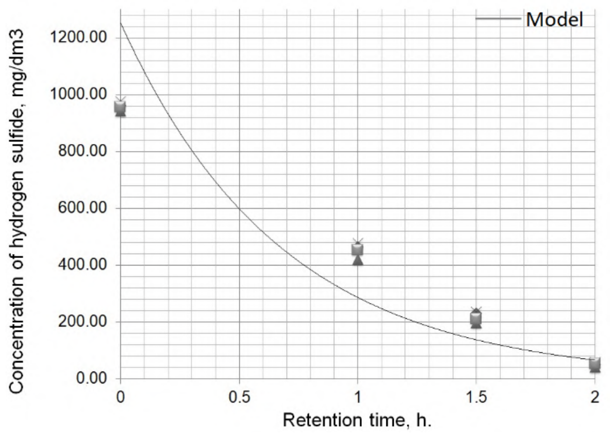

Fig. 7. Change of hydrogen sulfide concentration in biogas with time. Comparative analysis of experimental data and results of mathematical modeling (*r* = 0.923).

Experimental data of dependence of biofilm oxidative capacity (α_B) on the concentration of hydrogen sulfide (C) in biogas can be approximated by regression equation:

$$\alpha_{B=}–0.0034C^2+3.6775C–9.2637 \ (R^2 = 0.9737) \qquad (3)$$

Thus, such species of *Thiobacillus* sp. as *Th. Intermedius* and *Th. Permetabolis* grow under autotrophic conditions, which is associated with the ability of these bacteria to use carbon dioxide to form cell components:

$$CO_2 + H_2O + Enzymen \rightarrow \left[CH_2O\right] + O_2 \qquad (4)$$

Bacterial growth reaches a maximum ($3.5 \cdot 10^{10}$ CFU/g) with maximum removal of H_2S (95.34 %) when supported at pH = 5.0 and contact time of 10 hours [9]. There is a stratification of microbial groups with the development of a zone of facultative aerobiosis and anaerobiosis in the inner bioactive layer of modified phosphogypsum granules.

4 Conclusions

A comprehensive approach to modeling the removal of hydrogen sulfide from biogas and the analysis of the prospects for implementation of biomethanogenesis processes in Ukraine was described.

Simulation of hydrogen sulfide bio-oxidation process with the use of granulated carrier based on phosphogypsum was conducted using experimental data from previous studies to verify the adequacy of the proposed mathematical model.

Further research will focus on the experimental work of the integrated stage-by-stage production of biohydrogen and biomethane with the production of environmentally safe digestate.

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Development of software control tools for power systems of mining and metallurgical regions

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Abstract. There are presented results of developing a conceptual trigger chart of the functioning mechanism of the decision support system. The suggested model of visualizing algorithms as a trigger net of states of the computer decision support system provides for interaction of power objects of mining and metallurgical complexes and regions. The authors introduce new interpretation of components of the network trigger model. The model is interactively connected with both the user-operator's actions and states of power system components. With that, the state of the automatic model is associated with realizing a set of metarules to control the logic output. The authors elaborate a new formalism of representing algorithms of controlling knowledgebases interacting with the outer environment which aggregates primitives of conditions, triggers and transactions of operations and greatly generalizes standard languages of algorithm visualization. It enhances elaboration of standardized smart systems interacting with the external environment. This allows description of functioning algorithms of knowledgebases and the event-driven output to ensure development of reliable standardized smart systems interacting with control objects of power systems in mining and metallurgical regions.

1 Introduction

Advancement of mining and metallurgical complexes and regions is integrally characterized by significant irregularity and effects of some current crisis factors [1,2]. These circumstances call for new approaches to improving efficiency of mining and metallurgical complexes in terms of assessing parameters that define their functioning. As a result, there are developed various transient-free mathematical models and tools of engineering data processing [3, 4].

Large-scale industrial systems of the economy including electric grids of mining regions and metallurgical enterprises are specified by considerable damages associated with emergencies and accidents. In accident elimination, a so-called "human factor" is gaining significance with intensified requirements to managerial personnel. The personnel are under great psychological and physiological pressure in a compressed time frame suffering from high material and social responsibility for their actions. Due to this, managerial personnel are often unable to provide adequate reaction to an emergency and reduce its consequences efficiently [5, 6].

Present-day power system as an integral part of mining and metallurgical complexes is a complicated hierarchical control object characterized by simultaneous power generation, distribution and consumption. With this in mind, the computerized smart support of the managerial operating dispatch personnel's (ODP) decisions is becoming especially urgent. Decision support systems (DSS) are integrated into operating information-control complexes (OICC) of the automated Supervisory Control and Data Acquisition System (SCADA) [7].

Reliability and efficiency of dispatchers' operation is the factor involving reserves to reduce damages caused by accidents and unserved power. Identification of losses and damages in the power system is a complicated and ambiguous task comprising both reliability of power system components and that of dispatch personnel. Basic modern approaches to specifying accident (emergency, crisis) losses resulting from unserved power were analyzed. In general, there are direct losses/damages (lost resources due to breakdowns and accident elimination costs) and lost profits (income deficiency).

2 Problem analysis

Damages can be evaluated by using the following approaches:

– simulation of shutdown scenarios;
– methods of direct analytical calculation;
– market methods (readiness to pay for increased reliability);
– consumers' surveys;
– statistical methods.

To obtain multiple estimates of damages, reliability indices of the power consumption system and management. Meanwhile, specific damage from unserved power can be treated as tripled power costs.

The damage value for a customer is affected by the following parameters:

– the shutdown period;
– the suddenness rate of power interruption;
– depth of limited load;
– the shutdown moment.

Thus, reliability of power supply is a probabilistic index conditioned by a number of the power system's properties.

Analysis of the damage structure and essence in power systems reveals that damage can be reduced due to enhanced automation of emergency management. A decision maker is ODP of power systems [8]. Let us specify the role of dispatch personnel in reducing accident-related damages in power systems. Here, the rate of managerial decision making should correspond to that of accident development. Yet, the decision maker is unable to react in compliance with the set rate of an emergency. Main reasons for that include a great amount of data that require faultless evaluation in the shortest time possible and psychological pressure because of increased responsibility.

Note the generalized information model of technological process management. The model is universal and can be considered invariant in terms of a professional specificity of an enterprise. The given model realizes a cybernetic approach and combines a control object's input and output data with those of a subject. Let us introduce the following symbols: Δt_1 is the period of the information flow passing along the first information arc; Δt_2 is the period of the information flow passing along the second information arc; $\Delta t_{decision\ maker}$ is the period of personnel's decision making; $\Delta t_{Ц}$ is the total time period of the information cycle; S_1 is the control object's state at the moment t_1; S_2 is the control object's state at the moment t_2; t_1 is the moment of the beginning of collecting data on the control object; t_2 is the moment of complete realization of the controlling action on the control object by the control subject.

Thus, we obtain

$$S_1 = S(t_1), \tag{1}$$

$$S_2 = S(t_2).$$

With that,

$$\Delta t_ц = \Delta t_1 + \Delta t_{ЛПР} + \Delta t_2. \tag{2}$$

From (2) it follows that

$$t_2 = t_1 + \Delta t_ц = \Delta t_1 + \Delta t_{ЛПР} + \Delta t_2. \tag{3}$$

For any professional management environment, it is true that

$$t_1 \neq 0, \Delta t_{ЛПР} \neq 0, t_2 \neq 0, \Delta t_ц \neq 0. \tag{4}$$

Then

$$t_2 \neq t_1, S_2 \neq S_1. \tag{5}$$

From (5) provides an important conclusion on the paradox of control: any control is based on the knowledge of an object being in the state S_1 and is realized some time later in relation to another object being in the state S_2. That is why, any control is characterized by some degree of incompleteness, unreliability and ambiguity.

The obvious solution of the control problem is

$$\min \Delta t_ц(X), \tag{6}$$

where $\Delta t_ц(X)$ – is the time period of the control cycle as a function of multiple control factors $X=\{x_i|i=1,n\}$.

As managerial activity is mostly of information-based and cognitive character and the control cycle is based on processing and generation of information flows, solution of problem (6) is related to the IT field. The solution is based on inclusion of the information system into the control cycle. The information system acts as an information 'pump' increasing the speed and volumes of information flows in direct and reverse arcs of the control cycle. The information system nucleus is the data base management system (DBMS), which accumulates and processes information massifs. Application of the DBMS has a considerable time gain, thus enhancing reliability of managerial decisions.

However, reduction of losses calls for new levels of control/management quality. That is why, the information system is complimented with two information mechanisms – the automated process control system (APCS) and the DSS. The APCS is a set of hard- and software modules that ensure production processes. These modules are connected with industrial equipment and their speed of operation cannot be additionally increased to a great extent. On the other hand, expert systems of managerial decision support are predominantly software complexes and are solely associated with the ODP's information activity. Consequently, it is the DSS that is noted for maximum freedom, flexibility, scalability and adaptability in changeable conditions of power system functioning. That is why, the time period for decision-making can be greatly reduced.

Thus, it can be concluded that on the present-day development stage of hard- and software tools of realizing managerial activity in production, reduction of time for managerial decision making ($\Delta t_{decision\ maker}$) is one of the key factors of improving reliability of management and control. Conclusions like that are confirmed by numerous practitioners. This conclusion is gaining more topicality when being applied to managing power systems in emergency and crisis situations under time deficiency. For this reason, within the framework of the given problem, we should consider the issue of the automated dispatcher control system (ADCS) intellectualization.

3 Automation tools of emergency control over power system modes

Let us consider current scientific and practical solutions to automation of emergency control over power system modes. Emergency control of power systems is based on basic principles of emergency control applied to the professional field of power system functioning. Emergency control systems should prevent accidents and provide input of the system parameters into the area of accessible schedule values in the shortest time possible.

Functioning of the control system under the emergency (crisis) mode differs in the fact that emergencies occur unexpectedly and develop fast. Control schedules for stationary modes become inadequate. That is why, emergency control systems should be structurally and functionally different from those in stationary (standard) modes. Comparison of the two system types are in Table 1.

Table 1. Comparison of the control systems.

Conventional control systems	Emergency control systems
Constant functioning mode	Various functioning modes
Inflexible structure and clear distribution of functions for a long period	No inflexible structure and clear distribution of functions for a long period, flexibility
Narrow functional orientation	Wide and partially unpredictable application area
Monostructure	Polystructures
Regulated information flows	Dependency of information flows on a situation
Accurate information	Unreliable information
Excessive information	Insufficient information
Low rate of changes	High rate of changes
Predictability of situations	Unpredictabilityy of situations, past practice orientation, as a rule without any sense
Unanimity of duties and responsibility	Combination of undivided authority, distributed duties and responsibility
Functional potential	Managerial potential
Predominance of social and economic goals and functional criteria	The goal is effciency of elimination of accidents and their consequences; the criteria are reduction of time for goal achivement, minimal losses (victims)

ODP as a tool of operative dispatch emergency control can be considered as both ‘a week link’ of the ADCS and a reserve for increasing efficiency of power system management/control in emergencies.

It is evident that the nucleus of the ADCS is the operating information complex (OIC). The OIC is mostly used for standard modes with such functions as state assessment, reliability analysis and improvement of flow-distribution, which enhance reliable functioning of the power system. The pattern changes greatly if the OIC is to function under unpredictable circumstances or in case of emergencies in any important components of the power system. In these cases, the OIC acts predominantly as a system of data collection and transmission. Complicated applied software created for standard modes can be of no use here. In these conditions, it is mostly dispatch personnel’s responsibility to make decisions about eliminating an accident. The ODP faces the problem of analytical processing of large volumes of operative data which are characterized by considerable incompleteness or unreliability and have to make responsible decisions under severe time constraints. Managerial decision making is difficult to structure and formalize. Correct and efficient decisions are dependent on a dispatcher’s work experience, his/her ability to adequately react to unpredictable stressful situations and psychophysiological characteristics.

In [9], Budovskyi indicates that ‘in each individual case, technological failures are treated as suddenness that makes personnel face a number of various problems. In this case, especially on the initial stage of disturbance when the personnel are not ready to act and the emergency requires taking urgent steps, they are inevitably subject to emotional tension. Here, the personnel’s clear and correct actions are possible only in case of their high-quality readiness to work under given circumstances’. It is evident that there is a problem of improving the ODP’s quality and reliability as responsible part of the ADCS. The problem is solved in many fields including engineering psychology, situational software management, automated knowledge assessment, etc. To improve the ODP’s reliability, there are used multiple methods and approaches: situation evaluation trees, flowcharts and action plans, algorithmization of operative switching plans, observation maps, the business game theory, methods of deduction and expert systems.

The conducted analysis indicates that all the mentioned methods are quite effective and their application enhances reliability of dispatch personnel to some degree. Further increase of the ODP’s reliability is associated with application of training ICT and knowledge assessment – switching training simulators (STSs).

Application of STSs enables a dispatcher to acquire experience of solving operating control problems under standard and emergency modes of power systems. While building the STS, the results of analyzing a dispatcher’s breakdowns (errors) are required to be used. There are two types of dispatchers’ breakdowns – regular and random. Regular breakdowns are those occurring due to dispatchers’ forgetfulness or lack of knowledge as to corresponding sections of normative, directive materials. Random breakdowns are those caused by dispatchers’ mistakes, misses and errors.

To reduce the number of regular breakdowns, the methods of increasing and maintaining personnel’s technical knowledge are used including lectures and exams aimed to provide knowledge and skills of applying the content of normative and technical documents. To reduce the number of random breakdowns, there are used specific instructions, interviews and emergency trainings aimed at increasing personnel’s attention span and accurate responses.

As is mentioned, optimization of obtained knowledge and skills as well as control over the results are provided by simulators including the STSs. The most general features of simulators include:

– a mimic of an electric grid or a substation with indicated symbols and location of commutation equipment;

– simulation of bodies controlling commutation equipment and control indicators for correct accomplishment of operations;

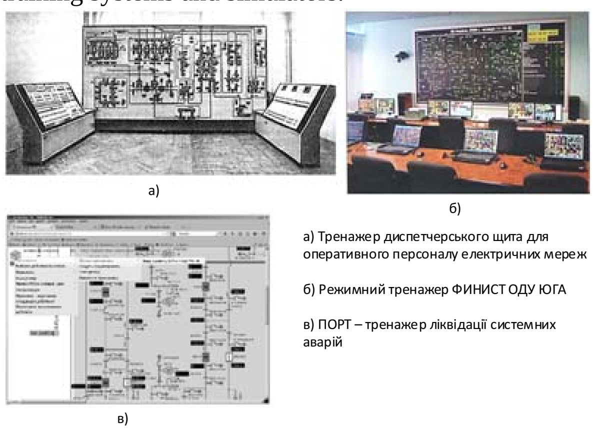
– a logical control block aimed to conduct training according to one or more ‘inflexible’ programmed scenarios – a set of sequences of operations required for a given problem or a given grid.

To acquire required skills for maintaining parameters of the power system mode in a given field under standard and emergency modes associated with sudden imbalances of active power and changes in the grid scheme, there are used mode simulators. They are actively applied to large-scale national power associations and companies of the USA, Canada, Western Europe, Russia and Japan. The mode simulator can be realized on:

– one of the OIC computers removed from the online mode during the training period;

– a computer intended for personnel's training.

In the 1990s, *TE*-2*M* was the most advanced simulator with both relatively simple and complex switching under standard modes with various (standard) schemes of substations as well as problems for dispatchers' independent actions to eliminate accidents. In subsequent years, universal programmed simulators have become popular including *Modus* and *TWR*-12. The simulators include a powerful graphic subsystem which enables reflection of electric grids of limitless sizes with the option of selecting a scheme in the given window. The schemes can be divided into functional blocks comprising separate parts and be united into multilevel hierarchical schemes. Under the supervision of Lyubarskyi, the simulator of the smart grid model *OPTIMAS* was created with multiple applications. The universal mode simulator *FENIKS* (Russia) is worth mentioning as it is widely used by dispatch departments and services of power associations. There are some other simulators used: *RETREN* (Russia), *Finist* (Russia), *KOMPAS-ASDU* (Russia), *EPRI OTS* (the USA), *FAST DTS* (the EU), and *PORT* (Ukraine). Fig 1 contains examples of technical training systems and simulators.



a) The dispatch board simulator for electric grid personnel
b) The mode simulator FINIST of the ODC
c) The accident elimination simulator PORT

Fig. 1. Examples of training systems and the stimulator.

The given analysis reveals that simulators allow increasing efficiency of emergency prevention in power systems. However, current statistics of the human factor impacts represents that 20-25% of all violations of block equipment modes and 30% of all failures in power engineering are caused by personnel's errors. About 90% of those committing a violation had good professional knowledge [10]. Considering the fact that human psychophysiological features have natural constraints to stress resistance, reaction extent, accuracy of big data processing with lack of time, it should be concluded that simulators are to be considered as an intermediate tool for limited improvement of the ODP efficiency. Smart DSSs are higher-level tools with greater reserves of growing efficiency of controlling power systems, i.e. intellectualization tools for power systems.

The research looks into the urgent problem of automatizing control over power grid modes by using software controllers of professional knowledge levels initiated by triggers of the controlled object.

Modern electric grids create a series of specific requirements both to the smart grid itself and to methods of designing it. Let us enumerate some basic requirements: simultaneous functioning with declarative and procedure forms of knowledge representation, identical functioning of the system under the modes of logical input in the knowledgebase and processing of the database, provision of the practical hardware interface with components of power objects and the automated dispatcher control system, implementation of the user visual interface with operating dispatch personnel (ODP), efficient translation into internal system codes and interpretation of controlling meta-rules, realization of the software mechanism of the inductive inference as transactions of meta-rules. The formulated requirements condition the necessity of a new exclusive approach to representing and visualizing structural and functional models of the software complex of the decision-support system (DSS). The model can be applied to solving the following problems: providing identical representation of algorithms of the DSS functioning and algorithms of knowledgebase translation and processing at all representation levels, actual fulfillment of the programme depending on parameters (signals) of conditions of the external surrounding of the smart system.

The research aims to investigate into new formalism of representing control algorithms of knowledgebases interacting with the external environment that aggregates primitives of states, triggers and transactions of operations and generalizes standard languages of algorithm visualization. Each formalism possesses both advantages and disadvantages as well as its preferential application fields. Analysis of their constraints is essential here.

4 Analysis of algorithm representation forms

The formal language of algorithm flowcharts is standardized and well tested. In most cases, based on a designer's talent, a problem can be reduced to visualizing the flowchart of an algorithm.

Dijkstra's flowcharts determine a certain alternative approach to visual modelling of algorithms [11]. Dijkstra introduced principles of structuring flowcharts, i.e. the topology constraint principle, the principle of vertical orientation of inputs and outputs, the single vertical principle, the principle of stringing typical flowcharts into a single vertical.

In order to 'consolidate' algorithm flowcharts and extinguish their complexity, the Nassi-Shneiderman method of visualization is suggested [12]. It ensures absolute observance of structured programming principles and top-down refinement of a problem without binding arrows.

The well-known transient graph is a graphical representation of the machine model. Automation formalisms are expressed by Mealy and Moore machines. Analysis of researches allows admitting the following models in formalizing algorithms – absence of a state hierarchy, generalization of transients.

The SWITCH-technology of designing and Harel's state charts are used as some solutions to the mentioned problems. The SWITCH-technology is based on representation of a programme as a hierarchy of interacting machines. The model enables recording external events.

R-charts are a technology of visualizing system design developed and applied in the Cybernetics Institute of the Academy of Sciences of Ukraine under the supervision of V.M. Hlushkov. Adoption of the standard indicates efficiency of the applied R-charts..

The L-network formalism suggested by M.F. Lekarev is an original solution in the field of modelling computing processes [13].

5 The state flowchart of the trigger DSS

The software current state triggers identify mode parameters at the input and generalize situational codes at the output. This state is associated with a transaction, the fulfillment of which implements operations related to the knowledgebase. Depending on the result of the transaction, the DSS proceeds to another state.

Fig. 2 contains a developed generalized flowchart of the DSS states based on transactions of meta-rules.

$$S = <Q, q_0, F, T, P>,$$

$$S = <s_i \mid s_i = <q_i, t_i, p_i>, q_i \in Q \vee q_i \in F \vee q_i = q_0>. \quad (7)$$

The flowchart conjugates with the chart of data interaction of the DSS with the external environment through hard- and software tools of the automatized dispatcher control system of the electric grid.

Let us introduce interpretation of components of the trigger state grid of the DSS. The series of operation positions (states) of the network is

The series of the network transients is

$$\Delta_\Sigma = \Delta \cup \Delta_t = \{\delta_i \in \Delta \vee \delta_i \in \Delta_i\}, \quad (8)$$

where Δ_Σ is a total series of network transients; Δ is a series of transients between the network states; Δ_t is a series of trigger transients of the network.

The series of the input functions is

$$I(S): S \to <Q_{-1}, V_\Sigma \cup W_\Sigma>, \quad (9)$$

$$I(s_i): s_i \to \{q_{i-1}, v_{i-1} \cup w_{i-1}\},$$

where Q_{-1} is a series of previous states as to the current state.

The series of output functions is

$$a: S \to s_a. \quad (10)$$

Thus, we reduce the machine trigger model to the operational trigger network of states

In the most general form, the example of model (11)

$$N_s = <S, \Delta\Sigma, I(S), O(S) >. \quad (11)$$

can be presented by the following graphical interpretation given in Fig. 3.

In the suggested model, a state is a block of a trigger, an operational transaction, and a result of calculations and output symbols (codes). We denote the state by a vertical line with the state indicator above. Depending on the obtained input codes, the network functioning becomes a branching process as a transient to the next state starts. If the state possesses more than one output, only one transient is chosen. Observance of the given condition guarantees unambiguity and determination of the performed algorithm. The operating cycle of the network is activity of a current state.

The presented considerations enable introducing the notion and the function of marking for the developed model of the operational state network. The presented considerations enable introducing the notion and the function of marking the operational state network for the developed model. The marking function in its essence is an activation function and it realizes choice of an active state out of a whole series of network states

$$a: S \to s_a, \quad (12)$$

where $\#(s_a)=1|s_a \in S$ is the only active state under the given cycle. The rest of the states are non-active − $\#(s_i) = 0 \mid \forall s_i \in S \wedge s_i \neq s_a$.

The marked state network will look like

$$N_s = <S, \Delta_\Sigma, I(S), O(S), a>. \quad (13)$$

On the basis of the developed state model, one can formulate a general principle of the network implementation. The network implementation (the course of implementing the computing algorithm of the software system) is determined by transients between states or state activation and denotes a step-by-step re-marking along some path on the state graph.

6 Algorithm implementation on the trigger state network

By solving the problem on the state network of the software system, we implement an algorithm expressed by a path on the transient graph. According to the structuring theory, the algorithm scheme can be reduced to a basis set of structures – a consequent cycle, branches and backouts (cycles). The trigger state model enables these principles.

The example of a fulfilled algorithm along the state path $s0 \to s2 \to snq \to s0$ of the considered network is reflected by the cycles presented in Fig.4. The trigger t_0 initiates the procedure.

Models enable specifying the model of a state depicted in Fig. 5.

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We should consider the fact that the programme is a sub-set of a set of paths on the graph of the state network.

$$PROG = B_{prog},$$

$$\forall s_{ik}\, \forall s_{ik+1}\, \forall k|\ s_{ik} \in S_i \wedge s_{ik+1} \in S_i \wedge k=1,2,\ldots,\ n_0{:}\, s_{ik} < s_{ik+1},$$

$$B_{prog} \subseteq N_s,$$

$$B_{prog} = \{b_i \mid I = 1,n_b\},$$

$$b_i = \{s_{i,k},\ s_{i,k+1},\ \ldots,\ s_{i,nbi,}\},$$

where PROG = Bprog is a programme (an algorithm of accomplishing a series of transactions); Bprog=$\{b_i|$i=1,$n_b\}$ is a set of branches (paths) of the algorithm of accomplishing the programme; b_i is the i-th branch of accomplishing the algorithm of the programme set as a strict sequence of states of the trigger network; N_s is a complete network of states.

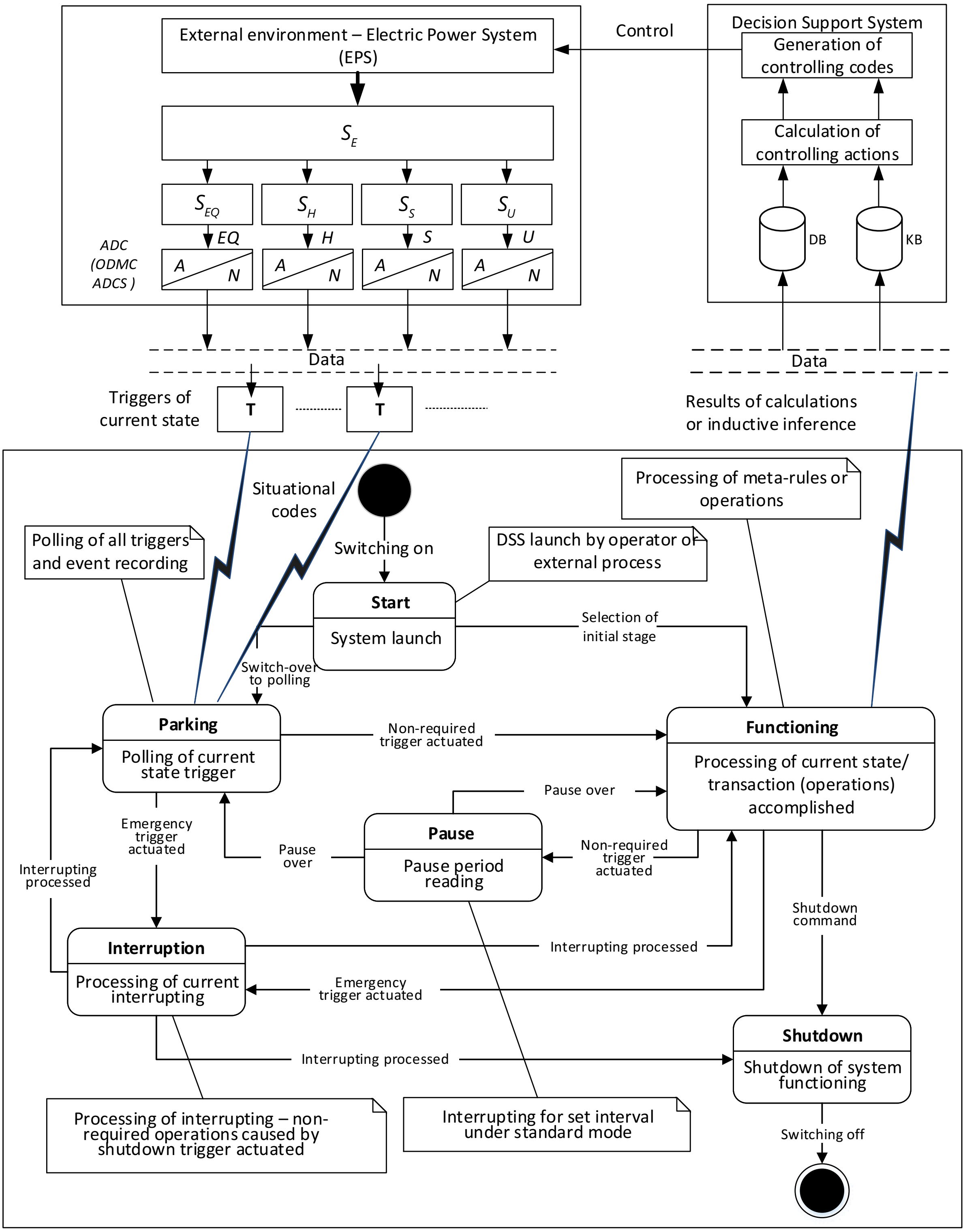

Fig 2. The state flowchart of the trigger DSS.

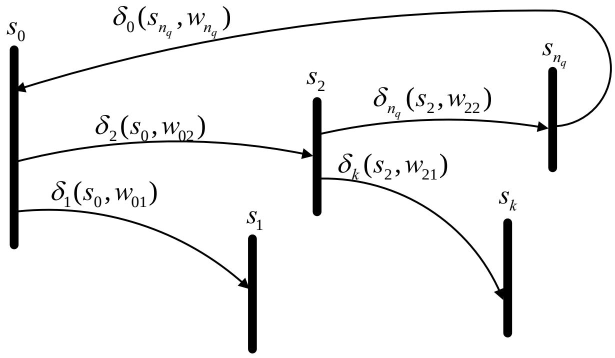

Fig. 3. The state flowchart.

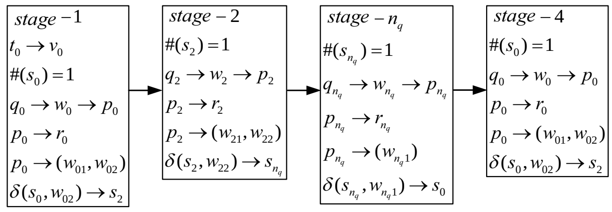

Fig. 4. Frames of step-by-step accomplishment of the algorithm on the trigger state network.

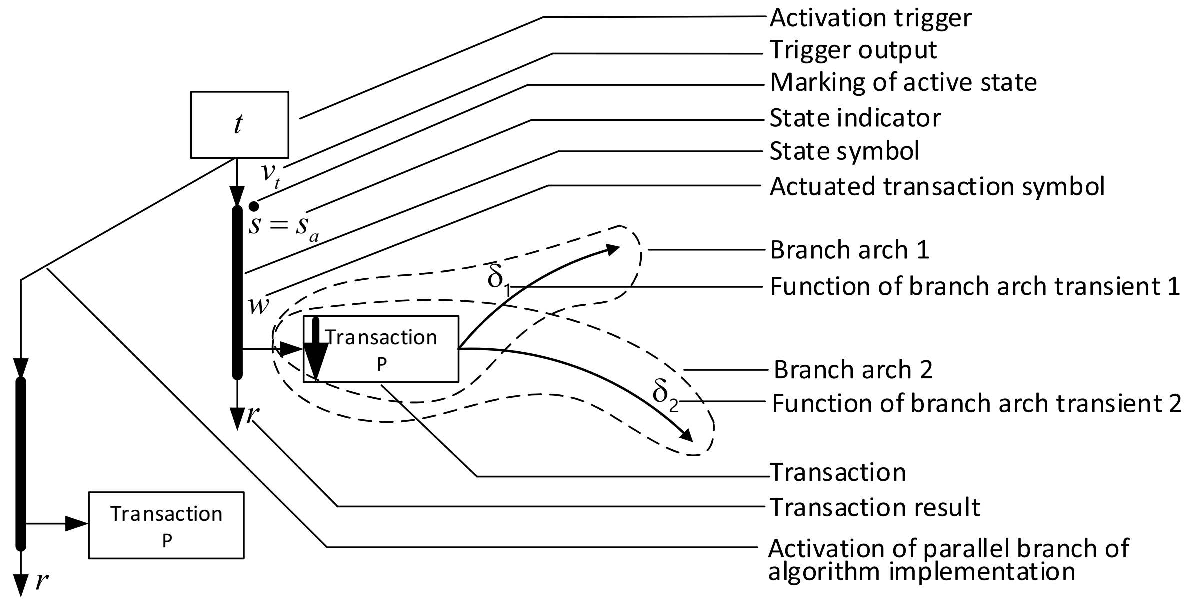

Fig. 5. A state of accomplishing the algorithm of the programme DSS system.

7 Practical software implementation of an automated system

Based on the obtained structural and logical models, a knowledge base was developed and the effectiveness of a professional thesaurus was evaluated.

Fig. 6 illustrates dynamics of relative efficiency of the thesauruses.

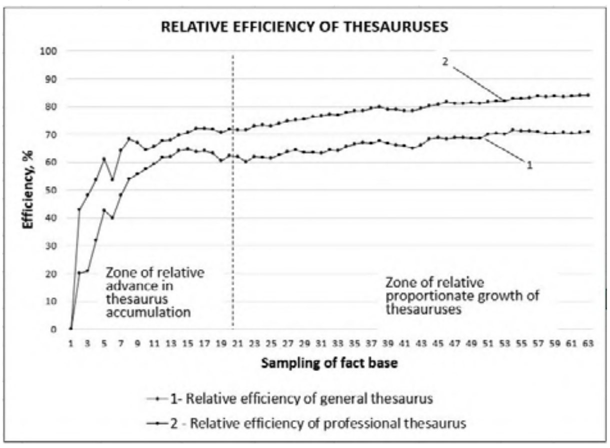

Fig. 6. Dynamics of growing relative efficiency indices of the general and specialized thesauruses.

The diagrams have two distinct zones – that of relative advance in thesaurus accumulation and that of relative proportionate growth of thesauruses. Efficiency of the specific slang and abbreviation thesaurus is higher than that of the general one. The zone of relative advance in thesaurus accumulation is characterized by accumulation of facts in a single terminological and semantic block while the thesaurus is formed rapidly and almost does not grow. The zone of relative proportionate growth of thesauruses indicates the increased volume of the linguistic corpus when new terminological and semantic blocks accumulate. In this case, the thesaurus starts growing again.

Expressions for calculating integral factors of efficiency of corresponding general and professional thesauruses of abbreviations and slang are given in the form of the formulae:

$$K_{ET} = \left(1-\frac{\alpha_T}{\alpha_B}\right)\cdot 100\% = \left(1-\frac{arctg(a_T)}{arctg(a_B)}\right)\cdot 100\%; \qquad (14)$$

$$K_{ETA} = \left(1-\frac{\alpha_{TA}}{\alpha_B}\right)\cdot 100\% = \left(1-\frac{arctg(a_{TA})}{arctg(a_B)}\right)\cdot 100\%,$$

where K_{ET} is an efficiency factor of the general thesaurus; K_{ETA} is an efficiency factor of the abbreviation and slang

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thesaurus; α_T is a slope angle of the approximated straight line for the general thesaurus; α_{TA} is inclination of the approximated straight line for the abbreviation and slang thesaurus; α_B is inclination of the approximated straight line for the fact base; a_T is a factor under V_{KB} in the straight line equation for the general thesaurus; a_{TA} is a factor under V_{KB} in the straight line equation for the abbreviations and slang thesaurus; a_B is a factor under V_{KB} in the straight line equation for the fact base.

Graphical results of approximation and explanations of calculations are given in Fig. 7.

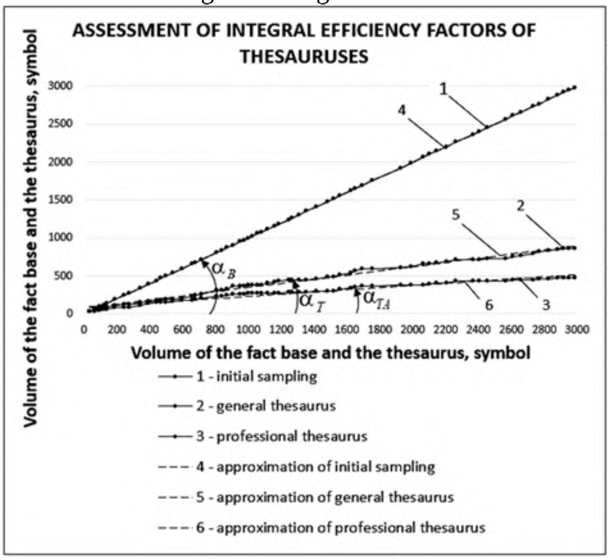

Fig. 7. Calculation of integral factors of thesaurus efficiency.

The physical meaning of the integral factor of thesaurus efficiency is a ratio of inclination of the approximated straight line of the thesaurus growth speed to the inclination of the approximated straight line of the growth speed of the initial base.

Substitution of calculated values provides the following results, %:

$$K_{ET} = \left(1 - \frac{arctg(0{,}2751)}{arctg(1)}\right) \cdot 100\% = 65{,}82;$$

$$K_{ETA} = \left(1 - \frac{arctg(0{,}1439)}{arctg(1)}\right) \cdot 100\% = 81{,}81.$$

Thus, calculations indicate that efficiency of the general thesaurus makes 65.82%, while that of abbreviations and slang is 81.88%. As a result, efficiency of application of knowledge bases increases when the DSS professional area is more specific. The professional area of emergency control over power system modes is highly specific and building its thesaurus is very reasonable.

After building the knowledge base and evaluating its effectiveness, the problems of connecting DSS to ADCS tools are solved. The main form of the developed software package is shown in Fig. 8.

8 Conclusion

There is a model of visualizing algorithms presented as a trigger network of states of a software system ensuring its interaction with the external environment. The trigger flowchart of states and event interaction of the DSS with power objects is developed. The machine model of the DSS functioning with specified semantics of states, transactions and triggers is implemented for the state flowchart. The developed model is generalized in relation to the classical machine model with an output. The model of visualizing a machine formalism as programme system states controlled by triggers is elaborated. Each state implements just one transaction of meta-rules.

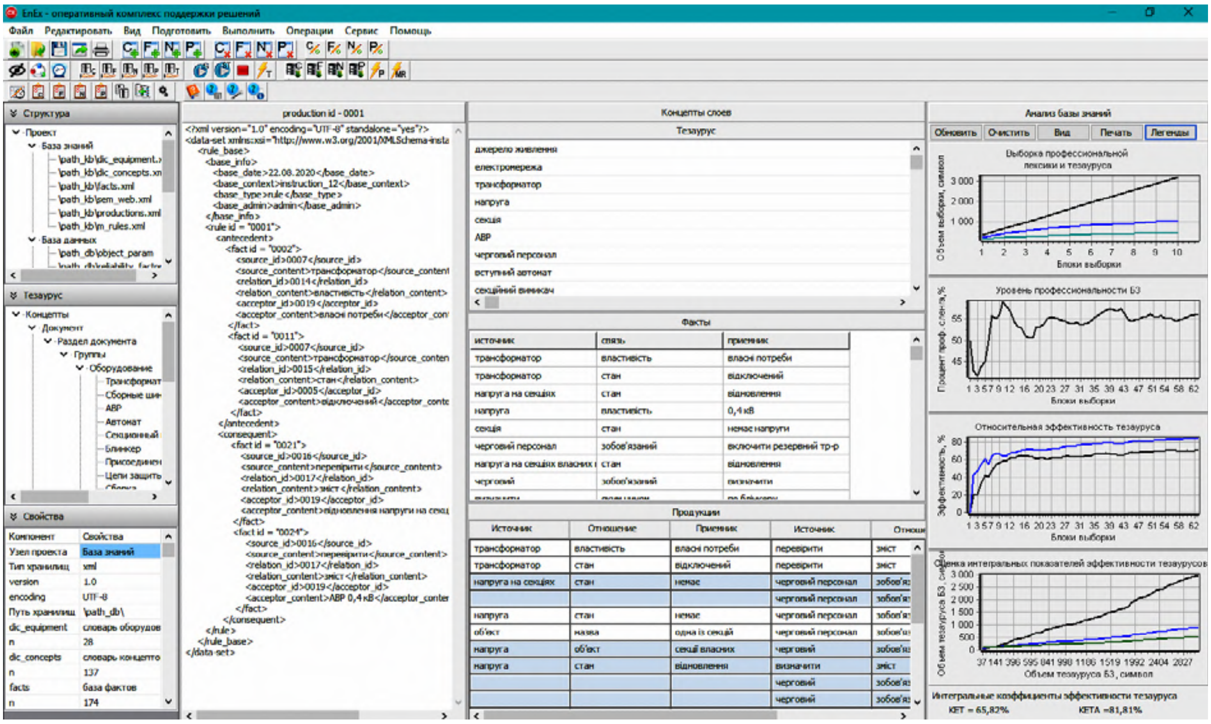

Fig. 8. The main form of the interface of the software package DSS.

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The research paper gives a developed structure and a fundamental generalized trigger flowchart of the algorithm of the DSS functioning. The suggested model of algorithm visualization presented as a trigger network of system states ensures interaction with the external environment. New interpretation of components of the trigger model is introduced.

Practical applicability, value and significance of the developed models and criteria for assessing efficiency of thesauruses are confirmed.

The assessment of the economic efficiency of the DSS in emergency modes of the power system. Metrics for assessing the quality of the DSS were developed and the quality of the developed DSS was assessed. DSS has shown advantages over analogues in terms of defining criteria. A methodology has been developed and the reliability of a dispatcher watch in emergency mode has been assessed. A quantitative assessment of the effect of increasing the reliability of the DCP from the use of the DSS in the elimination of an emergency violation of the EPS mode has been carried out. The practical increase in the reliability of the ODP from the use of the DSS in the elimination of the accident amounted to 37.2%. The use of the DSS provides an increase in the maximum permissible time of continuous operation of the ODP with a reliable elimination of the accident 1.5 years.

Further research involves developing flowcharts of interpreting the knowledgebase and an inductive inference block, which are functionally overlapped unlike the classical architecture of smart systems. It is suggested to include an ontology level selector into the DSS structure in order to select a form of knowledge and data representation online as well as modules of dynamic formation, verification and ontology replenishment.

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Modeling of thermal process in the energy system "Electrical network - asynchronous motor"

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Abstract. The paper discusses the influence of low-quality electricity on the temperature modes of operation of an asynchronous motor. In the course of experimental and analytical studies, the heat transfer coefficients and heat capacity of a particular electromechanical converter were determined. Experimental and analytical dependences of temperature changes of an asynchronous motor on time are given when it is connected to a supply voltage with different coefficients of sinusoidal distortion and negative sequence. The resulting model is tested for its adequacy to the real process and can be used as an element in the energy-economic model of an asynchronous motor to assess its uptime. This model that can be useful for simulation of thermal processes in asynchronous motors and optimising these devices for increasing the reliability.

1 Introduction

The presence of low-quality electricity in the shop networks of industrial enterprises leads to a decrease in the main indicators of the operation of asynchronous motors (AM), their accelerated physical aging, and, as a consequence, the occurrence of emergency situations. It is advisable to formulate this problem in the technical and economic plane, and its solution requires a detailed consideration of the system "electrical network - asynchronous motor" with the involvement of methods of mathematical modeling and implementation of computational experiments on a computer [1-3].

The economic assessment of various options for restoring electricity in shop networks to standard quality indicators is the basis proposed in [4-7] for a decision-making method for the operation of electrical equipment, including AM, operating in conditions of poor-quality supply voltage [8].

According to this methodology, according to the current indicators of the quality of electricity in the enterprise network [9-10] and on the basis of energy models [11-13] of the electromechanical converter, its energy indicators are calculated and the time interval of trouble-free operation.

In case of significant deviations of the indicators calculated in this way from the specified ones, various options for technical solutions for restoring the quality of the electric energy supplied to the engine are considered. For each of the options, a cost estimate is performed and a final decision is made on the conditions for its further work.

Wide experience in researching the effect of power quality on the operation of asynchronous motors with a has been accumulated by now [14-16].

Poor power quality in the workshops of industrial enterprises stipulates the increase in direct industrial costs due to the growing power consumption. Moreover, indirect costs related to the reduced operating life of electric machines are increasing as well.

As is known [10, 11], normative operating life of the all-purpose asynchronous motors is about ten years. However, that is true only for the cases when certain conditions are observed. The main condition here is the correspondence of the thermal mode of an electric machine to the insulation class.

Deterioration of the power quality results in the increase of heating losses and insulation temperature respectively. Combined with the overloads, that results in the considerable reduction of the operating life of the electric motors. Practice shows that in terms of 40% of all-purpose AM with nominal voltage of 0.4 kV, the operating life is 1.25-2 years [17].

The aim of the paper is to synthesize a mathematical model of an asynchronous motor, taking into account the influence of changes in the quality indicators of electricity on heating and heat transfer processes, for an economically justified choice of protective equipment.

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2 Materials and research results

To study the effect of the operating modes of an electric motor on its thermal conditions, so-called thermal models are applied [18-21]. They are the equivalent circuits where electric losses act as the heat sources; temperatures of structural components are within the nodes; and corresponding heat conductivities and capacities are located between them.

The considered models have different degree of detalization. A single-mass model, in which an electromechanical transducer is represented as a single homogeneous body with the overall temperature, is the simplest one. Although, the real temperature distribution is not uniform: temperature of the AM stator winding may exceed the case temperature by 15-20°C [22, 23].

More detailed models have minor prediction errors; however, that requires having additional data on heat conductivities and capacities of separate structural components of a motor. As a rule, such models are used only at the design stage. Besides, while applying those models, the transient-free thermal conditions are analyzed without consideration of their dynamics.

We consider that during the operation, it is the most expedient solution to use a single-mass thermal model; moreover, it is necessary to analyze the temperature of the AM component, being critical in terms of heating, - stator end winding – as the initial parameter of the model. It is well-known that this component is under the poorest cooling conditions since its thermal efficiency is effected mainly by means of the air.

A single-mass dynamic thermal model of the asynchronous motor is described by the following differential equation:

$$\Delta P = A \cdot \tau + \frac{\Delta\tau}{\Delta t} \cdot C \qquad (1)$$

here ΔP is the power of heating losses generated in the electric motor; τ is the exceedance of the motor temperature over the surrounding temperature; $\Delta\tau$ is the increment of the motor temperature per time Δt; A is the coefficient of thermal efficiency, J/(sec·C) (equal to the radiation heat loss per 1 sec in terms of the difference in the indicated temperatures τ = 1 °C); C is the heat capacity of the motor, J/°C. The indicated heat capacity is equal to the amount of heat required for AM heating by 1°C in terms of the nonavailable radiation heat loss.

As is obvious, equation of thermal balance (1) has two unknown values – A and C, which may be defined with the help of experimental data by composing a system of equations relative to the unknowns. In this context, it is possible to improve the accuracy of determining a coefficient of thermal efficiency and heat capacity of a motor at the expense of the totals of parameters measured in several experiments:

$$\begin{cases} \frac{\sum \Delta P}{N} = A \cdot \sum \tau + \sum \frac{\Delta\tau}{\Delta t} \cdot C \\ \frac{\sum \Delta P \cdot \tau}{N} = A \cdot \sum \tau^2 + \sum \frac{\Delta\tau}{\Delta t} \cdot \tau \cdot C \end{cases} \qquad (2)$$

Corresponding experiments have been carried out in terms of experimental workshop of Ukrspetsservis Ltd. Asynchronous motor of 4АХ80А4У3 type has been analyzed (nominal parameters are as follows: U_n=220/380 V (Δ/Y), P_n=1.1 kW, n_n=1400 rot/min, I_n=4.8/2.8 A, η=75%, cos φ=0.81).

The motor is loaded on a direct-current generator of П31У4 type (nominal parameters are as follows: U_n=230 V, P_n=1.0 kW, n_n=1450 rot/min, I_n=4.3 A, η=75%). During the experiments, AM was heated under the nominal load; the cooling took place in terms of the non-rotating rotor.

A hole was made in the motor cover to determine the temperature of winding faces with the help of laser pyrometer of Fluke 568 type. The hole was open only for a short period for measuring (5 sec); when the electric motor was operating, the hole was closed to prevent the heat exchange between the internal and external air. Currents and voltages were recorded with the help of a mobile measuring and diagnostic complex based on the current sensors of LA 25A type, voltage sensors LV100P (made by LEM, Switzerland), and AD converter E-440 (L-CARD, Russia). Table 1 shows the characteristics of the measuring channels.

Table 1. Characteristics of the measuring channels of a mobile measuring and diagnostic complex

Component	Characteristics
AD converter	
TYPE	E-440
Number of channels	16 differential ones
Digit capacity	12 bits
Conversion time	1.7 mcs
Input range	±5.12V;±2.56V;±1.024V;
Maximum conversion frequency	200 kHz
Zero shift	±0.5LOD; max 1LOD.
Voltage sensor	
TYPE	LV-400
Input range	0 – 500 V
Output range	0 – 10 V
Maximum static error	0.015%
Maximum dynamic error	0.03%
Current sensor	
TYPE	LA-100 C
Input range	0 – 250 A
Output range	0 – 10 V
Maximum static error	0.03%
Maximum dynamic error	0.08%

To eliminate the experiment error stipulated by the increased heating during the starting, the tested electric motor is accelerated with the help of a loading machine operating under the motoring conditions. Only when the facility reaches the idling speed, source voltage is supplied to the asynchronous motor, and a loading machine is placed in the dynamic braking mode (Fig. 1).

Table 2 represents the results of the experiment of test motor heating in terms of ideal supply voltage.

Fig. 2 shows the experimentally obtained curve of test motor heating in terms of ideal supply voltage.

Within the period of 62 minutes, the motor temperature has reached the final value of 76.3°C. The experiment results have made it possible to compose a system of equations (2) and to calculate the parameters of a single-mass thermal model. The parameters are as follows: coefficient of the motor's thermal efficiency while rotating is A=11.2 J/(sec×°C), heat capacity of the electric motor is C – 12.1 kJ/°C.

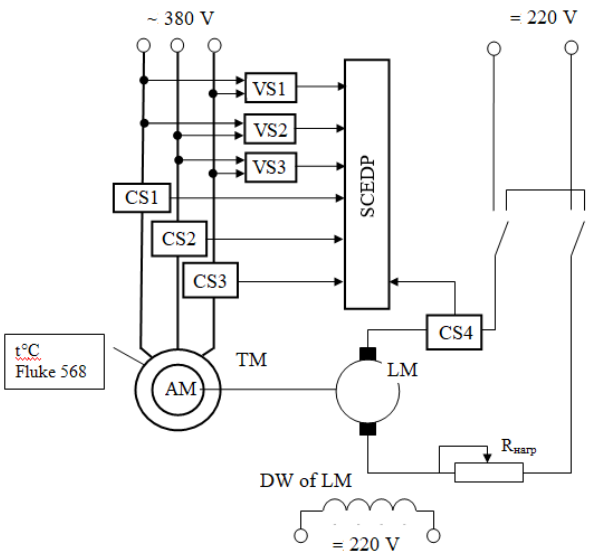

Fig. 1. Schematic of the experience to test adequacy of a thermal model of an asynchronous motor: TM, LM – test machine and loading machine; SCEDP– system to control electric drive parameters (measuring complex); VS – voltage sensor; CS – current sensor ; DW of LM – drive winding of loading machine.

Table 2. Results of experiment #1, ideal supply voltage.

Time, sec	Effective temperature value, °C	Temperature value predicted in terms of the model, °C	Absolute error, °C
0	0.0	0	0
120	5.4	6	1
240	10.4	12	1
360	12.0	17	5
480	14.7	21	6
600	26.1	25	-1
720	28.7	28	0
840	34.7	31	-3
960	37.6	34	-3
1080	40.1	37	-3
1200	43.4	39	-5
1320	45.0	41	-4
1440	46,7	42	-4
1560	47.7	44	-4
1680	48.7	45	-3
1800	50.0	47	-3
1920	50.0	48	-2
Final value	75.7	73	-2

Taking into account the fact that the reference literature contains rather scarce data on thermal parameters of the electric machines (as a rule, there is only the information concerning thermal time constants for motors of certain classes and power ranges), the considered method of their determination while identifying a specific AM model is rather topical.

Further, the heating experiments were carried out in terms of different degrees of distortion of the electric motor supply voltage. The experimental results are represented in Tables 3 and 4.

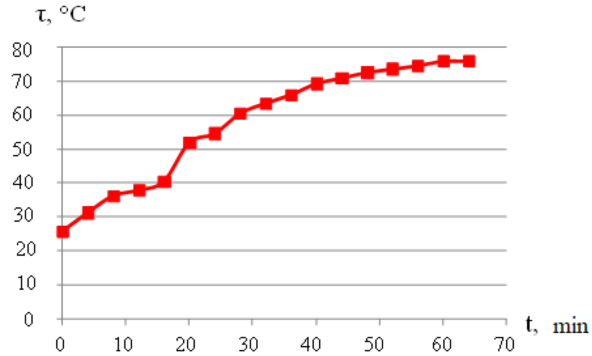

Fig. 2. Curve of motor heating while operating in terms of nominal load and ideal supply voltage.

Table 3. Results of experiment #2, distorted supply voltage.

Time, sec	Effective temperature value, °C	Temperature value predicted in terms of the model, °C	Absolute error, °C
0	0.0	0	0.0
120	12.0	12	0.1
240	23.1	21	1.7
360	30.8	29	1.6
480	33.9	36	-1.7
600	38.7	41	-2.0
720	44.0	45	-0.8
840	44.3	48	-3.9
960	52.0	51	1.0
1080	54.1	53	0.9
1200	54.4	55	-0.6
1320	56.4	56	0.0
1440	56.2	58	-1.4
1560	58.1	59	-0.5
1680	62.0	59	2.6
1800	58.9	60	-1.1
1920	61.2	61	0.6
Final value	86.0	86	0.0

Table 4. Results of experiment #3, distorted supply voltage.

Time, sec	Effective temperature value, °C	Temperature value predicted in terms of the model, °C	Absolute error, °C
0	0.0	0	0.0
120	13.8	13	0.6
240	21.9	24	-2.1
360	34.1	33	1.5
480	37.8	40	-1.9
600	46.9	45	1.5
720	47.9	50	-2.1
840	55.5	54	1.7
960	55.3	57	-1.6
1080	60.3	59	0.9
1200	61.1	61	-0.2
1320	64.3	63	1.4
1440	65.5	64	1.2
1560	62.8	65	-2.6
1680	62.8	66	-3.4
1800	69.7	67	2.8
1920	68.1	68	0.6
Final value	93.0	93	0.0

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Further experiments #2-4 were carried out in terms of different degrees of distortion of electric motor power supply. The quality indices of the latter (coefficient of distortion of the sinusoidal voltage curve k_U, coefficient of voltage unsymmetry on the reverse sequence ε_2) are given in Table 5.

Table 5. Power quality indices in the experiments and final temperature values of the AM winding.

Experiment No.	Coefficient of distortion of the sinusoidal voltage curve k_U, %	Coefficient of voltage unsymmetry on the reverse sequence ε_2, %	Final absolute temperature, τ°C
1	0	0	76.3
2	0	4	85.1
3	8	0	92.5
4	13.0	0	117.8

Experience #4 corresponds to the motor operation with the temperature exceeding the admissible one for that insulation class F(105°C); AM may be in such a state only for a short period of time due to the possibility of thermal breakdown of its windings.

The considered experiments have been used to test the adequacy of the proposed AM dynamic thermal model. Figures 3-5 show the comparison of the graphs of temperature exceedance of the motor over the surrounding temperature in those heating experiments with the calculated curves obtained with the help of electrochemical and thermal model of an asynchronous motor [24-26].

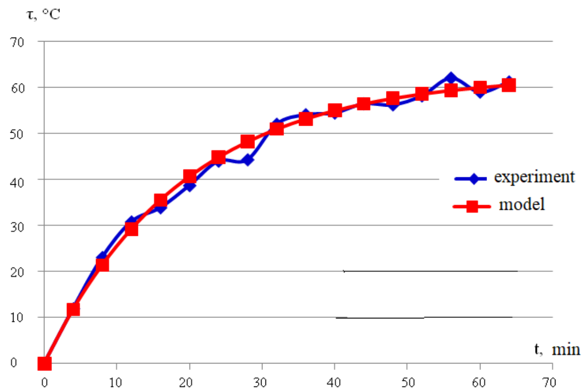

Fig. 3. Curves of motor heating in experiment # 2.

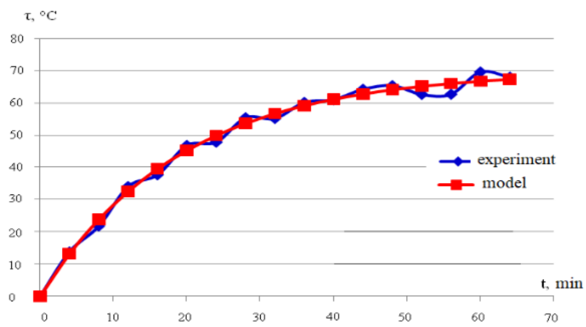

Fig. 4. Curves of motor heating in experiment # 3.

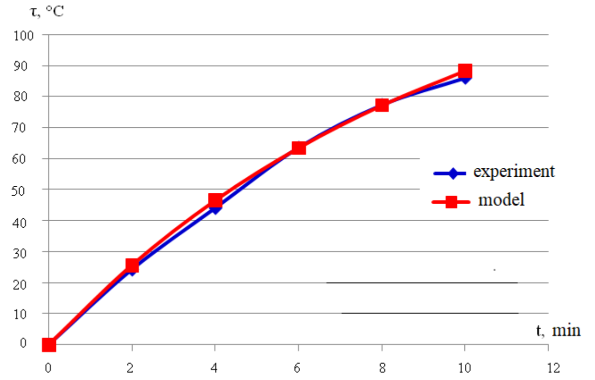

Fig. 5. Curves of motor heating in experiment # 4.

Next, error of the predicted temperature value in the heating dynamics was calculated. Fig. 6 demonstrates the experimental and calculated (predicted) temperature values for all the performed experiments which are used to test the model adequacy according to the method represented in [27-29]. In this context, different format of markers belongs to the corresponding experiments.

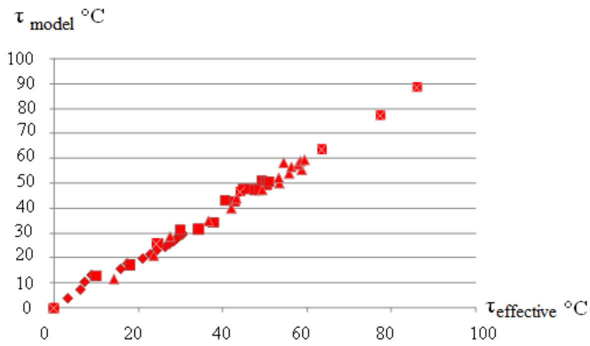

Fig. 6. Relations of the predicted $\tau_м$ and experimental τ_{ef} values of the temperature exceedance of AM winding.

The carried out test for the adequacy supposes obtaining of the following equation of linear regression:

$$Y_n^* = a_0 + a_1 Y_{ef} \qquad (3)$$

where

$$a_0 = \overline{Y_n} - r_{Y_{ef}Y_n} \frac{\sigma_{Y_n}}{\sigma_{Y_{ef}}} \overline{Y_{ef}};\ \ a_1 = r_{Y_{ef}Y_n} \frac{\sigma_{Y_n}}{\sigma_{Y_{ef}}} \qquad (4)$$

Here, $\overline{Y_n}$, $\overline{Y_{ef}}$ are the average values of the predicted and effective values; $r_{Y_{ef}Y_n}$ is the coefficient of correlation between them; $\sigma_{Y_n}, \sigma_{Y_{ef}}$ are the mean square deviations.

The indicated parameters were calculated according to the formulas:

$$r_{Y_{ef}Y_n} = \frac{\sum_1^L (Y_{ef} - \overline{Y_{ef}})(Y_n - \overline{Y_n})}{L\sigma_{Y_{ef}}\sigma_{Y_n}}, \qquad (5)$$

$$\sigma_{Y_{ef}} = \sqrt{\textstyle\sum_1^L \left(Y_{ef} - \overline{Y_{ef}}\right)^2/(L-1)}, \qquad (6)$$

$$\sigma_{Y_n} = \sqrt{\textstyle\sum_1^L \left(Y_n - \overline{Y_n}\right)^2/(L-1)}, \qquad (7)$$

where L=57 is the volume of statistic sampling (number of the temperature measurements in all the experiments).

The mean square absolute error of measurements was determined as:

$$\Delta Y_n = t_p \sigma^*_{Y_n}, \quad (8)$$

where t_p is the Student's coefficient for the given reliability and number of freedom degrees $k = L - 1$. In the case under consideration, reliability was taken as $p = 0.05$. Here, $\sigma^*_{Y_n}$ is the residual mean square deviation calculated according to the formula:

$$\sigma^*_{Y_n} = \sqrt{\sum_1^L (Y_n - Y^*_n)^2/(L-1)}. \quad (9)$$

The mean square relative error of prediction was determined as follows:

$$\delta_{Y_n} = |\Delta Y_n| / Y_{nmax} \quad (10)$$

where $Y_{n\max}$ is the highest value of the predicted one.

Finally, the obtained values are as follows:
σ_{Yef} = 21.2 ºC, $\sigma_{Y\pi}$ = 20.9 ºC, $r_{YefY\pi}$ = 0.99,
σ^*_{Yn} = 2.34 ºC, ΔY_n = 0.28 ºC, δ_{Yn} = 3.2%.

Conclusion

The obtained results show the adequacy of the proposed thermal model of an asynchronous motor operating in the mains with poor quality power. Taking into consideration the fact that in terms of many motor types, reference literature does not contain the required data on the coefficients of thermal efficiency and thermal capacity, and only thermal constants of time are given for certain motor types, values of the specified parameters of the model may be obtained basing on the methodology represented in the paper.

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Modeling and simulating dynamics of lithium-ion batteries using block-oriented models with piecewise linear static nonlinearity

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Abstract. The article deals with the research of the efficiency of modelling the dynamics of voltage change in lithium-ion rechargeable batteries in charging/discharging modes using nonlinear block-oriented systems. Drawing on experimental data, a structural and parametric identification of the Hammerstein, Wiener and Hammerstein-Wiener models with a polynomial structure of the linear dynamic block and piecewise linear static nonlinearities was performed. It has been established that the best modelling accuracy was ensured by using the Hammerstein-Wiener system with a linear model having the 6th order of the numerator and denominator polynomials and an input delay of 3 samples. It showed 15.67% and 6.2% higher accuracy compared to the Wiener and Hammerstein systems, respectively. The application of those models in battery management systems will make it possible to improve the control quality for battery assemblies of solar and wind power plants in the context of the variable nature of the charging/discharging processes due to the variability of weather conditions and fluctuations in power consumption during a 24-hour period. This will ensure a wider introduction of renewable power generation into existing power systems, which is currently the leading way to ensure sustainable development of the energy sector.

Introduction

The need to increase generating capacities due to the constant increase in demand for electricity makes the use of traditional energy resources inefficient. This is primarily explained by the rapid depletion of reserves of extractable fuel and energy resources, as well as by high emissions level of harmful substances that is characteristic of processing those resources, and by low enough efficiency of energy conversion.

As a result, designing electricity generation systems that use renewable energy sources and their further integration into existing electric power networks has now become the leading area of the power industry's sustainable development.

Solar and wind energy are by far the main renewable energy sources. One of the features of power plants that use such energy resources is the mismatch (imbalance) between the levels of electric power generation and consumption. This is due to the uneven nature of electric power consumption during the 24-hour period and the variability of weather conditions. In the first case, the efficiency of a power plant is reduced due to the fact that not all electricity produced is fully consumed. In the second case, the power plant does not provide the consumer with electricity, power outages occur, which leads to financial losses of the respective energy company due to non-compliance with contractual terms and conditions.

Thus, for example, at solar power plants, the maximum amount of power is produced during daylight [1] provided that the day is cloudless and the maximum insolation of the working surface of the solar panel is ensured, while the peak of power consumption occurs in the evening and at night. At wind farms, under unfavourable wind conditions, when the wind speed is within the range of the limit value necessary to start the wind turbine, electricity may not be generated at all [2]. Such periods can last for long timespans, sometimes even several days.

In order to reduce fluctuations in output power supply, solar and wind power plants are provided with energy storage facilities. As such facilities, secondary electrochemical sources of electric current that are characterized by the property of multiple recharging are used. In the alternative power engineering, lead-acid rechargeable batteries are the most common, but since some time ago, they have been in the process of being replaced by lithium batteries, in particular, lithium-ion (Li-ion) and lithium-metal-phosphate ($LiFePO_4$) ones. This is due to the fact that lithium batteries have a higher power density, smaller dimensions and a low cost.

The special features of lithium batteries are the operating voltage that ranges from 3.7 to 4.2 V (lithium-ion) or from 3.2 to 3.5 V ($LiFePO_4$), the inadmissibility of overheating, the non-renewable loss of capacity when discharged to a voltage value below 2.7… 3 V, the accelerated degradation when recharged above 4.2 V (lithium-ion) or 3.5 V ($LiFePO_4$), as well as the limited

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capacity of an individual battery. In order to create large storage capacities at grid-connected power plants integrated into central power systems, as well as at standalone power plants, lithium batteries must therefore be combined into series-parallel assemblies (battery packs).

The main condition for creating significant storage capacities on the basis of battery packs is the use in those packs of the batteries of the same type and with the same or slightly different parameters. That is, it would be highly ill-advised to incorporate lead-acid and lithium-ion batteries in one energy storage system.

For reliable operation of a battery pack, all connected elements must have the same level of voltage and capacity. The presence of at least one constituent element with different parameters leads either to the premature full discharge of the differing battery below the allowable discharge voltage value during discharging, which causes a non-renewable loss of capacity, or to exceeding the maximum voltage level during charging, which causes overheating of the battery in question and its thermal destruction. As a result, the load on other batteries in the pack increases, which leads to an acceleration of discharging and a decrease in the output voltage of the entire energy storage system of the power plant. This significantly reduces the efficiency of the power plant, because the charging rate of the batteries by the generating equipment may be lower than the intensity of their discharging. The resulting decrease in the output voltage of the energy storage system reduces the energy conversion efficiency by the inverter, through which the consumer receives power. There may also occur a situation where the voltage in the DC link drops below the permissible level, and the energy conversion with the subsequent transfer of the electric power into the network can stop altogether.

In order to eliminate the above situations, the processes of charging/discharging batteries are controlled using protection functions. Battery management systems (BMS) are used for that purpose. The operation efficiency of such a system depends primarily on the accuracy of measuring electrical parameters and predicting on their basis, depending on the mode of operation, the state of an individual battery and the pack as a whole. For predicting purposes, it is necessary to have a model that describes the battery charging/discharging processes with sufficient accuracy. In addition to direct simulation of the operation of a rechargeable battery-based energy storage system for the application as part of the BMS, such a model is also used in the control of generating and converting equipment of power plants that use renewable energy sources [3, 4], and electrical loads connected to battery packs, in particular, electric motors [5]. That makes it possible to improve the quality and reliability of operation.

1 Literature review

A fairly large number of papers deal with the development of rechargeable battery models. That being the case, approaches to simulating the main modes of operation of the principal types of batteries used in energy storage systems of power plants are considered, but special attention is paid to lithium batteries.

All models can be divided into analytical ones, which include electrochemical models [6–11] and models based on electrical replacement circuits [12–19], and data-driven ones [20–31].

Analytical models describe in detail the physical and chemical processes that occur when the battery is charged/discharged. Such models take into account a large number of parameters and use systems of differential equations and partial differential equations. This leads to high accuracy and illustrative nature of such models, but their calculation is accompanied by a high computational load, which reduces their efficiency when used in digital control devices with limited computing resources. Analytical models are convenient to use for studying modes of operation of batteries and establishing new patterns of the ongoing processes.

The research results presented in papers [32–35] show that the most efficient method for estimating the parameters of analytical models made, in particular, on the basis of equivalent replacement circuits is the use of the extended Kalman filter (EKF). Such an approach makes it possible to conduct even quick identification of the parameters of the battery model under the conditions of constantly changing characteristics during operation. However, the peculiarity of such a method lies in reducing the nonlinear model of the plant to a linearized one in the space of states and, as a result, in modelling the operation of the energy storage system in the operating point area. This significantly reduces the accuracy of the model for an essentially nonlinear plant, such as a rechargeable battery.

Data-driven models make it possible to predict the output values of an energy storage system only according to the law of change of input values without taking into account the internal processes of electrochemical transformation. They are characterized by high accuracy at low computational loads upon structural and parametric identification. An important distinctive feature of such models is the possibility, when using certain algorithms, of adapting to changes in the operating conditions of the object. Given the fact that the parameters of batteries, such as their maximum capacity, change with each charging cycle because of degradation processes, the presence of an adaptation mechanism improves the quality of such a model. Data-driven models can be used both when simulating individual batteries and the entire power storage system as a single object. They are therefore convenient to use when handling operational control tasks.

To date, a number of studies have been conducted dealing with the development and investigation of data-driven models of lithium-ion, lithium-polymer and lead-acid batteries used in solar and wind power plants. The main purpose of those studies was to predict such parameters as the battery voltage level during the discharging process, state of charge (SoC) or the depth of discharge (DoD), as well as the remaining useful life (RUL) or the state of health (SoH).

According to the type of response, data-driven models can be divided into linear and nonlinear ones.

Among linear models, polynomial structures are widely used. In papers [20, 21], it was proposed to simulate the modes of operation of lithium-ion batteries using autoregressive models with exogenous input (ARX), whose parameters are estimated by the EKF algorithm, the features of which have been described above. In paper [22], the model based on the equivalent replacement circuit is approximated using the ARX system. A parametric identification of the ARX model is performed based on the full set of experimental data using the least squares method, which reduces the adaptability of the model.

Given the nonlinear nature of the electrochemical processes occurring in a rechargeable battery, it can be argued that the scope of application of linear models is quite limited. Therefore, nonlinear models are normally used.

Machine learning methods are widely used to model and predict the state of rechargeable batteries. The models used for that are nonlinear, have pre-known structure defined at the stage of structural optimization [23], and apply experimentally obtained data for parametric identification. That is, they can be classified as data-driven models.

In papers [24, 25], studies are presented of a classical artificial neural network, a multilayer perceptron, that is a universal approximator, used to predict the RUL of the battery, but it does not always accurately describe the dynamic characteristics of the nonlinear plant. However, parametric identification algorithms for such a model are characterized by high quickness.

The nature of changes in the electrical parameters of the battery is modelled more precisely by recurrent neural networks. In papers [26] studies are presented of a recurrent neural structure based on a nonlinear autoregressive model with an exogenous input (NARX) used to indirectly estimate the RUL and SoC of a lithium-ion rechargeable battery. The studies presented in papers [27, 28] deal with predicting the RUL of a battery using an LSTM network having a recurrent architecture. The results obtained by the authors show that the models in question ensure a low error rate in relation to simulation and experimental data, but create a high computational load during the identification.

In order to predict the SoH and RUL of lithium-ion batteries, deep learning by means of neural network models with many hidden layers is also used [29]. As with recurrent neural networks, these networks can ensure high prediction accuracy, but require a significant amount of time for the structural and parametric identification.

In papers [30, 31], it was proposed to predict the SoC and SoH using an adaptive neuro-fuzzy inference system (ANFIS).

The analysis of literature data has shown that insufficient attention is paid to block-oriented models when simulating the dynamics of a rechargeable battery. At the same time, those models demonstrate high accuracy of simulating nonlinear dynamical systems, which is natural due to a distinctive feature of the configuration, i.e. the presence of a separate dynamic block in the structure of the model. The identification of parameters of such models is efficiently carried out both in off-line and on-line modes based on the algorithms given in [36, 37], which allows those models to be used in digital control systems.

2 Structure of nonlinear block-oriented systems

In order to model and predict the modes of operation of a rechargeable battery, this research proposes to use block-oriented systems. This is due to the fact that these models accurately describe the dynamics of essentially nonlinear plants [38]. Block-oriented systems contain two parts in their structure: a linear dynamic block and a nonlinear static one. Depending on the relative position of these parts when converting an input signal into an output one, the Wiener, Hammerstein, and Hammerstein-Wiener models are distinguished. The structures of those models are shown in Fig. 1.

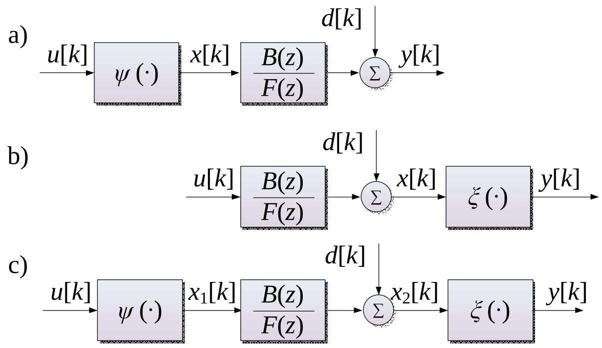

Fig. 1. A function block diagrams of the typical block-oriented systems: a) Hammerstein system, b) Wiener system; c) Hammerstein-Wiener system.

In the Hammerstein model (Fig. 1, a) a dynamic linear block is preceded by a linear static one, while in the Wiener model (Fig. 1, b), the opposite is the case, i.e. a linear block is placed before a nonlinear one. That is, these systems contain one element of each type in their structure. The Hammerstein-Wiener system (Fig. 1, c) consists of two static nonlinear blocks, at the input and output of the model, between which a linear dynamic block is placed.

Mathematically, the above structures are described by the following formulas.

The Hammerstein model:

$$\begin{aligned} x[k] &= \psi\left(u[k]\right); \\ y[k] &= \frac{B(z)}{F(z)} x[k - N_z] + d[k], \end{aligned} \tag{1}$$

where $u[k]$ – model input;

$y[k]$ – model output;

$d[k]$ – disturbance;

$\psi(\cdot)$ – input nonlinearity;

$N_F + 1$ – order of the denominator polynomial $F(z)$;

N_B – order of the numerator polynomial $B(z)$;

N_z – number of input delay samples.

The Wiener model:

$$x[k] = \frac{B(z)}{F(z)} u[k - N_z] + d[k]; \qquad (2)$$
$$y[k] = \xi(x[k]).$$

where $\xi(\cdot)$ – output nonlinearity.

The Hammerstein-Wiener model:

$$x_1[k] = \psi(u[k]);$$
$$x_2[k] = \frac{B(z)}{F(z)} x_1[k - N_z] + d[k]; \qquad (3)$$
$$y[k] = \xi(x_2[k]).$$

The linear part of a block-oriented system can be represented by a transfer function, a state-space model [38], a system of orthogonal basis functions (Laguerre [39], Kautz, Legendre), etc. However, the most widely used polynomial input-output models (BJ, ARX, ARMAX, OE) [38]. According to [40], when modeling dynamic systems, in contrast to prediction, linear polynomial models of the output error (OE) structure are used as part of nonlinear models. In such models, the output depends only on the past values of the input [40], taking into account the disturbances. Since in this paper the problem of modeling the dynamics of lithium-ion batteries is investigated, the OE model is adopted as the structure of the linear part of block-oriented systems.

Piecewise linear functions are used as static nonlinearities $\psi(\cdot)$ and $\xi(\cdot)$. Such an approach ensures flexibility during the identification, since linear functions can be used to approximate a function of any kind. That being the case, the accuracy will depend on the number of linear functions. Also, using a linear function, it is possible to determine the inverse function with low computational load, which simplifies the application of the obtained block-oriented model in digital control systems.

When conducting an analysis of the efficiency of using block-oriented structures for modelling the modes of operation of lithium-ion batteries, it is advisable to apply the following accuracy indicator of the model:

$$e = \left(1 - \frac{\sqrt{\sum_{i=1}^{N} \left(y[i] - \hat{y}[i] \right)^2}}{\sqrt{\sum_{i=1}^{N} \left(y[i] - \bar{y} \right)^2}} \right). \qquad (4)$$

where $y[i]$ – plant output at the i-th sample;

$\hat{y}[i]$ – model output at the i-th sample;

$\bar{y}$ – mean value of the plant's output;

N – number of samples.

This indicator is used due to the clarity and simplicity of calculation. When estimating the accuracy of the plant approximation by data-driven model, it is convenient to use the relative dimensionless errors, rather than errors in units of electrical parameters. This greatly simplifies the analysis and interpretation of experimental results.

3 Simulating dynamics of a lithium-ion rechargeable battery using block-oriented systems

When performing the research, the measurement results for electrical parameters of lithium-ion batteries during charging and discharging conducted and published by NASA were taken as experimental data [41].

The value of the battery voltage during operation, whose dynamic characteristics were approximated by nonlinear models, was assumed as an output variable.

In order to perform a structural and parametric identification of block-oriented systems, Dataset 1 [41] for Battery No. 5 with a nominal capacity of 2000 mAh containing 167 recharging cycles was used. For each recharging cycle, the data was divided into three data frames corresponding to charging, discharging, and impedance measurements. The battery was discharged with a load current of 1C.

Prior to conducting computational experiments, preliminary data preparation for identification was performed as follows. The measured battery voltage in the data frames for charging and discharging during each cycle was combined into one common array. The values of charging and discharging currents were also combined into common arrays, but for the periods that do not correspond to the actual mode of operation some currents were assigned a zero value. That is, the discharging current during charging process and the charging current during discharging have zero value.

At the first stage of the research, a structural and parametric identification of the linear dynamic part of the block-oriented model was carried out (Fig. 2). That being the case, the static nonlinear block had a fixed structure and consisted of 10 linear functions. The parametric identification of the model was carried out using the gradient descent method.

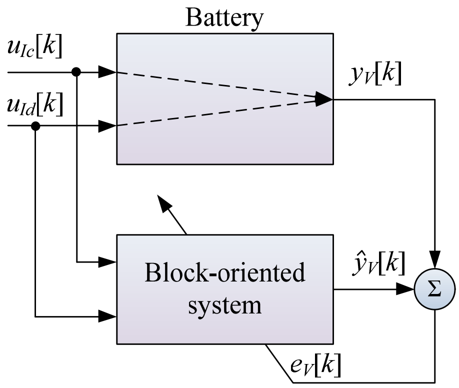

Fig. 2. A function block diagram of the block-oriented model identification process.

For Systems (1) - (3), direct scanning for parameters corresponding to the order of the linear dynamic block's polynomial model's numerator and denominator was performed, as well as that for the value of the input delay in the range from 1 to 6. As a result, 216 structures were obtained for each type of the block-oriented system. The data obtained in the computational experiments for the Wiener, Hammerstein and Hammerstein-Wiener models are shown in Tables 1 to 3. Ten models of the respective type were summarized in each table indicating the parameters of the linear dynamic part that demonstrated the best agreement between the simulation data and the experimental ones.

The analysis of the results for the Wiener system (Table 1) shows that the model, whose polynomial orders for linear blocks $F(z)$ and $B(z)$ are $N_F = 6$ and $N_B = 4$, has the best accuracy, with an input delay standing at $N_z = 4$ samples. The next most accurate model with the $N_F = 3$, $N_B = 3$, $N_z = 1$ structure has 4.35% lower value of the agreement between the simulation and experimental data (4). At the same time, the number of parameters that need to be determined is 2 times lower (7 vs. 14), which leads to a faster parametric identification. Using a personal computer with AMD Athlon II X4 645 3.10 GHz and 8 GB DDR3 RAM configuration, the identification process of Wiener 2 model was performed in 29.56 seconds, while that of Wiener 1 model was done in 33.99 seconds. When using digital control devices with limited computing resources, it is therefore advisable to use Model 2.

Table 1. The results of simulating the dynamic characteristics of the battery using the Wiener model.

No.	N_B	N_F	N_z	e, %
1	4	6	4	77.2154
2	3	3	1	73.8597
3	3	2	5	73.5438
4	5	2	3	73.4139
5	5	4	5	73.3675
6	6	2	6	69.8759
7	4	3	4	69.8349
8	4	3	5	69.5251
9	5	5	3	68.7211
10	4	4	1	68.5545

It should be noted that for structures 2 to 5 and 6 to 10 (cf. Table. 1) the error value differs insignificantly. Thus, the accuracy of Model 5 is only 0.67 % lower than that of Model 2, while the accuracy of Model 10 is 1.89 % lower than that of Model 6.

Models of the following structures that are not shown in Table 1 had the worst quality of simulating the dynamics of the battery voltage changes: $N_F = 4$, $N_B = 6$, $N_z = 4$ ($e = 1.0775$); $N_F = 2$, $N_B = 3$, $N_z = 3$ ($e = 1.7085$); $N_F = 5$, $N_B = 3$, $N_z = 1$ ($e = 1.2831$).

The structural identification of the linear part of the Hammerstein model was carried out next. The results of that identification are shown in Table 2.

A system with the $N_F = 2$, $N_B = 3$, $N_z = 5$ structure showed the best agreement between the model and the plant. The next most accurate model, the Hammerstein one (2, Table 2), has an agreement indicator that is 1.3% lower (4). Given that the number of parameters of the linear block for Structures 1 and 2 is identical, it is advisable to use Model 1 during practical implementation. The identification time for Hammerstein model 1 was 46.59 seconds, while that for Hammerstein model 2 was 46.78 seconds.

Table 2. The results of simulating the dynamic characteristics of the battery using the Hammerstein model.

No.	N_B	N_F	N_z	e, %
1	3	2	5	84.1008
2	3	6	1	82.9962
3	6	5	4	81.8405
4	4	4	2	80.4190
5	6	3	3	77.3667
6	5	4	6	76.2313
7	4	1	6	75.8068
8	3	5	4	74.6718
9	6	5	3	73.6970
10	4	2	6	73.3308

The accuracy of Hammerstein model 1 (Table 2) is 8.92 % higher than that of the Wiener system that has the best quality of simulating the battery dynamics among the models of its type (Table 1). In addition, the number of parameters that need to be estimated is fewer in the Hammerstein system than in the Wiener one, and is 10 versus 14. That is, the computational load of the parametric identification process for such a model is lower.

Let us note that as many as 5 models of the Hammerstein system (1 to 5, Table 2) have a better accuracy than Model 1 of the Wiener structure (Table 1).

A structural identification of the Hammerstein-Wiener model was carried out last at this stage of computational experiments (Table 3). On the whole, this structure demonstrates the best accuracy of modelling the dynamic characteristics of a rechargeable battery. All ten block-oriented systems of this structure have a better agreement with the experimental data compared to the most accurate Wiener and Hammerstein models. Model 1 of the Hammerstein-Wiener system ensures 15.67 % and 6.2 %, while Model 10 does 10.86 % and 1.79 % higher accuracy than Model 1 of the Wiener system (Table 1) and Model 1 of the Hammerstein system (Table 2), respectively.

Table 3. The results of simulating the dynamic characteristics of the battery using the Hammerstein-Wiener model.

No.	N_B	N_F	N_z	e, %
1	6	6	3	89.3127
2	3	4	1	88.0813
3	3	6	3	87.6644
4	5	4	5	86.9817
5	6	3	4	86.7851
6	3	5	5	86.7353
7	6	6	5	86.2524
8	3	5	2	86.0781
9	6	4	3	85.7581
10	3	4	3	85.6027

The agreement index (4) for the two most accurate models of the Hammerstein-Wiener system differs insignificantly. In Model 2, it is only 1.4% lower compared to Model 1. However, for the structure of the linear block of Model 2, it is necessary to determine 7 parameters fewer than for Model 1. The time of the parametric identification for Hammerstein-Wiener 1 model was 55.68 seconds, while that for Hammerstein-Wiener model 2 was 51.56 seconds. That is why it is advisable to use the Hammerstein-Wiener system with the $N_F = 4$, $N_B = 3$, $N_z = 1$ structure of the polynomial dynamic model in a digital control device to ensure a low computational load while providing high quality simulation of the battery dynamics.

A graphical interpretation of the results of the computational experiments is shown in Fig. 3 to 6. For better clarity, two block-oriented systems of each type that had demonstrated the best agreement with the experimental data were depicted in the figures.

Fig. 3 shows the voltage change in a real rechargeable battery and block-oriented models for the first seven recharge cycles. The graphs demonstrate that during the first three cycles, Hammerstein model 2 and Wiener model 1 have a significant error rate when simulating the charging process.

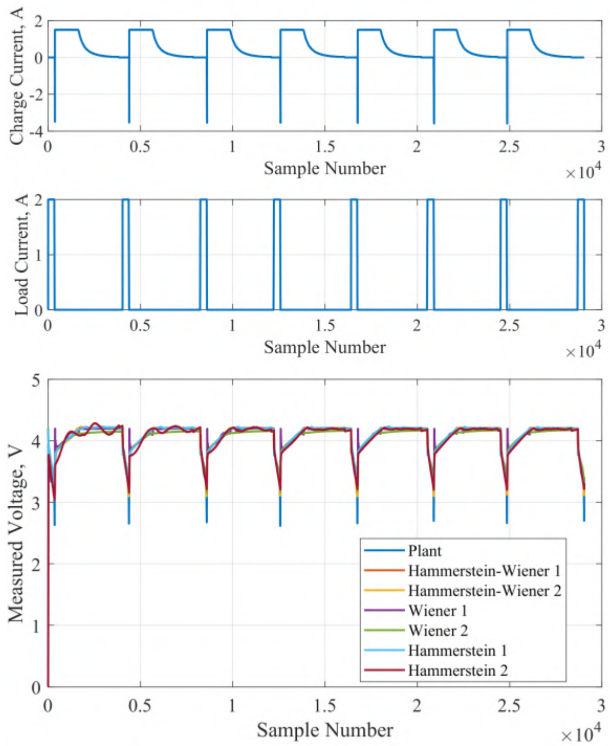

Fig. 3. The results of modelling changes in the battery voltage when using block-oriented systems.

This is corroborated by the detailed graphs shown in Fig. 4 for the first charging cycle. Wiener 1 model poorly describes the initial stage of the charging process, when the charging current is maintained constant (CC mode), while Wiener 2 model, on the contrary, has a high deviation from the experimental data at the stage, when the battery is charged at a constant voltage (CV mode). Hammerstein-Wiener models 1 and 2, as well as Hammerstein model 1, have the best fit.

After the fourth cycle, the accuracy of the models increases. This is evidenced by the graphs shown in Fig. 5.

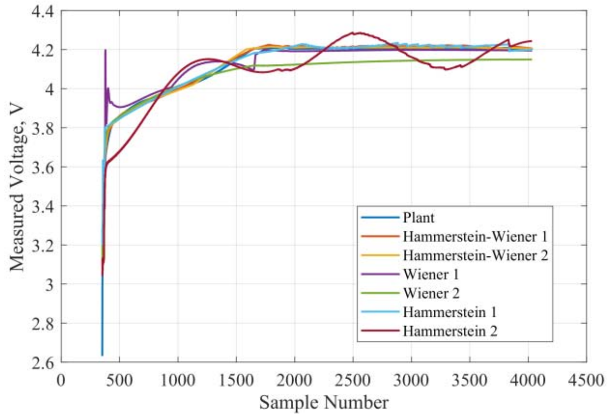

Fig. 4. The results of modelling changes in the battery voltage during the first cycle charging

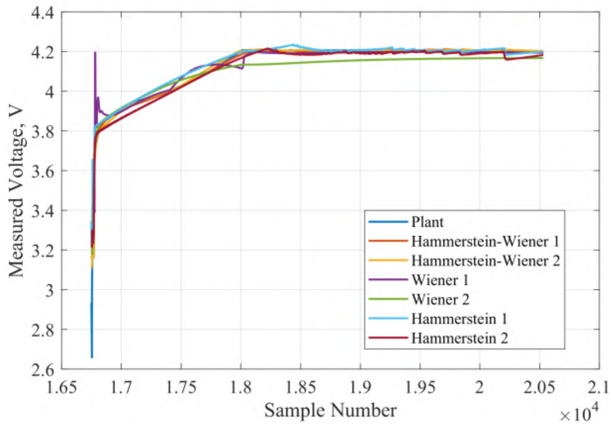

Fig. 5. The results of modelling changes in the battery voltage during the fifth cycle charging

The discharging process (Fig. 6) is best described by Hammerstein-Wiener 1 and Wiener 1 models, but the latter shows a delay at the beginning of discharging. In Hammerstein-Wiener 2 systems, as well as in Hammerstein 1 and 2 ones, periodic fluctuations occur, which generally reduces their accuracy. All the models considered do not make it possible to simulate a sharp drop in battery voltage during the final stage of the discharging process that begins at sample 4350.

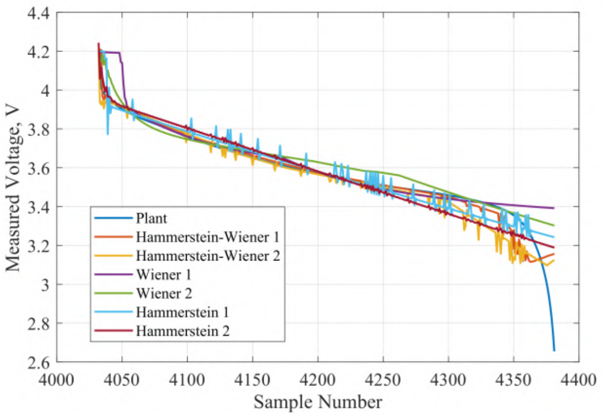

Fig. 6. The results of modelling changes in the battery voltage during the first cycle discharging

After the structural and parametric identification of the linear part of the block-oriented system containing a static nonlinear block, with a constant number of piecewise linear functions, computational experiments of the quality of modelling the change in the battery voltage when changing the configuration of the nonlinear part were performed. For that purpose, the number of piecewise linear functions was changed from 7 to 19 in increments of 3 units for the block-oriented systems of each type with the highest accuracy indices (cf. Tables 1 to 3) obtained at the previous stage of the research. The calculated data are summarized in Tables 4 to 6.

Table 4. The results of simulating the dynamic characteristics of the battery using the Wiener model $N_F = 6$, $N_B = 4$, $N_z = 4$.

Number of piecewise linear functions	**e, %**
7	75.226
10	77.21.54
13	71.6213
16	76.3325
19	64.9123

Table 5. The results of simulating the dynamic characteristics of the battery using the Hammerstein model $N_F = 2$, $N_B = 3$, $N_z = 5$.

Number of piecewise linear functions	**e, %**
7	44.6968
10	84.1008
13	71.8778
16	20.5270
19	35.4378

Table 6. The results of simulating the dynamic characteristics of the battery using the Hammerstein-Wiener model $N_F = 6$, $N_B = 6$, $N_z = 3$.

Number of piecewise linear functions	**e, %**
7	60.6098
10	80.0813
13	35.3615
16	48.195
19	40.5924

The analysis of the results obtained shows that setting the number of piecewise linear functions to a value other than 10 leads to a decrease in the accuracy of block-oriented systems in all three cases. It is therefore advisable to leave the structure of the nonlinear block unchanged.

Conclusions

In this paper, a research done has been presented of the efficiency of modelling the dynamic characteristics of lithium-ion rechargeable batteries and, in particular, the voltage change at the unit during charging and discharging processes using block-oriented systems with static nonlinearities on the basis of piecewise linear functions.

The Hammerstein-Wiener structures have been found to have the best accuracy. They adequately describe the process of charging the battery in the modes of constant current (CC) and constant voltage (CV), as well as the discharging process. At the same time, only the Hammerstein-Wiener systems with high orders of the linear model's polynomial components generally describe the discharging process in a quality way. Output fluctuations are observed in the low-order systems, which reduces their accuracy. However, such models ensure a low computational load on the digital control device.

The Hammerstein systems with high order polynomials of the linear model have demonstrated a simulation quality comparable to that of the low order Hammerstein-Wiener systems.

The Wiener models provide low agreement with a real nonlinear plant when describing the processes of charging a lithium-ion battery in the CC and CV modes, as well as discharging it at the rated loading current. When using them, an unstable nature of modelling the charging process was observed, viz. the accuracy at different cycles differed significantly. However, the Wiener systems did not have output fluctuations at the discharging stage unlike the Hammerstein systems.

All the block-oriented systems considered do not make it possible to describe a rapid decrease in the rechargeable battery voltage at the final stage of the discharging process.

Consequently, taking into account the high accuracy of individual structures of the block-oriented systems, they can be used in simulating and predicting the state of lithium-ion rechargeable batteries in control systems for both storage devices and generating and converting equipment of power plants that use renewable energy sources. An efficient control of energy storage systems will make it possible to improve the quality and reliability of solar and wind power plants in the context of changing weather conditions and fluctuations in electricity consumption during a 24-hour period. This will contribute to their wider implementation in energy systems of various levels and promote the sustainable development of the energy sector.

Further research will be devoted to the analysis of the efficiency of lithium-ion batteries electrical parameters prediction using block-oriented systems. The application of these models in nonlinear model predictive control systems of energy storage equipment of renewable-energy power plants will also be investigated.

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World market of liquid biofuels: trends, policy and challenges

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Abstract. This paper aimed at studying the current state of development of liquid biofuels' world market. The authors considered the theoretical bases of liquid biofuels production, their types, disadvantages and advantages. The world experience of introducing stimulation mechanisms of development and their influence on the sectors' growth is analyzed. In this study's frame, there is outlined the world leaders in the production of liquid biofuels. The findings represent the peculiarities of state regulation in implementing mandates for creating transport fuels with bioliquids. The current state of investment in the production of liquid biofuels was investigated. The obtained results contribute to the prospects for promoting world production of liquid biofuels to achieve the Paris Agreement's goals by 2030 under the sustainable development scenario.

1 Introduction

At the present stage of human development, most countries' main driver of economic growth is fossil energy resources. In turn, it negatively impacts the ecosystem. Therefore, the world community faces the problem to find energy resources, which will compromise the rate of economic growth and its impact on the environment. One of the promising areas aimed at reducing the anthropogenic impact is developing biomass potential for energy purposes. As the transport sector is one of the largest emitters of greenhouse gases, greening the industry is becoming increasingly crucial for the world. Given the current state of development of technologies related to the transport sector, the most promising direction to increase transport decarbonization may be liquid biofuels.

For Ukraine, the problem of liquid biofuels development has a special place because, despite the significant development of the agro-industrial sector, the market of liquid biofuels is in its infancy. Therefore, for implementing effective mechanisms to stimulate the growth of liquid biofuel production in the country, it is necessary to study current trends in the global biofuel market and analyze the experience of public policy created in countries that occupy leading positions in the market.

The article aims to study the main aspects of the world biofuel market development, determine the world leaders in biofuel production, and analyze the experience in creating a state biofuel policy. The paper provides an investigation on the development trend of world production of liquid biofuels.

Besides, there is an assessment of the prospects for achieving the Paris Agreement's goals by 2030 under the SDS (sustainable development scenario).

2 Theoretical bases of producing liquid biofuels from biomass

The modern branch of bioenergy offers the production of fuel for internal combustion engines based on raw materials of plant origin (liquid biofuel) [1,2], animal origin [2,3], organic waste (biogas) [3,4]. However, the use of liquid biofuels by the transport sector has become the most popular among the various types of renewable energy sources due to the convenience of the production process and higher energy density [5]. It stands to mention that liquid biofuels are usually producing by fermenting sugars (corn grains, sugar cane, etc.). That results in ethanol or by processing oilseeds such as rapeseed, soybean or palm oil into biodiesel.

Replacing biofuel, a traditional petroleum-based transport fuel, has several advantages. First, the production of biofuels helps to increase the country's energy security, reducing oil imports. Second, the use of bioliquids for transport helps reduce greenhouse gas (GHG) emissions [6]. Third, the production and use of liquid motor biofuels contribute to agricultural development, job creation and the filling of local budgets.

Note, the economic feasibility of liquid biofuel production directly depends on the choice of raw materials. When choosing a raw material base, it is necessary to consider the following [7]:

1. Crop capacity. This indicator is significant because the land resources used to grow energy crops are limited. For example, the yield of ethanol per acre is 462 gallons

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per acre of 165 bushels of corn. Approximately 35 tons of crop or about 560 gallons of ethanol can be obtained from a sugar cane hectare [8]. Therefore, it is advisable to use land resources efficiently and prefer raw materials with the highest yields.

2. The need for nutrients. Growing raw materials for the production of liquid biofuels should not require large amounts of fertilizers. In addition to nutrients, there is a need for water resources. Indeed, nowadays, water is a valuable and scarce resource, so growing plants must require a moderate amount of water.

3. Growing conditions. Finding useful raw materials is closely related to the country's climatic conditions. Thus, it is advisable to grow energy crops that are best adapted to a particular country's climatic conditions.

It worth noting that nowadays, there are three generations of liquid biofuels as follows:

1. Biofuel of the 1st generation. This category includes fuels such as bioethanol, biodiesel, etc. First-generation biofuel production technologies are not new in the modern world. Approximately 2% of the world's arable land is used to produce such biofuels. However, the commercial competitiveness of the 1st generation biofuels remains low compared to fossil fuels generally. The main difference characterizing the first generation of biofuels lies in the fact that it is producing from sugar and starch-rich plants, oilseeds and animal fats. Alternatively, the raw material could be used for food purposes [9].

2. Biofuel of the 2nd generation. This category includes biofuels made from non-edible raw materials and lignocellulosic biomass. Biofuel of the 2nd generation is considered to be advanced technology in the modern world. The development of second-generation biofuels could address using land for growing bioenergy crops [9].

3. Biofuel of the 3rd generation. This category includes biofuels produced from algae. The main advantage of this technology is the lack of need to attract agricultural land and use raw materials that could be used for food purposes. However, this technology is quite expensive. Therefore, it would not be able to compete commercially with other technologies for biofuels soon [10].

It stands to mention that the use of liquid biofuels has both advantages and disadvantages. Table 1 systematized the main of them.

Table 1. The main advantages and disadvantages of using liquid motor biofuels (based on [10,11,12]).

	Advantages	Disadvantages
Ethanol	The use of bioethanol reduces the emissions of carbon monoxide released by the vehicle's exhaust gases. Besides, bioethanol impurities to gasoline allow obtaining a fuel mixture with an increased octane number, which reduces fuel consumption.	The consumption of bioethanol in the engine power supply is by 51% higher than gasoline consumption. For using bioethanol in higher concentrations, modifications have to be made to the internal combustion engine.
Biobutanol	Compared to ethanol, butanol can be mixed in higher proportions with gasoline. Besides, biobutanol has the property of less solubility in water, less volatility and more excellent safety. Thus, it allows for transporting fuel through existing piping systems. The use of biobutanol in its pure form does not require additional modifications to the engine.	The process of biobutanol production is quite complicated and lengthy. Moreover, the production of biobutanol is low profitable and requires significant investment.
Biomethanol	Biomethanol production has significant economic advantages over the production of other liquid biofuels. In comparison with gasoline use, powering of the engine with fuel from a gasoline mix with impurity of methanol reduces emissions of harmful substances in the atmosphere.	The consumption of biomethanol in the engine power supply is greater than the consumption of gasoline. Besides, the use of biomethanol by the vehicle contributes to corrosion processes in the fuel system. Biomethanol requires special attention from the car owner because it is toxic. Moreover, it poses a potential danger to the human body.
Biodiesel (FAME)	The use of biodiesel fatty acid methyl ester (FAME) allows significantly reduce emissions of harmful compounds and particulate matter during engine operation compared to traditional diesel. At the same time, biodiesel has good lubricating properties, which allows increasing the engine's service life.	The use of biodiesel to power the engine in winter requires additional compounds because the fuel begins to thicken at low temperatures. Biodiesel is more aggressive against polymer and rubber engine parts than gasoline.
Bio-diesel	The use of HVO (hydrotreated vegetable oil) biodiesel reduces NOx, PM and CO2 emissions compared to traditional diesel fuel. Compared to biodiesel, FAME has a longer shelf life and higher energy content.	The price of fuel is relatively high. Therefore, it is impossible to compete with traditional diesel fuel. Limited feedstock when using only vegetable oil.
Dime-thyl	Proportional performance and efficiency with diesel fuel while having a high cetane number and low particulate emissions.	Compared to diesel fuel, it has less heat of combustion and kinematic viscosity. Besides, DME is a strong solvent, so it destroys rubber products

3 The world trends in the liquid biofuels sector development

Nowadays, the liquid biofuel sector is showing high growth rates. Currently, a large number of countries declare strategic goals for the development of the biofuel sector.

However, despite increased energy efficiency, an increase in the number of electric vehicles, and a steady increase in biofuel consumption persists transport as the industry with the lowest share of renewable energy sources [1, 13]. Thus, liquid biofuels provide only about

3%) of the world's fuel needs in the transport sector (Fig. 1).

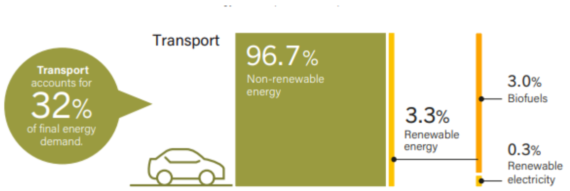

Fig. 1. The share of renewable energy in the total final energy consumption of the transport sector (based on [15]).

Nowadays, the production and use of biofuels such as biodiesel and bioethanol are the most widespread in of liquid biofuels market. Besides, approximately 65% of total world production is ethanol, and almost 35% – biodiesel [14].

Nowadays, the United States, Brazil, the EU and Asia-Pacific are the world leaders in liquid biofuels production (Fig. 2). However, the undisputed leaders who provide more than half of liquid biofuels' world production are the United States and Brazil.

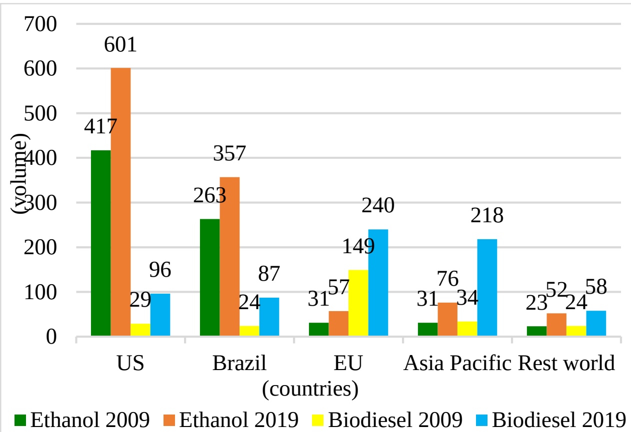

Fig. 2. Biofuels production (thousand barrels of oil equivalent per day) (based on [14]).

The United States and Brazil provided more than 80% of world bioethanol production in 2019. It worth noting that these countries had been holding their leading positions in the bioethanol market for more than ten years. In turn, biodiesel production technology has gained the most popularity in the EU. Herewith, the EU had been in the lead for over ten years. It stands to mention that the rapid growth in biodiesel production occurred in Asia-Pacific, where production increased by six times over the past decade [14].

The world market for liquid biofuels has an annual growth rate of 3% (54 thousand barrels of oil equivalent per day), while in the last decade, the growth rate was two times higher [14].

In general, biodiesel production is experiencing higher industry growth than ethanol (13% vs 2% relatively). Thus, Indonesia demonstrated a rapid increase in biodiesel production (7%) [14].

It could be assumed that the global liquid biofuels sector has been growing for more than a decade. However, the growth rate has slowed significantly. Besides, biodiesel production, which is confidently increasing its share in the global fuel and energy sector structure, is gaining popularity. In turn, the Asia-Pacific countries show a significant contribution to the worldwide growth of liquid biofuels. These countries consider the industry as an effective mechanism for disposing of agricultural residues and increasing energy sovereignty.

4 Energy policies to promote sector of liquid biofuels development

Figure 3 demonstrates that implementing an effective strategy for developing the industry at the national level results in the liquid biofuel sector's positive effect. However, there is still a lack of a comprehensive strategy for decarbonizing transport in many countries. Besides, policies to promote renewable energy in the transport sector continue to focus mainly on road transport, which accounts for the vast majority of energy use in the transport sector, while ignoring aviation and shipping.

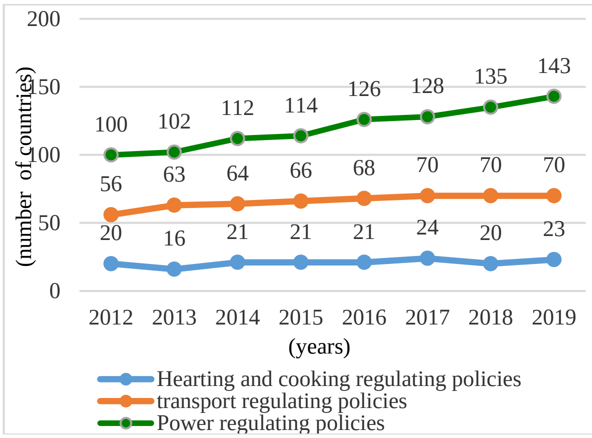

Fig. 3. Number of countries implementing Renewable Energy Policies (2012–2019) (based on [15]).

Policies for support biofuels' production and using include blending mandates, financial incentives, public procurement, and infrastructure support for refuelling and blending. Herewith, mandates for blending biofuels are the most widely accepted type of policy to increase renewable fuels in the transport sector, common in all regions and countries

Table 2 demonstrates that the number of countries with the authority to mix biofuels has recently remained stable (70 countries in 2019). However, mandates for blending are not always fulfilled.

The trend of stimulating the development of liquid biofuels' production and using the mandate to create fuel mixtures has recently gained popularity in many countries due to the increase in the mandate to create fuel mixtures. However, the most significant changes took place in Indonesia (from B20 in 2018 to B30 in 2019), Brazil (where the blending standard increased from B10 to B11 in 2019; besides, the country approved the sale and use of B15) and France (where agreed with an increase in the mandate for mixing bioliquids from 7.9 to 8.2 in 2020) [15].

According to Ren 21, the global biofuel market demonstrates the growing popularity of advanced biofuels. In 2019, the EU and eight other countries had mandates to mix advanced biofuels, while 24 countries were preparing to introduce such mechanisms [15].

Table 2. Biofuels Global Production in 2019 (Top-10 countries and EU-28) (based on [15,16]).

Country	Ethanol	Biodiesel (Fame)	Blend Mandate		
	Billion litres		Ethanol	Biodiesel	Advanced biofuel
USA	59,7	4,0	E2-E20	B2-B10	-
Brazil	35,3	5,9	E27	B11	-
Indonesia	0	7,9	E3	B30	-
China	4,0	0,6	E10	-	-
Germany	0,8	3,8	-	-	0.05% from 2020 (for fuel suppliers supplying at least 20 PJ/a).
France	0,9	2,8	7.9% biofuels in motor fuel		2.3% of diesel and 3.4% of petrol from advanced biofuels by 2023
Argentina	1,1	2,5	E12	B10	-
Thailand	1,6	1,7	E5	B7	25 million litres per day by 2022
Spain	0,5	2	Overall 6		0.1% from 2020
EU-28	4,7	12,4	-	-	0.2% by 2022, 1% by 2025; 3.5% by 2030

Table 2 shows the leaders of world production of liquid biofuels. The assessment of the structure of national policies of mandates for mixing reflects the industry trend and the prospect of further changes in the construction of fuel consumption by the transport sector. However, liquid biofuel producers' success is due to the introduction and other individual mechanisms to stimulate the production and consumption of liquid biofuels, consider the most significant of them, for individual leaders in the global biofuel market (Table 3).

The total amount of investment in liquid biofuels production decreased in the last decade, while RE's investment income almost doubled (Fig. 4). This fact explains the slowdown in sectoral growth in biofuel production and the shallow renewable energy level used in the global transport sector.

Despite the low level of investment support in the industry, there is still a significant increase in investment activity for some types of biofuels. Recently, increasing investor attention has focused on advanced biofuels technology, including HVO.

Table 3. The policy of the state stimulating the development of liquid biofuel production and its efficiency (based on [17,18]).

Co-unt-ry	Public policy	Efficiency
USA	The loan guarantee program is designed to support new innovative bioenergy facilities. Several programs have been created at the federal level that encourage increased production, biofuels, and the development of biomass supply logistics.	The United States provides 50% of world production of ethanol and 14% of biodiesel. Over the last decade, many experimental, demonstration, and commercial projects of 2nd generation biofuels have emerged.
Brazil	Tax benefits for producers and users of liquid biofuels. The quota for duty-free imports of ethanol is 600 million litres per year. Providing subsidies for producers of raw materials used in the process of biofuel production. Financial incentives for the development of 2nd generation biofuel production.	Brazil provides 26% of the world production of ethanol and 12% of biodiesel. Two commercial and one demonstration plant for cellulose ethanol production has been established. The possibility of joint processing of crude oil and vegetable oils is actively studied.
China	Producers of ethanol from non-food crops have the opportunity to receive tax benefits in the form of exemption from excise duty and VAT. Discounts on VAT for exporters of ethanol and biodiesel. The government provides a subsidy of \$ 0.07 per litre for cellulosic ethanol producers. China focuses on ethanol production.	In 2019, China produced 4 bln litres of ethanol and ranked third in the world in terms of ethanol production and consumption. The ethanol producers' support scheme often depends on the country's grain stocks. The use and production of biodiesel in the country is 0.2% of diesel fuel volume.
Germany	Various types of funding programs focus primarily on stimulating the production of advanced biofuels and, to a lesser extent, conventional biofuels. For example, “energy transition in the transport sector” no longer any unique counting of biofuels mechanism included in the national legislation.	In average, since 2007, ethanol's total production and use have grown annually by 10-12%, while annual biodiesel production remains relatively unchanged. Several demonstration research projects aimed at the production of advanced biofuels have been created.
India	The import of biofuels is banned. However, it is allowed for importing raw materials for biofuel production. State support aimed at stimulating the production of 2nd generation biofuels. Biofuel policy provides permission for foreign direct investment in the biofuel facility's equity in the amount of 100%.	The current share of biofuels in India's transport sector is approximately 1.2%. The percentage of mixing ethanol with gasoline is 2%, biodiesel – 0.1%. The effectiveness of state policy on the development of liquid biofuels is low. The main limiting factor in developing the liquid biofuels market is the lack of the required volume of raw materials.

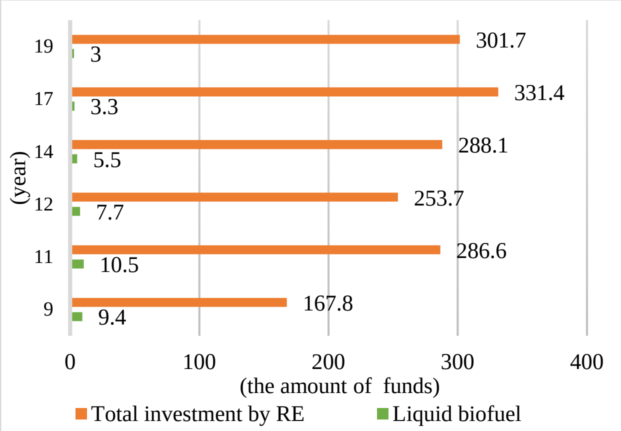

Fig. 4. New Investments by Technology, bln USD, (2009-2019) (based on [11]).

The growth of investment attention to the HVO is primarily due to a significant increase in demand for biofuels from heavy goods vehicles and aviation. According to REN 21, if the planned HVO projects are successfully implemented, the industry's global production capacity will triple to 22 bln litres annually.

It is worth noting that despite the prevalence of investor attention to HVO technology, this industry provides only 6% of biofuels, while biodiesel FAME 35%.

5 Paris Agreement and perspectives biofuels

The modern world market of liquid biofuels characterized by the dominant role of production and consumption of 1st generation biofuels; however, the need to produce new generation liquid biofuels are multiplying.

According to the International Energy Agency (IEA) forecasts, liquid biofuel production's growth rate would be 3% in the next five years. Simultaneously, to achieve the Paris Agreement's goals, the minimum amount of sectoral growth should be 10% by 2030. To comply with the SDS (sustainable development scenario aimed at achieving the goals set out in the Paris Agreement), world production and consumption of liquid biofuels should increase by three times by 2030 (to 298 Mtoe). However, given the current pace of biofuel production, most countries would not reach the required level provided for in the SDS (Fig. 5). It is also necessary to increase the pace of development of advanced biofuel consumption and the adoption of biofuels in aviation and marine transport to achieve these goals. Only sustainable biofuels have a place in the SDS [20].

The main limiting factor that slows down the global transport sector's greening is the lack of strong political support and insufficient development of technological innovations that would help reduce the cost of production of advanced biofuel.

Biofuel production in the US and EU countries lags far behind SDS rates. The increase in demand for biofuels in these countries is due to fuel mixtures containing bioliquids. Therefore, given the tendency to increase the efficiency of vehicles, and as a consequence, the decrease in fuel demand, the rate of increase in biofuel production does not change significantly. However, if countries change their market regulation policies to increase mandatory mandates for blending fuels, the share of liquid biofuels in the country's fuel and energy sector could grow[20].

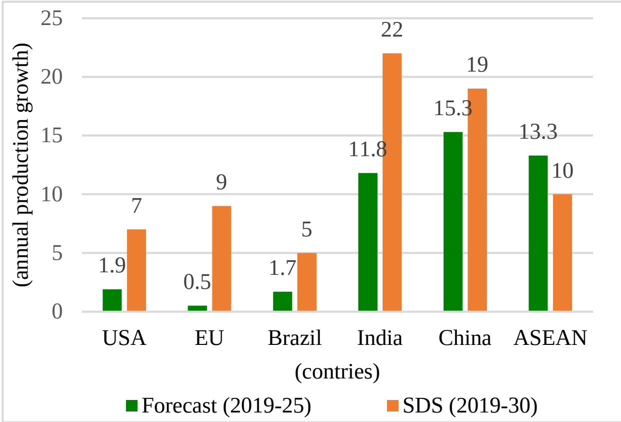

Figure 5. Prospect for key biofuel markets (% of growth) (based on [18])

In turn, Brazil is already one of the leading producers of biofuels. The country is also increasing its mandate for blending fuel mixtures and is actively increasing production capacity for ethanol production. However, according to IEA forecasts, the government would not achieve a pace of sectoral growth to meet the SDS goals [20].

Given the current state of biofuel production in India, the country would not achieve the SDS goals. However, recently the production of biofuels in the country is actively growing. The government also introduced a new regulatory policy in 2018. This policy expanded the authorization to use different types of raw materials that could be used for ethanol production. Moreover, it provided subsidies aimed at expanding production capacity for ethanol production. However, it stands to mention that the country focuses only on ethanol production[20].

In turn, China and the ASEAN countries could reach the SDS level while maintaining the current growth rate. China is actively increasing new production capacity for ethanol production and plans to introduce the E10 standard in 10-15 provinces.

It worth emphasizing that the main barrier that slows down the global transport sector's greening is the lack of strong political support and insufficient development of technological innovations that would help reduce the cost of production of advanced biofuel [20].

Recently, researchers have paid more attention to the introduction of Euro 7 (for cars) and VII (for heavy). The new Euro 7 emission standard is to enter into force in the EU in 2025. The planned Euro-7 standard provides for clear emission standards for vehicles from 2025. Thus, new vehicles will emit only 30 mg of NOx (nitrous oxide) per kilometre, and in the second scenario - only 10 mg per kilometre. The current limit is 60 mg for gasoline and 80 mg for diesel cars. Besides, CO2 limits should be sharply reduced to 300 or 100 mg, depending on the car category

[21]. The adoption of relevant legislation is expected to increase the transport sector's transition rate to the use of low-carbon and sustainable renewable fuels [22]. New realities open up great opportunities for the liquid biofuel industry, in particular new generation biofuels.

Conclusion

Several advantages of liquid motor biofuels produced from bioenergy raw materials testify to the prospect of their production against the background of depletion of oil reserves and global environmental challenges.

World production of liquid biofuels is growing every year, gaining more and more supporters among different countries. The global biofuel market is competitive and fragmented, with several well-known international players. The last trends of the leading countries in the organizational and economic mechanisms on stimulating the liquid biofuel industry indicate the prevalence of state support, namely in the production of advanced biofuels.

By regional segmentation, the global biofuel market can grow in North and South America, Europe, Asia Pacific (APAC), the Middle East and Africa (MEA). According to forecasts, North America will hold a leading position in the global market for liquid biofuels. Besides, high growth rates of liquid biofuel production will be observed in the EU, China, the United States and Brazil.

The obtained results showed that the level of investment in biofuel production remains relatively low. Therefore, it makes the transport sector one of the largest greenhouse gas emitters. The forecast on the industry's development and the assessment of the possibility to achieve the Paris Agreement goals indicates that most countries would not achieve the required levels of liquid biofuels production by 2030.

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Predictive control of induction motor drive

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Abstract. The work is devoted to the study of the possibilities of using the predictive torque control system instead of the currently widely used direct torque control system. Aspects of using the system of direct torque control of an induction motor are considered and it is found that its significant disadvantage is the variable frequency of semiconductor switches. As a further development of the direct torque control system, a predictive torque control system is analyzed, which contains blocks for estimating unmeasured state variables, as well as predicting the state of a dynamic system when applying possible control signals. The systems were compared by mathematical modeling in Matlab / Simulink.

1 Introduction

Recently, the vector control system and the direct torque control system have proved to be the main control systems for AC electric drives [1, 2]. The advantages of the latter include the ability to work without an angular velocity sensor on the shaft, simple structure and high dynamic quality control. At the same time, the main disadvantages of this system are the high level of torque ripple, which becomes especially sensitive when working at low angular velocity, as well as the presence of a variable switching frequency of power switches. A number of researchers' works in the field of automated electric drive are devoted to solving these problems. In [3], a modification of the direct torque control system was proposed, which is aimed at achieving a low level of torque ripples and ensuring a constant switching frequency of the power switches. In [4] the system of direct torque control with the involvement of neuro-phase technologies to achieve a low level of distortions of the motor current and its pulsations is investigated. In [5], a sliding mode system was used to implement sensorless control at very low angular velocities. In [6], the direct torque control system was supplemented by space-vector pulse-width modulation to obtain a constant switching frequency of the inverter switches. At the same time, it is easy to see that the further development of such systems requires more precision in controlling the values of stator flux coupling and torque. Therefore, currently predictive control systems for converters and electric drives are being actively developed [7].

Among such systems, the system of predictive torque control deserves special attention, which can be considered as an alternative to the system of direct torque control for electric drives with induction motors. To use such a system, it is necessary to use discrete models of the power converter and induction motor, and the values of stator flux and torque are considered as control variables of the system. The use of the mentioned discrete models allows to estimate and predict the values of stator flux linkage and torque, and further on the basis of these predictions the cost function is calculated, which allows to select the optimal control effect for the next discrete interval of the system. The synthesis of the cost function is carried out using weight coefficients that allow you to combine different sizes with each other and set priorities regarding their importance to achieve the desired control goal. Therefore, the quality of control of such systems depends very much on the choice of weight coefficients. Despite the fact that a number of publications have been devoted to the choice of weight coefficients [8, 9], this problem still remains relevant, as this step is important at the stage of synthesis of the electric drive control system.

2 Direct torque control system

The structure of the electric drive using the direct torque control system is shown in Fig. 1. In such a system, the induction motor is powered by a voltage-fed inverter. The task of the system is to provide the ability to independently control the values of the stator flux and motor torque by selecting the appropriate states of the inverter. As you know, a voltage-fed inverter is able to create 6 non-zero space voltage vectors, shifted by 60 degrees, as well as 2 zero voltage vectors. The system uses relay hysteresis torque and flux regulators, which allows to provide high dynamic control of the electric drive system, and expanding the width of the hysteresis allows to reduce the switching frequency of the inverter switches and, consequently, the power of losses in it.

The principle of direct torque control can be explained by considering the mathematical expression for the electromagnetic torque in the following notation:

$$T_e = \frac{3}{2} p \frac{L_m}{L_s L_r} |\boldsymbol{\psi}_s| \cdot |\boldsymbol{\psi}_r| \sin(\theta), \qquad (1)$$

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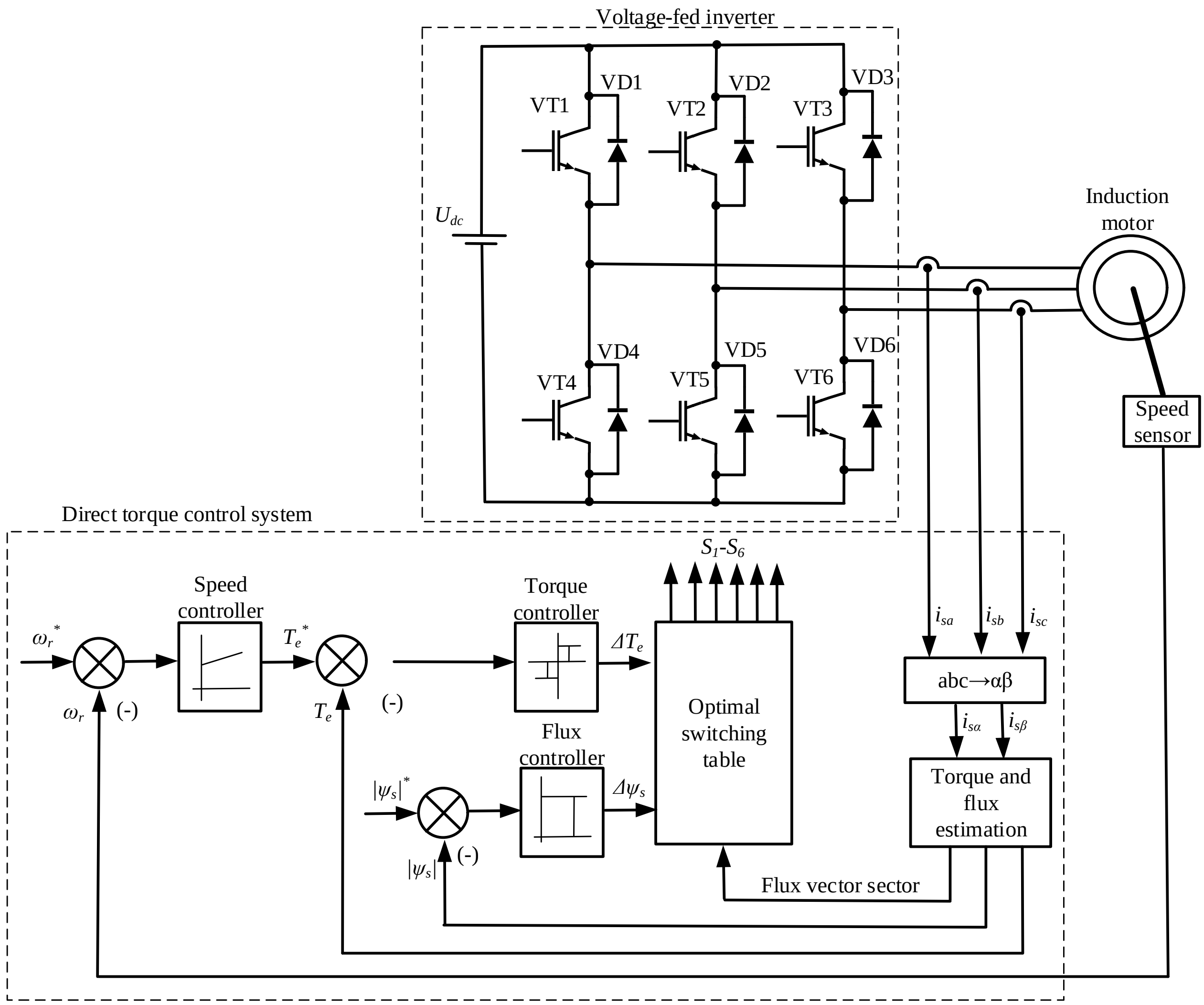

Fig. 1. Structure of direct torque control system.

where p – the number of pole pairs; L_s and L_r – inductance of the stator and rotor windings of the motor, respectively; L_m – mutual inductance of stator and rotor windings; $\boldsymbol{\psi}_s$ – flux linkage vector of the motor's stator windings; $\boldsymbol{\psi}_r$ – flux linkage vector of the motor's rotor winding; θ – angle between the flux linkage vectors of the stator and rotor.

It is believed that the stator flux vector reacts less inertially to the voltage applied to the motor windings, because the rotor time constant is significant. For simplicity, it is assumed that at one discrete interval of the system, the vector of flux linkage of the rotor is stationary. Therefore, the rotation of the stator flux vector in the direction of rotation leads to an increase in the value of the angle θ and increases the amount of torque. If the space voltage vector applied by the inverter causes the flux vector to rotate in the direction of convergence with the rotor flux vector, which will reduce the angle θ, the torque generated by the motor will decrease. Since the stator flux linkage, when the value of the active resistance of the motor stator windings is small, can be found by integrating the voltage applied to the motor, the selection of the appropriate inverter voltage vector also allows to control the stator flux value. Thus, the use of a direct torque control system allows independent control of torque and stator flux linkage. The selection of the appropriate voltage vector and the state of the inverter switches is carried out using the table of optimal switching, which is presented in Table. 1.

Table 1. Switching table of direct torque control system of induction motor drive.

$\Delta\psi_s$	ΔT_e	Sectors					
		1	2	3	4	5	6
1	1	U_2	U_3	U_4	U_5	U_6	U_1
	0	U_0	U_7	U_0	U_7	U_0	U_7
	-1	U_6	U_1	U_2	U_3	U_4	U_5
0	1	U_3	U_4	U_5	U_6	U_1	U_2
	0	U_7	U_0	U_7	U_0	U_7	U_0
	-1	U_5	U_6	U_1	U_2	U_3	U_4

3 Predictive torque control system

Predictive control systems for converters and electric drives are currently being actively developed. The principle of predictive control is to predict further changes in system state variables using a mathematical model of the system. In the next step, a certain optimization principle is used to compare possible options for changing the state of the system with each other in order to identify the most profitable in terms of achieving the ultimate goal of control. It is necessary to use a discrete model of the control object, which will allow you to predict changes in the state variable values.

The equations of electrical equilibrium of the stator circuits of the motor in a stationary frame of reference αβ have the following form:

$$\frac{d\psi_{s\alpha}}{dt} = U_{s\alpha} - R_s i_{s\alpha}; \quad (2)$$

$$\frac{d\psi_{s\beta}}{dt} = U_{s\beta} - R_s i_{s\beta}, \quad (3)$$

where $U_{s\alpha}$, $U_{s\beta}$ – projections of the stator voltage vector on the axis of the stationary coordinate system αβ; $i_{s\alpha}$, $i_{s\beta}$ – projections of the stator current vector on the axis of the stationary coordinate system αβ; R_s – active resistance of the motor stator winding; $\psi_{s\alpha}$, $\psi_{s\beta}$ – projections of the stator flux vector on the axis of the stationary coordinate system αβ.

Convert equations (2) and (3) into a discrete form using Euler's method:

$$\psi_{s\alpha}[n+1] = \psi_{s\alpha}[n] + U_{s\alpha}[n] \cdot \Delta t - R_s \cdot i_{s\alpha} \cdot \Delta t; \quad (4)$$

$$\psi_{s\beta}[n+1] = \psi_{s\beta}[n] + U_{s\beta}[n] \cdot \Delta t - R_s \cdot i_{s\beta} \cdot \Delta t, \quad (5)$$

where Δt is the discrete time of the system.

The obtained equation allows to calculate the flux linkage of the stator $\psi_{s\alpha}[n+1]$, which refers to the discrete step $n+1$, based on the value of the flux linkage of the stator $\psi_{s\alpha}[n]$, which refers to the previous discrete step n.

The components of the flux vectors of the stator and rotor can be recorded through the appropriate inductances and currents:

$$\psi_{s\alpha} = L_s i_{s\alpha} + L_m i_{r\alpha}; \quad (6)$$

$$\psi_{s\beta} = L_s i_{s\beta} + L_m i_{r\beta}; \quad (7)$$

$$\psi_{r\alpha} = L_r i_{r\alpha} + L_m i_{s\alpha}; \quad (8)$$

$$\psi_{r\beta} = L_r i_{r\beta} + L_m i_{s\beta}, \quad (9)$$

where $i_{r\alpha}$, $i_{r\beta}$ – projections of the rotor current vector on the axis of the stationary coordinate system αβ.

Since the rotor current is not a measurable value for motors with a short-circuited rotor, we get rid of its use through the combined use of equations (6) - (9):

$$\psi_{s\alpha} = \left(L_s - \frac{L_m^2}{L_r}\right) i_{s\alpha} + \frac{L_m}{L_r}\psi_{r\alpha}; \quad (10)$$

$$\psi_{s\beta} = \left(L_s - \frac{L_m^2}{L_r}\right) i_{s\beta} + \frac{L_m}{L_r}\psi_{r\beta}. \quad (11)$$

The dynamics of change of the components of the flux coupling vector of the rotor can be described by the following dependences:

$$\frac{d\psi_{r\alpha}}{dt} = -\frac{R_r}{L_r}\psi_{r\alpha} + \frac{L_m R_r}{L_r} i_{s\alpha} - \omega_r \psi_{r\beta}; \quad (12)$$

$$\frac{d\psi_{r\beta}}{dt} = -\frac{R_r}{L_r}\psi_{r\beta} + \frac{L_m R_r}{L_r} i_{s\beta} + \omega_r \psi_{r\alpha}. \quad (13)$$

where R_r – the active resistance of the motor rotor winding, ω – the angular velocity of rotation of the rotor.

Using the Euler method, the prediction of the stator current can be performed in accordance with the following dependencies:

$$i_{s\alpha}[n+1] = \left(1 - \frac{\Delta t(R_s L_r^2 + R_r L_m^2)}{L_r(L_s L_r - L_m^2)}\right) \cdot i_{s\alpha}[n] +$$

$$+ \frac{\Delta t(R_s L_r^2 + R_r L_m^2)}{\Delta t(R_s L_r^2 + R_r L_m^2) + L_r(L_s L_r - L_m^2)} u_{s\alpha}[n] +$$

$$+ \frac{\Delta t L_m R_r}{\Delta t(R_s L_r^2 + R_r L_m^2) + L_r(L_s L_r - L_m^2)} \psi_{s\alpha}[n] +$$

$$+ \frac{\Delta t L_m L_r \omega}{\Delta t(R_s L_r^2 + R_r L_m^2) + L_r(L_s L_r - L_m^2)} \psi_{s\beta}[n]; \quad (14)$$

$$i_{s\beta}[n+1] = \left(1 - \frac{\Delta t(R_s L_r^2 + R_r L_m^2)}{L_r(L_s L_r - L_m^2)}\right) \cdot i_{s\beta}[n] +$$

$$+ \frac{\Delta t(R_s L_r^2 + R_r L_m^2)}{\Delta t(R_s L_r^2 + R_r L_m^2) + L_r(L_s L_r - L_m^2)} u_{s\beta}[n] +$$

$$+ \frac{\Delta t L_m R_r}{\Delta t(R_s L_r^2 + R_r L_m^2) + L_r(L_s L_r - L_m^2)} \psi_{s\beta}[n] -$$

$$- \frac{\Delta t L_m L_r \omega}{\Delta t(R_s L_r^2 + R_r L_m^2) + L_r(L_s L_r - L_m^2)} \psi_{s\alpha}[n]; \quad (15)$$

Prediction of the value of the electromagnetic torque can be obtained using the predicted values of the stator flux and stator current:

$$T_e[n+1] = \frac{3}{2} p \times$$

$$\times \left(\psi_{s\alpha}[n+1] i_{s\beta}[n+1] - \psi_{s\beta}[n+1] i_{s\alpha}[n+1]\right), \quad (16)$$

where p is the number of pole pairs.

The cost function is composed using the deviations of the torque value from the specified value and the deviation of the modulus of the flux linkage vector from the corresponding rated level:

$$c = |T_e[n+1] - T_e^*| +$$

$$+ w_\psi \left| \sqrt{\psi_{s\alpha}^2[n+1] + \psi_{s\beta}^2[n+1]} - |\boldsymbol{\psi}_s|^* \right|. \quad (17)$$

where w_ψ – a weighting factor that reflects the relative importance of flux control in relation to torque control. As the initial setting of this parameter it is advisable to use the following value:

$$w_\psi = \frac{T_{rated}}{\psi_{srated}}, \quad (18)$$

where T_{rated} – the value of the rated torque of the motor; ψ_{srated} – rated value of stator flux linkage.

The structure of the system of predictive torque control of an induction motor is presented in Fig. 2. By analogy with the previous system, the torque reference signal is formed by the PI controller, and the magnitude of the stator flux linkage when operating at a speed lower than the rated, usually set at the nominal level and attenuated when switching to higher nominal. Based on the measured values of motor current and voltage, the values of the torque and flux linkage of the stator are estimated, because the direct measurement of these values is difficult to implement. Based on the obtained equations, the values of motor torque and stator flux coupling are predicted by applying each of the eight possible voltage vectors generated by the voltage inverter. In accordance with equation (17) get eight values of the objective function, from which the minimum value is selected and in the next interval of discreteness of the system, the inverter applies to the motor a vector with a number corresponding to the obtained minimum value of the objective function.

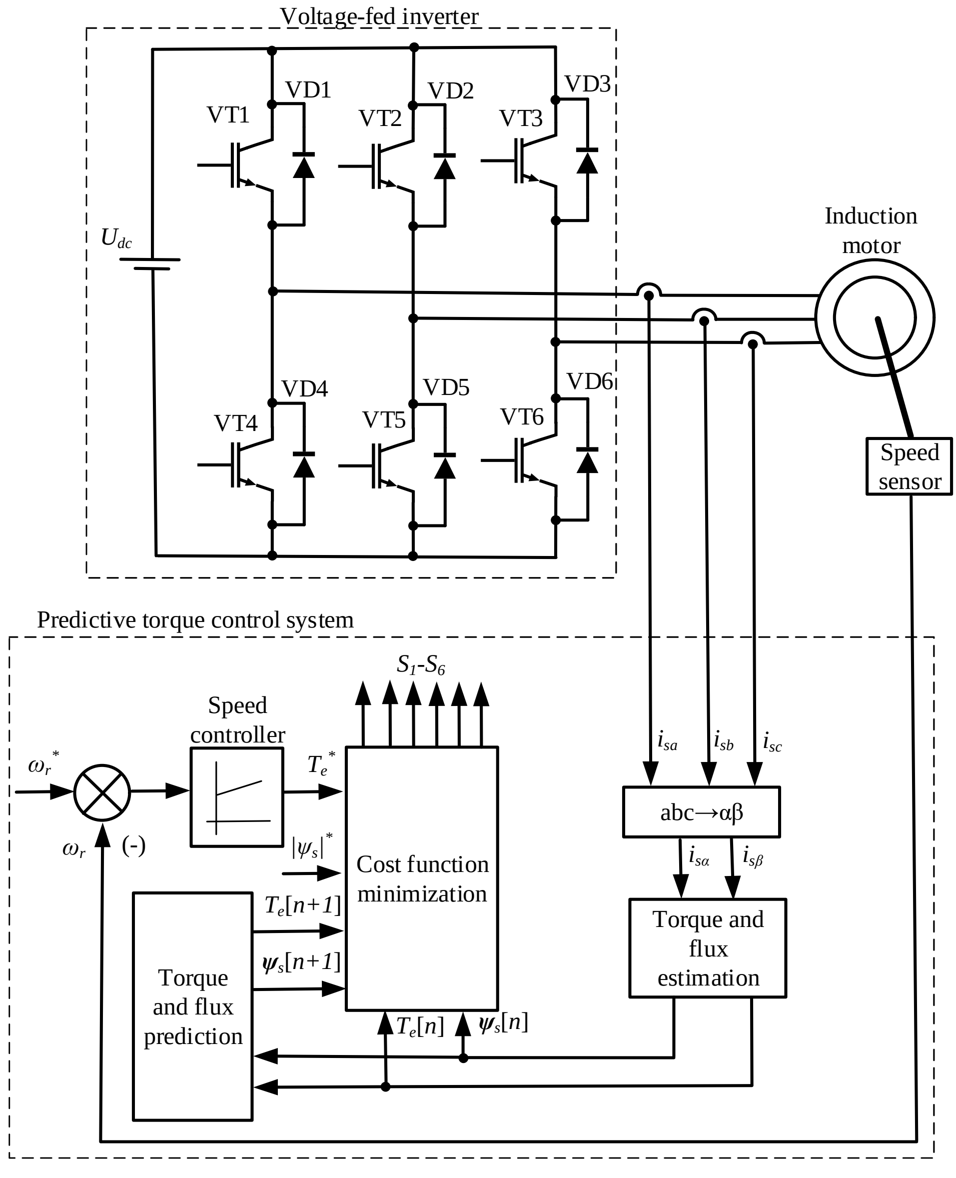

Fig. 2. Structure of predictive torque control system.

4 Simulation results

A mathematical model in the Matlab / Simulink environment was developed to analyze the predictive torque control system of an induction motor. The parameters of the engine used in the simulation are given in Table 2.

Fig. 3 shows a comparison of motor torques when using direct torque control and predictive torque control in steady state operation. The graphs show that the use of predictive control reduces the level of torque ripple.

Table 2. Switching table of direct torque control system of induction motor drive.

Parameter name	Parameter value
Rated power P_{rated}	75 kW
Number of pole pairs, p	2
Active resistance of the stator winding, R_s	0.035 Ohm
Active resistance of the rotor winding, R_r	0.021 Ohm
Leakage inductance of the stator winding, $L_{\sigma s}$	330 mH
Leakage inductance of the rotor winding, $L_{\sigma r}$	330 mH
Mutual inductance of stator and rotor windings, L_m	0.015 H

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Fig. 4 shows the shape of the currents flowing through the stator windings. They show that the use of predictive control reduces the distortion of the current shape, increasing the energy efficiency of electromechanical equipment.

Fig. 5 shows the response of the system to changes in load torque. The graphs show that the predictive control system has a higher speed.

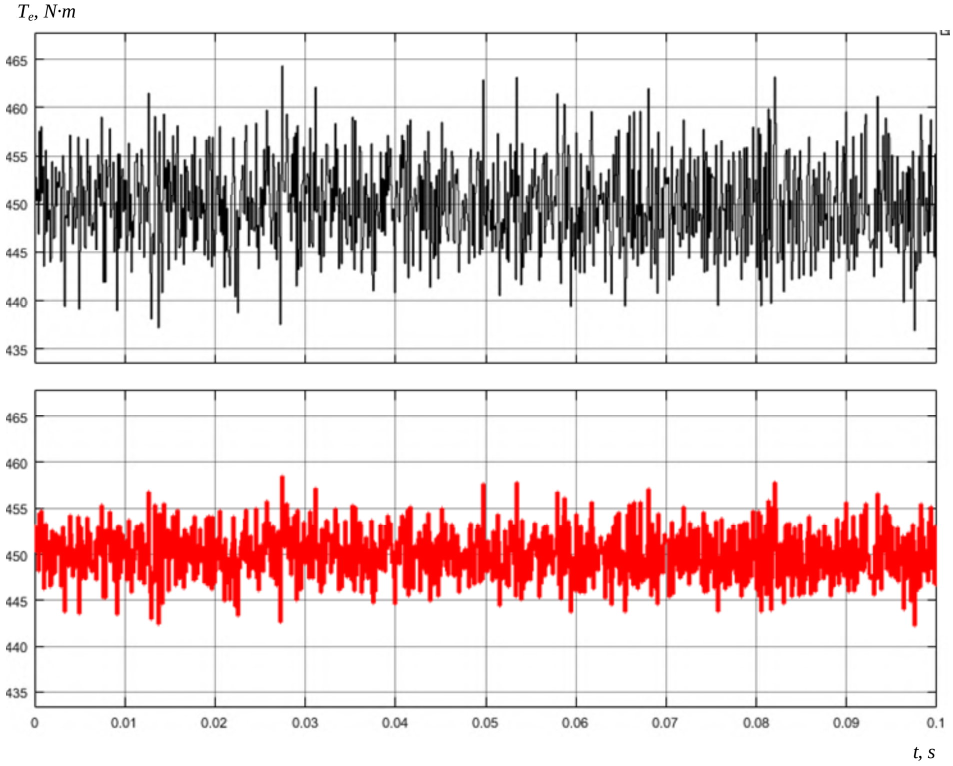

Fig. 3. Motor torque in steady-state with direct torque control system (top) and predictive torque control system (bottom).

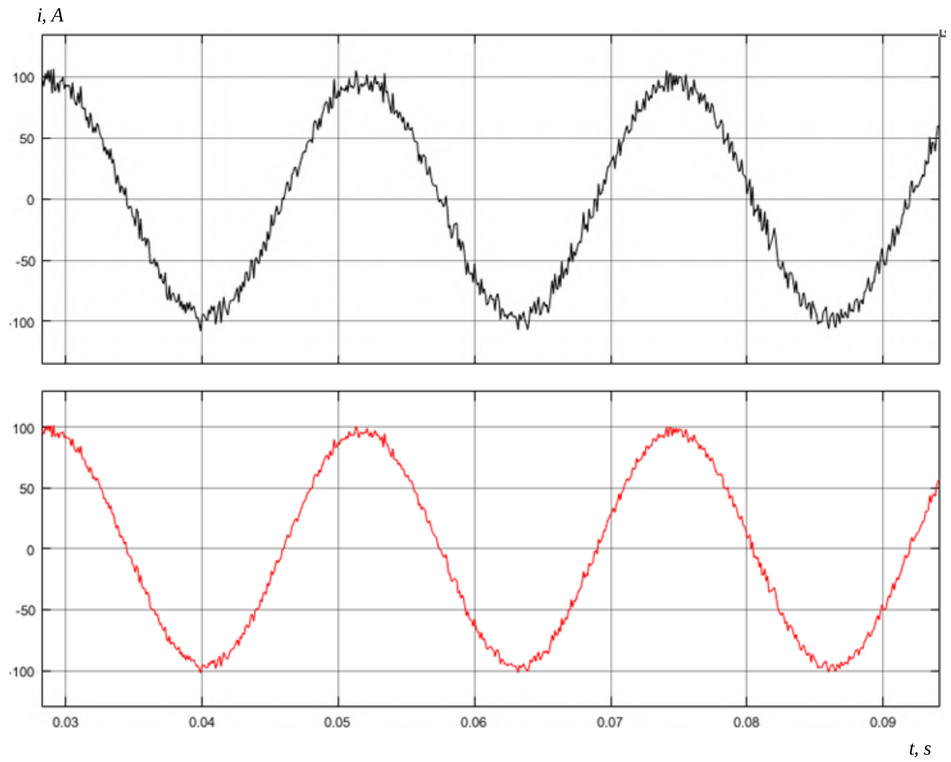

Fig. 4. Motor current in steady-state with direct torque control system (1) and predictive torque control system (2).

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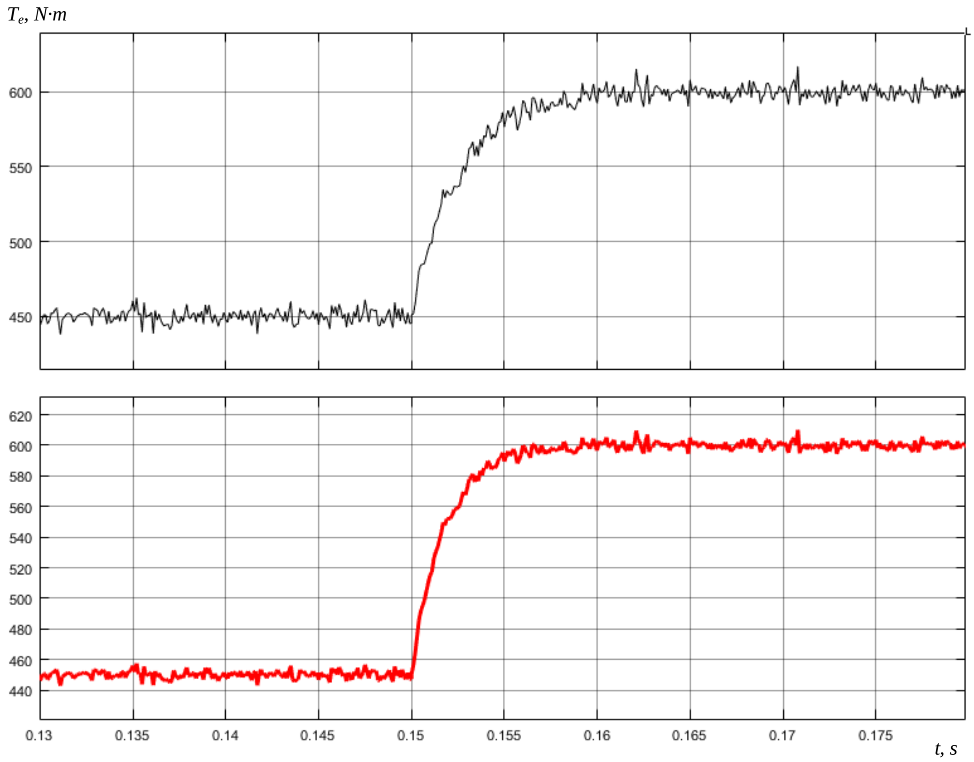

Fig. 5. Motor torque when load torque changes with direct torque control system (top) and predictive torque control system (bottom).

Conclusions

The paper considers the system of direct torque control and the predictive torque control system of an induction motor. The direct torque control system selects the voltage vector based on pre-calculated rules that allow to take into account the sector to which the stator flux vector currently falls, as well as the output signals of two relay hysteresis regulators - stator flux regulator and motor torque regulator. This structure allows this system to have a simpler structure compared to the vector control system, eliminating the need to use coordinate transducers. However, a significant disadvantage of the direct torque control system is the variable switching frequency of the keys and the presence of a noticeable torque ripple. A variant of predictive torque control of an induction motor is considered, which contains a discrete mathematical model for calculating the predicted values of stator current, stator flux and torque for the next step of the system discreteness. Since the number of voltage vectors generated by the voltage inverter is limited, it is possible to calculate the value of the objective function for each variant of the control effect. In the future, the choice of option that corresponds to the minimum value of this function. To compare the two systems, mathematical modeling was performed in the Matlab / Simulink environment, which showed that the use of predictive control reduces the level of torque ripple and improves the dynamic control of the electric drive. In the subsequent stages of research it is necessary to carry out the analysis of influence of deviations of parameters of the engine on indicators of system of predictive control.

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Balancing Ukraine's energy system: challenges under high renewable energy penetration and the COVID-19 pandemic

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Abstract. The paper deals with the problems of balancing the United Energy System of Ukraine caused by high renewable energy penetration and the impact of the COVID-19 pandemic on the energy sector. The paper analyses the trends in renewable energy development, the dynamics and structure of electricity consumption and export in pre-epidemic and epidemic periods and identifies the main challenges to operational security of the United Energy System of Ukraine. The methodical approach to improve the methodology for estimation of country's energy security level by considering the index of developing capacities for balancing the United Energy System of Ukraine is suggested. In addition, proposals have been made to reduce threats to the stable work of the United Energy System of Ukraine by putting into operation of energy storage capacities, promoting the development of мaneuvering renewable energy capacities, and implementation of other appropriate measures in this field.

Introduction

One of the important indicators that affects the energy security of any country is the stable operation of the energy system. The peculiarity of the United Energy System of Ukraine is deficit of мaneuvering energy capacities, as nuclear power plants cover about 50% of electricity demand in the country [1]. In recent years, this problem has been enhanced by putting into operation of renewable power plants, especially solar and wind ones, electricity generation based on which is unstable, as it is directly dependent on the season, time of day and weather conditions.

This issue has developed into the energy crisis in 2020. During the quarantine restrictions caused by the COVID-19 pandemic, the rapid growth of green electricity generation was compounded by the problem of declining domestic demand for electricity and limiting opportunities for its export [2]. This, in turn, has caused technical difficulties with integrating renewable electricity into the United Energy System of Ukraine and its balancing.

The purpose of this paper is to: 1) study of the main challenges for the operational security of the United Energy System of Ukraine caused by high renewable energy penetration and the impact of the COVID-19 pandemic on the country's energy sector; 2) improve the methodology for assessing the energy security of Ukraine by taking into account the level of development of capacities for balancing the United Energy System of Ukraine; 3) develop the recommendations on effective balancing the United Energy System of Ukraine taking into account the priorities for the transition to a carbon-free economy.

1 Features of Ukraine's United Energy System operation

The United Energy System of Ukraine is a set of power plants operating on conventional and renewable energy resources, main and distribution networks, which are united by a common way of production, transmission, and distribution of electricity [1].

The mode of the United Energy System of Ukraine is determined based on the balance of generation and consumption of electricity, repairs of power grids and generating equipment, as well as the possibility of emergency response in case of disconnection of generating equipment at power plants and main power lines. The balance between generation and consumption of electricity provided through the process of scheduling. The main dispatcher of the United Energy System of Ukraine is the National Power Company "Ukrenergo", which takes the necessary measures to prevent violations of its mode of operation.

Peaks in electricity consumption occur during the day and evening. Maneuvering capacities of thermal power

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plants, hydropower plants, including pump storage power plants, are used for regulation and passage of peak loads.

Part of the capacities of hydropower plants is in the "hot reserve" – on idle, but heated steam generators and turbines are maintained nominal operating parameters, so they can be started in minutes. Today, the capacity of the "hot reserve" in the electricity generation of Ukraine is about 300-400 MW [1].

The balance between мaneuvering generating capacities and power plants that cannot maneuver quickly is one of the conditions for the stable functioning the United Energy System of Ukraine.

2 Challenges to the United Energy System of Ukraine caused by high renewable energy penetration and the COVID-19 pandemic

In recent years, the balance between мaneuvering and non-мaneuvering generating capacities in the United Energy System of Ukraine has been disturbed due to the dynamic putting into operation of renewable power plants, especially solar and wind ones, the generation of electricity based on which is difficult to predict (Table 1).

Table 1. Number and structure of renewable power plants put into operation in Ukraine in 2017-2019 [3, 4, 5].

Renewable power plants	2017	2018	2019
Solar power plants	3203	7806	22548
including solar power plants of private households	*3010*	*7450*	*21969*
Wind power plants	20	31	69
Biomass power plants	27	43	64
Small hydropower plants	137	149	157
Total	3387	8029	23111

As shown in Table 1, the number of renewable power plants in 2019 increased 6.8 times compared to 2017. The largest growth was shown by solar power plants, both in the business sector and the private households. The increase in the number of renewable power plants, therefore, contributed to the increase in the amount of electricity generated on their basis (Table 2).

Table 2. Dynamics and structure of electricity generation by renewable power plants in Ukraine in 2017-2019, million kWh [3, 4, 5].

Renewable power plants	2017	2018	2019
Solar power plants	737.4	1172	3235
including solar power plants of private households	*22.7*	*92*	*303*
Wind power plants	973.5	1180.2	2022
Biomass power plants	194.8	275.4	309
Small hydropower plants	212.5	241.6	242
Total	2118.2	2869.2	5808

According to Table 2, it can be concluded that the amount of electricity generated by renewable power plants in 2019 increased 2.7 times compared to 2017 and 2 times compared to 2018.

The predominance in the structure of generation of solar and wind energy is due to the maturity of these technologies. Global experience shows that most investors prefer to invest in these technologies. Thus, in 2018, solar energy accounted for 48.9%, wind energy – 47.2% of total new investments [6]. However, other countries, along with promoting these technologies development, pay considerable attention to the effective integration of such electricity into the national energy systems, but in Ukraine such measures have not been taken.

In 2020, this problem was exacerbated by the impact of quarantine restrictions caused by the COVID-19 pandemic, which contributed to significant reduction in domestic demand for electricity (Table 3).

Table 3. Dynamics and structure of electricity consumption in Ukraine for 9 months of 2017-2020, million kWh [7].

Consumer groups	9 months 2018	9 months 2019	9 months 2020
Total	89659.8	89553.9	86238.6
including:			
1. Industry	38655.3	38550.9	36493.5
including:			
Energy sector	2623.8	2533.4	2378.9
Metallurgical sector	22117.2	22063.4	20366.7
Chemical and petrochemical sector	2395.4	2702.2	3099.9
Machine-building sector	2972.0	2734.2	2256.6
Building materials sector	1681.1	1668.5	1676.9
Food and processing sector	3259.9	3294.6	3152.0
Other sectors	3606.0	3554.6	3562.4
2. Agricultural sector	2864.9	2778.0	2798.4
3. Transport sector	5090.7	4856.4	4117.0
4. Construction	691.1	711.1	669.9
5. Utility consumers sector	11357.5	11276.5	10289.1
6. Other non-industrial consumers	4975.3	5444.4	5264.6
7. Population	26024.9	25936.6	26606.1

As shown in Table 2, electricity supply to final consumers for 9 months of 2020 decreased by 3315.3 million kWh compared with 9 months of 2019. The decrease in consumption was observed in almost all consumer groups. The exception were the chemical and petrochemical sector, agricultural sector, and households. Adding to the above problems it was the reduction in electricity exports, as quarantine measures caused by the COVID-19 pandemic led to the reduction in electricity demand in importing countries, namely Hungary, Romania, Poland, and Belarus (Figure 1).

As can be seen from Fig. 1, starting from March 2020, the period of implementation of the lockdown due to the COVID-19 pandemic, electricity export declined sharply, and only in July began to show growth with positive dynamics. However, in September it was still 1.6 times less than in March 2020 [5].

The above trends have caused the problem of effective balancing the United Energy Systems of Ukraine, violating the equality of electricity supply and demand. To solve this problem, the government has decided to shut down several power units of nuclear power plants in the country [8]. This choice was caused the fact that nuclear power plants cannot maneuver their capacity, and the dynamic growth of renewable energy requires the flexibility of the energy system. The decision to limit the green electricity generation was not made because according to Ukrainian law, the state has obligations to: 1) purchase the total amount of green electricity by feed-in tariff until 2030 [9]; 2) increase the share of green electricity in the total energy mix, in the framework Ukraine’s membership in the European Energy Community; 3) achieve strategic goals for renewable energy development, specified in the Energy Strategy of Ukraine until 2035 [10].

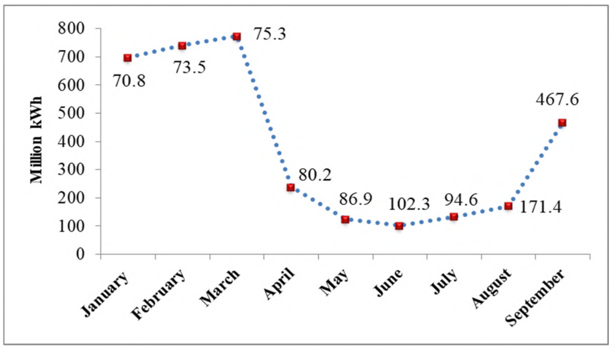

Fig. 1. Dynamics of electricity exports for 9 months of 2020, million kWh [11].

It should be noted that nuclear power plants generate the cheapest electricity in country (580 UAH / MWh), while electricity from renewable energy sources is purchased at the feed in tariff that is one of the highest in Europe (the average feed-in tariff for all renewable energy technologies represented on the Ukrainian market is 4705 UAH / MWh) [12]. It has led to a significant increase in the weighted average unit cost of electricity and, as result, to increasing in electricity prices for households and industry. To partially reduce the effects of rising electricity prices, the government has decided to reduce the feed-in tariff by 7.5% for wind farms and 15% for solar power plants. It is predicted that it will provide savings of about 6 bln UAH each year until the end of the period to support scheme for renewable energy promotion based on feed-in tariff in 2030 [13]; however, at the same time, it will worsen the investment climate in the renewable energy sector.

3 Improving the methodology for assessing the energy security of Ukraine

Unstable functioning the United Energy System of Ukraine is a direct threat to both energy and economic security of the country, so the indicator of development of capacities for balancing the energy system should be included in the calculation of the integrated indicator of energy security.

Today, the level of energy security of Ukraine is determined based on the Guidelines for calculating the level of economic security of Ukraine, approved by the order of the Ministry of Economic Development and Trade of Ukraine No 1277, 29.10.2013 [14]. According to [14] the integrated indicator of energy security is calculated based on 10 indicators, namely:

− the share of own sources in the balance of fuel and energy resources of the state, %;

− the level of import dependence on the dominant resource in the total supply of primary energy, %;

− the share of fuel import from one country (company) in the total amount of its import, %;

− depreciation of fixed assets of the fuel and energy complex, %;

− the ratio of investment in the fuel and energy sector to gross domestic product, %;

− energy intensity of gross domestic product, kg of fuel equivalent / UAH;

− natural gas reserves, months of consumption;

− coal reserves, months of consumption;

− the share of renewable energy resources in the total supply of primary energy, %;

− the share of losses in the transportation and distribution of energy, %.

It is worth noting that the capacities for balancing the United Energy System of Ukraine include maneuvering power plants and energy storage systems.

Thus, the indicator of development of capacities for balancing the United Energy System of Ukraine can be calculated by the formula:

$$I_b = \frac{\sum MP_i + ES}{\sum PP_i}, \qquad (1)$$

where I_b – index of development of capacities for balancing the United Energy System of Ukraine; MP_i – installed capacity of the *i*-type of maneuvering power plants, *ES* – installed capacity of the *i*-type of energy storage systems, MW; EP_i – installed capacity of the *i*-type of power plants in the United Energy System of Ukraine, MW.

The optimal value of the above index is reached at values close to unity. In this case, the maximum level of development of energy capacities for balancing the United Energy System of Ukraine is provided, which has a positive effect on increasing the level of energy security of the country.

It should be noted that at present balancing the United Energy System of Ukraine is carried out by thermal power plants and hydropower plants (including pump storage power plants). For this purpose, it also can be used combined heat and power plants and biopower plants. At the same time nuclear, solar, and wind power plants are not flexible and can be used for balancing energy system. The dynamics of the installed capacity of power plants in the United Energy System of Ukraine in 2017 - 9 months of 2020 are shown in Table 4.

The data presented in Table 4 show significant increase in the installed capacity of solar and wind power plants that worsens the balance between flexible and non-flexible power plants and threatens the stable functioning the United Energy System of Ukraine. These risks can be reduced by implementing several measures, which are discussed in more detail in the next section.

Table 4. Installed capacity of power plants in the United Energy System of Ukraine in 2017 - 9 months of 2020, MW [15, 16, 17, 18].

Power plants in the United Energy System of Ukraine	Installed capacity, MW			
	2017	2018	2019	9 months 2020
Thermal power plants	24565	21842	21842	21842
Combined heat and power plants	5972.3	6099.5	6097	6070
Hydropower plants (including pump storage power plants)	6228.7	6170.2	6520	6300
Biopower plants	96.9	97.5	170	177
Nuclear power plants	13835	13835	13835	13835
Solar power plants	758.4	1388.3	4925	4938
Wind power plants	328.4	532.8	1170	1071

4 Measures for effective balancing the United Energy System of Ukraine

A few measures can be used for effective balancing the United Energy System of Ukraine, namely: introduction of additional flexible capacities of conventional power plants, promotion of development of flexible renewable power plants, installation of energy storage systems, import of electricity from other countries, introduction of more accurate forecasting methods, responsibility for imbalance, electricity demand management, etc. [19].

Balancing energy system by existing fossil fuels power plants and construction of new ones is the least appropriate in terms of considering the priorities for the transition to a carbon-free economy.

In should be noted that currently Ukraine holds the leading position in the world for energy intensity of gross domestic product and it is included to 30 world countries, which are the largest polluters with CO_2 emissions due to burning fossil fuels [20]. It is an energy sector takes the first place for CO_2 emissions among other sectors of national economy in Ukraine: its share was about 76% of total CO_2 emissions during the last years.

Besides, Ukraine has a commitment to reduce greenhouse gas emissions by 40% from 1990 level by 2030 and by 70% by 2050 under the Paris Climate Agreement (Figure 2) [21].

The construction of new power plants based on fossil fuels for this purpose is impractical not only from environmental point of view, but also from economic one. Thus, the costs of electricity generation by solar photovoltaic plants and onshore wind plants decreased by 82% and 39%, respectively, compared to 2010. More than half of the renewable power plants put into operation in 2019 achieved lower electricity generation costs than fossil fuel power plants [22].

Partly improve the situation with balancing the United Energy Systems of Ukraine it is possibly by regulation of construction of new renewable power plants under the new support scheme for renewable energy promotion – the green auctions.

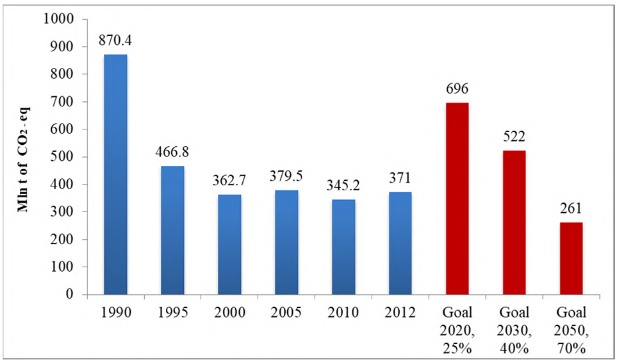

Fig. 2. Greenhouse gas emissions in Ukraine in 1990-2012 (million tonnes of CO_2 eq) and targets for 2020-2050 (%) [22].

This mechanism is designed to identify renewable power projects that will receive state support for electricity generation. Green auctions based on following: the winner is the investor who offers the lowest price for green electricity. The starting price of bidding is the rate of the feed-in tariff established by the Ukrainian legislation. The winner gets the opportunity to build new renewable power plant and sell electricity at a price determined at the auction for 20 years from the date of commissioning of the power plants [23].

Under this mechanism, the government sets annual support quotas for the next five years. The size of quotas determines how many new renewable power capacities the state is ready to support. Quotas will be calculated in accordance with Ukraine's international obligations, Energy strategy of Ukraine, conformity assessment of generating capacities, etc.

The total support quota is divided into three lots – solar, wind and other renewable energy sources. Competition at green auctions takes place between projects in one category. The share of quotas for each category cannot be less than 15%. It should be noted that the legislation also provides for the possibility of conduction of technology-neutral auctions [25].

Green auctions are a market mechanism; this is its main advantage over the feed-in tariff. Competition allows to determine a fair price for green electricity, that will be more beneficial for the state and final consumers.

The start of green auctions, which would legally limit the number of renewable power plants, was planned in 2020, but was postponed due to the lack of annual quotas determining the total capacity of renewable energy projects that claims the feed-in tariff [24].

It should be noted that within the framework of this mechanism it is reasonable to introduce additional incentives aimed at promoting the development of hydropower and biopower plants. In addition to the advantages associated with the stability of electricity generation based on them, the ability to maneuver capacity, the electricity generation cost based on such power plants is much lower compared to solar and wind ones that, in turn, will put less pressure on the final consumers.

Financial liability for electricity imbalances, when producers and consumers pay for an inaccurate forecast, can partially improve the situation with balancing the energy system. Although its introduction does not increase the flexibility of the energy system, it encourages market participants to build balancing capacities or use more accurate systems to forecast electricity generation.

This approach is already provided for by the amendments to the Law of Ukraine "On the Electricity Market" [25]. Thus, according to [25] producers are obliged to bear financial responsibility for the imbalance of electricity, in case of non-compliance with the hourly schedules of its transmission. For producers of electricity from renewable energy resources, this legislative norm will take effect from January 1, 2021 – for power plants put into operation after April 2017, which are part of the balancing group of producers at the feed-in tariff. It is 10% of the cost of settling the imbalance and will grow by 10% annually.

Another requirement regarding reimbursing the cost of the imbalance to 31 December 2029 is the occurrence of conditions when the deviation of the actual hourly electricity supply from the hourly schedule exceeds 20% for wind farms, 5% – for small hydropower plants, and 10% – for solar power plants [26].

The most promising option for balancing the energy system in the conditions of rapid development of renewable energy and instability of electricity demand is the development of energy storage facilities.

Energy storage systems have several advantages because they allow [27]:

– to regulate the generation and consumption of electricity, accumulating its surplus in the least necessary time for consumers and giving it to the network when demand exceeds supply;

– to avoid financial responsibility for imbalances in case of non-fulfillment of hourly schedules of electricity transmission;

– increase the security of electricity supply in case of emergencies. when the electricity generation at power plants is impossible. In such cases, energy storage systems will be able to provide an uninterrupted supply of electricity for a certain period.

To date, no energy storage system has been installed in Ukraine. The first projects to build a network of energy storage facilities with capacity of 220 MW are planned to be implemented by the National Power Company "Ukrenergo" together with the European Bank for Reconstruction and Development and the International Finance Corporation within the framework of the signed memorandum in 2019 [28]. However, large-scale implementation of energy storage systems requires the formation of a legal framework and the introduction of motivational mechanisms under new or existing schemes supporting the renewable energy development.

It should be noted that above measures should be considered in conjunction with other ones that may have a positive impact on the effective integration of green electricity into the United Energy System of Ukraine. Such measures include: connection of Ukraine's energy system to the grid of the European Union with a permit to import electricity [29]; introduction of demand management mechanisms, when consumers are actively involved in balancing the grid, for example, charging electric cars in moments of excess electricity [29]; development of decentralized energy systems based on renewable energy resources [30, 31], as a large number of geographically spaced renewable power plants will reduce the unevenness of the electricity production schedule and increase the flexibility of the grid.

Conclusions

The COVID-19 pandemic has become a global determinant that has had a significant negative impact on Ukraine's energy market. One of the consequences of the quarantine restrictions caused by the COVID-19 pandemic for the Ukrainian energy market was a decrease in domestic demand for electricity and a reduction in electricity export. Against the background of the growing share of green electricity in final energy consumption, these problems have escalated into an energy crisis and created challenges to the operational security of the United Energy System of Ukraine. This leads a revision of the state policy on the renewable energy development, implementation of appropriate measures to increase the flexibility of the energy system and on their basis improving the current methodology for calculating the country's energy security. The main such measures include the development of мaneuvering energy capacities and electricity storage systems. These measures can be strengthened by the implementation of a number of secondary measures, which are described in this paper.

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Workability conditions determination of network distribution with overhead lines power transmission with the 6-35 kV

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Abstract. The principal of identification of isolation workability in relation to a ground was proposed. It is based on the electrosafety criteria usage and a minimum current flow to a ground. The conditions of workability of isolation of distribution network is calculated in look of changes of isolation workability restrictions in relation to regulations and standards. A mathematical model for the calculation of isolation workability in a look of a relation of workability indicators to the isolation parameters according to a ground. By analyzing the adequacy it as set that introduced formed models assumptions result in the appearance of a method error to 3,5 %.

1 Introduction

For the workability conditions determination of any object or system two ways can be used the first way for the object diagnostics (OD / DO) wish mostly overhead homogeneous structure of elements, that have a small amount of parameters that can be directly calculated first are theoretically researched for the selection of items of a technical condition (TC). Based on certain criteria's that should be necessarily previously noted, the analysis of possible of OD should be held by its control. Data that forms a diagnostic model of OD forms the workability conditions of OD. The checking of informative evaluation of a chosen complex of controlled items should be done.

According to another approach the previously chosen controlled items are used, that can describe TC of diagnostic object. Then for the DO the amount of experimental researches is made for the setting of sensitivity impact on a chosen complex of items on a technical condition of an object. The next stage contains she mathematical model of a change description of TC and then statistical reference of data basis being formed or neuron network that gives the opportunity of identify object TC according to the result of chosen items control. Given method is used in cases, that theoretically can`t explain the ability of controlled items to show TC through the difficulty of DO. Specifically, the workability conditions of DO can be formulated on the basis of analysis of theoretically formulated model or can be get experimentally [1].

The most unreliable part of network distribution is a overhead power lines (OPL) [2-4] where in a from of isolation the glass, porcelain and recently polymeric isolators are used. Isolators OPL are by direct impact of aggressive environment, which reveals in a look of a contamination of isolators top by dust, salt compounds that while hydrated cause the formation of leading on the top of isolator in accordance with current flow to the ground [5-10].

The determination of isolation workability in conditions of exploitation is more complicated because of the absence of precise quantitative methods of impact factors evaluation that worsen the isolation condition. That factors are the aging isolation process, hydration, contamination, mechanical impact, overstrain, corrosion etc. That`s why for the TC isolation control is practically used by average electrical items: neutral bias voltage, the tangent of the dielectric loss angle, common active resistance in relation to a ground, current and resistance zero sequence, phase conductivity according to a ground. [11-12].

To solve the calculation problem of isolation workability IW it is proposed to take precise and understandable for the isolation workability IW calculation. As such criteria safety operation conditions of isolation equipment from current flow to the ground that that form through the defects of isolation damages should be used as such criteria.

The aim of the study is the determinations of conditions of isolation workability of network distribution in relation to a ground by the technical conditions evaluation of isolation through the safety criteria`s and a minimum loss of electrical current from the current flow to the ground.

2 Research result

To gainthe set goal the following algorithms is proposed. The first step is to explain the criteria`s for the isolation workability conditions determination that should the multiple TC isolation divide into two submultiples of workable condition and unworkable condition.

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The second stage is to determine the workability conditions. DN isolation to a ground should be looked upon as a whole integral object of technical condition that is described as the group parameter change-active phase conductance DN in relation to a ground. The item selection of technical isolation condition should be ground on correspondence analysis the whole items complex, that in one way or another characterize the processes of isolation technical conditions change through the chosen criteria`s of TC isolation evaluation: safe usage DN and economical functioning. [13].

The main reason of isolation DN TC change is from isolated neutral is damage in relation to a ground, that`s why it is known that technical condition of sub phases isolation does not largely influence on its common TC. And its influence can be unnoticed. The phase unity in relation so a ground (C_a, $C_в$, C_c) depends on constructive network parameters and that's why their numbers are considered as constants. Small increase of common volume is observed only by isolator top hydration. Active isolation conductance in relation to a ground (q_a, q_b, q_c) can be changed in a rather wide range of significations. These changes characterize the process of formation of isolation damages. It`s main reason is the formation of shunting connections within network phases and ground.

Two boundary processes of TC are isolation change determined:

1. Symmetrical increase of active conductance's of isolation phases in relation to a ground, as a result of hydration and contamination of isolators top.
2. Non-symmetrical major increase of active conductance of certain phases in relation to a ground, as a result of appearance of shunting connections in them with the ground.

As we know [14] there is a standard in Ukraine in accordance with which current that can flow through a human body is restricted by the number 50 Hz, a magnitude no more than 6MA within the continuous protection work from the single-phase earth closure that is no more than 1s.by calculating the voltage and current though a human body it is modeled in electrical chain by a resistor with the resistance in a continuous protection act from SPEC to 1s - kOhm, more 1s – 6 kOhm. So, for the explanation of safety criteria of operation, indicator of isolation damage, that has a connection with the isolation damaging process and current through a human body that appears in the process should be introduced. Such an indicator can be current in shunting connection, created by a person with his touch to a current conducting part of electro setting. For the explanation of the choice of a taken indicator a special model of appearance of isolation damages should be built and considered. [15].

According to another criteria, it`s obvious that, the main way of economical functioning of network distributions is losses in the process of transmission of electroenergy. The instant characteristic is active power of electroenergy loss of the current flow to the ground (ΔP_{iz}). It can be considered as a way of economical functioning of isolation DN and according to the indicators of workability in a use of this criteria.

As an explanation of electrosafety criteria let`s look at the case when human touch appears in grounded parts of electrosetting (body, carcass, metallic construction). (Fig. 1),

where r_a, r_b, r_c,- active isolation phase resistance DN;

C_a, C_b, C_c - volumes of certain phases in relation to a ground;

r_1, L_1 – parameters of transformer substitute scheme of voltage (TV), isolation control;

Z_N– equivalent resistance load ;

r_l –human body resistance, (r_h *=6 kOhm*[16]),

R_g – grounded equipment resistance,

r_d– additional transitional resistance.

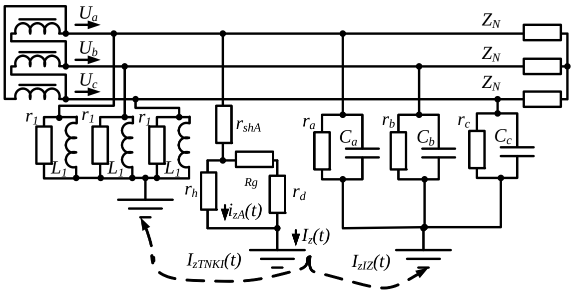

Fig. 1. Backup scheme for the description of a process of shunting connection appearance and human touch to the grounded elements electrosetting.

For the modelling of the most unfavorable case let`s consider that isolation damage happens in electrosetting with the simplest way of grounding. And additional transitive resistance of current flow to the ground is approximately the same as the wire that fell on the ground [17]and thus in the place of spread on the ground it approximately eques 100 Ohm for the raw soil. For the most unfavorable case let`s consider that the damage appears simultaneously in 2 different phases and human touch happens in a most damaged place of an isolation and current (i_{zA}), flows in a human body and it should not be more than 6 mA.

For that conditions limit values of workability conditions of an isolation can be calculated as:

$$\begin{cases} I_{z\mathrm{A}} = U_A \dfrac{g_{sh\mathrm{A}} \cdot g_h}{g_{sh\mathrm{A}} + g_h + g_g} \le 6 \cdot 10^{-3}\mathrm{A}; \\ I_{zB} = U_B \dfrac{g_{shB} \cdot g_h}{g_{shB} + g_h + g_g} \le 6 \cdot 10^{-3}\mathrm{A}; \\ I_{zC} = U_C \dfrac{g_{shC} \cdot g_h}{g_{shC} + g_h + g_g} \le 6 \cdot 10^{-3}\mathrm{A}. \end{cases} \quad (1)$$

where U_A, U_B, U_C – voltage phase A, B,C in relation to a ground (active items);

g_{shA}, g_{shB}, g_{shC} – shunting connection transmission appeared damages in certain phase;

g_l- human body transmission that equally ($g_h = 1/ r_h – 1/(6{\cdot}10^3)$) ;

g_3 = ground transmission that is calculate das ($g_g = 1/ R_g +1/ r_a$, where R_g – nominal resistance of grounded gear, that should not be more than 10 Ohm; r_d– additional transmission resistance of a ground).

Shunting connection transmission if for different can be calculated in a way of measuring in active phases in relation to a ground in the primary time moment (r_{a0}, $r_{в0}$, r_{c0}), for example, after putting to a work of electrosetting and its current repairmen and also these resistances calculation in any time moment (r_a, $r_в$, r_c) and their further comparison with the primary numbers and formulas:

$$\begin{cases} g_{shA} = 1/r_a - 1/r_{a0} - 1/r_S\,; \\ g_{shB} = 1/r_b - 1/r_{b0} - 1/r_S\,; \\ g_{shC} = 1/r_c - 1/r_{c0} - 1/r_S\,, \end{cases} \quad (2)$$

where r_s – symmetric reduce of isolation resistance in relation to a ground as a result of hydration of isolators top in a time of atmospheric precipitations that can be calculated as:

$$r_s = Min(r_{a0} - r_a); (r_{b0} - r_b); (r_{c0} - r_c)\,. \quad (3)$$

Stream usage in shunting connecting in a way of technical condition isolation item and a formation on a basic of these conditions of isolation workability (1) lets restrict the isolation workability condition multiples, based on equipment usage conditions.

Voltage in phases in a relation to a ground also depends on the isolation parameters

$$\begin{cases} U_A = I''\sqrt{\left[g_b + g_c + \frac{\omega}{\sqrt{3}}(C_c - C_b)\right]^2 + N}; \\ U_B = I''\sqrt{\left[g_a + g_c + \frac{\omega}{\sqrt{3}}(C_a - C_c)\right]^2 + M}; \\ U_C = I''\sqrt{\left[g_b + g_a + \frac{\omega}{\sqrt{3}}(C_b - C_a)\right]^2 + K}; \\ I'' = \frac{1{,}5\ \cdot U_f}{\sqrt{(g_a + g_b + g_c)^2 + (\omega(C_a + C_b + C_c) - B_L)^2}}; \\ N = \left[\frac{g_b - g_c}{\sqrt{3}} + \omega(C_b + C_c) - \frac{2B_L}{3}\right]^2; \\ M = \left[\frac{g_c - g_a}{\sqrt{3}} + \omega(C_a + C_c) - \frac{2B_L}{3}\right]^2; \\ K = \left[\frac{g_a - g_b}{\sqrt{3}} + \omega(C_b + C_a) - \frac{2B_L}{3}\right]^2, \end{cases} \quad (4)$$

where U_f – network distribution phase voltage;

ω- angle frequency DN;

C_A, C_B, C_C – volumes of certain phases in relation to a ground;

g_A, g_B, g_C– active transmission network phases in a relation to a ground;

B_L – sum reactive transmission of all inductive elements set to DN in a relation to a ground (transformer volume winding to the isolation control ZNOM , NTMI type and also arc extinguishing reactors and resonant grounding neutral devices): ($B_L = 3/\omega(L_{TNKI\sum 1} + L_{DGR} + L_{PRZN})$), thus, the winding induction TNKI is considered as linear items (for the state work regimes in a network).

Take (4) in an equation (1) we get mathematical model for the workability calculation using mentioned above criteria's.

Using safety criteria's of usage of mathematical model for the isolation workability calculation looks as:

$$\begin{cases} I_{gA} = I'' \cdot g_{shA} \cdot g_h / (g_{shA} + g_h + g_g) \cdot \sqrt{G_{A'} + G_{A''}}; \\ I_{gB} = I'' \cdot \frac{g_{shB} \cdot g_h}{g_{shB} + g_h + g_g} \cdot \sqrt{G_{B'} + G_{B''}}; \\ I_{gC} = I'' \cdot \frac{g_{shC} \cdot g_h}{g_{shC} + g_h + g_g} \cdot \sqrt{G_{C'} + G_{C''}}; \\ G_{A'} = \left[g_b + g_c + \frac{\omega}{\sqrt{3}}(C_c - C_b)\right]^2; \\ G_{A''} = \left[\frac{g_b - g_c}{\sqrt{3}} + \omega(C_b + C_c) - \frac{2B_L}{3}\right]^2; \\ G_{B'} = \left[g_a + g_c + \frac{\omega}{\sqrt{3}}(C_a - C_c)\right]^2; \\ G_{B''} = \left[\frac{g_c - g_a}{\sqrt{3}} + \omega(C_a + C_c) - \frac{2B_L}{3}\right]^2; \\ G_{C'} = \left[g_b + g_a + \frac{\omega}{\sqrt{3}}(C_b - C_a)\right]^2; \\ G_{C''} = \left[\frac{g_a - g_b}{\sqrt{3}} + \omega(C_b + C_a) - \frac{2B_L}{3}\right]^2. \end{cases} \quad (5)$$

The power of electroenergy loss from the current flow to the ground can be calculated using the information about power and active transmission network phases in a relation to a ground

$$\begin{cases} \Delta P_{iz\sum} = \Delta P_{izA} + \Delta P_{izB} + \Delta P_{izC}; \\ \Delta P_{iz\sum} = U_A^2 \cdot g_a + U_B^2 \cdot g_b + +U_C^2 \cdot g_c. \end{cases} \quad (6)$$

A gotten number of power loss in isolation ($\Delta P_{iz\sum}$) is compared to normative (ΔP_{iz}^{norm}), that can be calculated, having such technical data about a network as a type (OL or CL) common length L, nominal volume and cable type preferable, according to a described method in [18]:

$$\Delta P_{iz\sum} \leq \Delta P_{iz}^{norm}. \quad (7)$$

Thus, over normative power isolation can be calculated as restriction on its number for the formation of the workability conditions. Thus, the taken restrictions can be separated for different phases:

$$\Delta P_{izA} \leq \Delta P_{iz}^{norm}/3\,;$$
$$\Delta P_{izB} \leq \Delta P_{iz}^{norm}/3\,;$$
$$\Delta P_{izC} \leq \Delta P_{iz}^{norm}/3.$$

According to a method [18], there are few states of environment, where the researches has been alone (LvivORG-RES) and has been got the normative isolation power loss numbers. They are: 1) rain, wet snow, drizzle; 2) fog; 3) dew, no precipitation. So, for the calculation of isolation workability DN calculation should first calculated normative power loss in isolation for those three states of environment and only after that compare the factial number of power loss in isolation with the normatives for the certain hydration level of environment that should be controlled. Using the economical criteria's of mathematical model functioning for the isolation workability calculation looks:

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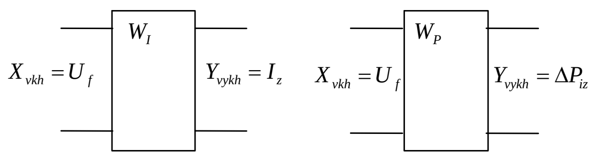
$$\begin{cases} \Delta P_{iz\mathrm{A}} = I'''(N' + M'); \\ \Delta \mathrm{P}_{\mathrm{iz}B} = I'''(N'' + M''); \\ \Delta \mathrm{P}_{\mathrm{izA}} = I'''(N''' + M'''); \\ I''' = \dfrac{2{,}25 \cdot U_f^2 \cdot g_a}{(g_a + g_b + g_c)^2 + (\omega(C_a + C_b + C_c) - B_L)^2}; \\ N' = \left[g_b + g_c + \dfrac{\omega}{\sqrt{3}}(C_c - C_b\right]^2; \\ M' = \left[\dfrac{g_b - g_c}{\sqrt{3}} + \omega(C_b + C_c) - \dfrac{2B_L}{3}\right]^2; \\ N'' = \left[g_b + g_c + \dfrac{\omega}{\sqrt{3}}(C_a - C_c\right]^2; \\ M'' = \left[\dfrac{g_c - g_a}{\sqrt{3}} + \omega(C_b + C_c) - \dfrac{2B_L}{3}\right]^2; \\ N''' = \left[g_b + g_c + \dfrac{\omega}{\sqrt{3}}(C_b - C_a\right]^2; \\ M''' = \left[\dfrac{g_a - g_b}{\sqrt{3}} + \omega(C_b + C_c) - \dfrac{2B_L}{3}\right]^2. \end{cases} \tag{8}$$

As we see, the main part in describing the change process of isolation DN technical phase are the active transmission network phases in a relation to a ground (g_a, g_b, g_c). They are the only numbers in correlations (7) and (8), that change in a developing damaging process, because later we will consider them as diagnostical items for the isolation workability calculation.

Given the above, the diagnostic model for the method of determining the efficiency of insulation can be represented as a four-pole network with the input signal – phase voltages of the distribution network, and output: in the first case (using the criterion of operational safety) – currents flowing to ground through the shunt connection (Fig. 2.a); in the second case (when applying the criterion of economy of functioning) – the power of electricity losses from currents flowing to ground (Fig.2.b).



a) б)

Fig. 2. Diagnostic model for determining the efficiency of insulation.

a) – when applying the criterion of operational safety; b) – when applying the criterion of economy of functioning; in the diagram (W_I) is the transfer function when used as an output signal of the current in the shunt connection, (W_P) – is the transfer function when used as an output signal of the power of electricity losses from currents flowing to ground.

Determination of operability can be obtained from the relationship between the transfer functions (W_I) and (W_P), since both the currents in the shunt and the power of electricity losses from currents flowing to ground depend on the phase voltages of the network relative to ground:

$$W_I = |W(i\omega)| \cdot \frac{g_{shX} \cdot g_l}{g_{shX} + g_l + g_z}; \quad Wp = |W(i\omega)|^2 \cdot g_x \tag{9}$$

Where (x) is the index of the corresponding phase of the network; ($W(i\omega)$) is a complex of the transfer function, when the phase voltage (x) of the network relative to ground is used as the output signal.

As can be seen, both transfer functions have a common component: a complex of transfer functions ($W(i\omega)$). To simplify the problem of constructing a characteristic equation, we will further use it as a diagnostic model.

Let's define the transfer function for the received diagnostic model and the characteristic equation for carrying out check of correctness of a choice of indicators of efficiency of isolation.

Complexes of transfer functions at consideration of various phases of a network is going to be identified by the formula:

$$W_X(i\omega) = \frac{\dot{U}_X}{U_f}.$$

To simplify the calculations in further research, we will consider only networks with isolated neutral, in which there are no inductive elements that have a connection to ground, ie. ($B_L=0$).

$$W_A(i\omega) = \\ = \frac{\sqrt{3}\left[(g_b + i\omega C_b)e^{i30^0} + (g_c + i\omega C_c)e^{-i30^0}\right]}{(g_a + g_b + g_c) + i\omega(C_a + C_b + C_c)};$$

$$W_B(i\omega) = \\ = \frac{\sqrt{3}\left[(g_c + i\omega C_c)e^{i30^0} + (g_a + i\omega C_a)e^{-i30^0}\right]}{(g_a + g_b + g_c) + i\omega(C_a + C_b + C_c)};$$

$$W_C(i\omega) = \\ = \frac{\sqrt{3}\left[(g_a + i\omega C_a)e^{i30^0} + (g_b + i\omega C_b)e^{-i30^0}\right]}{(g_a + g_b + g_c) + i\omega(C_a + C_b + C_c)}. \tag{10}$$

In ratios (10) the expressions for the complexes of the voltages of the network phases relative to the ground were obtained by using the formula for the bias voltage of the neutral (U_0) in complex form.

To move from a complex to the operator form of the record (operational method is used: ($i\omega \to p$)) open the complexes in the numerator of expressions (10) and multiply the numerator and denominator on the conjugate denominator complex. As a result, we get:

$$W(p) = \frac{\sqrt{3}(a_3p^3 + a_2p^2 + a_1p + a_0)}{(g_a + g_b + g_c)^2 + \omega^2(C_a + C_b + C_c)^2}, \tag{11}$$

where a_0, a_1, a_2, a_3 - coefficients of the characteristic equation.

For getting the characteristic equation, it is necessary to equate the numerator of expression (11) to zero.

$$a_3 \cdot p^3 + a_2 \cdot p^2 + a_1 \cdot p + a_0 = 0 \quad (12)$$

For phase A the coefficients of the characteristic level

$$\begin{cases} a_3 = -\left[\frac{1}{2 \cdot w} \cdot (C_b - C_c) \cdot (C_a + C_b + C_c)\right]; \\ a_2 = \frac{1}{2 \cdot w} \cdot (C_b - C_c) \cdot (g_a + g_b + g_c) - \\ -\left[\frac{1}{2 \cdot w}(g_b - g_c) + \frac{1.5}{\sqrt{3}}(C_b + C_c)\right](C_a + C_b + C_c); \\ a_1 = -\frac{1.5}{\sqrt{3}} \cdot (g_b - g_c)(C_a + C_b + C_c) - \\ -\left[\frac{1}{2 \cdot w}(g_b - g_c) + \frac{1.5}{\sqrt{3}}(C_b + C_c)\right](g_a + g_b + g_c); \\ a_0 = \frac{1.5}{\sqrt{3}}(g_b + g_c)(g_a + g_b + g_c); \end{cases} \quad (13)$$

For phases B and C the coefficients of the characteristic equation are similar to expressions (13) with the only difference that instead of the factors ($g_b \pm g_c$) and ($C_b \pm C_c$) for phase B there will be factors ($g_c \pm g_a$) and ($C_c \pm C_a$), and for phase C – ($g_a \pm g_b$) and ($C_a \pm C_b$).

To check the correctness of the choice of insulation performance indicators (diagnostic indicators) we will study the sensitivity of the roots (poles) of the characteristic equation (13) to change of diagnostic indicators (parameters of isolation of phases – active conductivities of isolation of the distributive network concerning the ground). With the help of this study, you can qualitatively assess the degree of influence of the selected diagnostic indicators on the technical condition of the object of diagnosis, namely the isolation of the distribution network concerning the ground. In the final result we should receive confirmation of correctness of a choice of set of diagnostic indicators and the information for their ordering according to degree of influence. For the convenience of research, a real distribution network of overhead power lines with a voltage of 10 kV with a total length of 70 km was taken.

Based on its technical data, the normative power of insulation losses for all three environmental conditions was determined according to the method [18] by the formula:

$$\Delta P_{iz\_i}^{norm} = I_{iz}^2 \cdot R_i \cdot T_i \cdot \frac{L}{100},$$

where I_{iz} - specific square value of the ground fault current (given in tabular form in [18] for air distribution networks of different voltage classes) for the corresponding i-th level of ambient humidity, A/ 100km;

R_i - the specific value of the equivalent active resistance of the insulation relative to the ground for the i-th level of humidity, Ohm 100km;

T_i - duration for a year of weather with the i-th level of humidity, hours (from the reference of the hydrometeorological center);

L – is the total length of the distribution network.

For given distribution network: $\Delta P_{iz_{100\%}}^{norm} = 23377\ W$; $\Delta P_{iz_{80-100\%}}^{norm} = 17910\ W$; $\Delta P_{iz\_<80\%}^{norm} = 6643\ W$.

Initial conditions of the study:

1. At the initial moment of time, the active insulation of the network phases relative to the ground is symmetrical ($r_{A0}=r_{B0}=r_{C0}=100\ kOmh$). Accordingly, we introduce the concept of the normal value of the active conductivity of the phase insulation relative to ground, which is equal to ($g_n=10^{-5}\ Sm$). Any current value of active conductivity, the effect of which on the poles is investigated, can be represented as the sum of the normal value and the current value of its deviation ($g_i=g_n+\lambda_i$).

2. Capacities of isolation of phases concerning the ground are symmetrical, are ($C_a=C_b=C_c=C_f=0.5\ mcF$) and remain unchanged.

3. When studying the effect of a diagnostic indicator on the poles, it is believed that all other indicators remain unchanged.

4. The extreme change of the diagnostic index is considered to be the permissible deviation of the active conductivity (λ_i), in which the active conductivity in the phase of shunting (phase A) is equal to the active conductivity of the phase whose change is investigated (phase B or C), at critical performance of working conditions (6) and (7) It is believed that the damage occurred simultaneously in two phases and gained maximum development, up to the limit of the efficiency of the insulation.

5. For working conditions (6) and (7) the simulation is carried out and the limits of change of active conductivities are determined for the given initial conditions:

– for performance conditions (7) in the study of the effect of active conductivity of phase B – ($\lambda_B=5.39\cdot10^{-5}$); of phase C – ($\lambda_C=6.692\cdot10^{-5}$);

– for performance conditions (6) in the study of the effect of active conductivity of phase B: ($\lambda_{B\ 100\%}=4.118\cdot10^{-4}$, $\lambda_{B\ 80\text{-}100\%}=2.992\cdot10^{-4}$, $\lambda_{B<80\%}=8.766\cdot10^{-5}$) ; of phase C: ($\lambda_{C\_100\%}=4.118\cdot10^{-4}$, $\lambda_{C\_80\text{-}100\%}=2.992\cdot10^{-4}$, $\lambda_{C\_<80\%}=8.766\cdot10^{-5}$);

With a symmetrical increase in the conductivities of all three phases simultaneously: ($\lambda_{sym\_100\%}=2,238\cdot10^{-4}$, $\lambda_{sym\_80\text{-}100\%}=1,691\cdot10^{-4}$ $\lambda_{sym\_<80\%}=5,644\cdot10^{-5}$);

Since the capacitances of the phases are symmetric, the characteristic equation will be quadratic and will have the following roots:

$$x_1 = \frac{g_a + g_b + g_c}{C_a + C_b + C_c} = \frac{g_n}{C_f};$$
$$x_2 = \frac{-\frac{1,5}{\sqrt{3}} \cdot (g_b + g_c)}{-\frac{1,5}{\sqrt{3}} \cdot (g_b + g_c) + -\frac{1,5}{\sqrt{3}} \cdot (C_b + C_c)} = -\frac{g_n}{C_f}. \quad (14)$$

Given the above initial conditions, we write the expressions of the characteristic equation for three cases:

1. In the study of the impact g_a:

$$-3\sqrt{3}C_f^2x^2 + \sqrt{3}\lambda C_f x + 3\sqrt{3}g_n^2 + \sqrt{3}\lambda g_n = 0. \quad (15)$$

2. In the study of the impact (g_b):

$$\left(3\sqrt{3}C_f^2 - \frac{3C_f}{2w}\lambda\right)\left[\frac{\lambda^2}{2w} + \left(\sqrt{3}C_f + \frac{3g_n}{2w} - \frac{3\sqrt{3}C_f}{2}\right)\lambda\right]x + \\ +3\sqrt{3}g_n^2 + \frac{5\sqrt{3}g_n}{2}\cdot\lambda + \lambda^2 = 0. \quad (16)$$

3. In the study of the impact (g_c);

$$\left(\frac{3\lambda C_f}{2w} - 3\sqrt{3}C_f^2\right)x^2 + \left[\left(\frac{-\lambda^2}{2w}\right) + \left(\sqrt{3}C_f - \frac{3g_n}{2w} - \frac{3\sqrt{3}C_f}{2}\right)\lambda\right]x + 3\sqrt{3}g_n^2 + \frac{5\sqrt{3}g_n\lambda}{2} + \lambda^2 = 0 \quad (17)$$

To assess the sensitivity of the poles to diagnostic indicators and to organize them according to the degree of influence, we will use the method of determining the norm of the vector of relative sensitivities [1]. In general, the norms of the vectors of relative sensitivities of the poles (in the form of dependence on the deviation λ) to change the relevant diagnostic parameters will take the form:
in the study of the impact (g_a):

$$\mathrm{Ta}(\lambda) = \mathrm{const} = \\ = \sqrt{\left[\frac{\sqrt{3}C_f\cdot x_1 + \sqrt{3}g_n}{6\sqrt{3}C_f\cdot g_n\cdot x_1}\right]^2 + \left[\frac{\sqrt{3}C_f\cdot x_2 + \sqrt{3}g_n}{6\sqrt{3}C_f\cdot g_n\cdot x_2}\right]^2}, \quad (18)$$

in the study of the impact (g_b):

$$\mathrm{Tb}(\lambda) = \\ = \sqrt{\frac{\left[\left(\frac{-3C_f}{2w}\right)\cdot x_1^2 + \left(\frac{\lambda}{w} + \frac{3g_n}{2w} - \frac{\sqrt{3}C_f}{2}\right)\cdot x_1 + 2\lambda + \frac{5\sqrt{3}g_n}{2}\right]^2}{-6\sqrt{3}C_f\cdot g_n\cdot x_1} + \frac{\left[\left(\frac{-3C_f}{2w}\right)\cdot x_2^2 + \left(\frac{\lambda}{w} + \frac{3g_n}{2w} - \frac{\sqrt{3}C_f}{2}\right)\cdot x_2 + 2\lambda + \frac{5\sqrt{3}g_n}{2}\right]^2}{6\sqrt{3}C_f\cdot g_n\cdot x_2}}, \quad (19)$$

in the study of the impact (g_c):

$$\mathrm{Tc}(\lambda) = \\ = \sqrt{\frac{\left[\left(\frac{3C_f}{2w}\right)\cdot x_1^2 + \left(\frac{-\lambda}{w} - \frac{3g_n}{2w} - \frac{\sqrt{3}C_f}{2}\right)\cdot x_1 + 2\lambda + \frac{5\sqrt{3}g_n}{2}\right]^2}{-6\sqrt{3}C_f\cdot g_n\cdot x_1} + \frac{\left[\left(\frac{3C_f}{2w}\right)\cdot x_2^2 + \left(\frac{-\lambda}{w} - \frac{3g_n}{2w} - \frac{\sqrt{3}C_f}{2}\right)\cdot x_2 + 2\lambda + \frac{5\sqrt{3}g_n}{2}\right]^2}{6\sqrt{3}C_f\cdot g_n\cdot x_2}} \quad (20)$$

The norm of the vector of relative sensitivity to change (g_a) is a constant value, and is equal to (T_a=$3.333\cdot10^{-4}$). This is explained by the fact that the dependence of the roots of the characteristic equation from (g_a) has a linear character (compiled to consider the possibility of damage in phase A), and therefore at differentiation for definition (T_a) as a result a constant will be received. The norms of the vectors of relative sensitivities to the change of (g_b) and (g_c) are functions of the deviation (λ). Graphs of dependencies are going to be built for a visual assessment of sensitivity for each diagnostic indicator, Figure 3.Thus, as a result of the conducted researches it is established that influence of all three conductivities of phases on poles (roots of the characteristic equation) has approximately one order of magnitude, and influences (g_c) and (g_b) are almost identical that it is possible to observe in fig. 3 (curves of the dependence of the norm of the sensitivity vector on the deviation for phases B and C are almost coincide). Therefore, the set of diagnostic indicators was chosen correctly and the diagnostic model is appropriate.

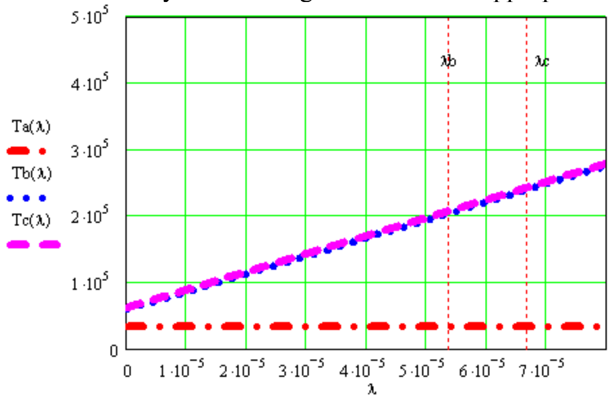


Fig. 3. Dependences of norms of vectors of relative sensitivities on deviation: a – is general schedule of dependencies.

3 Conclusion

The main reason isolation damage is appearance of shunting connecting's within conductive part and a ground in electrical distribution network with the voltage 6-35 kV. In this case there are 2 processes-smooth symmetrical reduce of active isolation resistance of isolation phases as a result of hydration work on the isolator top and non-symmetrical harsh reduce of isolation active resistance of separated phase in a relation to a ground as a result of shunting connecting appearance. Isolation workability conditions calculation of distribution network in a look of restriction of isolation workability items change in relation to a ground, based on official documents and standards should carry out the current reduce through shunting connection with the electrosafety criteria's and active power loss in isolation from current flow to a ground with the economical criteria of minimum electroenergy loss.

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Research of modular multilevel converter with phase-shifted pulse-width modulation

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Abstract. The work is devoted to the study of performance of a multilevel electric energy converter using phase-shifted pulse-width modulation. Equations describing the state of a dynamic system multilevel converter - load are investigated and a mathematical model of the system in Matlab / Simulink environment has been constructed. Variants of implementation of phase-shifted pulse-width modulation systems from the point of view of influence on harmonics of output voltage and magnitude of circulating current in the converter are investigated.

1 Introduction

The introduction of an adjustable frequency electric drive for low-voltage AC motors over the last decade has proven to be an effective method of improving energy efficiency in industry and utilities [1–3]. The uncontrolled rectifier- voltage-source inverter circuit has become a kind of industry standard for low- and medium-power AC drives [4]. However, high-power electric drives using medium-voltage motors also have significant energy saving potential. There is no single approach to the construction of power converters of such systems [5]. Another area of use of high-power converters is distributed generation systems, which provide for the integration of renewable energy sources into power supply systems. Therefore, the development of means of converting electricity in systems with a medium level of rated voltage is an important area.

Cases of using direct converters in systems with a medium level of rated voltage are isolated, specific industrial models that are mass-produced are absent [6], and therefore it is advisable to focus on converters with intermediate DC link, which, in turn, are divided into converters based on voltage-source inverters and converters based on current-source inverter depending on the configuration of passive elements of the DC link. The advantage of converters based on current-source inverters is the ability for the electric drive to work in four quadrants without the use of additional hardware or software. However, their main parts must have a controlled rectifier, which leads to an increase in reactive power consumption levels. In addition, this type of converter is able to switch the inverter switches only when operating on active-capacitive load, and therefore its use without additional capacitive elements is possible only when used as a motor synchronous motor with excitation that is greater than the rated one. Therefore, more promising now is the use of circuits based on voltage-source inverters [7 – 9]. These circuits, in turn, are divided into two-level converters and multilevel converters. However, due to the fact that the operation of a two-level converter in a system with a medium level of rated voltage will lead to significant values of du / dt, their use in this case is not possible [10]. The use of multi-level converters allows to reduce the du / dt, as well as the total harmonic distortion ratio (THD), which reduces the size of the filters on the AC side [11]. Multi-level converters based on a circuit with cascaded H-bridges, circuits with "flying" capacitors, with a diode-clamped converters and modular multi-level converters are currently being mass-produced [12]. In addition, scientists are constantly developing new schemes that are certain combinations of existing options. The main disadvantage of the circuit with cascaded H-bridges [13] is the need to use a phase-shift transformer to obtain several galvanically isolated DC sources. The disadvantages of circuits with "flying" capacitors and clamped diodes are the difficulty of balancing the voltages on the capacitor dividers. The scheme of a modular multilevel converter does not require a complex transformer, and therefore its use is more appropriate for reasons of economy and reliability.

2 Analysis of the modular multilevel inverter and mathematical dependences describing its state

The generalized structure of the modular multilevel inverter is shown in fig. 1. It consists of three legs designed to power the load phases and connected to a common DC link. A three-phase symmetrical load is connected to the midpoints of the inverter legs through an inductor L.

Each arm consists of a number of semiconductor (SM) cells connected in series. Inductors L are designed to limit

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the intensity of the current rise in the circuit on the DC and AC side, as well as to compensate for the difference between phase voltage and voltage in the DC link caused by voltage changes on cell capacitors or other reasons. However, the active component of the resistance of these inductors leads to an increase in the overall level of losses in the converter. A significant advantage of such a circuit is the ability to build it using the same type of circuit modules, which provides the ability to replace them quickly in case of failure of semiconductor elements. In this case, there are a significant number of options for constructing circuits of individual cells, which allows you to modify the general characteristics of the converters and the number of output voltage levels.

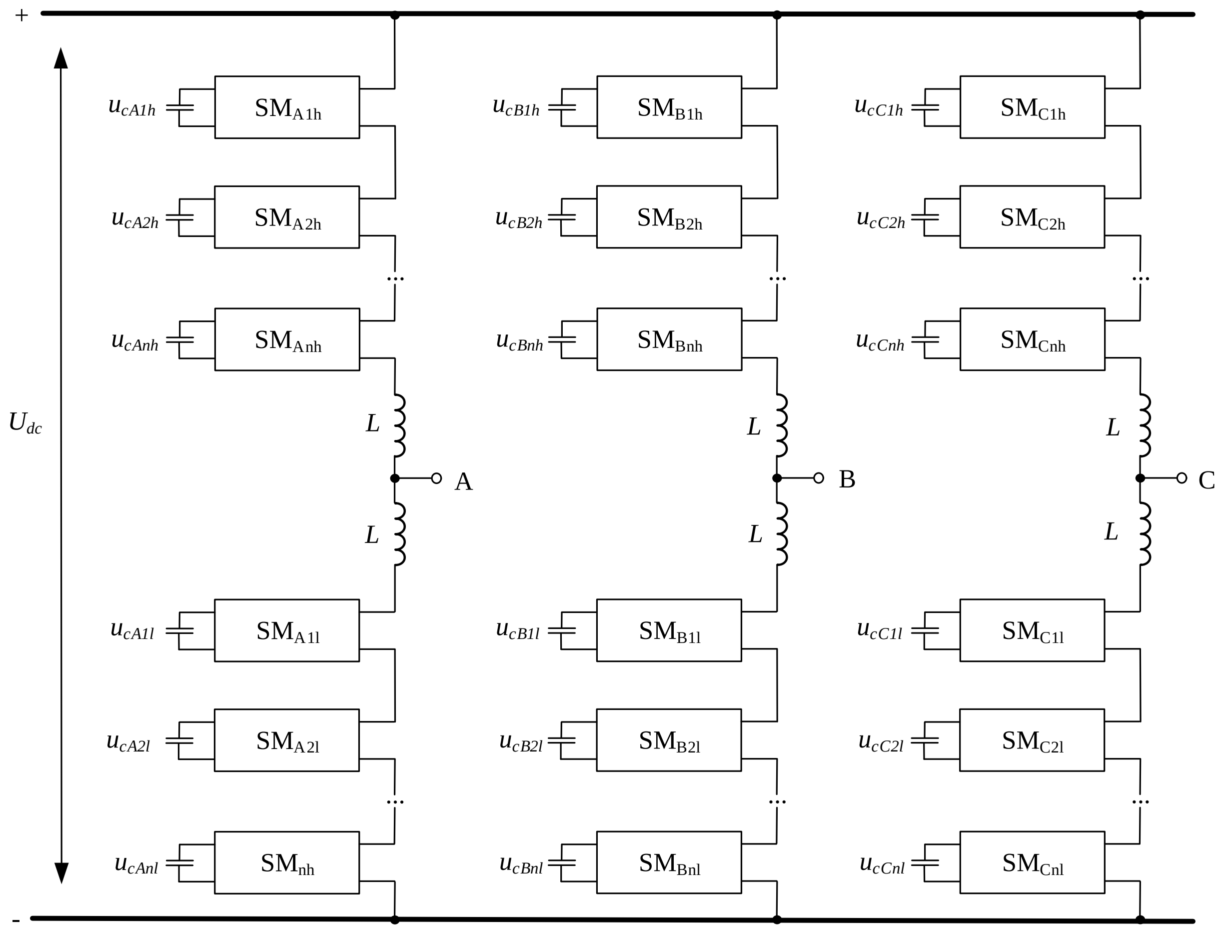

Fig. 1. The structure of a modular multilevel converter.

The most popular is the scheme of half-bridge modules, which is shown in Fig. 2a. It contains two switches operating in inverse mode and provides two levels of output voltage - zero voltage and a voltage equal to the voltage on the capacitor u_c. This scheme is able to provide a low level of energy loss and high reliability. The use of more complex schemes of converter modules is explained by the need and expediency to have more levels of output voltage, which reduces the total number of semiconductor elements used and the overall dimensions of the modular multilevel converter. As such modules their full-bridge variant which is shown in fig. 2b. This scheme allows to obtain a bipolar output voltage, which is useful both in terms of increasing the flexibility of voltage balancing on capacitors, and in terms of the possibility of reducing the magnitude of the emergency current. The use of circuits with a fixed zero point (Fig. 2c) and with "flying" capacitors (Fig. 2d) allows to significantly expand the number of switching states, and therefore requires more complex control methods with the ability to maintain voltage balance on capacitors.

Consider the equivalent scheme of one phase of a modular multilevel inverter (Fig. 3). The voltage in the DC link is divided into two sources with voltages of $\frac{1}{2}U_{dc}$ to obtain an artificial zero point. The output voltage of phase j is denoted by u_{jout}, and the output current is denoted by i_{jout} $(j \epsilon \{a, b, c\})$. In the upper and lower arms, switching of the semiconductor switches of the modules leads to the sequential turning-on of a certain number of capacitors and the emergence of voltages u_{jh} and u_{jl}, respectively. The currents i_{jh} and i_{jl}, respectively, flow in the upper and lower arms.

Using Kirchhoff's second law for the contour of the upper and lower arms, the following equations can be obtained:

$$\frac{1}{2}U_{dc} - u_{jh} - u_{jout} = i_{jh}R + L\frac{di_{jh}}{dt}; \quad (1)$$

$$\frac{1}{2}U_{dc} - u_{jl} + u_{jout} = i_{jl}R + L\frac{di_{jl}}{dt}. \quad (2)$$

As a rule, in order to reduce the overall dimensions of inductive elements, conditions are created for the occurrence of mutual inductance between them. If we

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denote the mutual inductance of inductive elements M, then equations (1), (2) can be written as:

$$\frac{1}{2}U_{dc} - u_{jh} - u_{jout} = i_{jh}R + L\frac{di_{jh}}{dt} + M\frac{di_{jl}}{dt}; \quad (3)$$

$$\frac{1}{2}U_{dc} - u_{jl} + u_{jout} = i_{jl}R + L\frac{di_{jh}}{dt} + M\frac{di_{jh}}{dt}. \quad (4)$$

The voltage on the inductive elements of the invertor's leg can be determined as follows:

$$u_{jL} = L\frac{di_{jh}}{dt} + M\frac{di_{jl}}{dt} + L\frac{di_{jh}}{dt} + M\frac{di_{jh}}{dt}. \quad (5)$$

With a unit coefficient of mutual inductance $L = M$, then:

$$u_{jL} = 4L\frac{di_{jc}}{dt} = U_{dc} - u_{jh} - u_{jl}, \quad (6)$$

where i_{jc} – the circulating current of the converter's arm that feeds the load phase j and flows in the upper and lower converter's arms, which can be defined as:

$$i_{jc} = \frac{1}{2}(i_{jh} + i_{jl}). \quad (7)$$

Ideally, the phase load current i_{jout} is divided equally between the upper and lower arms, then the arm currents can be defined as follows:

$$i_{jh} = \frac{1}{2}i_{jout} + i_{jc}. \quad (8)$$

$$i_{jl} = \frac{1}{2}i_{jout} + i_{jc}. \quad (9)$$

The output voltage of the converter through the voltages of the upper and lower arms of the previously obtained dependences can be expressed as:

$$u_{jout} = \frac{1}{2}(u_{jl} - u_{jh}). \quad (10)$$

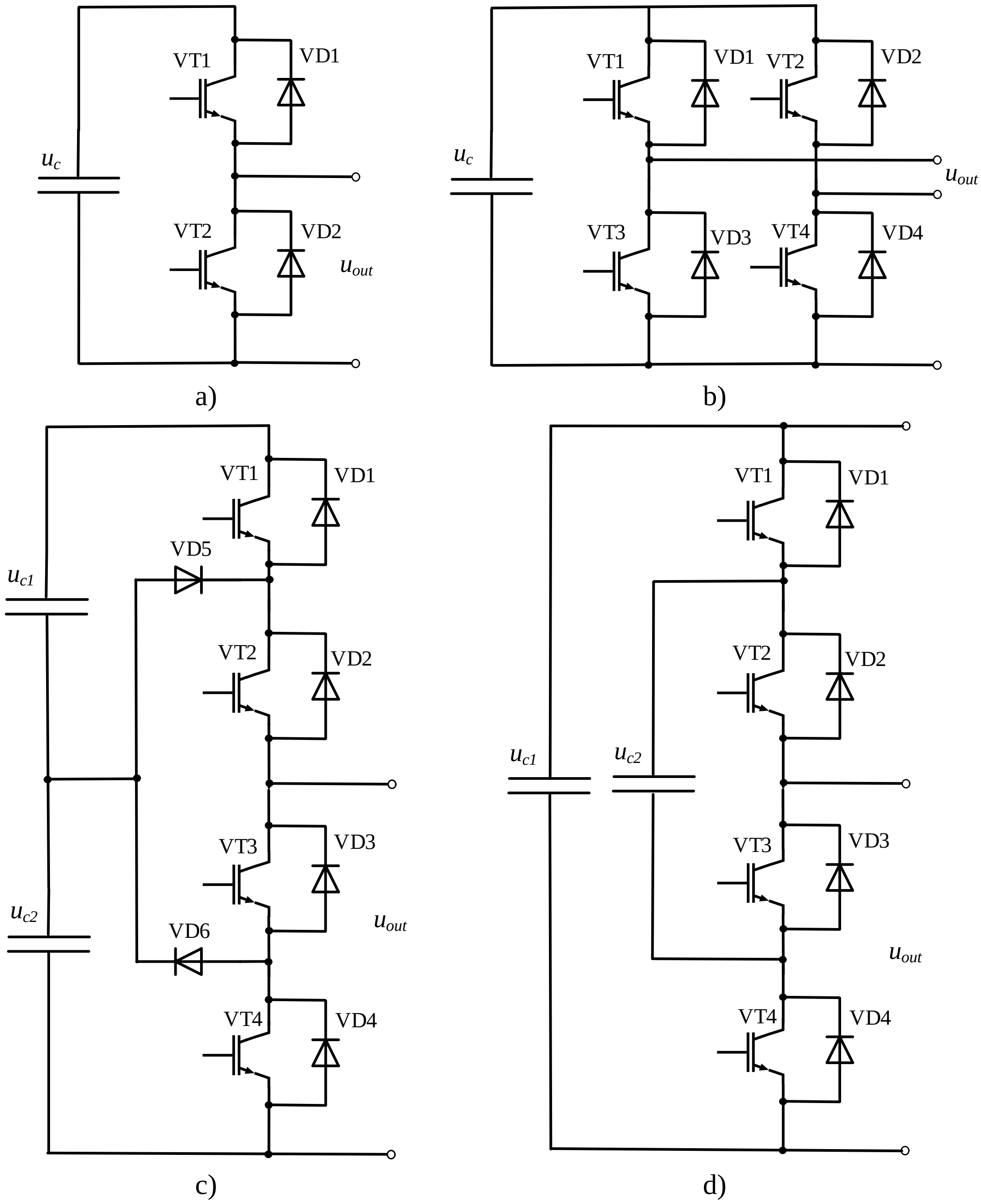

Fig. 2. Some cell diagrams that are suitable for use in a modular multi-level converter circuit.

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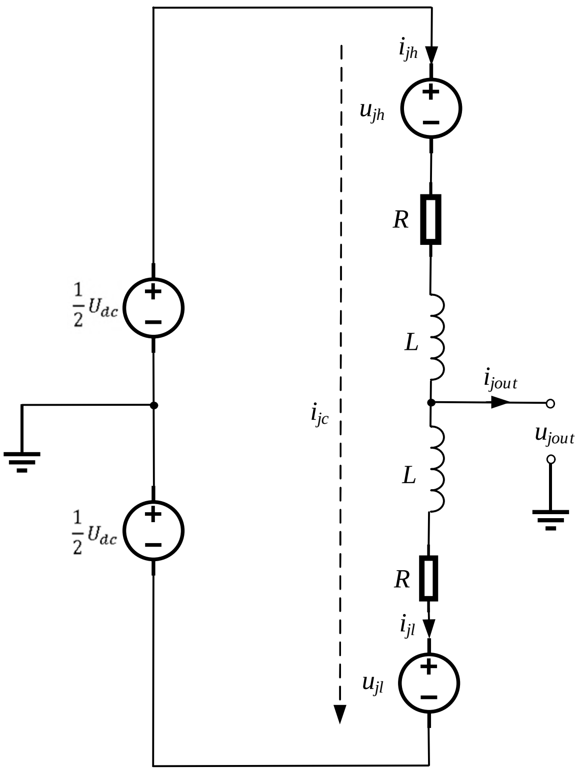

Fig. 3. Equivalent scheme of one leg of the converter.

From equation (6) the circulating current of the converter can be determined as follows:

$$i_{jc} = \frac{1}{4L}\int_0^t u_{jL}dt + I_{jcDC}, \tag{11}$$

where I_{jcDC} is a constant component of the circulating current.

3 Phase-shifted pulse-width modulation

The principle of pulse-width modulation with phase shift of the carrier signals is presented in Fig. 4. To obtain the switching signals of the switches of the converter modules containing N modules in one arm, N phase-shifted triangular carrier signals are generated to control the upper half of the circuit and N the same signals to control the switches of the lower half of the circuit. The frequency of the triangular signal carriers is selected depending on the required switching frequency of the semiconductor elements. Subsequently, the sinusoidal reference signal of each phase is compared with a number of triangular carrier signals and the corresponding control signals of the circuit switches are obtained. To improve the coefficient of total harmonic distortion between the triangular carrier signals, a phase shift of θ = 2π / N is set. Thus, it is expedient to investigate the influence of the magnitude of this shift on the performance of a modular multilevel converter.

A mathematical model in Matlab / Simulink environment has been developed to study the influence of the carrier shift angle on the operation of a modular multilevel converter. The parameters of the simulated converter are given in Table. 1.

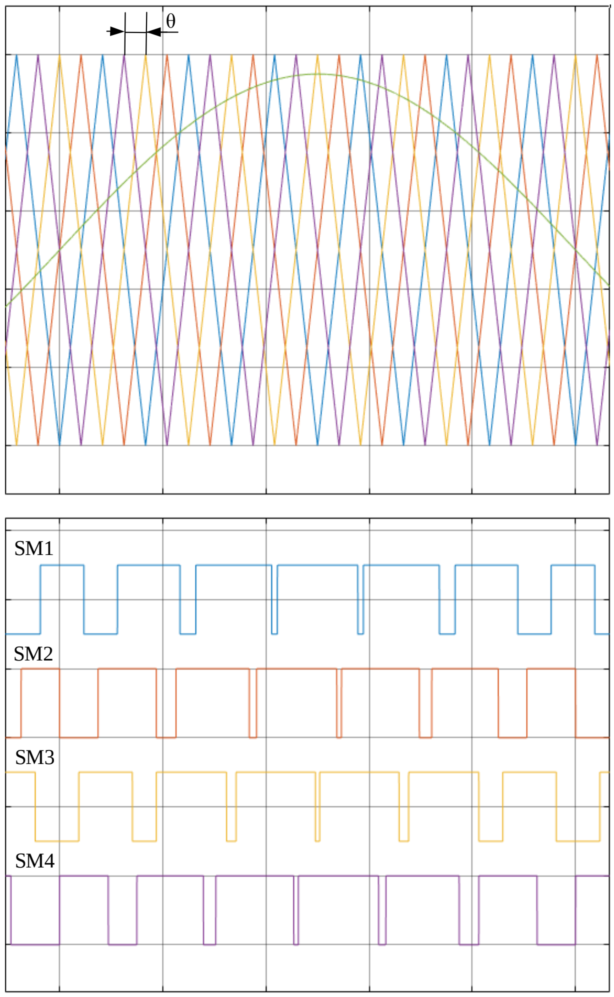

Fig. 4. The principle of phase-shifted pulse-width modulation.

Table 1. The parameters of the simulated converter

Parameter name	**Parameter value**
Number of converter modules per arm	4
The scheme of the module of the converter	half-bridge
Voltage in the DC link U_{dc}	4000 V
The capacitor capacity of each converter module	750 μF
The inductance of the arm of the converter	0.02 H
Modulation factor	0.9
Frequency of carrier signals	500 Hz
The frequency of the reference signal	50 Hz
Active load resistance	85 Ohm
Load inductance	0.167 H

Fig. 5 represents the simulation results of a modular multilevel inverter with a shift of carrier signals by θ = 2π / N. The shape of the output voltage (Fig. 5a) has a clearly visible number of levels, which corresponds to the number of modules in each arm of the converter, circulating current (Fig. 5b) has a frequency, which corresponds to the frequency of the output voltage of the converter, and its root mean square value for this case is 6.157 A. A positive property of this method of modulation is the ability to balance voltages on capacitors (Fig. 5c) without the use of additional hardware or software. The

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amplitude of voltage ripple on the capacitors in steady state does not exceed ± 40 V, which is quite satisfactory. Analysis of the output voltage spectrum of the converter (Fig. 5d) shows the presence of significant harmonic components in the vicinity of 2000 Hz, and the total coefficient of nonlinear distortion (THD) was 26.99%.

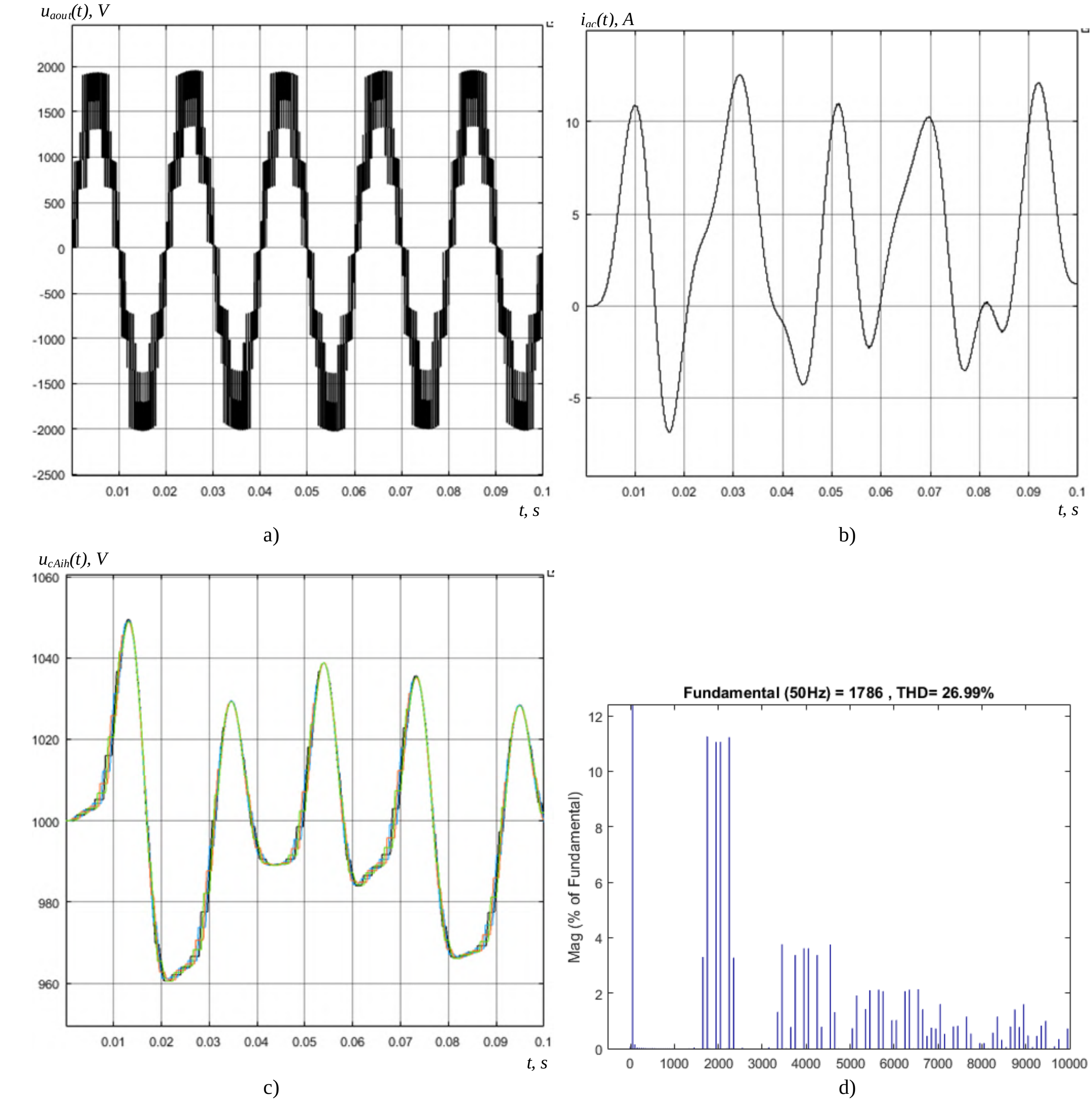

Fig. 5. The results of modeling the operation of a modular multilevel converter when the carrier signals are shifted by 2π / N: a – change in the output voltage of the converter; b – change in the magnitude of the circulating current; c – voltage change on the capacitors of the upper arm of the circuit; d – the spectrum of the output voltage of the converter.

Fig. 6 represents the results of modeling a modular multilevel inverter when reducing the values of the shift of the carrier signals to the level of 2/3 of the previous case. The graph of the output voltage (Fig. 6a) shows a visually greater sinusoidality than in the previous case. The frequency of pulsations of the circulating current (Fig. 6b) has become much higher than the frequency of the output voltage of the converter, although the fundamental harmonic, which corresponds to the frequency of the output voltage, is visually noticeable. However, the rms value of the circulating current increases almost twice to 11.8 A, which leads to an increase in losses in the converter. Another significant disadvantage of this method of modulation is the loss of the ability to balance the voltages on the capacitors of the modules (Fig. 6c), which during observation (0.1 s) are significantly unbalanced, which allows us to conclude that such a system is unsuitable for practical implementation without developing additional measures to reduce imbalance voltage. The positive effect of using such a system is the reduction of the total harmonic distortion to 21.71%, which confirms the previously described conclusions about the greater sinusoidality of output voltage of the converter. Therefore, in the future it is advisable to perform a search for the shift angle, which minimizes the coefficient of total harmonic distortion without losing the ability to self-balance the voltages on the capacitors of the modules.

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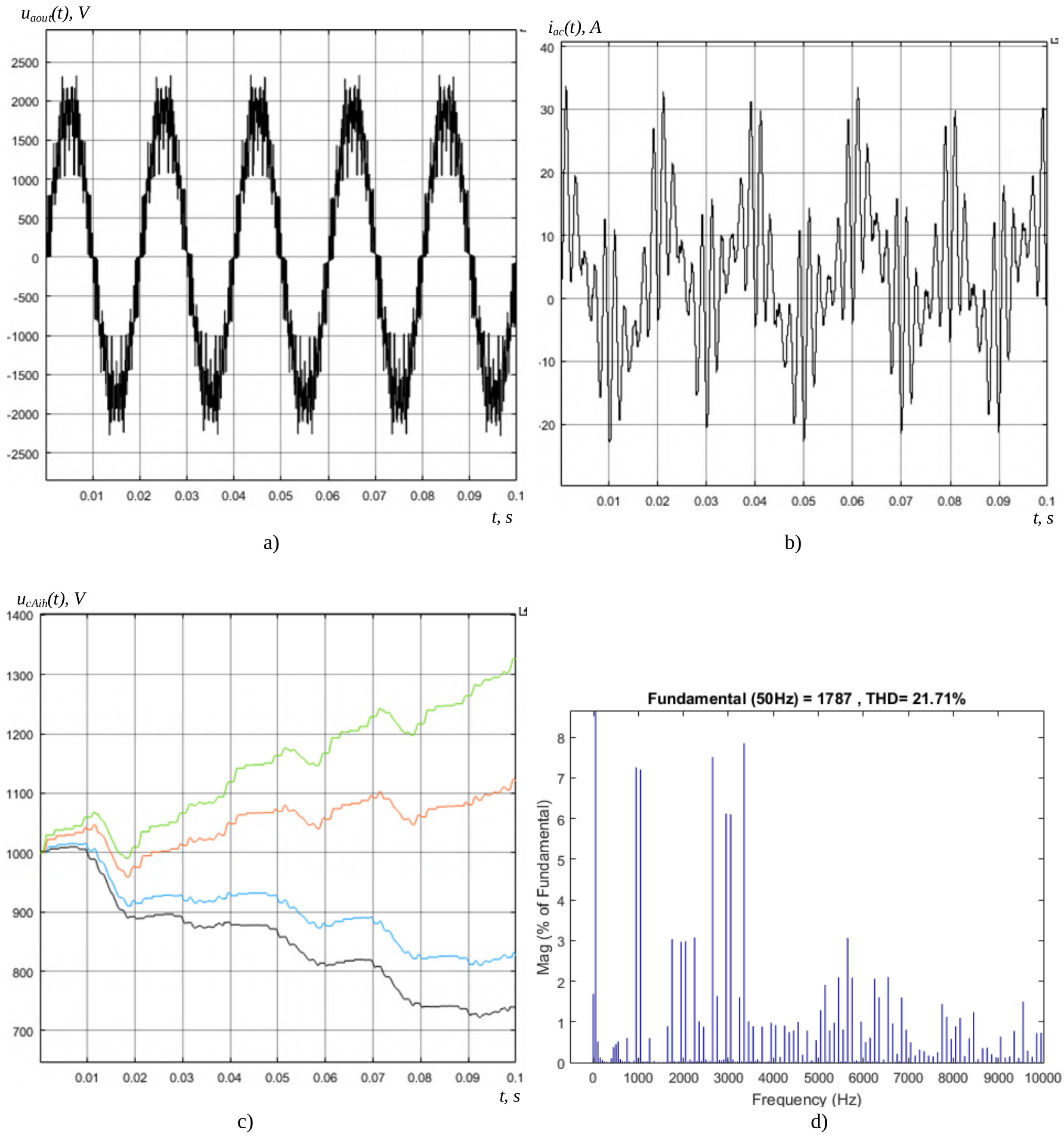

Fig. 6. The results of modeling the operation of a modular multilevel converter when the carrier signals are shifted by $4\pi / 3N$: a – change in the output voltage of the converter; b – change in the magnitude of the circulating current; c – voltage change on the capacitors of the upper arm of the circuit; d – the spectrum of the output voltage of the converter.

Fig. 7 represents the results of modeling a modular multilevel inverter when reducing the values of the shift of the carrier signals to the level of 1/2 from the previous case. The graph of the output voltage (Fig. 7a) visually shows even greater sinusoidality than in the previous case, the presence of individual discrete voltage levels is almost invisible. The nature of the pulsations of the circulating current (Fig. 7b) corresponds to the previous case, but the current value increases significantly to the level of 19.52 A. The ability to balance voltages on capacitors modules is lost (Fig. 7c), as in the previous case, showing a significant difference with time. The coefficient of total harmonic distortions of the output voltage (Fig. 7d) remains lower than when using modulation with a shift of $\theta = 2\pi / N$, and is equal to 21.81%. In the demonstrated spectrum, harmonic components with a frequency equal to twice the switching frequency of the converter's switches are clearly distinguished, which are lower frequency compared to the dominant harmonic components of the previous cases, and therefore easily eliminated from the output current due to load inductance.

Let's analyze the operation of a modular multilevel inverter using pulse-width modulation with in-phase carrier signals, i.e. in the absence of phase shifts between them. The results of modeling such a system are presented in Fig. 8. The output voltage graph (Fig. 8a) shows a significant decrease in output voltage levels, which is a negative phenomenon, because in this case it is necessary to use more cumbersome passive output filters to bring the output voltage in line with current standards. The current

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value of the circulating current (Fig. 8b) almost corresponds to the previous case and is 19.36 A, which leads to the need to increase the value of the inductance in the arms of the converter to reduce the level of losses due to the influence of this current. A positive characteristic of such modulation is the ability to balance the voltages on the capacitors of the converter modules (Fig. 8c), the average deviation of these voltages does not exceed ± 30 V, which is the best result among the analyzed options. The decrease in the output voltage levels leads to a significant increase in the coefficient of total harmonic distortion to the level of 50.49%, which is the worst result among the options analyzed.

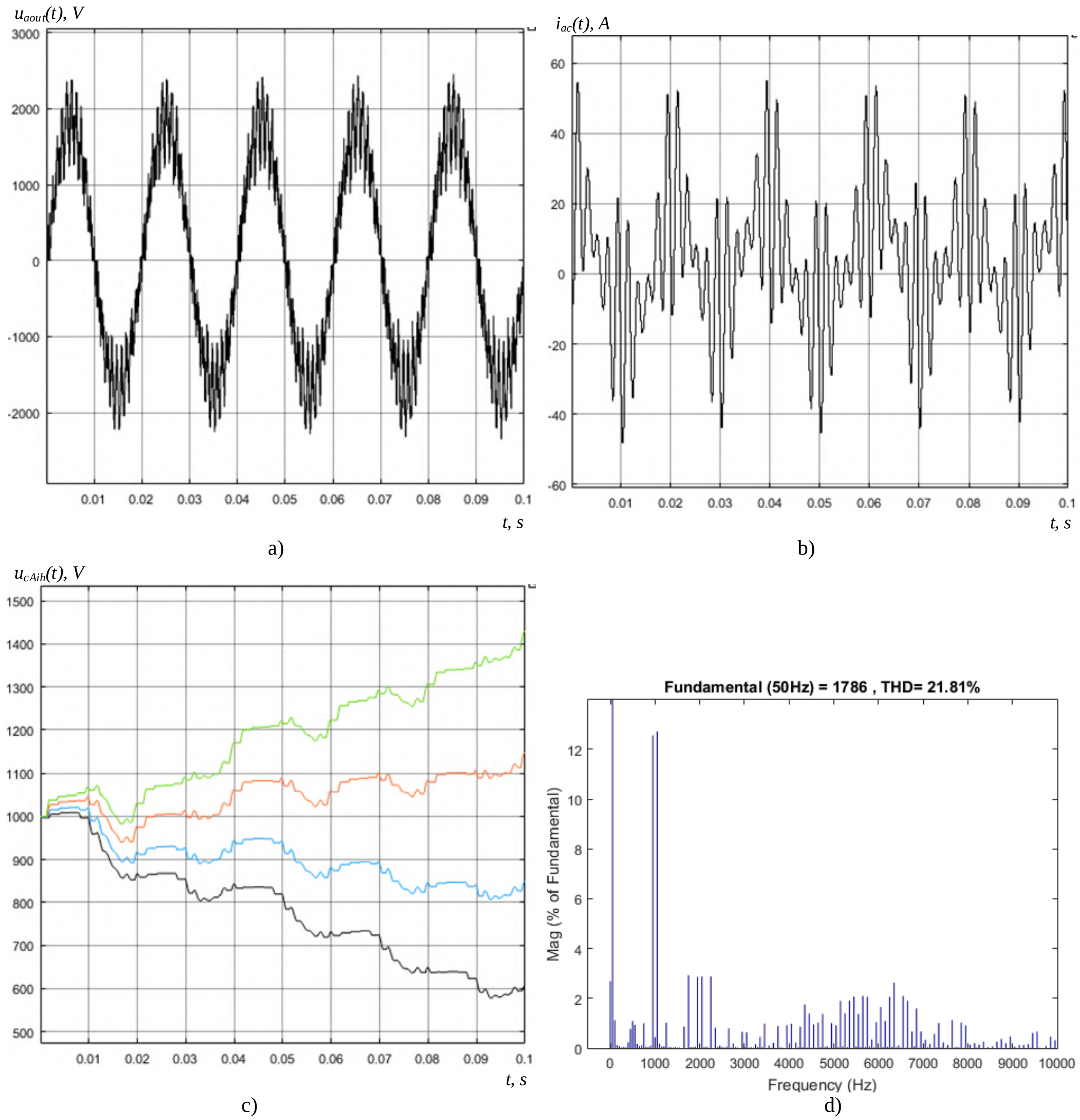

Fig. 7. The results of modeling the operation of a modular multilevel converter when the carrier signals are shifted by $2\pi / 3N$: a – change in the output voltage of the converter; b – change in the magnitude of the circulating current; c – voltage change on the capacitors of the upper arm of the circuit; d – the spectrum of the output voltage of the converter.

Conclusions

The aspects of functioning of the modular multilevel converter at use of pulse-width modulation with shift of carrier signals on a phase are analyzed in the work. The general structure of such converter is considered, and also the most widespread circuit decisions concerning construction of modules. The general analytical dependences describing the relationship between the main variables of the state of the converter are analyzed. A mathematical model in the Matlab / Simulink environment is compiled and the behavior of a modular multilevel converter at different values of the phase shift between the carrier signals of pulse-width modulation is analyzed. It is proved that the absence of this shift shows

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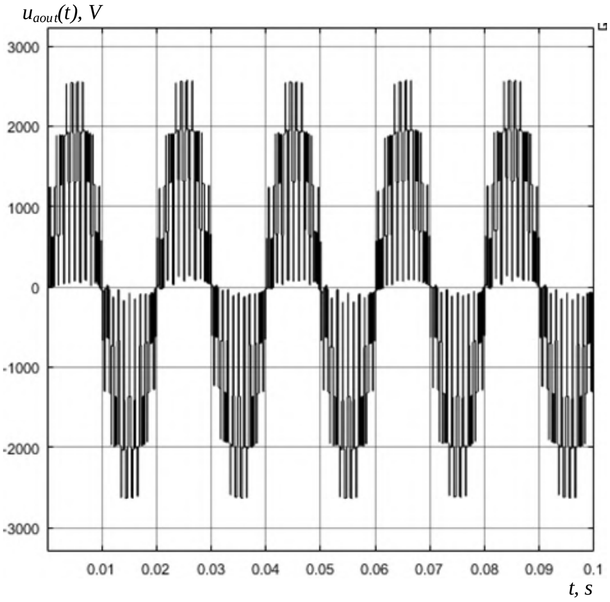
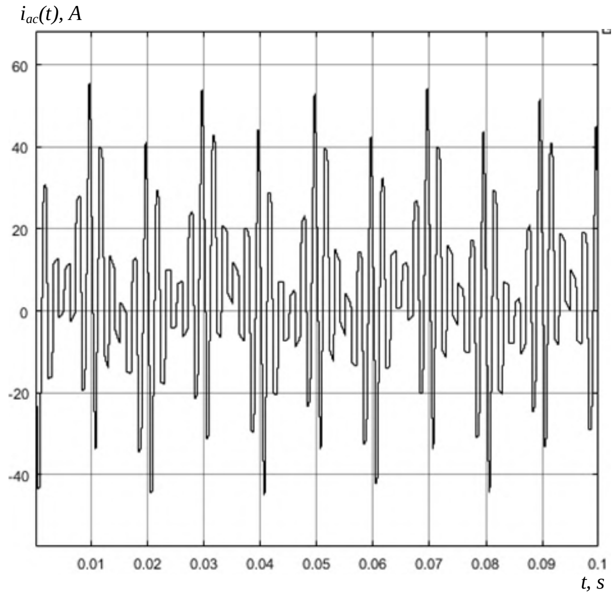
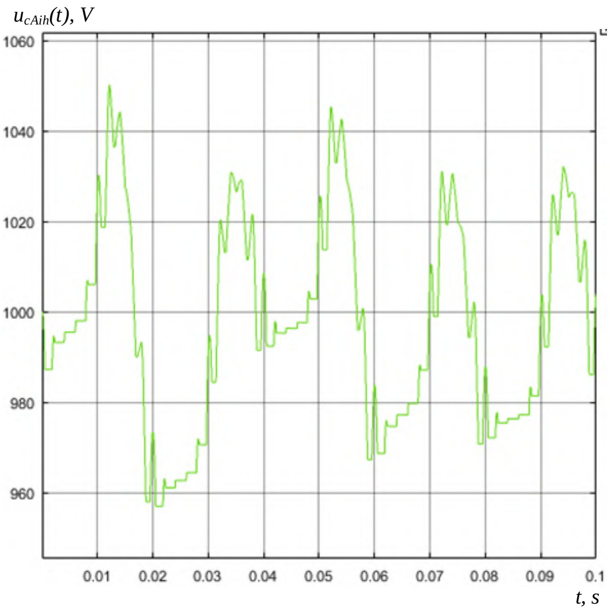
the worst indicators in terms of the coefficient of total harmonic distortion of the output voltage of the converter, but the best in terms of accuracy of voltage balancing on the capacitors of the circuit modules. The presented analysis of shift values proves the compromise of the choice of the shift angle in terms of the total harmonic distortions of the output voltage, the magnitude of the circulating current in the converter arm and the ability to balance voltages on the capacitors of the circuit.



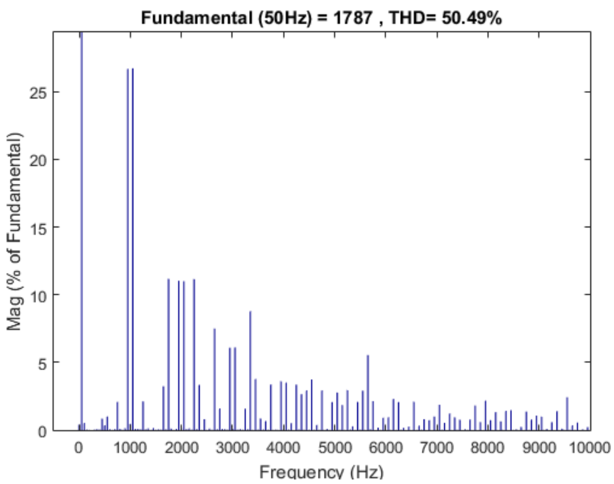
a)



b)



c)



d)

Fig. 8. The results of modeling the operation of a modular multilevel converter when the carrier signals are not shifted: a - change in the output voltage of the converter; b - change in the magnitude of the circulating current; c - voltage change on the capacitors of the upper arm of the circuit; d – the spectrum of the output voltage of the converter.

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Research of the synthesis of radiant intensity indicatrix of multi-component beam diode module

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Abstract. Widespread use of semiconductor radiation sources in optoelectronic devices for various purposes requires further study of the mechanisms of formation of photometric characteristics of the integrated device in the near illumination zone, where the law of inverted squares is violated. A mathematical model of the multicomponent beam-diode module is proposed. On its basis the analysis of influence of the parameters of separate beam sources on the deformation of the indicatrix of radiant intensity at transition from the far zone to the near one is carried out. It is shown that the determining parameter of the indicatrix change in longitude and polar distance is the distribution in the plane of the modulus of the product of the radiant intensity of a single diode on its polar radius vector. The displacement of the polar angle of the maximum of the vector of the diode radiant intensity is more significant for wide radiation patterns than for concentrated ones. For specific parameters of diodes and geometry of their location the suitability of the proposed model for a priori modeling of beam-diode modules is illustrated.

1 Introduction

Successful development of unmanned aerial vehicles encourages the development and improvement of optoelectronic devices (OED) for light signals and reconnaissance purposes. They are mainly implemented by introduction of new element base of higher quality where not the last place belongs to artificial sources of infrared (IR) radiation. Increasing the range of security and reconnaissance OEDs is achieved by their transition to active mode, increasing the power of sources, the use of longer wavelengths of the IR range of electromagnetic waves (EMW). Among the artificial sources of spontaneous radiation, undoubtedly, the most promising are the semiconductor sources of injection electroluminescence of p-n junctions – light-emitting diodes (LEDs) (visible area of EMW) and beam diodes (ultraviolet and infrared areas of EMW). Beam-signal and other devices of active action of the IR range have significant operational advantages at the working lengths of the EMW, which correspond to the "windows" of the transparency of the atmosphere in the middle range of the IR spectrum: (3.3 – 4.2) μm, (4.5 – 5. 1) μm, (8–13) μm. Modern technological advances in the production of ultra-bright p-n-emitters in these parts of the spectrum require further study of the mechanisms of formation of the basic physical and technical characteristics of multicomponent beam-diode sources of directional action.

Due to the topicality of replacing traditional light sources with more efficient ones in many respects, a large number of scientific papers are devoted to the development and design of LED-based lighting devices. Most of the papers are limited to offering a mathematical model for calculating the lighting characteristics of the LED module and computer software for these calculations. This is enough to perform practical tasks and the problem consists only in choosing the most rational model. From a theoretical point of view, it is important to study the peculiarities of the formation of light intensity curves (LIC) for the development of light intensity algebra. The non-triviality of these questions lies in the specific use of the category of light intensity for non-point sources. By definition, the intensity of light is a characteristic of a point source located at the apex of the solid angle and to arithmetically add vectors of light intensity from several sources is valid only for vectors of one direction when the source is at one point [1, 2, 3]. The method of virtual transfer of radiating components to one point to obtain a diagram of the direction of light intensity of the integrated device can be approximated only in the far illumination zone. The transition to the near zone raises the question of the legitimacy of the use of the light intensity characteristic.

Obviously, the pattern of light intensity or LIC of the integrated lighting device depends on the lighting characteristics of individual LEDs and the geometry of their placement. In principle, the LIC of any LED, even with secondary optics, can be calculated by considering the course of the beams in a semiconductor crystal [4, 5, 6]. However, in practice a less costly approach is used. A simplified parametric model is selected for the empirically obtained data set. Such analytical models are the basis for the classification of the main types of LIC for sources of any radiation mechanism [7, 8, 9]. Together with the idealized diagram $f(\theta)=\cos^{-3}\cdot\theta$ (θ –a

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polar distance) there are 8 such types. Using the specified classification or point-discrete representation of empirical data for LIC diodes, the coordinate distribution of illumination from the multicomponent module E(x, y) is determined as follows:

$$E(x,y)=\sum_i\sum_j(I(x,y,i,j)\cdot cos[\theta(x,y,i,j)])/((x-i\Delta x)^2+(y-j\Delta y)^2+l^2), \quad (1)$$

where *i* – the number of LEDs along axis x with distance Δx between them; *j* – the number of LEDs along axis *y* with distance Δy between them; $I(x,y,i,j)$ – the intensity of light of the LED; *l* – the distance from the LED module to the lighting plane; $\theta(x,y,i,j)$ – the angle of incidence of light from a single LED.

Due to the cumbersomeness of formulas and the specificity of simulation modeling, the identification of physical patterns of formation of integrated characteristics is complicated. Numerical results do not reflect the functional relationships of the characteristics of the isolated LED with the characteristics of the module. Therefore, the patterns of formation of integrated parameters of LED modules, determined at present, are the result of the analysis of graphical dependencies and are expressed verbally.

Basically, they are as follows:

1. The most uniform illumination can be provided by [10, 11, 12]:

– modules of the cluster variant with a large number of low-power LEDs;

– placement of powerful LEDs in groups with non-concentrated LIC;

– turns of LED, which is convenient in this case because of small occupied area and storage of a light flow.

2. When the module size is compared with the observation range, the illuminance with a change in distance changes insignificantly for non-turned diodes and for turned diodes with LIC with large radiation angles [14–18].

3. The anomalous coordinate dependence of the deviation coefficient on the law of inverse squares $K(r)$ is manifested when the beams are focused. Maximum values $K(r)$ increase as the angles of radiation of the LED decrease. With anomalous $K(r)$, value $E(r)$ sharply changes in the near illumination zone [13,14, 17–19].

4. Normal dependences of $K(r)$ are observed when using unturned LEDs with cosine-type LIC, as well as when defocusing the module [14, 16, 15, 19, 20-22].

5. The more gently sloping dependences $K(r)$ are the less the decrease of $E(r)$ is [13, 18, 19, 23–24].

6. Dependences of relative uniformity of light distribution (RULD) are non-monotonic with minima in the near zone. For the near zone, defocusing results in higher RULD values than focusing [16–19].

7. High RULDs are achieved by reducing the maximum illuminance [16–22].

Purpose of the paper – to analytically research the peculiarities of the formation of the spatial distribution of the radiant intensity of the integrated beam-diode module, depending on the parameters of its components.

2 Results

For p-n-diode emitters with a spectrum outside the visible range the term "beam diode" is more correct than the term "LED". Suppose we have an integrated planar module assembled from *N* beam-diode point sources. The irradiance at the observation point *A* of the parallel plane (Fig. 1) is determined as follows:

$$E(r,\theta,\varphi)=\sum_{k=1}^{N}(I_k(\theta_k,\alpha_k,\rho_k,\varphi_k))/(L_k^2(r,\theta,\varphi,\rho_k,\varphi_k))\cdot cos\theta_k, \quad (2)$$

where L_k $(r,\theta,\varphi,\rho_k,\varphi_k)$ – the distance from the *k*-th source to the point of observation; θ_k – polar distance of spherical coordinates with the pole at the location of the *k*-th source; r,θ,φ – radius vector, polar distance, longitude of spherical coordinates with pole at selected point of module plane; ρ_k,φ_k – the polar coordinates of the *k*-th source; αk – half the width of the radiation pattern of the *k*-th source; $I_k(\theta_k,\alpha_k,\rho_k,\varphi_k)$ – radiant intensity (light intensity) of the *k*-th source.

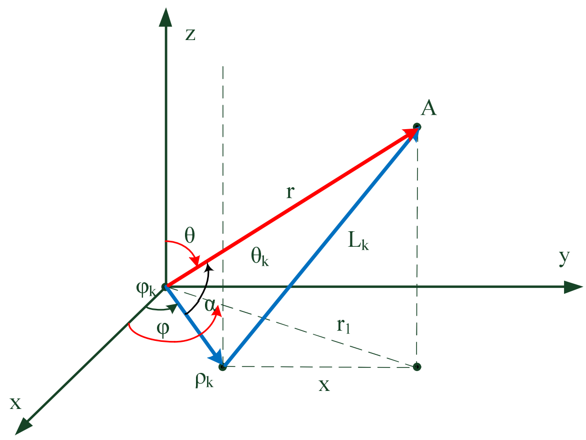


Fig. 1. The geometry of the analysis of illumination at point A from a point source with polar coordinates ρ_k, φ_k.

Taking into account that (Fig. 1):

$$L_k(r,\theta,\varphi,\rho_k,\varphi_k)=r\cdot\sqrt{(1-2r_k\cdot sin\theta\cdot cos\Delta\varphi_k+r_k^2)}$$

and

$$\theta_k\ (r_k,\theta,\varphi)=arccos(cos\theta/\sqrt{(1-2r_k\cdot sin\theta\cdot cos\Delta\varphi_k+r_k^2)}),$$

where $r_k=\rho_k/r;\ \Delta\varphi_k=\varphi-\varphi_k$.

Expression (2) can be presented as follows:

$$E(r,\theta,\varphi)=cos\theta/r^2\cdot\sum_{k=1}^{N}(I_k\ (r,\theta,\Delta\varphi_k,\alpha_k,\rho_k))/[1-2r_k\cdot sin\theta\cdot cos\Delta\varphi_k+r_k^2]^{3/2}. \quad (3)$$

With $r_k\to0$ irradiation $E(r,\theta,\varphi_k)\to cos\theta/r_2\cdot\sum_{k=1}^{N}I_k$ (θ,α_k), describing the irradiance of the module as a point source with radiant intensity $\sum_{k=1}^{N}I_k\ (\theta,\alpha_k)$. Based on this and the form of expression (3), the value

$$I_m(r,\theta,\varphi)=\sum_{k=1}^{N}[I_k(r,\theta,\Delta\varphi_k,\alpha_k,\rho_k)]/[1-2r_k\cdot sin\theta\cdot cos\Delta\varphi k+r_k^2]^{3/2}, \quad (4)$$

where $r_k^2-2r_k\cdot sin\theta\cdot cos\Delta\varphi_k\neq1$ can be conditionally interpreted as radiant intensity of the module at $r\gg\rho_k$, i.e.

for far illumination. In the near zone, where the coefficient of deviation of the irradiance from the law of inverse squares $K(r)$ <0.95, such an interpretation of expression (4) is problematic, because at such distances from the module it is far from point one and for it the classical definition of radiant intensity cannot be applied.

Multiplier $\psi k(r,\theta,\varphi)=[1\text{-}2r_k\cdot sin\theta\cdot cos\Delta\varphi_k+r_k^2]^{-3/2}$ takes into account the influence of a single source on the radiant intensity of the module depending on its location, or, on the other hand, takes into account its contribution to the "non-point nature" of the module. For the ease of analysis, we present ψ_k as a power series. So, provided $|2r_k\cdot sin\theta\cdot cos\Delta\varphi_k\text{-}r_k^2|<1$, which corresponds to the variation of r from $r\gtrsim\rho_k/2.4$ at $sin\theta\cdot cos\Delta\varphi_k=1$ to $r\gtrsim\rho_k$ at $sin\theta\cdot cos\Delta\varphi_k=0$, we have [10]:

$$\psi_k\ (r,\theta,\varphi)=1/\Gamma(3/2)\cdot\sum_{n=0}^{\infty}\Gamma(n+3/2)/n!\cdot (2r_k\cdot sin\theta\cdot cos\Delta\varphi_k\text{-}r_k^2)n, \qquad (5)$$

where $\Gamma(x)=\int_0^{\infty}t^{x\text{-}1}\cdot e^{\text{-}t}\cdot dt$, $(Re\ x>0)$ – gamma function [25, 26].

Condition $r>\rho_k$ is sufficient for the legitimacy of the representation of ψ_k by expression (5) with arbitrary values of θ and $\Delta\varphi_k$. Satisfied with the approximation at $max\ n$=1, we have:

$$\psi_k(r,\theta,\varphi)\cong 1+3r_k\cdot sin\theta\cdot cos\Delta\varphi_k\text{-}3/2\ r_k^2. \qquad (6)$$

Then the radiation pattern of the modulus of radiation taking into account (4) and (6) can be represented in the following way:

$$f(r,\theta,\varphi)\cong\sum_{k=1}^{N}(Ik/I_0)+(3sin\theta/r)\sum_{k=1}^{N}[Ik\ (I_k\cdot\rho_k)/I_0]\ cos\Delta\varphi_k\text{-}3/(2r^2)\sum_{k=1}^{N}(I_k\ \rho_k^2)/I_0\ , \qquad (7)$$

where $I_0=\lim_{\top}(r\to\infty)\sum_{k=1}^{N}I_k\ (r,\theta_k,\alpha k,\rho_k,\varphi_k)$.

(To simplify expression (7), the record of the functional dependence $I_k\ (r,\theta_k,\alpha_k,\rho_k,\varphi_k)$) is omitted.

The first term in (7) describes the pattern of the algebraic sum of the radiation intensity of all point sources that are components of the module virtually located in the spherical coordinate pole.

The second term characterizes the deformation of the diagram in the meridional and azimuthal planes and is determined by the weighted average radial size and azimuthal arrangement of sources $\bar{r}=\sum_k(I_k\cdot\rho_k\cdot cos\Delta\varphi_k)/I_0$.

The third term describes the effect on the axial value of the diagram θ=0 of the average radiation-weighted square of radial size $\bar{r}^2=\sum_k(I_k\cdot\rho_k^2)/I_0$.

With $r\gg\bar{r},\bar{r}^2$, corresponding to the far illumination zone, the pattern is determined by the first term (7). Experimental measurements of LIC or radiation patterns describe the dependence that corresponds to the first term (7) because the measurements are made in the far zone at the length of photometry where the radiant intensity does not depend on the distance from the source. It is obvious that dependences (4) and (7) can be used to interpret empirical data obtained in the near illumination zone with a large approximation.

The radiation pattern of the module is fixed relative to the selected pole of the spherical coordinates and the shape of the diagram in the near zone depends on this choice. It is most effective to choose the pole at the point of the plane of the module with the largest statistical contribution of the radiation of the diodes to the total radiant intensity or in the center of the weighted average radiation size of the module [27, 28].

The configuration of the radiation pattern of the isolated beam-diode is fixed relative to the pole located at the point of placement of the diode at a time when in the integrated device it is measured relative to the selected center of the spherical coordinates. However, in the integrated device, a large number of diodes are located outside the center of the spherical coordinates. Let us analyze the influence of the distance of the isolated diode from the center of registration of radiation force.

Based on a Lambert emitter with polar coordinates (ρ_k,φ_k) and axial symmetry of its own diagram, the diagram of its radiation intensity in the module can be represented as follows:

$$f_k(r,\theta,\varphi)=[cos(P_k\cdot\theta_k)\cdot R(\theta_k,\alpha_k)]/ [1\text{-}2r_k\cdot sin\theta\cdot cos\Delta\varphi_k+r_k^2]^{3/2}, \qquad (8)$$

where $P_k=\pi/(3\alpha_k)$ – the concentration parameter of the Lambert pattern [29];

$R(\theta_k,\alpha_k)=H(\theta_k)\text{-}H(\theta_k\text{-}(3\cdot\alpha_k)/2)$ – limiting function for polar distance θ_k;

$H(z)$ – asymmetric unit function.

Fig. 2 (a, b) contains the change of the shape of the meridional section $(\Delta\varphi_k=\varphi\text{-}\varphi k=0)$ of the indicatrix of the radiation intensity of a single diode when the position of the diode shifts relative to the pole of the spherical coordinates of the module. With the diode distance $\rho_k=0.2\cdot r$ the maximum length of the radiation force vector θ_{max} shifts by a certain value depending on α_k and makes 45° for $\alpha_k=\pi/3$ and 15° for $\alpha_k=\pi/12$. Displacement θ_{max} in plane $\Delta\varphi_k$=0 may theoretically reach 90°, in other meridional planes with $\Delta\varphi_k\neq 0$ it will be less significant. Comparison of dependences of the coefficient of illumination deviation from the law of inverted squares (LIS) $K_r(r_k)$ and $\theta_{max}(r_k)$ (Fig. 2 e) shows that at the boundary of the near and far zones of illumination $(K_r\cong 0.95)$ displacement θ_{max} for the Lambert source is ~30°.

The deformation of the indicatrix in the azimuthal plane occurs in the direction of displacement of the diode relative to the pole and is more significant for diodes with smaller α_k.

For the axial force of the beam, taking into account (8), we obtain:

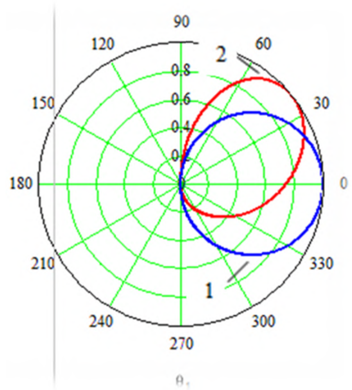
$$I_{м.о}(r)=\sum_{k=1}^{N}\{I_{0k}\cdot cos[P_k\cdot arccos1/\sqrt{(1+r_k^2)}]\cdot R(r,\alpha_k)\}/ (1+r_k^2)^{3/2}, \qquad (9)$$

where $R(r_k,\alpha_k)=H(r_k)\cdot H(r_k\text{-}tg\ 3/2\ \alpha_k)$;

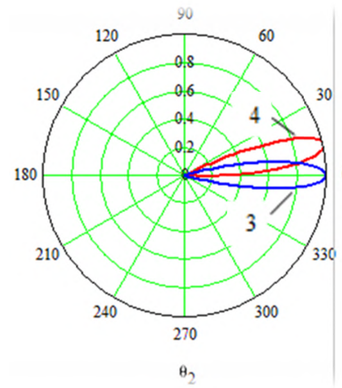
$$I_{0k}=I_k(\theta_k=0).$$

For the Lambert emitters P_k=1 axial radiant intensity $I_{м.о.л}$ of the module with the Lambert components takes the form:

$$I_{м.о.л}(r)=\sum_{k=1}^{N}I_{0k}/(1+r_k^2)^2 \qquad (10)$$



a



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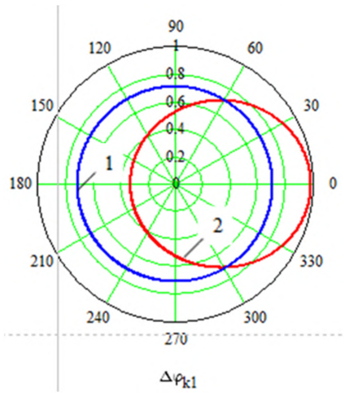

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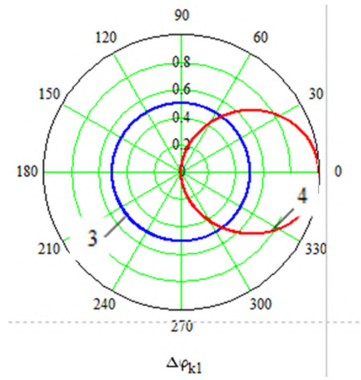

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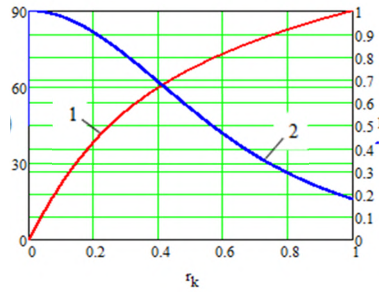

e

Fig. 2. Deformation of radiation patterns of diodes with $\alpha_k=\pi/3$ (a, c) and $\alpha_k=\pi/12$ (b, d) on frontal plane $\Delta\varphi_k=0$ (a, b) and azimuthal plane (c, d), curves: 1, 3 – $r_k=0$; 2, 4 – $r_k=0.2$; e) dependence θ_{max} (1) and coefficient LIS (2) for the Lambert diode on $r_k=\rho_k/r$.

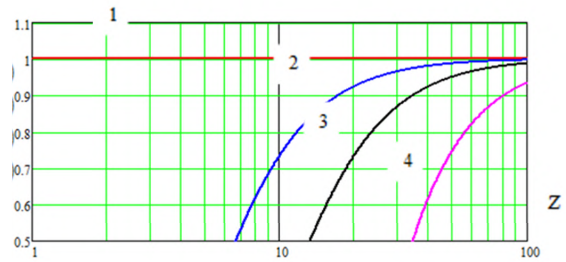

Fig. 3. Dependence of the normalized axial force of the diode radiation on the distance to the observation point Z, curves: 1 – $r_k=0$, $\alpha_k=\pi/6$; 2 – $r_k=0.1$, $\alpha_k=\pi/6$; 3 – $r_k=0.2$, $\alpha_k=\pi/6$; 4 – $r_k=0.1$, $\alpha_k=\pi/36$.

From expression (10) it follows: if N identical beam-diodes are placed radially symmetrically with respect to the pole (geometric center of the circle) then the total axial radiation intensity of the module $I^*_{м.о.л}(r)$ is:

$$I^*_{м.о.л}(r)=N\cdot I_{0k}/(1+r_k^2)^2 \qquad (11)$$

Fig. 4 (a, b) contains the radiation patterns of the radiation of the module according to formula:

$$f(r,\theta,\varphi)=1/I_0\sum_{k=1}^{N}\{I_{0k}\cos[P_k\cdot\theta_k(r_k,\theta,\varphi)]\cdot R[\theta_k(r,\theta,\varphi),\alpha_k]\}/(1-2r_k\cdot\sin\theta\cdot\cos\Delta\varphi_k+r_k^2)^{3/2} \qquad (12)$$

It should be noted that the radiation pattern for the axial radiant intensity expresses the coefficient of deviation of irradiation (illuminance) from the law of inverse squares $K(r)$:

$$f(r,\theta=0)=K(r)=[J_м\,(r,\theta=0)]/I_0\,. \qquad (14)$$

3Conclusions

1. The proposed analytical model of a multicomponent beam module is suitable for a priori modeling of light intensity curves (radiant intensity curves).

2. The proposed model includes:

a) the synthesis of radiant intensity and its indicatrix of the module integrated from point sources is performed according to the formulas (4), (12);

b) in the far illumination zone (K_k>0.95) the indicatrix of the radiant intensity of the module does no

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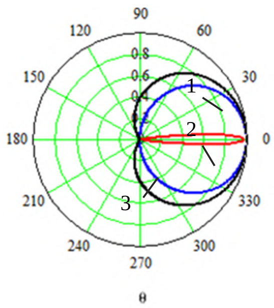
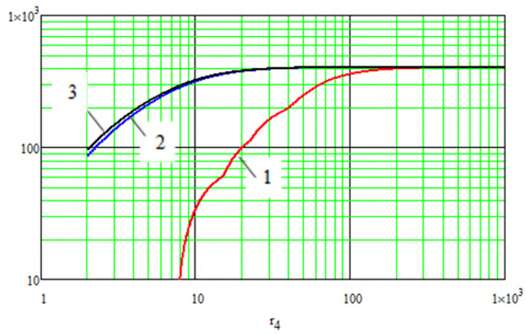
depend on the nature of the placement of the diodes and is determined by the first term of expression (7);

c) the deformation of the indicatrix of the radiant intensity of a multicomponent module during the transition from the far illumination zone to the near one depends on the geometry of the diodes relative to the pole of the spherical coordinates of the module and is determined by statistical values $\bar{r}$ and $\overline{(r^2)}$.

d) the displacement of the longitude of the maximum of the radiant intensity vector of a single diode depending on the distance to the coordinate pole is more significant for beam diodes with a wide pattern than with a concentrated one. The nature of the displacement of the azimuthal projection of the maximum of the vector is exactly the opposite.



a



b

Fig. 4. a) radiation patterns of the radiant intensity in the frontal plane (φ=0) of the module with diode parameters (13) for α_k: curve 1 – α_k=π/36; curve 2 – α_k=π/3; curve 3 – α_k=4/9 π; b) dependence of the axial intensity of the radiation of the module on the distance to the observation point for diodes with different parameters: curve 1 – α_k=π/36; curve 2 – α_k=π/3; curve 3 – α_k=4/9 π.

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Efficient use of energy resources in the context of sustainable development of the pulp and paper industry of Ukraine

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Abstract. The article is devoted to the problem of increasing the efficiency of using energy resources of enterprises of the pulp and paper industry in Ukraine. It has been determined that the pulp and paper industry belongs to energy-intensive types of economic activity. Based on the results of the correlation and regression analysis, a connection was revealed and an economic and mathematical model was formed of the dependence of energy costs for the production of 1 ton of paper on the productivity of paper machines, equipment wear and the volume of investments in energy saving measures. Application of the proposed model will improve information support for the analysis of the effectiveness of energy saving measures, forecasting energy costs and strategic energy management in general. It was carried out at pulp and paper mills, the main obstacles to replacing fossil fuels with biomass in heat production were identified. This made it possible to develop a scientific and organizational model for the energy modernization of enterprises in the pulp and paper industry. It includes financial, organizational, environmental, regulatory, technological, scientific and educational tools. Their application at management will help improve the infrastructure of enterprises in terms of the use of renewable energy resources.

1 Introduction

The pulp and paper industry plays an important role in the economy, in meeting social needs and in the implementation of low carbon energy systems, but it is an energy intensive activity. According to the Technological Map of the European Strategic Plan for Energy Technologies, the average energy costs in the pulp and paper industry of the European Union countries are from 16 to 30%, and in Ukraine they measure up to 40% [25]. In 2018, in the production of paper and cardboard in Ukraine, they used 65,8 million m^3 of water, emitted 256 million tons of carbon dioxide into the atmosphere, and discharged 254 million m^3 of wastewater [20].
Reduction of energy costs in the pulp and paper industry of Ukraine, bringing them to the average European level are especially relevant in the context of adaptation to environmental changes caused by the global pandemic Covid-19. In particular, energy efficiency is an important reserve for reducing operating costs, which, in turn, can to be directed for maintenance of financial stability in the conditions of decrease in demand for production, disturbance of supply chains, growth of logistic expenses. Therefore, increasing the efficiency of the use of energy resources is a priority task to ensure sustainable development, maintain market positions, increase the competitiveness of pulp and paper enterprises in the context of the introduction of European environmental, technical and energy standards.

2 Literature review

Scientists of various fields of scientific activity are engaged in solving the problem of increasing the efficiency of the use of energy resources. Talita Mariane Cristino, Antonio Faria Neto and Antonio Fernando Branco Costa [1] have compiled and systematized scientific publications on energy efficiency in buildings. In their opinion, the greatest contributions were made by scientists from the United States, China and the United Kingdom, namely from the Lawrence Berkeley National Laboratory, the Hong Kong Polytechnic University and City University of Hong Kong.

Honggang Zhang, Andreas Gladisch, Mario Pickavet, Zhifeng Tao and Werner Mohr [2] substantiated that the current stage in the development of the information society is accompanied by a rapid growth in energy demand and consumption. This entails certain difficulties in terms of energy supply. In particular, the unprecedented expansion of wired and wireless networks has led to significant increases in energy consumption and a significant environmental footprint. Therefore, the energy costs of mobile service providers (operators) can reach half of the annual operating costs. In these conditions the introduction of energy management system and development of innovative solutions in the field of energy efficiency is especially important. Technologies for efficient energy distribution are being actively developed in the introduction of a sound DLT and IoT system, which

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in the future will lead to increased energy efficiency. Therefore, it is important to combine the development of technological innovations with energy efficient technologies.

Khan et al [3] argue that the quality of the environment in the long run depends on the consumption of natural resources and renewable energy. Researchers have proposed policies that control the overuse of natural resources, promote sustainable living and set an environmental budget to ensure the country's sustainable development.

António Cardoso Marques, José Alberto Fuinhas, Carla Tomás [4] formulated a hypothesis that investments and organizational measures in the field of energy efficiency contribute to the sustainable development of the country's economy in general and the energy sector in particular. To prove the hypothesis, scientists have applied the ARDL model, which allows analyzing short- and long-term relationships for upward and downward movements of variables. For the analysis, indicators of the development of the industrial sector of 11 countries of the European Union from 1997 to 2015 were used. The results obtained indicate that investments increase energy efficiency in industrial enterprises, while reducing greenhouse gas emissions. At the same time, economic growth, in turn, directs the economy towards greater energy efficiency.

Saffet Akdag and Hakan Yıldırım studied the relationship between energy efficiency and greenhouse gas emissions through panel cointegration, panel causation, and FMOLS and DOLS analysis [5]. Using data from the European Union for 1995-2016, the authors also concluded that there is a close relationship between energy efficiency and greenhouse gas emissions. In particular, greenhouse gas emissions decrease with increasing energy efficiency. Maozhi Chen, Avik Sinha, Kexiang, Hu Muhammad, Ibrahim Shah [6] studied the impact of technological innovation on energy efficiency and sustainable development in the context of the "Fourth Industrial Revolution". Scientists claim that in the era of Industry 4.0, energy efficiency issues can be crucial in terms of sustainable development. The authors analyzed the dependence of the above economic factors on the example of the Middle East and North Africa (North African Republic of the Middle East) during 1990-2016.

Shuaiyin Ma, Yingfeng Zhang Yang Liu, Haidong Yang, Jingxiang Lv and Shan Ren [7] argue that the circular economy plays an important role in energy-intensive industries, since it is aimed at sustainable development of society. Scientists believe that in the context of Industry 4.0, advanced technologies (e.g., cloud computing, Internet of things, cyber-physical system, digital twin and big data analytics) provide numerous opportunities for implementing cleaner production strategies and developing smart manufacturing.

Burlov et al. [8] developed a mathematical model for managing the energy sector of the region, which was based on three main system-forming indicators describing the social, economic and ecological systems. Cosmi et al. [9] suggested using the R-MARKAL model to study the possibility of using renewable sources for the production of electricity and heat. Beyzanur Cayir Ervural, Selim Zaim and Dursun Delen [10] proposed a two-stage analytical methodology for assessing energy efficiency (a combination of different energy sources, mainly based on renewable sources) in Turkey.

Incekara and Ogulata [11] show that the main goal of optimal energy distribution is to reduce the cost of energy production, create a minimum impact on the ecosystem and use uninterrupted, clean energy sources under the light of the UNFCCC and the Kyoto Protocol. Ukrainian scientists [12, 13] have proposed models for providing the Ukrainian economy with energy resources, in particular, electricity and natural gas. At the same time, many scientists [14, 15] are exploring the issue of the relationship between the policy of reliable energy supply and environmental safety and sustainable development. Yemelyanov et al. [16] and Andrusiv et al. [17] argue that the economic growth of the national economy directly depends on the efficient consumption of energy resources. Conditions are modeled under which economic growth is accompanied by a decrease in the level of dependence of the economy on energy imports. Semerikov et al. [18] in their work consider the impact of the COVID-19 pandemic on the sustainable development of the national economy.

Despite the previous scientific results, energy efficiency and energy modernization of production remain relevant for most sectors of the economy and are of particular importance for Ukraine in connection with the proclaimed European Green Deal.

Therefore, the purpose of the article is to develop theoretical foundations and practical recommendations for increasing the efficiency of energy resources use at the pulp and paper industry in the context of environmental modernization of production and the introduction of alternative energy sources at enterprises.

3 Research methods

To achieve the goal of the study, traditional methods of economic analysis were used, in particular, statistical, mathematical, sociological. Thus, the volume and trends in the use of energy resources in the pulp and paper industry of the countries of the European Union and Ukraine were studied using the series of dynamics, comparison, average values and groupings. The methods of correlation and regression analysis made it possible to identify factors affecting the efficiency of energy resource use, to establish a relationship between energy costs per 1 ton of paper and the productivity of paper machines, equipment wear and the level of investment in energy saving measures. To identify obstacles to the use of biomass for the production of heat energy at the pulp and paper industry, a SWOT analysis and an expert survey of industry specialists were carried out. The experts were 26 top and middle managers in the field of energy management (chief engineers –18 people, heat and power engineers – 3 people, specialists in the field of energy management – 5 people) who work at the pulp and paper industry. The modelling method was used in the development of a scientific and organizational model of energy production modernization aimed at increasing the efficiency of energy resources use.

4 Results and discussion

4.1 The state and dynamics of energy consumption at the enterprises of the pulp and paper industry

The pulp and paper industry is an energy-intensive sector of the economy. Consumption of energy resources in this area in 2017 was 2.4% in Ukraine, 5.6% in the EU, 6.8% in the United States and Canada, and 9.4% in China of their total industrial consumption [19].

The dynamics of consumption of energy resources in the pulp and paper industry of individual countries of the European Union and Ukraine is different. In 2018, among the countries of the European Union, Finland consumed more energy resources in the pulp and paper industry – 6245.8 thousand tonnes of oil equivalent (toe), Germany – 5691.6 thousand toe, France – 2398.4 thousand toe and Great Britain – 1817.6 thousand toe. During 2010-2017, the average annual growth rate of energy consumption in the pulp and paper industry in Hungary amounted to 14.2 thousand toe, or 7.0%, Poland – 46.1 thousand toe or 2.82%, Portugal – 0.9 thousand toe or 0.1%, Belgium – 6.3 thousand toe or 0.9%, Great Britain – 46.9 thousand toe or 2.8%. At the same time, the average annual consumption of energy resources in the pulp and paper industry decreased in Denmark – by 190.0 thousand toe or 1.5%, in Germany – by 32.8 thousand toe or 0.6%. France – by 86.7 thousand toe or 3.3%, Spain – by 28.2 thousand toe or 3.6%. In the pulp and paper industry of Ukraine, the consumption of energy resources in the period under review decreased by 36 thousand toe or 12.9% (Table 1).

Table 1. Dynamics of consumption of energy resources by enterprises of the pulp and paper industry in Ukraine and some EU countries, 2014-2018, thousand toe ([19, 20]).

Country	2014	2015	2016	2017	2018	on average for 2014-2018		
						absolute increase	growth rate, %	rate of increase, %
Finland	5886	5936	5881	6060	6245,8	90.0	101.5	1.5
Germany	5823	5821	5672	5542	5691,6	-67.2	99.4	-0.6
France	2745	2384	2310	2369	2398,4	-86.7	96.7	-3.3
UK	1630	1629	1624	2082	1817,6	46.9	102.8	2.8
Spain	2052	1800	1681	1645	1764,9	-71.8	96.3	-3.7
Poland	1571	1552	1568	1637	1755,2	46.1	102.8	2.8
Portugal	1405	1311	1351	1367	1408,7	0.9	100.1	0.1
Belgium	715	707	737	708	740,3	6.3	100.9	0.9
Hungary	182	196	190	205	238,9	14.2	107.0	7.0
Ukraine [1/]	280	240	221	214	243,0	1.0[2/]	100.4[2/]	0.4[2/]
Denmark	169	76	75	74	74,0	90.0	101.5	1.5

In 2018, Ukraine the most energy resources has used in ferrous metallurgy - 8608 thousand toe (tons of oil equivalent), food and tobacco industry - 1484 thousand toe, mining - 1463 thousand toe. The pulp and paper industry together with the printing industry consumed 264 thousand toe. It should be noted that in other industries, similar in terms of average annual gross output, this indicator was significantly lower (construction – 197 thousand toe, transport equipment – 159 thousand toe, textile and leather industries – 62 thousand toe). Thermal energy prevails in the structure of consumption of energy resources of domestic enterprises of the pulp and paper industry.

It accounts for more than 57.2% of the total consumption of energy resources, while electricity accounts for more than a third and natural gas – 7%. Over the past five years, the consumption of all types of these resources has increased (on average by 2.4% per year), except for renewable sources, the volume of which is insignificant – 0.3 thousand toe, which does not correspond to global trends.

The energy intensity of paper and cardboard production by the pulp and paper industry in 2018 was 0.335 toe/t (Table 2).

Table 2. Level and dynamics of energy intensity of paper and cardboard production in Ukraine and some countries of the European Union, 2010-2017, kgoe/t ([21-22]).

Country	2010	2014	2016	2017	2018	2018 to 2010	
						kgoe/t	%
Portugal	1279,0	942,8	869,3	931,3	960,6	-318,4	75,1
Finland	746,3	793,9	801,7	853,8	868,0	121,7	116,3
Sweden	661,5	709,6	797,9	798,4	796,5	135,1	120,4
UK	740,5	1009,4	2267,9	808,9	673,6	-66,9	91,0
Norway	654,0	677,9	563,3	552,5	600,2	-53,8	91,8
Austria	409,3	502,1	467,6	481,9	532,4	123,2	130,1
Poland	480,3	546,7	603,0	504,3	524,7	44,3	109,2
Ukraine	518,2	555,0	473,9	426,8	480,4	-37,8	92,7
France	322,8	487,7	413,4	423,9	427,2	104,4	132,3
Italy	353,1	-	383,3	453,9	406,8	53,7	115,2
Spain	340,7	464,4	387,6	377,9	405,5	64,8	119,0
Germany	372,6	371,4	358,5	349,9	354,6	-18,0	95,2
Netherlands	351,8	356,9	302,7	306,5	282,4	-69,4	80,3

Thus, in comparison with the developed EU countries, Ukraine has a high energy intensity of production in the studied area. Therefore, in 2017, 480.4 kgoe/t was spent on the production of paper and cardboard, while in Italy and Spain – 406-407 kgoe/t, which is 15-16% less, Germany – 354.6 kgoe/t (26.2% less) and in the Netherlands – 282.4 kgoe/t (41.2% less).

In world practice, in order to improve energy efficiency and ensure energy independence, pulp and paper industry enterprises are increasing the use of renewable energy resources. According to the Technology Map of the European Strategic Energy Technology Plan, the average energy consumption in the pulp and paper industry of the European Union countries is between 16 and 30%. At the same time, 55% of the energy used comes from the combustion of biomass, 38% – from natural gas [21].

Despite the large reserves of biomass in the agricultural sector and forestry, the pulp and paper industry in Ukraine uses very little renewable resources and lags far behind foreign countries. In 2017, the share of used renewable energy sources in total energy consumption was only 0.1%, while in Austria – 45.1%, Poland – 46.1, Finland – 57.6, Portugal – 60.7 and Sweden – 65.5 % (Table 3).

Table 3. The share of renewable energy resources in total energy consumption in the production of paper and cardboard in Ukraine and individual EU countries, 2013-2018, % (according to data [23-25]).

Country	2013	2014	2015	2016	2017	2018	2018 to 2013, p.p.
Sweden	62.1	64.2	95.5	66.6	66.8	65.5	3.4
Portugal	64.7	65.8	63.3	60.8	63.2	60.7	-4.0
Finland	48.9	51.5	52.9	54.7	56.1	57.6	8.7
Poland	35.8	41.4	41.7	1.9	44.5	46.1	10.3
Austria	36.5	39.5	39.1	37.1	43.9	45.1	8.6
France	28.1	22.0	2.3	26.3	31.5	35.0	6.9
Spain	23.0	29.6	17.4	31.0	40.2	32.6	9.6
UK	0.0	0.0	0.0	0.0	19.9	24.0	24.0
Norway	34.3	32.0	15.4	16.6	16.2	20.5	-13.8
Germany	10.7	10.9	11.5	10.9	10.8	12.7	2.0
Netherlands	0.6	0.6	0.9	0.7	0.9	0.9	0.3
Ukraine	0.0	0.0	0.0	0.9	0.0	0.1	0.1
Italy	0.0	0.0	0.0	0.0	1.8	0.0	0.0

The general trend in 2013-2018 was the increase in the share of renewable energy resources in the total energy consumption of the pulp and paper industry, most of countries shown in Table 3. In particular, high growth rates for this indicator are observed in the UK – 24 p.p. and Poland – 10.3 p.p. At the same time, the UK pulp and paper industry began to use renewable energy resources only in 2016. The share of Spain increased by almost 10 p.p. (9.6%). Austria and France are next with 8.6 p.p. and 6.9 p.p. respectively. In Ukraine, the share of renewable energy sources in 2018 was only 0.1%. Domestic pulp and paper mills began to use renewable energy resources only in 2015.

4.2 Factor analysis of energy efficiency in enterprises

The efficiency of energy resources use in pulp and paper enterprises is influenced by a combination of internal and external factors. Mathematically, the dependence of the efficiency of energy resources in enterprises on organizational, production, energy and other factors should be reflected as a function

$$f\ (x_1, x_2 \dots \dots \dots x_n\ )\ , (1)$$

where f is a dependent variable, an indicator of energy efficiency,

$x_1, x_2 \dots \dots \dots x_n$ – factors influencing the efficiency of energy resources.

For a more detailed analysis of the influence of factors on the efficiency of the use of energy resources in the pulp and paper industry, production, economic, environmental, energy and personnel indicators are systematized and grouped by the authors (Table 4).

Table 4. Groups of indicators for factor analysis of the efficiency of using energy resources of enterprises of the pulp and paper industry.

Group of indicators	Indicator	Unit
Organizational and production	Paper machine productivity	t / day
	Efficiency of production equipment	%
	Wear and tear of production equipment	%
	Heat losses in production facilities	Gcal
	Heat losses during energy transportation	Gcal
Economic	The price of electricity	UAH / kW · hour
	The cost of thermal energy	UAH / Gcal
	Capital investments in energy saving measures	UAH
	Environmental tax rate per 1 ton of CO_2 emissions into the atmosphere	UAH / t
	The share of energy costs in the cost of paper or cardboard	%
	Costs for the operation of the energy management system	UAH
	The share of investment resources attracted through state and local targeted energy saving programs	UAH
Energy	Electrical capacity of products	kW · hour / t
	Heat capacity of products	Gcal / t
	Fuel capacity of products	m^3 / t
	Heat losses in networks	%
	Share of renewable energy costs	%
Ecological	The volume of CO_2 emissions, per 1 toe of fuel consumption	t
	Water intensity of production of 1 Gcal of thermal energy	thousand m^3 / 1 Gcal
	Share of recycled waste	%
Personnel	The amount of remuneration to employees for saving energy resources	UAH
	Expenses for measures to improve the qualifications of employees	UAH

4.3 Modeling the impact of factors on energy efficiency of enterprises

Based on the results of the preliminary study, it is possible to formulate a hypothesis about the existence of a relationship between the level of energy costs for the production of 1 ton of paper (cardboard) (resultant sign) and the following indicators (factor signs): paper machines productivity, the share of heat recovery, the share of renewable energy resources, equipment wear and tear, investments in energy saving measures. To confirm the hypothesis, let us group 27 pulp and paper enterprises in Ukraine according to the above performance indicator (Table 5).

Table 5. Dependence of the level of energy consumption for the production of paper (cardboard) on organizational and production, energy and environmental factors at pulp and paper enterprises of Ukraine, 2016-2018.

Indicator	Groups of enterprises in terms of energy consumption per 1 ton of paper, UAH / t			On average (total)	The ratio of indicators of group I to group III, %
	I	II	III		
	below 3600	3600-4000	above 4000		
Average energy consumption in the group, UAH	3450	3820	4220	3835	81.8
Number of enterprise years, units	8	11	7	26	114.3
Productivity of paper processing machines, t / day	232.6	196.8	156.7	194.7	148.4
The share of heat recovery, %	36.2	28.4	22.6	29.4	13.6 p.p.
Share of renewable energy resources, %	56	33	8	32	48.0 p.p.
Equipment wear, %	52	68	72	62	-20 p.p.
Investments in energy saving measures, UAH / t	125	95	52	88.5	240.4
CO_2 emissions, thousand tons	18560	18756	15692	17126	118.3
Share of recycled waste, %	14	17	12	13	-2.0 p.p.

Thus, group I includes enterprises with the lowest energy costs per 1 ton of products – below UAH 3600. In them, the productivity of paper machines is 232.6 t/day, the share of heat recovery is 36.2%, the share of renewable energy resources is 56%, equipment wear is 52%, investments in energy saving measures are 125 UAH/t.

Group II includes pulp and paper enterprises, in which energy costs per 1 ton of products range from UAH 3,600 to 4,000. Here, the productivity of paper machines is 196.8 tons / day, the share of heat recovery is 28.4%, the share of renewable energy resources is 33%, equipment wear is 68%, investments in energy saving measures are 955 UAH / ton.

The enterprises of group III have the highest expenses – more than 4000 UAH. In such enterprises, the productivity of paper machines is the lowest in comparison with other groups – 156.7 tons / day, investments in energy saving measures – 52 UAH / ton, as well as high wear and tear of production equipment – 72%.

In order to identify the direction and closeness of the relationship, we will perform a correlation-regression analysis based on data from 27 enterprise-years of the pulp and paper industry of Ukraine. Taking into account the previously obtained data for the formation of a multivariate regression model, the following main factors are included:

performance indicator – Y – energy costs per 1 ton of paper or other products, UAH/t;

factor features:

x_1 – productivity of paper machines, t/day;

x_2 – equipment wear, %.

x_3 – investments in energy saving measures, UAH/1 t

Using the specialized program of statistical data processing Statistica 10, the primary statistical analysis of the initial data was carried out (Table 6).

Table 6. Numerical characteristics of variables.

	Y	X_1	X_2
Average	3835	84,5	326.5
Standard error	28	12,5	34.8
Median	3674	86,5	315.4
Mode	2158	83.5	301.4
Standard deviation	25	16	41
Sample variance	326,4	36.2	47.5
Excess	174	47	65
Asymmetry	21	12	11
Interval	374	165	465
Maximum	3985	96.8	578.1
Minimum	3145	47.2	112.4
Sum	148759	165871	2165846

According to the results of regression analysis, the following multifactor regression equation is obtained

$$Y_{x_1} = 3860 - 428_{x_1} - 365_{x_2} + 65_{x_3} \qquad (2)$$

Multiple correlation coefficient r=0.728 indicates a strong relationship, and the coefficient of determination R^2 = 0.5298 shows that almost 53% of the energy consumption of paper and other paper products is formed under the influence of the above factors included in the model.

Of course, many more factors (social, managerial, environmental, etc.) influence on energy costs. They require further in-depth research. Thus, Tatenda Taodzera, Bhekisipho Twala, Johnson Carroll [26] developed an econometric model in which factors determine almost 90% of the change in performance.

Bazylevych et al determined that the profitability of organic production by more than 80% is determined by such indicators as profitability of fixed assets, the share of agricultural land engaged in organic farming and energy consumption. 10 tons of organic wheat [27].

To increase the energy efficiency of the pulp and paper industry, it is advisable to implement the following measures:

– technical re-equipment, modernization of production equipment, in particular, paper machines in order to increase their productivity;

– increase in investments in energy efficient technologies, reconstruction of the heat supply system, use of renewable energy sources, introduction of energy management systems, reduction of anthropogenic impact.

4.4 Model of energy modernization of enterprises

In the context of decreasing reserves of fossil fuels, the introduction of sustainable development principles, the priority task of increasing the energy efficiency of enterprises in the pulp and paper industry is the use of renewable energy resources. Given the natural and climatic conditions, a promising source is the production of heat energy from biomass. The most common types of biomass in Ukraine are:

– agricultural waste – straw, stalks and rods of corn, stalks and husks of sunflower;

– forestry waste – bark, wood chips;

– energy crops – willow, poplar, miscanthus.

In the pulp and paper industry, successful projects for the production of thermal energy from biomass have been implemented. In 2016, a new boiler house with a boiler for burning wood fuel with a moisture content of up to 60% was put into operation at PJSC "Kokhavian Paper Factory". The average annual heat production is 24 thousand Gcal. Annual consumption of wood chips is about 14 thousand tons / year (40 tons / day at maximum load). As a result of the energy modernization, the enterprise completely abandoned the use of natural gas (over 3 million m3 / year) and reduced the volume of greenhouse gas emissions.

Despite the obvious advantages, the use of renewable energy resources in the pulp and paper industry is accompanied by a number of risks (Table 7).

To identify the most significant barriers to the use of biomass for heat production at the pulp and paper industry in 2019, the authors conducted an expert survey of industry experts. According to the results of an expert survey, it was found that the use of renewable energy resources in the pulp and paper industry of Ukraine is constrained by the following reasons: lack of funds for capital investments, insufficient development of infrastructure for storing and transporting biomass, low supply of processed biomass, the need to re-equip the internal energy supply system (Table 8).

Thus, 26.9% of respondents indicated a lack of funds for the re-equipment of heat production, 19.2% highlighted the problems of the biomass market (weak development of infrastructure for transportation and storage of biomass, low supply in the biomass market), 15.4% stated the complexity of the technical re-equipment of the main production.

Table 7. SWOT-analysis of the use of renewable energy resources in the pulp and paper industry.

Environment	Positive influence	Negative influence
Internal environment	Opportunity to use waste of own production. Cost reduction of 1 Gcal of thermal energy. Reducing the cost of 1 ton of paper.	Increased energy costs. The need to ensure a stable supply of energy resources. The need to re-equip the energy supply system.
External environment	Introduction of state incentive instruments (tax benefits). Great potential of biomass in the agricultural and forestry sectors of Ukraine.	Rising prices for fossil energy resources (coal, natural gas). Strengthening the regulation of the anthropogenic impact of enterprises. The need to establish conditions for the supply of biomass. Underdevelopment of the biomass market in Ukraine.

Table 8. Distribution of answers of specialists of pulp and paper enterprises to the question "What are the obstacles to the use of renewable energy resources?"

Obstacle	**Number of answers**	
	people	**%**
Lack of funds for capital investments	7	26.9
Weak development of infrastructure for transportation and storage of biomass	5	19.2
Low supply in the biomass market	5	19.2
The need for technical re-equipment of basic production	4	15.4
High costs for biomass transportation	3	11.5
The need to stop production	1	3.8
The complexity of the operation of the equipment	1	3.8
Total	26	100.0

To increase the efficiency of energy resources use, we propose a scientific and organizational model of energy modernization of the pulp and paper industry. It aims to replace fossil and fuel energy resources with thermal energy from biomass. It contains a set of economic and organizational tools that are systematically implemented at the regional and local levels and are aimed at the formation of intersectoral logistics, marketing, financial, scientific and information flows (Fig. 4).

The implementation of the proposed scientific and organizational model will contribute to the technical and energy modernization of thermal energy production of the pulp and paper industry, in particular through the combustion of biomass of various types.

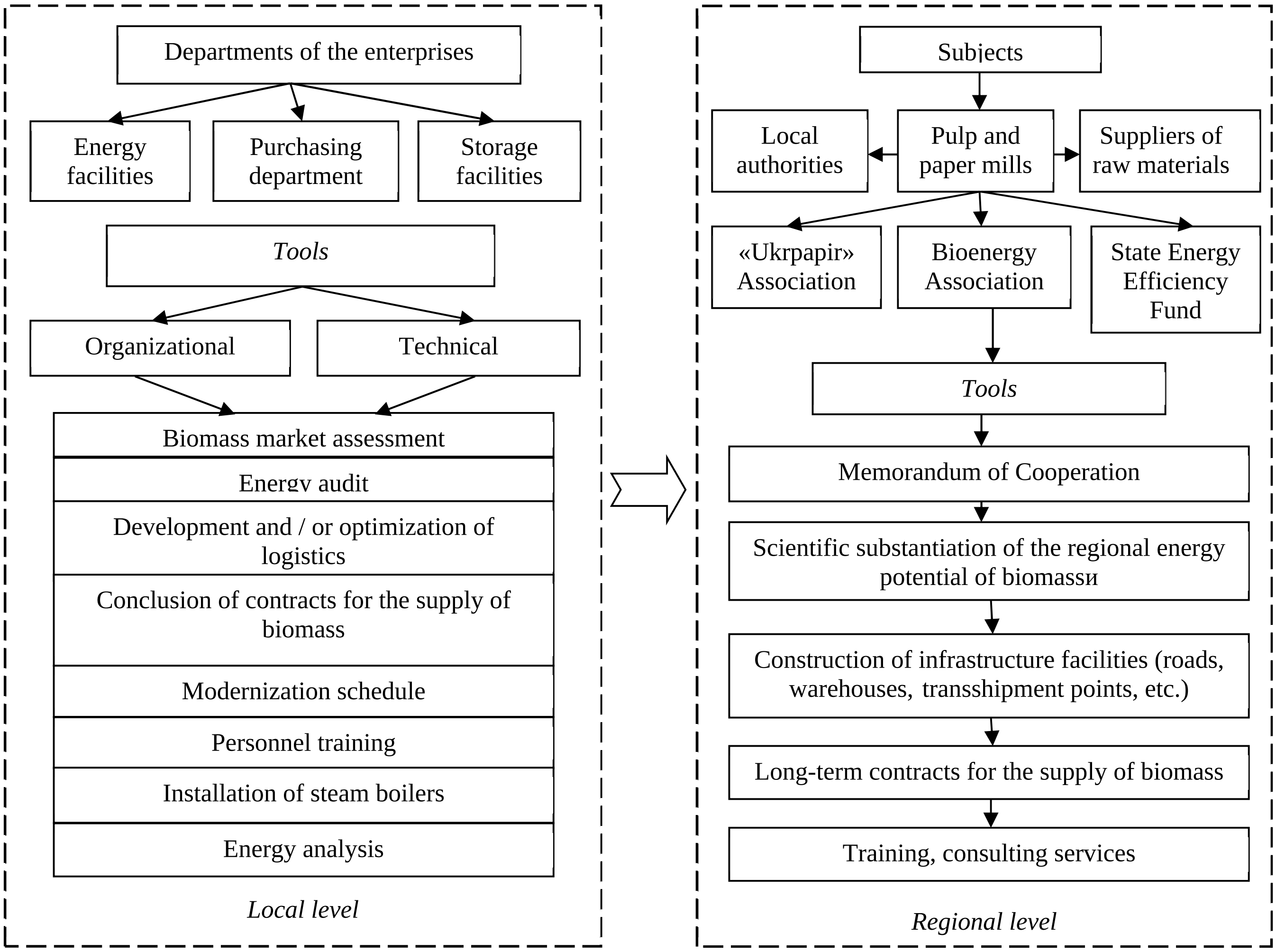

Fig. 4. Scientific and organizational model of energy modernization of the enterprises of the pulp and paper industry of Ukraine for the production of thermal energy from biomass.

5 Conclusion

In the context of reforming the energy sector of Ukraine, the introduction of a new model of energy markets, the harmonization of national legislation in accordance with European standards, an urgent requirement of the time is to increase the efficiency of using traditional and renewable energy sources in the production activities of business entities, in particular in the pulp and paper industry. In this industry, energy resources play a decisive technological and economic role in the production of paper and cardboard. Rational, scientifically grounded use of such resources will help reduce energy intensity, production costs, as well as the level of anthropogenic impact on air, water and land resources.

In recent years, at the enterprises of the studied industry, there has been a tendency towards an increase in the volume of consumption of energy resources. In 2018, compared to 2014, the volume of energy consumption here increased by 244 thousand toe, or 12%, including electricity – by 14 thousand toe or 20.5%. At the same time, in the past two years, the growth rate of energy resources consumption exceeded the rate of increase in the volume of production. As a result of rising prices, the share of energy costs in the structure of the cost of paper and cardboard has almost doubled, which has made the enterprises in the industry unprofitable.

To improve the information base for the analysis and assessment of energy consumption, the implementation of innovative measures for energy conservation, and the forecasting of energy costs, it is proposed to apply the developed multivariate correlation-regression model. It describes the dependence (multiple correlation coefficient = 0.728 – strong relationship) of the level of energy costs for the production of 1 ton of paper or cardboard (effective indicator) on the impact of production (productivity of paper machines, equipment wear) and environmental and economic factors (investments in energy saving measures, share of renewable sources).

To stimulate pulp and paper enterprises for energy modernization using renewable energy resources, it is necessary to implement a set of measures aimed at accumulating financial resources, forming and developing institutional and organizational ties between biomass producers and consumers, and strengthening information and educational training of engineering and management personnel. A scientific and organizational model of energy modernization of enterprises of the pulp and paper industry of Ukraine is proposed. It includes financial and economic, organizational, environmental, regulatory, technological, scientific and educational (personnel) and other tools for implementation at various levels of management, in particular, at the regional (biomass exchange, cross-industry research projects for assessing the biomass market, energy efficiency standards, mandatory energy audit and certification of the energy management system) and local (cooperation of producers and consumers of biomass) levels.

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Model investigations into assessing optimal power consumption modes for major pump stations of iron ore underground mines

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Abstract. The article investigates into the level of energy efficiency of main water pump stations of iron ore underground mines in case of time-of-day electricity rate. There are developed and suggested methods of analyzing the influence of pump electric capacity on electricity cost based on multifactor regressive models. The data on power consumption of iron ore mines indicates a complex character of analyzing the results obtained. However, application of information technologies enables using static materials in a new way including indices of power consumption, costs, water intake, mining depth, the number of pumps and their capacity by synthesizing mathematical models as complicated objects through in-depth procession of static materials and substantiation of the obtained results. For the first time, there are used multifactor regressive models considering multicollinearity and non-linearity of pump capacity in order to study its influence on power costs by using the elasticity factor. Analysis of mathematical simulation results relevant to static materials and applying the algorithm of studying dependency of the consumed power costs on pumps' capacity reveals some critical values resulting in corresponding effects. The authors recommend to apply the elaborated algorithm to conducting corresponding calculations by for mining enterprises to monitor formation of the strategy of providing energy efficiency under time-of-day electricity rates.

1 Introduction

Mining enterprises are considered energy-intensive or, to be exact, electric power-intensive [1-4]. The fact that power makes about 90% of the whole energy consumption and over 30% of the cost forms the basic component of the current level and constantly increasing power-intensity of mineral mining, thus negatively affecting mining enterprises' economy and their competitive character on the international market of raw materials [3-5].

The characteristic of the research object. The problem of controlling power supply and consumption in terms of some technological factors is challenging and real-life among other issues of reducing energy-intensity of mineral mining [6-7]. To do this, there are some positive steps taken at mining enterprises including ore underground mines. Among those, are a limited number of energy-intensive consumers consuming about 90% of the total power (Fig. 1) [8, 9]. Facts like these a priori are highlighting the vector-related character of developing the strategy of researching into control over power-supply/consumption of such enterprises by transforming energy-intensive consumers into power regulators [8-10]. Besides, this process is stimulated by the *Law on power in Ukraine* which has actually intensified the 'power load' on mining enterprises, thus enhancing this process [8].

2 Research materials

Analysis of distributing power consumption levels among energy-intensive consumers of iron ore underground mines enables or rather testifies to the individual character of each enterprise (Fig. 1).

Without generalizing solutions to the energy-efficiency problem of all energy-intensive consumers of iron ore underground mines, from all the mentioned issues (Fig. 1), we focus on investigating into power consumption and control levels of major pump stations.

According to Fig. 1, Batkivshchina mine has the highest power consumption level, while Hvardiiska – the lowest. It should be noted that besides typical conditions of pump stations, unlike other power consumers, they are noted for functioning not only in periods of enterprises' active operation, but also after their full or partial conservation (closure) [3-5].

It is essential to accentuate that power consumption of pump stations at non-operating underground mines is actually higher than that of operating ones (Fig. 2-3) [9-

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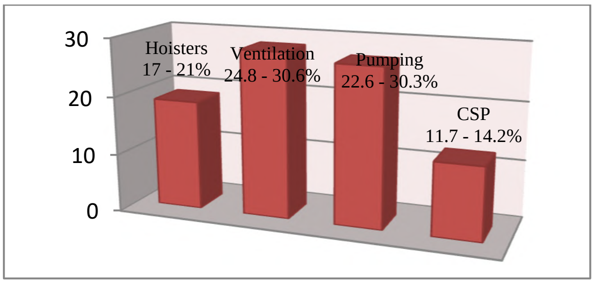
12]. At some underground mines, systems of underground water pumping are often combined into a single power complex. This causes some additional aspects affecting the choice of a pumping scheme design and operation modes of corresponding equipment.



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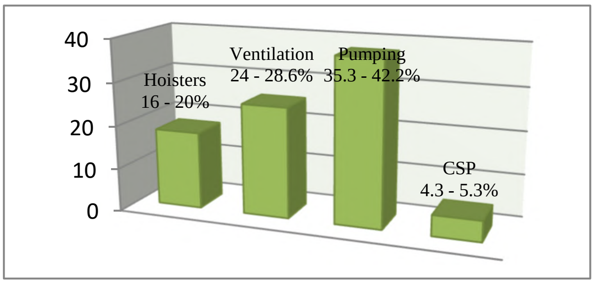

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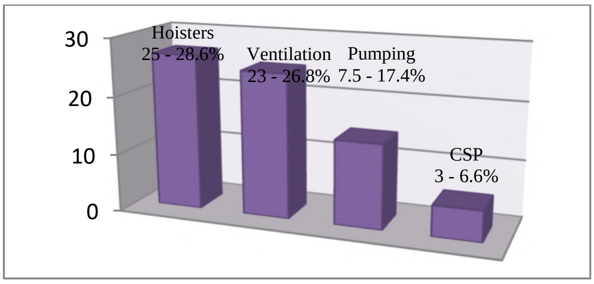

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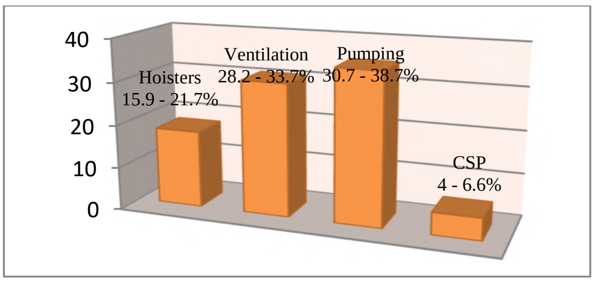

d)

Fig. 1. Variations of power consumption levels by types of mine consumers: a – Zhovtneva, b – Batkivshchina, c – Hvardiiska, d – Ternivska.

Yet, the basic component forms the foundation for the pumping structure of an individual underground mine and remains as given in Table 1.

According to Fig. 2-3, power consumption levels do not change greatly form year to year and tend to be stable.

Energy efficiency of underground mining enterprises' pump stations can be enhanced by:

- improving the technology of their 24-hour functioning and transferring them from the maximum pumping to a more economical mode of power consumption;
- creating return-water pump stations.

The latter will allow mining enterprises to generate their own electric power. The algorithm of major pump stations functioning is as follows: during 'economical time periods' water is pumped from the mine into the surface to corresponding water storage ponds, while during 'non-economical' ones, part of water from those ponds is pumped to the mine and pump motors start generating power [11-14].

Table 1. Established capacity of motors at Kryvyi Rih underground mines.

Mine	Motors		
	Capacity, kW	Number	Total capacity, kW
Ternivska	800	9	7200
	315	4	1260
	250	4	1000
			Total 9460
Hvardiiska	800	9	7200
	630	3	1890
	500	1	500
	315	3	945
			Total 10535
Zhovtneva	800	8	6400
	400	8	3200
			Total 9600
Batkivshchina	800	20	16000
	560	6	3360
			Total 19360

In other words, the power supply complex structure is transformed into the distributed power generation pattern [8].

With that, it is also necessary to develop (elaborate) the structure of pump stations' functioning under the power generation mode and upgrade the pump stations themselves both under the pumping mode and the power generation one.

To analyze the given process, one should develop mathematical models to analyze and elaborate trends of implementing theoretical results.

It is possible by introducing modern system-based approaches and mathematical and statistical methods.

By analyzing power consumption of pump stations, we can identify basic impact factors for individual iron ore underground mines (Table 2) [15-19].

While treating a power-consuming object (an underground mine) as a structural scheme, we can single out some input changes with controlling and disturbing actions of a corresponding energy-intensive unit, while the total electricity load of a mine is an output value.

In its general form, the mathematical model of the iron ore underground mine's consumption can be set by the function of input variables [6]:

$$P_{\Sigma} = F(\nu, n_i, Q_j, Q_\omega, q_j, R_j) \qquad (1)$$

where P_{Σ} is the total electric load of a mine, kW/year; v is intensity of the skip hoister functioning, t/year; n_i is the number of operating pumps at the j-th pumping stage, units; Q_j is efficiency of the j-th mine fan, (m^3/*sec*); Q_ω is total efficiency of underground mining

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sites, (t/year); q_j is water inflow for the *j-th* pumping stage, (m^3/sec); R_j is resistance of the fan network of the *j*-th main mine fan. For model (1) variables ν, n_j, Q_j are controlling, while Q_w, q_j, R_j are disturbing.

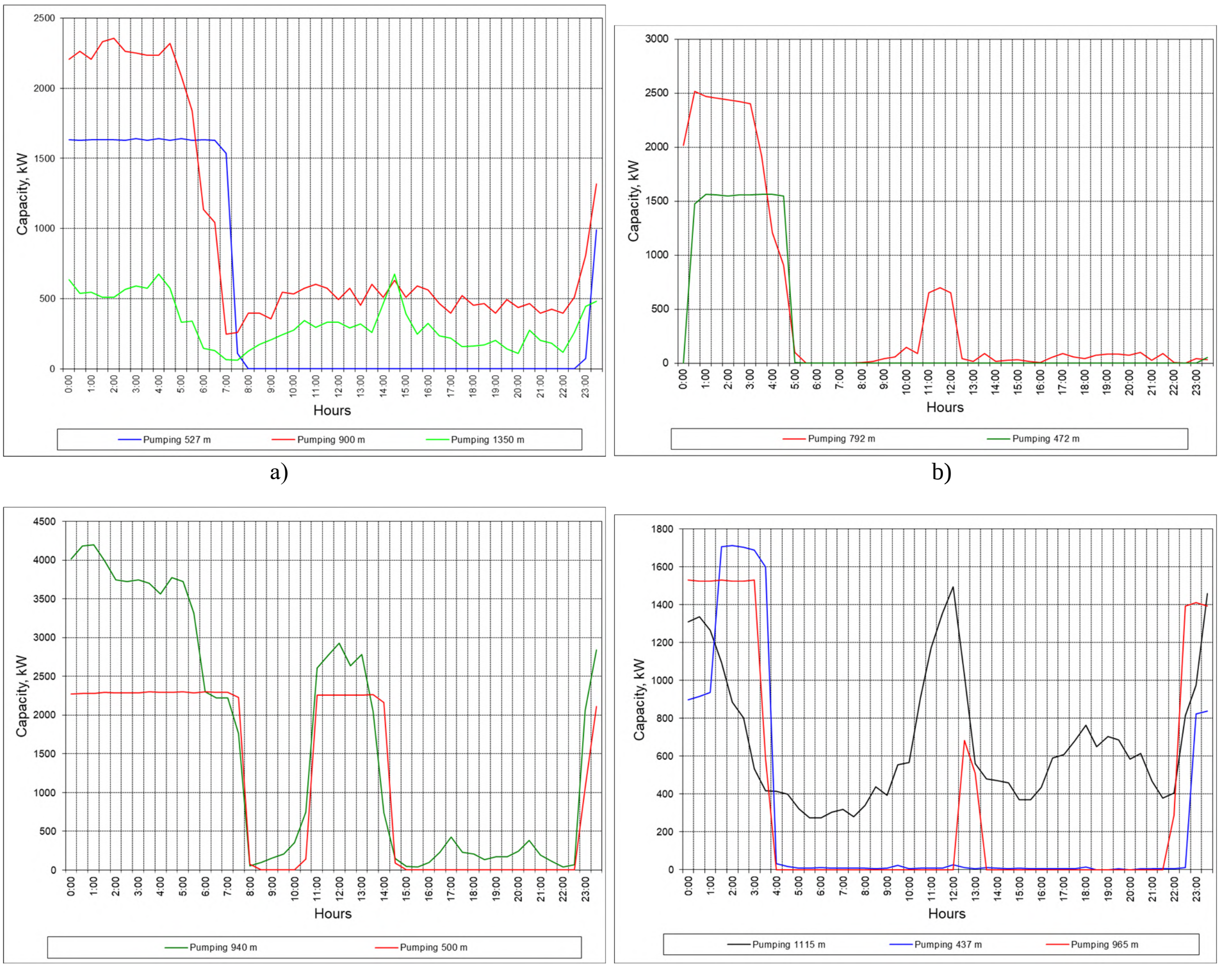

Fig. 2. Power consumption levels at major pump stations of some Kryvyi Rih iron ore mines in May 7, 2012: a – Ternivska, b – Hvardiiska, c – Batkivshchina, d – Zhovtneva.

Table 2. Basic factors impacting Kryvyi Rih iron ore mines' power consumption.

Power consumption of pump stations, kW/year			**Mining depth, m**	**Water inflow, m^3**			**Number of pumps, units**	**Capacity, kW**
2014	2015	2016		2014	2015	2016		
Ternivska								
11307677	10742330	8984057	1350	1585407	1494432	1211279	4	315
Hvardiiska								
9888508	8258434	6556150	1350	1310352	1136586	844396	3	315
Zhovtneva								
1037486	9293986	8482342	1265	1466460	1273886	1167783	1	400
Batkivshchina								
25801367	26878130	25583364	1465	4416601	4619121	4394257	4	800

According to established formalization, power consumption of pump stations can be set as:

$$P_\Sigma = F(\nu_1, n_i, q_j, R_j) \qquad (2)$$

where P_Σ is total power load of corresponding pump stations, kW/year; ν_1 is a level, m; n_i is the number of operating pumps at the *j*-th pumping stage, units; q_j is water inflow for the *j*-th pumping stage, (m^3/sec); R_j is capacity, kW.

For (2), variables ν_1, n_i, Q_i are controlling, while R_j is disturbing.

After considering the diagram of total power load realization of various combinations of input variables and recognizing dependency of power consumption of corresponding pump stations on controlling and disturbing actions, we can control functioning of the energy-intensive station according to the set criterion.

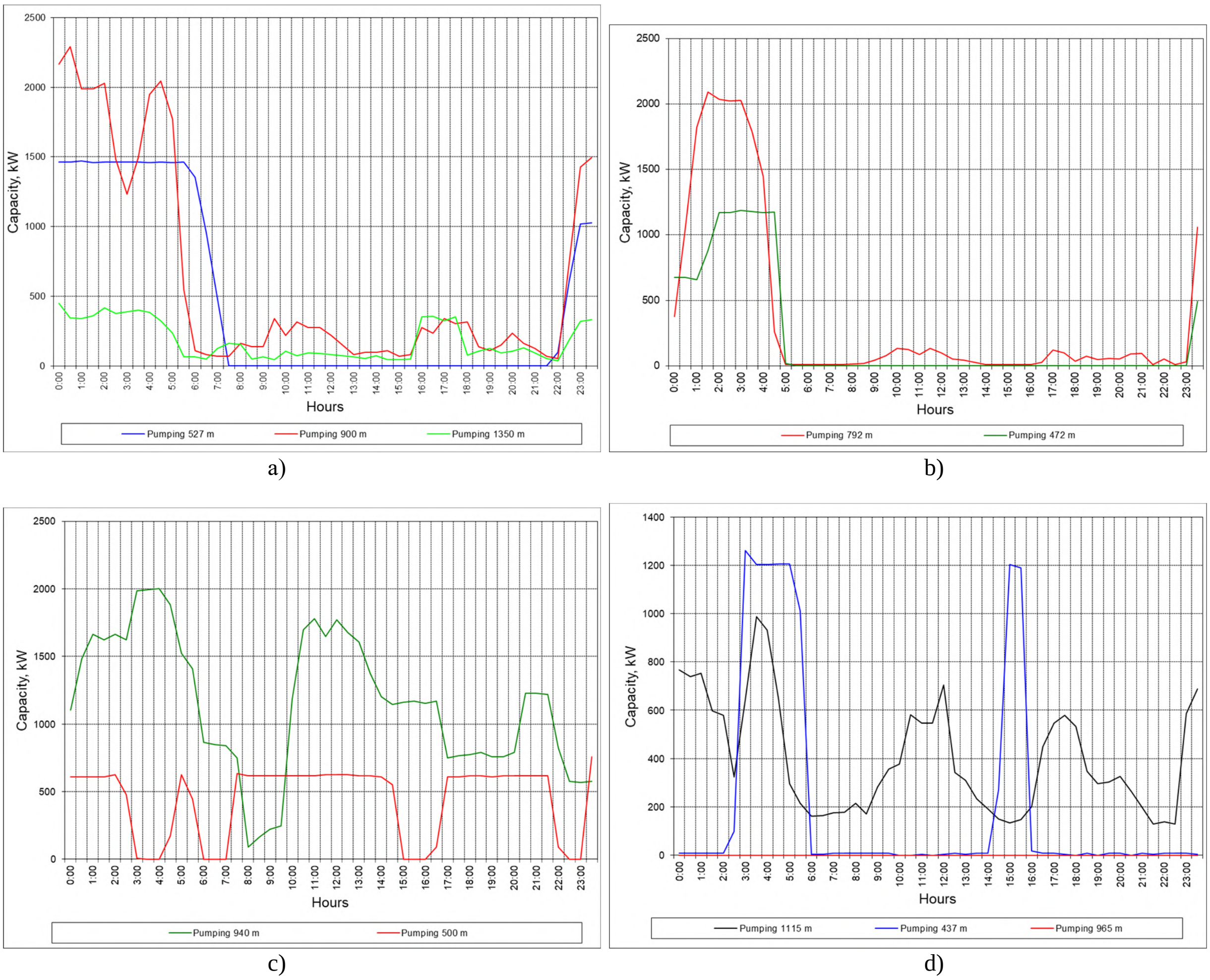

Fig. 3. Power consumption levels at major pump stations of some Kryvyi Rih iron ore mines in February 15, 2019: a – Ternivska, b – Hvardiiska, c –Batkivshchina, d – Zhovtneva.

The simplified two-area time-of-day rate can be written as:

$$C_{\Sigma} = C_{\partial} + C_{н} \tag{3}$$

where C_{∂}, $C_{н}$ are expenditures considering two-area (day, night) rates, *UAH*.

Besides, we can write:

$$C_{\Sigma} = C_1 \cdot W_{\Sigma}, C_{н} + C_2 \cdot W_{\Sigma},$$

where C_1, C_2 are area rates, *UAH/kW*.

According to [9], the maximum effect of controlling consumption is achieved by reducing loads in peak hours of the power system. In this case, the formula for expenditures required to minimize loads for pump stations can be set as the criterion:

$$C = \frac{C_1}{T_1}\int_0^{T_1} P_{\Sigma}\,(t)dt + \frac{C_2}{T_2}\int_0^{T_2} P_{\Sigma}\,(t)dt \rightarrow min \tag{4}$$

where T_1, T_2 are selected intervals of day and night hours, *hours*.

Thus, the problem involves finding values controlling variables$v_1(t)$; $n_i(t)$; $g_i(t)$ which, with set values of disturbing actions R_j will form the diagram of power consumption $P_{\Sigma}(t)$ that will have the criterion at least (4). The choice of values of controlling actions should consider some technological constraints associated with continuity of the process and provision of standard working conditions at an underground mine. The conditions include:

- keeping the accumulating underground bunker unfilled:

$$\int_0^T Q_{ш}(t)dt = \int_0^T v(t)dt, \tag{5}$$

- keeping the water level in water storage ponds stable:

$$\sum_{j=1}^{n}\int_0^T q_j(t)dt = \sum_{j=1}^{n}\int_0^T Q_{nj}\cdot n_j(t)dt, \tag{6}$$

where Q_{nj} is efficiency of a pump of the *j*-th pumping rate, m^3/sec; n is the number of pumping stages.

Real-time solution to the given problem with constraints (5) and (6) calls for application of calculation controlling devices and industrial programming controllers. On the first stage, they should forecast power consumption of an underground mine and provide a controller with recommendations for taking relevant controlling actions.

Meanwhile, reduction of criterion (4) in a general form is quite a complicated task even when applying computers. To simplify this problem, it is expedient to divide total target function (4) into local target functions.

The solution provides for in-depth preliminary analysis of the factor research.

For comparative analysis, we use Z-scaling to obtain a single interpretation system for indices equaling from 0 to N.

By way of illustration, we accentuate the research conducted at Batkivshchina mine with the largest water inflow among underground mines of Kryvyi Rih iron ore basin. Thus, we obtain the following diagram:

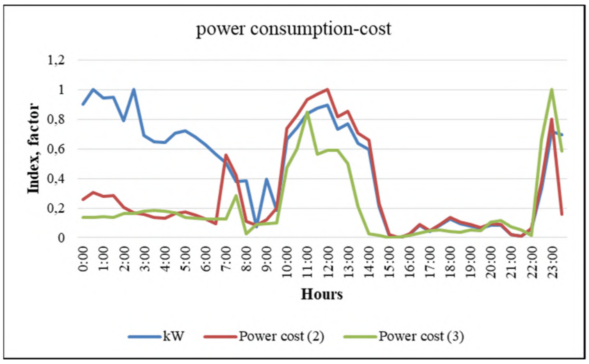

Fig. 4. Dependency of power consumption and its cost on the time of the day.

Visual analysis of the diagram enables stating some correlation of power costs and time-of-day power rates (Fig. 4). Yet, after totaling the output data, we observe excessive power costs for area power rates in comparison with the two-area one. In other words, it is expedient to conduct a multifactor research into power consumption. In a general case, the form of the multifactor regressive model is indefinite. Yet, while investigating into efficiency of power consumption, it is reasonable to use a linear form of a model structure representing it in an additive manner. On the basis of Batkivshchina mine data, $\hat{Y}$ is the consumed power cost (UAH), x_1 is water inflow (m^3/year), x_2 is mining depth (m), x_3 is the number of pumps (units), x_4 is motor capacity (kW) [9-12],

$$\hat{Y} = a + a_1 x_1 + a_2 x_2 + a_3 x_3 + b x_4^2 + \varepsilon \;, \qquad (7)$$

where a, a_1, a_2, a_3, b are parameters; ε is uncontrolled disturbance.

The next step of building the model involves identification of parameters through determining their values that are included into (7).

Processing output data in MS Excel enables identifying these parameters by the least-square method.

The multifactor regressive model results in the following (7).

To identify multicollinearity, according to the output data, we build a correlation matrix of input variables.

$$R = \begin{pmatrix} 1 & 0,886 & 0,702 & 0,572 \\ 0,886 & 1 & 0,665 & 0,611 \\ 0,702 & 0,665 & 1 & 0,420 \\ 0,572 & 0,611 & 0,420 & 1 \end{pmatrix} \qquad (8)$$

Analysis of correlation table (8) reveals that there is a close correlation between variables x_1 and x_2 which indicates multicollinearity. As the variable x_1 can be expressed by x_2, the variable x_1 can be excluded from input variables. The correlation matrix of input variables results in the following:

$$R_1 = \begin{pmatrix} 1 & 0,665 & 0,611 \\ 0,665 & 1 & 0,420 \\ 0,611 & 0,420 & 1 \end{pmatrix} \qquad (9)$$

Analysis of correlation matrix (9) indicates no close correlation between input variables, i.e. there is no multicollinearity.

In the given research, it is reasonable to apply a linear model representing it in an additive form.

Identification of model parameters by processing the corresponding statistic materials enables finding these parameters by means of the least-square method. Multifactor regressive model (9) results in:

$$Y = -0,391x_2 + 2,728x_3 + 33,23x_4 \qquad (10)$$

With that, the determination factor makes R^2 = 0.824, while the Fischer criterion is F = 14.1. The table value of the Fischer criterion is $F_T\left(0,05;3;8\right) = 4,07$. As $F = 14,1 > F_T\left(0,05;3;8\right) = 4,07$, equation (10) is statistically significant.

Absence of the nonlinear member for pump capacity indicates a monotonous character of dependency of power costs on pump capacity.

Thus, on the basis of the simulation results for Batkivshchina mine, it is expedient to conclude that the influence of pump capacity on power costs is positive, i.e. it increases this value. With that, elasticity of power costs in compliance with pump capacity is calculated by:

$$E_{Y/x_4} = \frac{33,23x_4}{-0,391\overline{x}_2 + 2,728\overline{x}_3 + 33,23\overline{x}_4}, \qquad (11)$$

Fig. 5 shows the diagram of function (11).

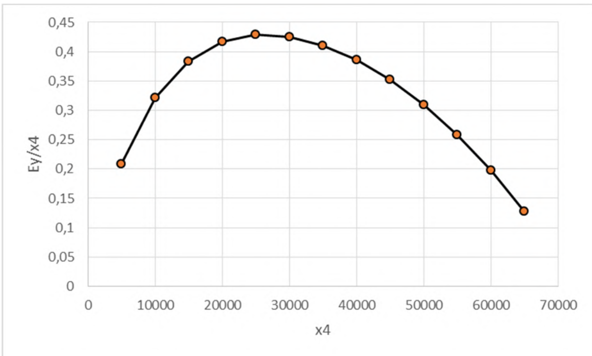

Fig. 5. Elasticity of power costs by pump capacity at Batkivshchina underground mine.

Analysis of Fig. 4 reveals that elasticity depends on power costs in compliance with motor capacity of Batkivshchina mine being positive and increases monotonously. Thus, there are developed methods of economic and statistical analysis that enable obtaining high-quality evaluation by using critical power costs depending on motor capacity as well as assessing its influence on power costs.

3 Conclusions

1. The suggested methods involve innovative approaches to evaluating power costs for operating pump stations of iron ore underground mines.
2. Application of modern IT enables digital methods of processing statistic data of power consumption indices including consumed electricity costs, the water inflow

level, the mining depth, the number of pumps and capacity of motors.

3. After synthesizing mathematical models as complex objects, the authors assess the influence of pump capacity on power consumption and conduct numerical analysis by using the elasticity factor to determine dependency of power costs on the capacity index of pump motors. This approach is worth applying in practice to forming the strategy of providing energy efficiency with time-of-date electricity rates.

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Determining the parameters of the trajectory of the bucket of mining quarries excavators

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Abstract. The bucket positioning of the excavator in three-dimensions (3-D) is the precondition of the robotic excavator starting automatized works. The electric excavator is one of the most widely used machinery in the mining industry, mainly due to its versatility and portability. Among the tasks performed by the excavator, there is a significant number of repetitive movements associated with moving the bucket to the unloading point and back to the face. Using automated functions to perform such repetitive tasks will not only significantly increase overall productivity, but also reduce energy consumption. This research is carried out to create a method of coordinate control of electric drives of the boom, dipper stick, and bucket of an electric excavator to perform accurate and efficient work. On the basis of the kinematic analysis of the excavator's attachment system, the trajectory of the end of the working body can be determined from the point of view of the coordinated movement of the electric drives of the main mechanisms of the excavator. Thus, the complex algorithm of the excavator bucket 3-D position control can be carried out by coordinated control of the movement of three separate electric drives. This coordinate control algorithm was tested on the example of the EKG-8I excavator, and the results of the verification showed that this developed control method can satisfactorily perform the function of automatic control of the bucket position in three-dimensional space. Optimization of control will be further carried out based on the analysis of the energy efficiency of various possible trajectories.

1 Introduction

The excavator is an earth-moving machine designed for excavation of soil with lifting, moving it and unloading it into a dump or onto vehicles. Excavators play an important role in opencast mining of ore deposits, are used in land reclamation and road construction, dredging and port work, and the building of defensive constructions.

The most powerful excavators are used in open pit mining both for stripping operations and for reloading the rock mass and forming dumps. Discontinuous single-bucket excavators are most widely used in these production conditions. Discontinuous (cyclic) excavators perform work operations in a specific sequence, forming a full working cycle; the movement of the machine itself is carried out after performing several cycles.

They are made with various types of interchangeable working equipment (Fig. 1), but in any case, the working body has rigid connections with the machine mechanisms, which limits its degrees of freedom.

In the mining industry, the production of new generation equipment is characterized by a functional and constructive combination of electromechanical converters with energy and information components with a high level of organization of control processes, i.e., the creation of mechatronic complexes. A modern excavator is a complex of interconnected electrical, mechanical, electromechanical and electronic systems of high complexity [1]. This allows us to consider the technological units of the excavator as mechatronic modules, combined into a complex mechatronic complex [2].

For mechatronic complexes of mining machines, due to their significant installed capacity, the energy efficiency of their functioning is of great importance. Increasing the efficiency of using electrical energy in industry and, consequently, mechatronic systems of mining machines is a determining factor in the development of technical systems in the near future [3].

In this regard, the study and modeling of energy processes is of decisive importance in the design of mechatronic systems for mining machines.

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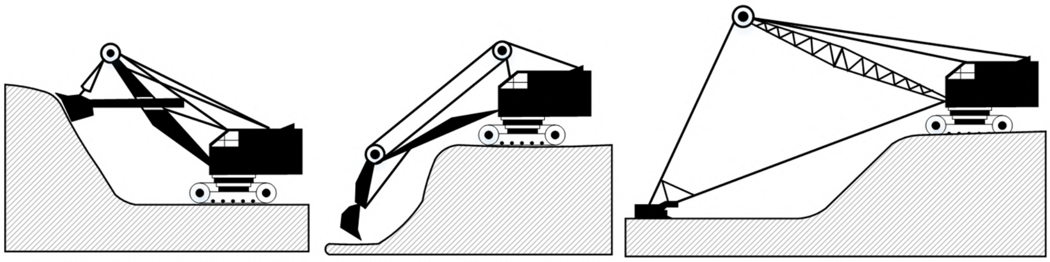

Fig. 1 The main types of single-bucket excavators: a) a power shovel; b) a backhoe; c) a dragline.

2 Literature review

At present, this task is becoming extremely urgent due to the fundamental renewal of both the power equipment of the excavator electric drives and the technical means of control. Energy calculation remains the most difficult and critical stage in the design of mechatronic systems. At present, it is carried out using separate methods [4], which do not take into account the settings of regulating devices and the features of power converters.

Analysis of modern scientific and technical literature indicates that at present there is no general theoretical approach to the analysis and synthesis of control systems that ensure the rational use of electricity in mechatronic systems, and effective models of energy processes for the study and design of mechatronic systems. Modern methods of designing mechatronic systems make it possible to synthesize the structure with a given quality of transient processes [5, 7]. Standard methods for adjusting the regulators of slave circuits of electric drive systems – modular and symmetric optima [6, 7], do not take into account not only energy losses and the influence of power supplies, but also the different physical essence of control processes in a mechatronic system. For electric drive systems with thyristor and transistor energy converters, the operation of which is characterized by harmonic distortions of the shape of currents and voltages, both calculations and measurements of energy characteristics turn out to be difficult, since specialized measuring instruments for these purposes are not produced, and models and estimates of the parameters of electric power processes for nonlinear systems do not have unambiguous and generally accepted definitions [8, 9]. The synthesis of control systems that are optimal in terms of the minimum energy consumption is a complex problem, which in many cases does not have an unambiguous solution [10]. In addition, as shown in [11], the minimum energy consumption is not identical to the increase in the energy efficiency of technical systems.

The synthesis of control systems optimal in terms of energy efficiency is significantly hampered by the lack of scientific papers devoted to a comprehensive analysis of the interrelated movements of excavator mechanisms to implement the desired trajectories of the bucket movement during the working cycle. A significant part of well-known scientific works is devoted to the study of individual excavator mechanisms, isolated from the general complex. The interconnected operation of the electric drives for lifting and head during the digging process is considered in articles [12, 13], but the operation of the same mechanisms in other sections of the trajectory is not considered.

Thus, there is a contradiction between the practical need to increase the energy efficiency of industrial mechatronic systems, on the one hand, and the limited capabilities of modern methods of analysis and synthesis and control algorithms for solving this problem. An important distinguishing feature of mechatronic devices is the presence of a perfect system for monitoring and controlling the position of the working bodies [14]. But it should be noted that the modern equipment of mining excavators does not contain a system for controlling the position of the working body. These functions are performed by the excavator operator by the joint or separate movement of individual elements of the kinematic chain with visual control of the result, which significantly reduces the possibility of automatic optimization of productivity, energy consumption, increases the requirements for the operator's qualifications.

The solution to this problem is possible only with the correct formulation of a complex of interrelated scientific and practical problems: the formation of indicators of the energy efficiency of mechatronic systems of mining machines, taking into account both energy costs and changes in productivity when implementing various control laws; automating the development of optimal trajectories for moving the working bodies of mechatronic systems in space; implementation of high-quality positional control systems that ensure the development of these trajectories; verification of the obtained technical solutions and their approbation in industry.

The formulated range of tasks cannot be considered in detail within one publication. The aim of this work is to develop a mathematical model of the mechanical part of open-pit excavators, which provides a solution to the inverse kinematics problem, i.e. establishing the required law of motion of individual mechanisms of a mining excavator to ensure a given trajectory of movement of the working body, which will further determine and optimize energy and technical and economic indicators when performing a working cycle.

3 Excavator design features. Excavator-related coordinate systems

The most common type of powerful mining excavators in the conditions of Ukrainian mining enterprises are shovel excavators – EKG-5, EKG-8, EKG-10, EKG-12.5, EKG-20. These excavators have a similar design of the main mechanisms, differing in geometric dimensions and minor structural elements.

The further presentation will be carried out in relation to the EKG-8I excavator, in our opinion, the most common model of a mining excavator in the conditions of the Kryvyi Rih iron ore basin. In fig. 2 shows the layout of the equipment on the platform of the EKG-8I excavator.

The main movements of the excavator, performed during the execution of the working cycle – lifting / lowering the bucket when digging and unloading (hoisting mechanism); a linear movement of the dipper stick during digging and unloading (crowd mechanism) and rotation of the platform to the place of unloading and digging (swing mechanism). We do not mention the mechanism of the excavator's travel, since the movement of the excavator is carried out separately from the working cycle.

The formulation of the problem of controlling the movement of the working bodies of an excavator requires the solution of kinematic problems typical for mechatronic systems: determining the position of the bucket in space for the given values of the positions of the crowd, hoisting and swing mechanisms (the direct problem of the kinematics of the mechanical subsystem) and determining the positions of the crowd, hoisting and swing mechanisms for a given position bucket in space (the inverse problem of the kinematics of the mechanical subsystem). The main difficulty in determining the position of the working bodies in space is that individual mechanisms perform different types of movements, and the axes of rotation of individual mechanisms do not coincide with each other.

Figure 3 a simplified kinematic diagram of the mechanisms of a power shovel excavator is presented. The position in space of the excavator bucket is fully described by the three-dimensional coordinates of the digging point K .

The lift of the bucket is carried out by changing the angle of rotation around the axis passing through point 1, perpendicular to the plane of the figure.

The extension and retraction of the bucket occur with linear movement in the saddle bearing located at point 1 and is carried out by the linear movement of the dipper stick L_N . The platform rotates around a vertical axis passing through its center of mass and is carried out by changing the rotation angle φ_R . Figure 4 illustrates the relative position of the boom and bucket of an excavator at various limiting values of the angle φ_P of the bucket and the linear movement of the dipper stick.

Thus, the controls action can be represented by the vector $u = [L_N \ \varphi_R \ \varphi_P]$, the state vector, that describing the position of the bucket, is given by the Cartesian coordinates of the digging point $s = [X \ Y \ Z]$.

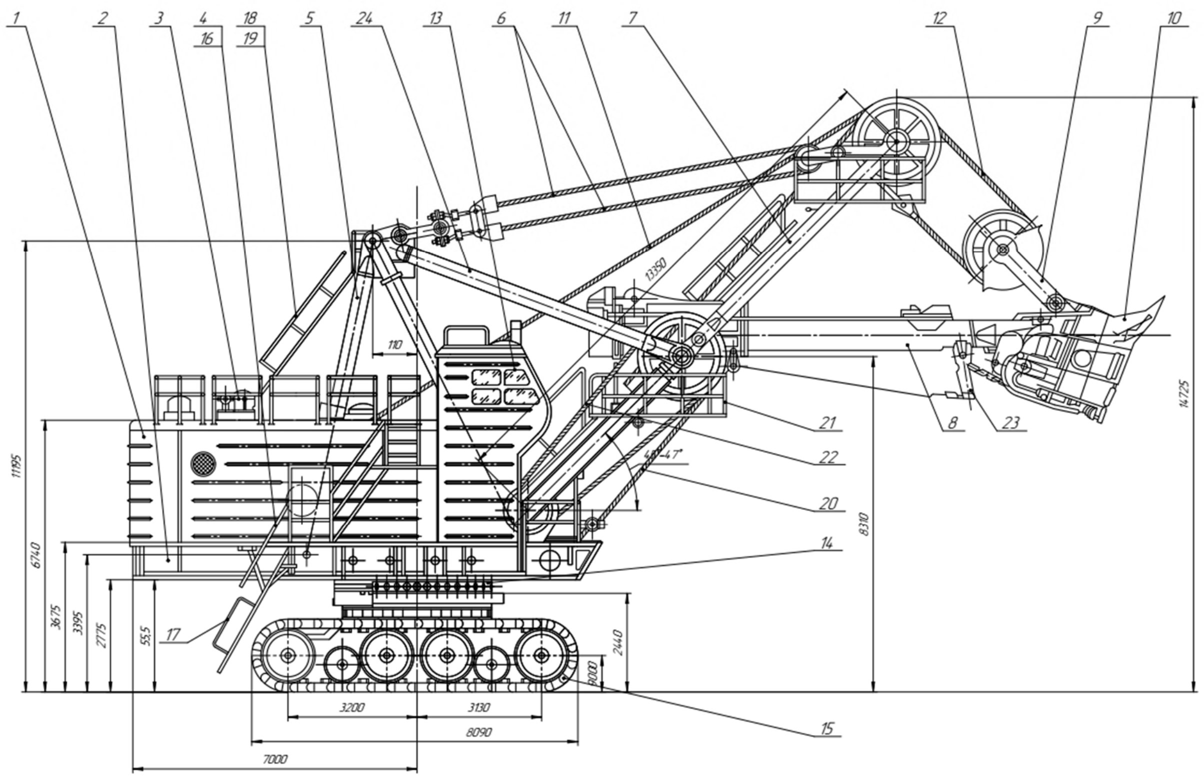

Fig. 2. Equipment layout and geometrical dimensions of the EKG-8I excavator. 1 – revolving deck; 2 – body; 3 – auxiliary winch; 4 – steps; 5 – two-legged stand; 6 – cables; 7 – boom; 8 – dipper stick; 9 – bucket suspension; 10 – bucket; 11 – rope; 12 – hoisting rope; 13 – driver's cab; 14 – roller circle; 15 – undercarriage; 16 – fence; 17 – entrance steps; 18 – steps; 19 – fence; 20 – rope; 21 – platform on the boom; 22 – rope.

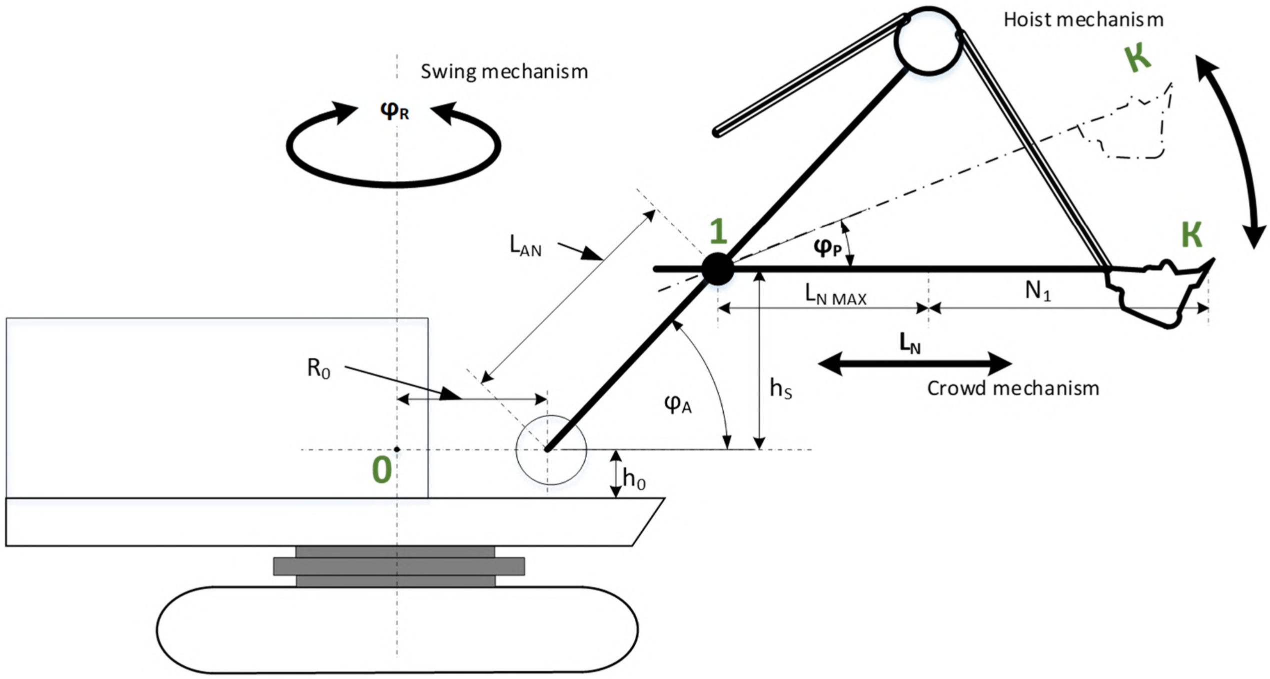

Fig. 3. Simplified kinematic diagram of the mechanisms of a power shovel excavator.

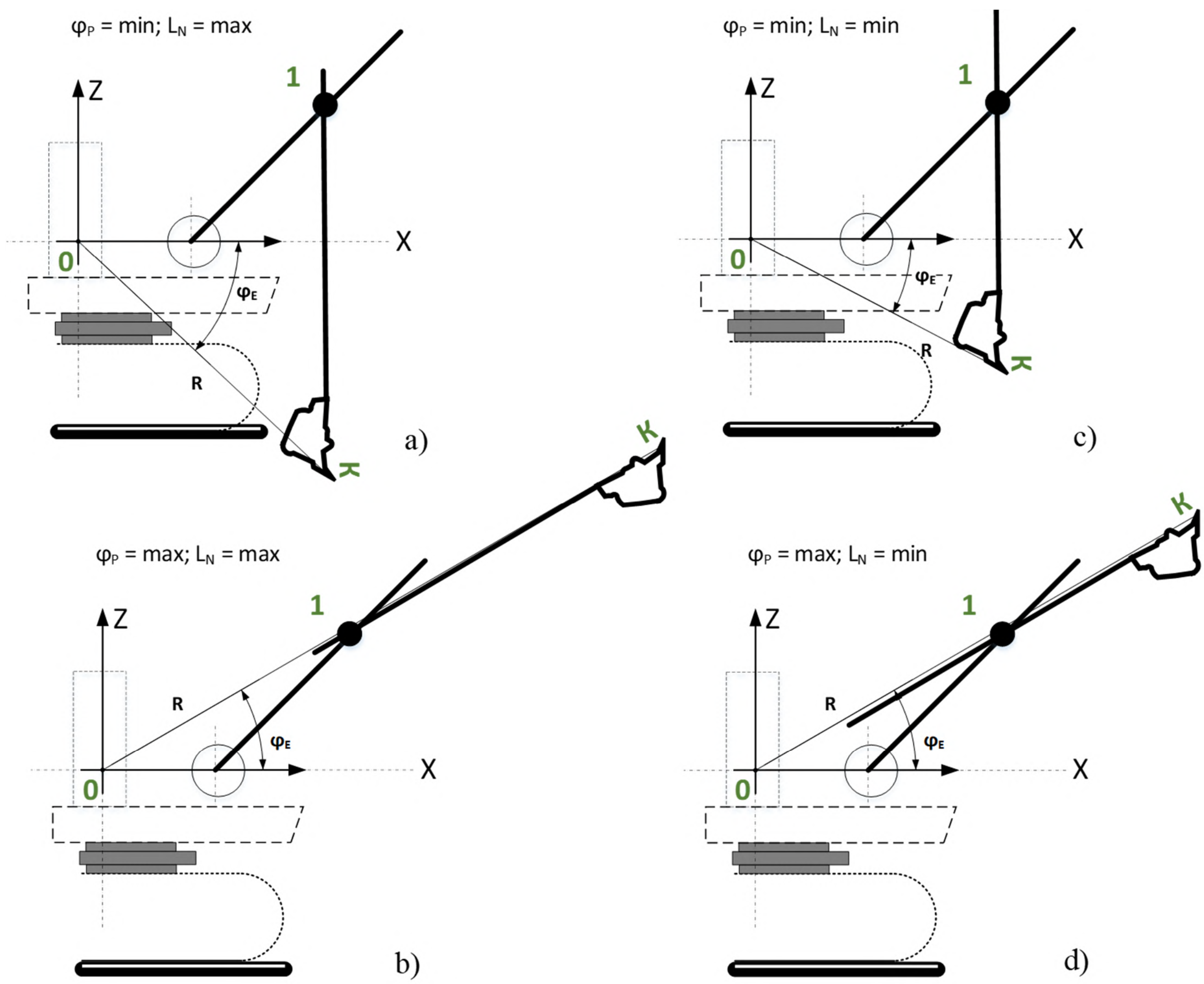

Fig. 4. Diagram of the mutual arrangement of the boom and dipper stick of an power shovel at various limiting values of the ascent angle of the dipper stick φ_P and linear movement of the dipper stick L_N : a) $\varphi_P = min$; $L_N = max$; b) $\varphi_P = max$; $L_N = max$; c) $\varphi_P = min$; $L_N = min$; d) $\varphi_P = max$; $L_N = min$.

Since the working bodies of the excavator make two different rotational movements, it is most natural to consider the movement of the working bodies of the excavator in a spherical coordinate system. The center of the spherical coordinate system of the excavator is located at point O on the platform rotation axis at a height equal to the height of the boom heel attachment, Fig. 5, Fig. 2.

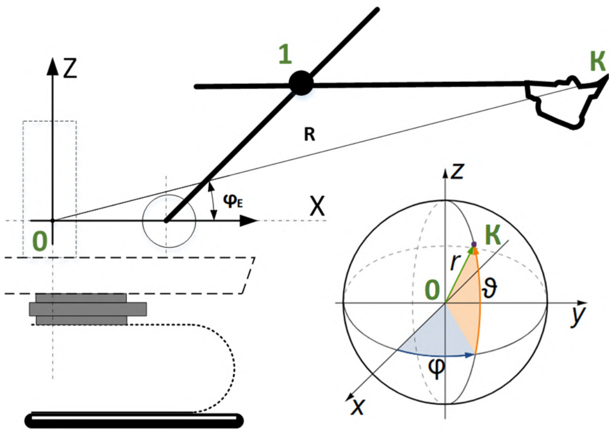

Fig. 5. Spherical coordinate system associated with the power shovel.

In this case, the spherical coordinate φ will be equal to the angle of rotation of the power shovel revolving deck φ_R, the spherical coordinate r will be equal to the length of the segment $0K$, the spherical coordinate ϑ will be equal to the angle $K0X$ (angle φ_E).

The traditional way to derive kinematic equations for backhoe/excavator or generic robots is to start with Denavit-Hartenberg parameters and transformation matrices [15]. In this paper, a less traditional approach will be used to take advantage of the fact that the stick and bucket move in a plane that is rotated by the swing joint (see Fig. 4). Taking advantage of this fact, the position vectors can first be derived using spherical coordinates and then converted into Cartesian coordinates (Fig. 5). With this location of the center of the coordinate system and the accepted direction of the coordinate axes of the orthogonal Cartesian coordinate system, the level of the excavator is characterized by a negative value of the coordinate Z.

4 Solving the direct problem of power shovel kinematics

It is necessary to determine the Cartesian coordinates of the position of the digging point K $(X, Y,\ Z)$ according to the specified values of the control coordinates of the excavator – the linear movement of the shovel L_N, the angle of the boom φ_P, the angle of rotation of the platform φ_R.

Consider how the coordinates r and ϑ of the spherical coordinate system are related to the lift angle φ_P and linear movement of the shovel L_N.

Let's define the coordinates of the point K K in the coordinate system $Z0Y$.

$$\begin{cases} K_X = R_0 + L_{AN}\,cos(\varphi_A) + (L_N + N_1)\,cos(\varphi_P) \\ K_Z = L_{AN}\,sin(\varphi_A) + (L_N + N_1)\,sin(\varphi_P) \end{cases} \quad (1)$$

Then the spherical coordinates of the point K can be determined as follows:

$$\begin{aligned} r &= \sqrt{K_X^2 + K_Z^2} \\ \vartheta &= \arctan\left(K_Z / K_X\right) \end{aligned} \quad (2)$$

The transition from a spherical coordinate system to three-dimensional Cartesian coordinates is carried out using the well-known expressions:

$$\begin{cases} X = r\,cos(\vartheta)\,cos(\varphi_R) \\ Y = r\,cos(\vartheta)\,sin(\varphi_R) \\ Z = r\,sin(\vartheta) \end{cases} \quad (3)$$

Formulas (1-3) give us a closed solution to the direct problem of excavator kinematics and determine the equations for the transformation of the excavator control coordinates $(L_N,\ \varphi_R,\ \varphi_P)$ to the Cartesian coordinates of the digging point $(X, Y,\ Z)$.

5 Solution of the inverse problem of power shovel kinematics

It is necessary to determine the excavator control coordinates $(L_N,\ \varphi_R,\ \varphi_P)$ using the specified Cartesian coordinates of the position of the digging point .

The transition to spherical coordinates from Cartesian coordinates is carried out using the well-known expressions:

$$\begin{cases} \varphi_R = arctan\frac{Y}{X} \\ \vartheta = arctan\frac{Z}{\sqrt{X^2+Y^2}} \\ r = \sqrt{X^2 + Y^2 + Z^2} \end{cases} \quad (4)$$

Using equations (2), we obtain the following relations:

$$\begin{cases} K_X = \frac{1}{\sqrt{1+tan^2(\vartheta)}} \\ K_Z = \frac{tan(\vartheta)}{\sqrt{1+tan^2(\vartheta)}} \end{cases} \quad (5)$$

And finally, based on equations (1), we get the follows:

$$\begin{aligned} \varphi_P &= \arctan\frac{K_Z - L_{AN}\sin(\varphi_A)}{K_X - R_0 - L_{AN}\cos(\varphi_A)} \\ L_N &= \frac{K_X - R_0 - L_{AN}\cos(\varphi_A)}{\cos(\varphi_P)} - N_1 \\ \varphi_R &= \arctan\frac{Y}{X} \end{aligned} \quad (6)$$

When solving the inverse problem of power shovel kinematics, it is necessary to take into account that not all points in space $(X, Y,\ Z)$ are reachable, which is associated with the existence of design constraints on the control coordinates of the excavator.

Therefore, equations (4–6) must be supplemented with the following restrictions:

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$$\begin{cases} L_{N\min} \le L_N \le L_{N\max} \\ \varphi_{P\min} \le \varphi_P \le \varphi_{P\max} \\ \varphi_{R\min} \le \varphi_R \le \varphi_{R\max} \end{cases} \quad (7)$$

Equations (4–6) subject to constraints (7) gives us a closed solution for the inverse problem of excavator kinematics.

6 Computational experiment

To validate the obtained expressions, a number of calculations were performed using the example of the EKG-8I excavator. The overall dimensions of this excavator used in the calculations are shown in Table 1. Fig. 6 shows the results of calculations of the working area of the EKG-8I excavator, which shows the entire area of space reachable by the excavator bucket under the constraints indicated in Table 1. The working area of the EKG-8I excavator has a complex spatial shape, limited in the front and rear by areas of the sphere.

Using the obtained expressions, a number of trajectories were calculated for moving the bucket after the end of digging from point 1 to point of unloading the bucket 2 (Fig. 7).

Trajectory 1 is obtained with the uniform motion of all excavator mechanisms. The Trajectory 2 was obtained by implementing a rectilinear movement from point 1 to point 2. Since a part of this trajectory went beyond the limits of the excavator's working area, a curvilinear section was formed in its middle part, corresponding to movement along the border of the working area.

Table 1. Dimensions of the power shovel EKG-8I

Parameter	Value
Boom length, m	13.35
φ_A – Tilt angle of boom, deg	47
Dipper stick length, m	11.425
Dipper stick stroke, m	4.3
R_0 – Distance from the revolving deck rotation axis to the boom heel attachment point, m	
N_1 – Dipper stick length minus dipper stick stroke, m	
L_{AN} – Distance from the point of attachment of the boom heel to the saddle bearing, m	
L_{Nmin} – The minimal value of dipper handle position, m	0
L_{Nmax} – The maximal value of dipper handle position, m	4,3
φ_{Pmin} – The minimum value of the angle of the hoisting mechanism, deg	-90
φ_{Pmax} – The maximal value of the angle of the hoisting mechanism, deg	45
φ_{Tmin} – The minimum value of the swing angle of the power shovel revolving deck, deg	0
φ_{Tmax} – The maximum value of the swing angle of the power shovel revolving deck, deg (determined by the parameters of the power shovel working area)	120

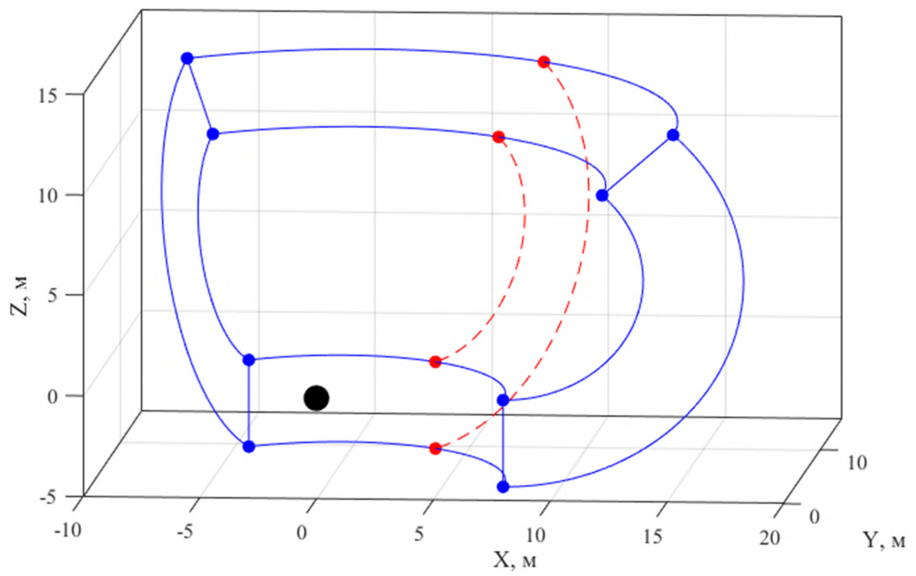

Fig. 6. Working area of the power shovel EKG-8I.

Trajectory 3 was obtained by sequentially turning the platform and then lowering the bucket to point of unloading 2.

The implementation of Trajectory 1 and Trajectory 2 requires the simultaneous coordinated operation of the electric drives of all the main mechanisms of the excavator, which may require high qualifications of the operator. Trajectory 3 is ensured by the sequential operation of the electric drives of the main mechanisms of the excavator.

The calculations showed that the length of these trajectories differs significantly: from 25 m (Trajectory 2) to 33 m (Trajectory 3), which is 32%.

Conclusion

The analysis of the mechanical structure of a mining bucket excavator was carried out, which made it possible to solve the inverse problem – according to a given trajectory of movement of the working body, taking into account technological limitations, at each point, the coordinates of individual actuators were calculated. The obtained trajectories of movement show the available possibilities for optimizing the operation of mining excavators, in particular, for minimizing the length of trajectories. However, it should be borne in mind that only the length of the trajectory cannot serve as an optimization criterion, since it does not take into account the speed of movement of the bucket along the trajectory and the associated energy costs of individual mechanisms, in which not only the speeds and accelerations but also the equivalent moments of inertia change during the movement.

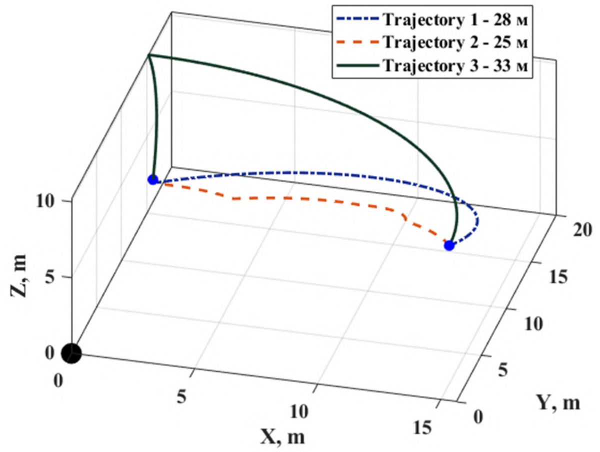

Fig. 7. Trajectories for moving the bucket after digging to the point of bucket unloading

The analysis of the energy costs of individual mechanisms, which is planned in the future, depending on the specified trajectory of the working body, will serve as the basis for optimizing the energy consumption and productivity of mining excavators when performing a full working cycle and can automate the processes of controlling the position of its individual mechanisms.

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Methods of improving power indices of electric drive active rectifiers for mine hoists

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Abstract. The research deals with analyzing peculiarities of using active rectifiers in frequency controlled electric drives of underground mine hoists. There are developed MATLAB models aimed at comparing two types of control systems – hysteresis-based and the one with pulse-width modulation. The research aims to analyze power modes and parameters of active rectifiers, quality of voltage control, current and power of active rectifiers and to determine ways of improving power indices of electric equipment of hoists as well as provide power compatibility of electric equipment and underground mines' grids. Main attention is paid to analyzing circuitry of control systems of active rectifiers, parameters of power transformers and reactor equipment at underground mines' substations, frequency converters and synchronous slow-speed motors. There are also analyzed statistic data on power consumption at underground mines equipped with automated systems of commercial and technical power meters and specific consumption of power. The research results reveal advantages of the pulse-width modulation control system as compared with the hysteresis one by using such indices as speed-performance, quality of control, potential of controlling reactive power and the power factor. Application of the research results will enable determining structures and methods of adjusting control over the active rectifier in the frequency-controlled drive of underground mine hoists.

1 Introduction

Kryvyi Rih iron ore basin is a large producer of iron ore and raw materials for metallurgical enterprises (pellets, sinter) not only in Ukraine, but also in post-Soviet countries. Kryvyi Rih houses the largest metallurgical works, ArcelorMittal Kryvyi Rih, four mining and concentration plants (InGZK, PivdGZK, Central GZK, PivnGZK) with open pit ore mining and Kryvyi Rih iron ore works with underground ore mining.

At Kryvyi Rih underground mines, iron ore mined possesses a higher iron content than that from open pits of the mining and concentration plants. Power consumption of ore mining and haulage from underground levels of 1300m-1500m is higher than that at 200m-300m.

Four underground mines of Kryvyi Rih iron ore works (Rodina, Zaria, Hvardiiska and Ternovska), Yuvileina (Sukha Balka deposit) and the underground mine named after Artem (ArcelorMittal Kryvyi Rih) mine and hoist iron ore in Kryvyi Rih basin. Skip hoists with automated DC/AC drives perform these operations [1-3].

In the1960s-1970s, skip hoists primarily used DC drives with the Ward-Leonard drive system. This system enables required power of DC motors, smooth adjustment of mined mineral hoisting and minimal impacts of an electric drive on the main. The drawbacks of this drive system include necessity to install extra powerful large machines – a synchronous motor (SM) and a DC generator. This also involves additional maintenance expenses, increased power losses for idle performance of the generator and the DC motor, etc.

In the 1980s, there appeared powerful thyristor machines produced by Kharkiv electric-mechanical plant and Zaporizhzhia production association *Preobrazovatel*. This arouse the issue of applying these machines to replacing Ward-Leonard drives to increase electric drive capacity because of increased mining depth. The research institute *Kryvbasproekt* developed a design of modernizing some underground mines using a thyristor drive-motor (TD-M) system (Pervomaiska, the underground mine named after Lenin (Ternovska now), Yuvileina).

Practice of exploiting these drives has revealed both their efficiency and drawbacks. When reducing power consumption per a ton of mined ore, weight-size indices of electric equipment and maintenance costs, it is determined that the TD-M system impacts power quality in 6kV transmission grids of underground mines, their sub-consumers (municipal mains, electric transport, water treatment, etc.). This impact is revealed through voltage slumps and sinusoidal wave

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deformation when starting hoist drives, resonant phenomena when changing parameters of the supply main because of consumer switching, etc. The measures provided on the stage of electric drive designing and implementing (installation of harmonic filters) enabled partial reduction of this impact. With condensers of harmonic filters getting obsolete and broken, there appeared a problem of replacing TD-M drives of hoists by more effective ones [4-6].

AC electric drives with the FC-SM (frequency convertor-synchronous motor) and FC-AM (frequency convertor-asynchronous motor) systems came into use worldwide in the 2000s. These drive systems use AC motors which are more efficient as compared to the DC ones (smaller sizes, inertia moments, copper consumption for winding, no collector and costs for its maintenance, etc.) [7,8].

Besides, application of IGBT-transistors in frequency convertors of these drive systems allows developing and improving their control algorithms aimed at ensuring the higher-order harmonic, reactive power and the power factor.

The world-leading producers of powerful frequency convertors (ABB, General Electric, Siemens, Danfoss) are engaged in improving their power indices, quality of electric power in the main, reducing weight-size indices, providing better maintenance and service, etc.

In 2011, the skip hoist drive at Ternivska underground mine was modernized in order to increase its hoist capacity from 25t to 35t and mining depth up to 1800m. That included replacement of the TD-M system by the FC-SM one with the frequency convertor produced by ABB. Instead of two DC motors of the ПБК – 120/60 type, the AC motor AMZ 2500 LL 16 was installed. To supply this motor, there was installed a frequency convertor ACS 6000 with the microprocessor system of direct torque control in the main circuit of which ARU is an active rectifier, CBU is a unit of condensers; INU is an invertor unit.

Main advantages of the ACS 600 drive include:

- high operational characteristics;
- fast and accurate control combined with low power consumption ensures the best operational characteristics;
- control over the motor by the ACS 6000 through applying the highly effective direct torque control (DTC) method developed by ABB;
- the DTC method ensures the best dependency between torque and speed ever achieved in medium-voltage drives, thus providing fast and smooth control in any condition;
- the ACS 6000 drive uses the latest semiconductor switch contacts IGCT (gate turnoff thyristors with control units) developed by ABB on the basis of their own researches;
- the network power unit for the two-quadrant work with the constant power factor of 0.96 within the whole speed range;
- the active rectifier unit for the four-quadrant work with reduced harmonic content and controlled power factor;
- the DC bus for working with one or more motors and power recuperation;
- breaking energy generated in a single motor can be conveyed to other invertors along the DC bus without feeding from the main;
- recuperation of rotation energy;
- low noise and vibrations.

Operation of the hoist drive with the frequency convertor ACS 6000 at Ternovska underground mine during 12 years has revealed efficiency of electric equipment and minimal impact on the main.

In 2016, the skip hoist of Zaria underground mine was modernized with the TD-M system replaced by the FC-SM with the frequency convertor made by ABB and two AC motors AMZ 2500 LL 16. To supply these motors with power, two frequency convertors ACS 6000 with the microprocessor system of direct torque control were installed. Installation of the two motors and the two convertors was caused by greater hoisting capacity (50t) and the need to increase ore mining depth.

Greater driving power deteriorated quality of electric power in grids. At the 6kV section of 150/6kV Oktiabrska substation, there are much more significant deviations of voltage than those at Leninska substation with the FC-SM of the skip hoist (Fig. 1).

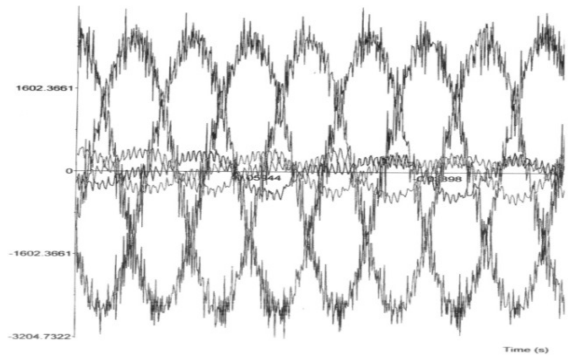

Fig. 1. Diagrams of voltage and current in the 6kV section.

Besides increased driving power of the skip hoist, some other factors also affect the grid including different standard capacities of power transformers at the substations (Oktiabrska - TDTN-40, Ternovska – TDTN-32), the structure of power supply diagrams, presence of shunt reactors, condenser units, etc.

The single-line diagram of power supply of Kryvyi Rih iron ore works' mines includes a power transformer of the step-down substation 154/6kV, a shunt reactor harmonizing the 6/3.1kV frequency convertor and a synchronous motor.

Hvardiiska underground mine is the next to upgrade its skip hoist drive. The 154/6kV substation contains two TDTN-63 transformers. Thus, in our opinion, while designing technical tasks to upgrade the drives, one should analyze their possible influence on the mains and quality of power. This analysis should consider technical potentials of active rectifiers of frequency converters. To do this, the research simulates electromagnetic processes and analyzes power quality control indices in the grid.

2 Characteristic of the control object

Table 1 contains data on power transformers and reactors of mine substations (1 – Ternovska, 2 – Zaria, 3 – Hvardiiska, 4 – Rodina).

Table 1. Parameters of power transformers of mine substations.

Parameter	1	2	3	4
Transformer type	TDTN	TRDN	TDTN	TRDN
$S_{н}$, MVA	40	32	63	32
$U_{кз}$,%	18	11	18	11
$\Delta P_{кз}$, kW	185	175	280	175
$U_{1л}$, kV	158	158	158	158
$U_{2л}$, kV	6.6	6.3	6.6	6.3
$S_{кз}$, MVA	222	291	350	291
$R_{тр}$, Ohm	0.005	0.007	0.003	0.007
$X_{тр}$, Ohm	0.196	0.143	0.124	0.143
Reactor type	РБА	РБА	РБА	РБА
I_{nom}	2000	2000	2000	2000
$L_{р}$, %	8	8	8	8
$R_{р}$, Ohm	0.003	0.003	0.003	0.003
$X_{р}$, Ohm	0.14	0.14	0.14	0.14

Parameters of the power convertor transformer and the synchronous motor are in Table 2.

Table 2. Parameters of the convertor transformer and the synchronous motor.

Parameter	Transformer	Motor
Transformer type	Resibloc	-
$S_{Н}$ kVA	3200	-
$U_{1л}$, kV	6.0	-
$U_{2л}$, kV	3.15	-
$U_{кз}$,%	12	-
$\Delta P_{кз}$, kW	22.61	-
Motor type	-	AMZ 2000
$P_{н}$, kW	-	3705
$U_{н}$, kV	-	3.15
$I_{н}$, A	-	717
$n_{н}$, rpm	-	58
J, kg·m^2	-	55300

The three-phase active rectifier and the self-commutated voltage inverter invertor with high power indices are used in the frequency convertor. This diagram enables the power factor close to one, the DC mode and recuperation of power flow, i.e. the potential to transmit power to the mains.

3 Simulation of operational modes

This convertor type is similar to the self-commutated voltage inverter with the only exception that the diagram works in the rectifier mode and ensures the power factor close to one [9-16]. The key switches of the active rectifier can be controlled by the pulse-width modulation system or the hysteresis control system. Fig. 2 presents the diagram of the active rectifier model with the pulse-width control system. The control system has feedback signals along the input voltage U_1 and input current I_1.

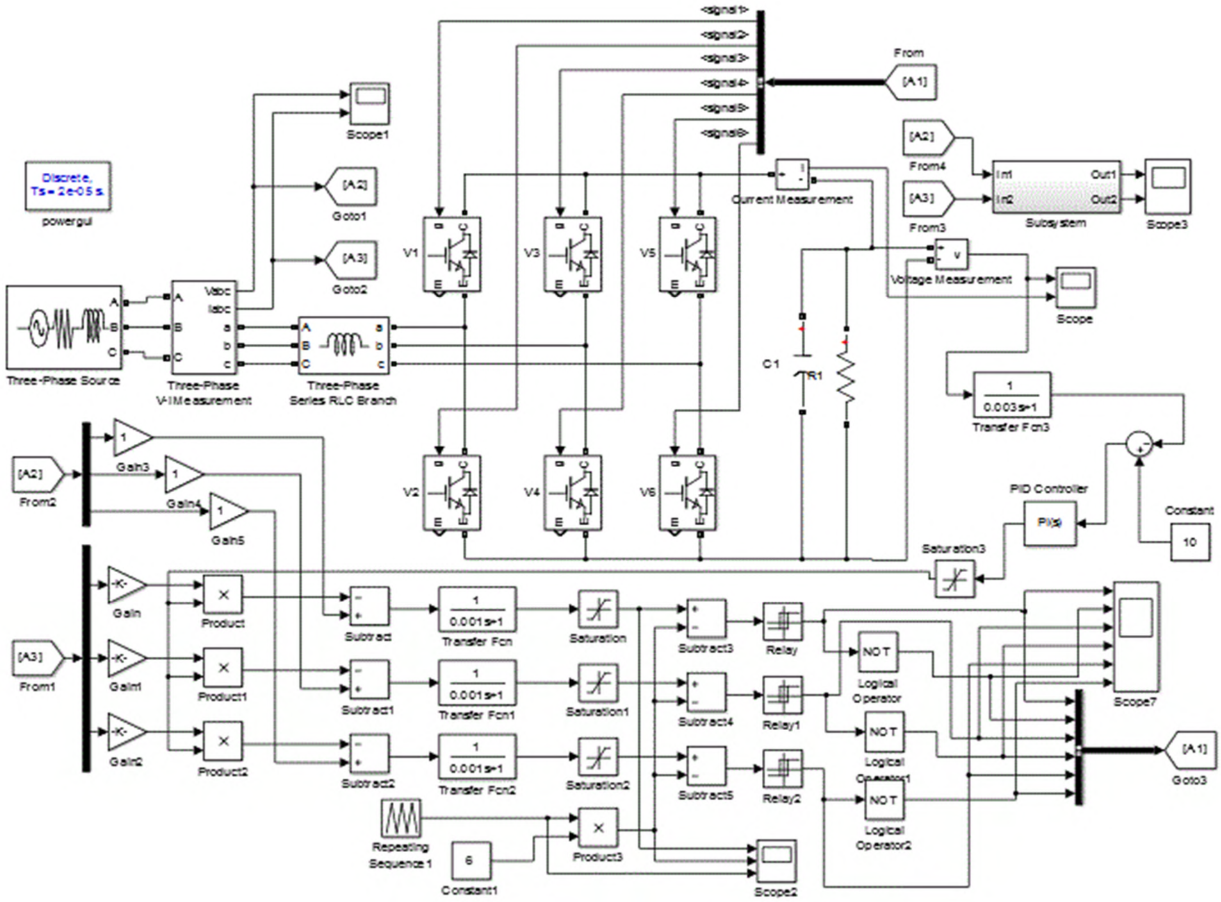

Fig. 2. Diagram of the active rectifier model with the pulse-width control system.

Pulse-width modulation is provided by comparing the controlling signal with that of the triangle waves. There is also a proportional-integral controller of input voltage U_d and a unit calculating consumed active and reactive power (Fig. 3).

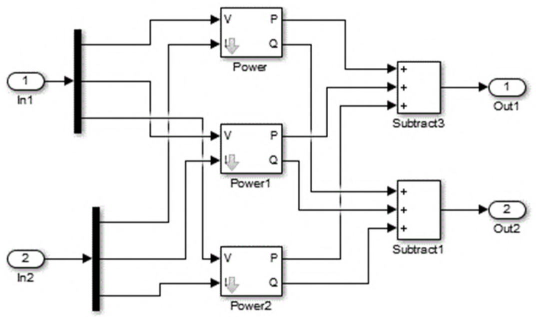

Fig. 3. Diagram of the model of calculating active and reactive power.

In simulating, dynamics of electric parameters of the active rectifier is under study. Fig. 4 shows an oscillogramme of the output current and voltage of the active rectifier.

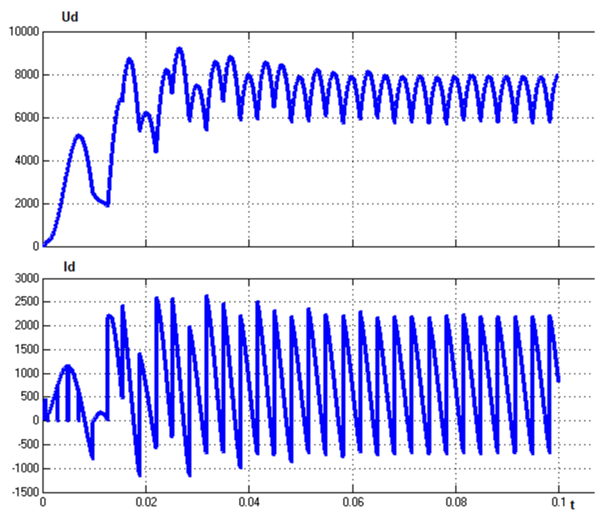

Fig. 4. Oscillogramme of the output current and voltage of the active rectifier with pulse-width modulation.

As is seen in the given diagrams, the control system enhances high-speed performance of voltage control (t_h=0.05÷0.06 c). Fig. 5 contains diagrams of the input current and voltage of the active rectifier. As is seen, the current curve coincides in phase with that of voltage, thus providing the power factor of 1.0.

The form of the current curve is determined by the two-level active rectifier and ratio of active and inductive resistance of the power transformer of the mine substation. The time of the output voltage increase to reach the set value makes 0.02sec, the pulse number is m=6.

Fig. 6 shows the diagram of the active rectifier model with the hysteresis control system.

Fig. 7 contains the oscillogramme of the output current and voltage of the active rectifier, while Fig. 8 presents oscillogrammes of the input current and voltage.

As is seen from the given oscillogrammes, the voltage and current curves of the same phases are cophased, that indicating the power factor being close to one. The primary current curve of the active rectifier differs from a sinusoid and can be improved by making the rectifier diagram more complex to increase its levels.

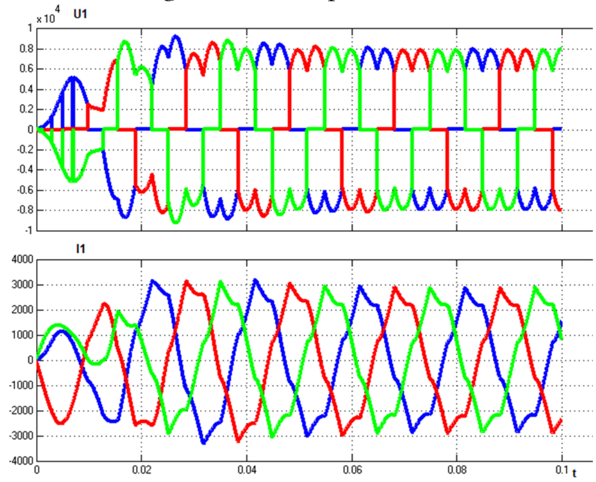

Fig. 5. Oscillogramme of the output current and voltage of the active rectifier with pulse-width modulation.

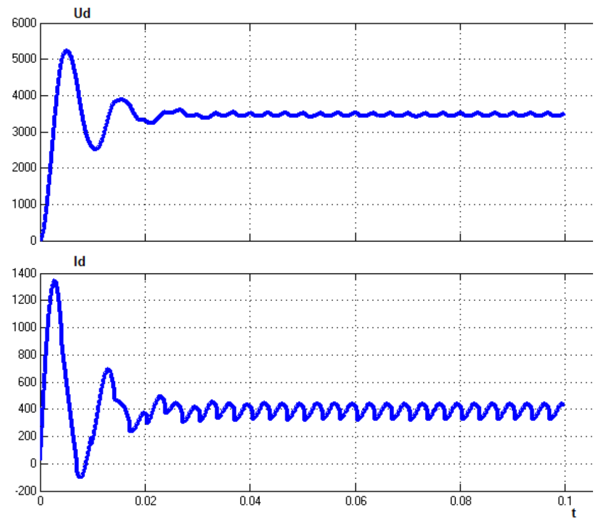

Fig. 7. Oscillogramme of the output current and voltage of the active rectifier with hysteresis control system.

The form of the input voltage and current can be improved by increasing inductance of the input filter of the active rectifier. As is seen, the diagrams of the output voltage and current of the active rectifier with the same parameters of the model elements indicate overcontrol of these parameters as absence of pulse-width modulation reduces speed-performance of control over output voltage of the self-commutated rectifier.

To reduce voltage overcontrol, the control system and the output voltage controller are to be readjusted. The time of the output voltage increase to reach the set value makes 0.02 sec, the pulse number of the rectifier scheme is m=6.

The curves of input currents of the active rectifier with the hysteresis control system have significant deviations as compared with the active rectifier with the pulse-width modulation control system. The form of these parameters can be improved by changing parameters of the input filter of the active rectifier.

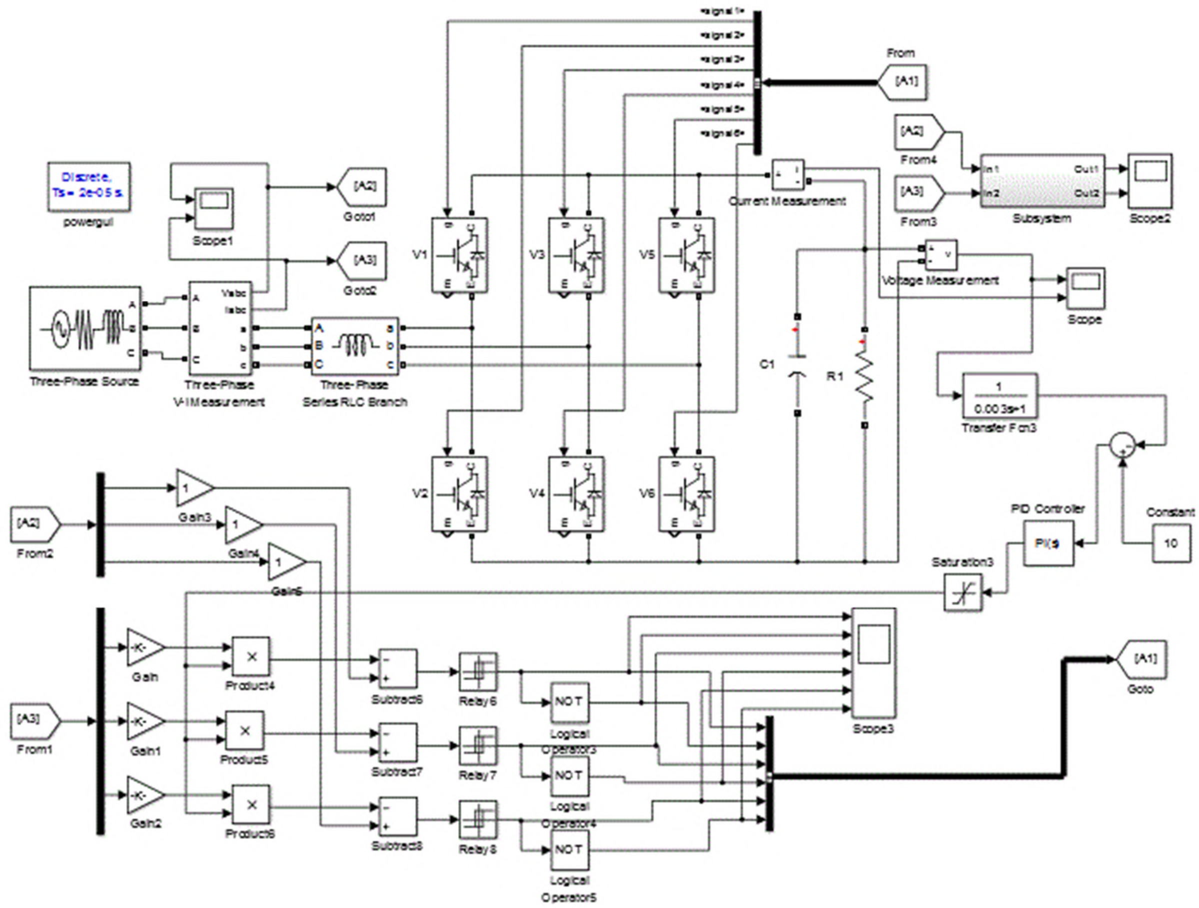

Fig. 6. Diagram of the active rectifier model with the hysteresis control system.

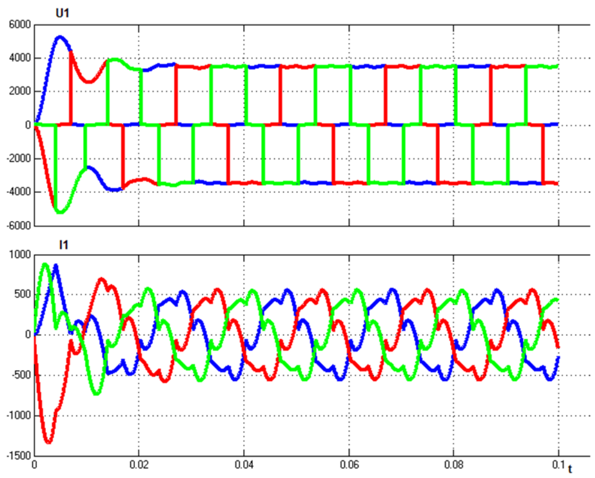

Fig. 8. Oscillogramme of the output current and voltage of the active rectifier with the hysteresis control system.

Fig. 9 shows oscillogrames of active and reactive power of the active rectifier.

Pulsations of signals of active and reactive power are conditioned by pulsations of the input voltage and current. To use these signals as feedbacks, it is necessary to set corresponding filters.

There are MATLAB researches into the drive model of the FC-SM system with the active rectifier. Fig. 10 presents a drive model with the active rectifier.

This model has units of the three-phase voltage source, the three-phase voltage and current meter, the self-commutated synchronous motor with subsystems of the synchronous motor, the rectifier, the DC chain, the invertor, the speed controller, the rectifier controller and the vector controller, the demultiplexor of motor parameters and the calculator of active and reactive power from the grid.

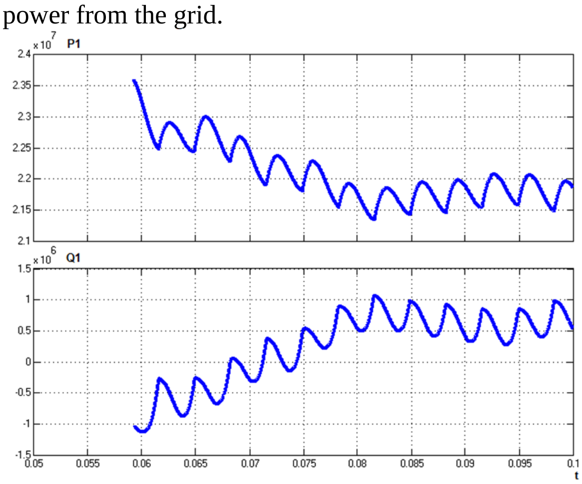

Fig. 9. Oscillogramme of active and reactive power of the active rectifier.

Fig. 11 contains diagrams of the rotor speed of the synchronous motor, electromagnetic torque, active and reactive power. This model reduces reactive power from the grid. The reaction of the drive to load surge and changes of consumed active and reactive power are studied. As is seen from the speed diagram the astatic control system after the load surge reacts to dynamic speed slumps and monitors the signal by the speed. The diagram of consumed active power is determined by the motor speed and torque. Reactive power is minimal and

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provides the power factor close to one. The system is also able to generate reactive power. The system has four control channels – by the input reactive current of the active invertor, by the set output voltage of the active rectifier, by frequency and the pulse ratio of the invertor voltage.

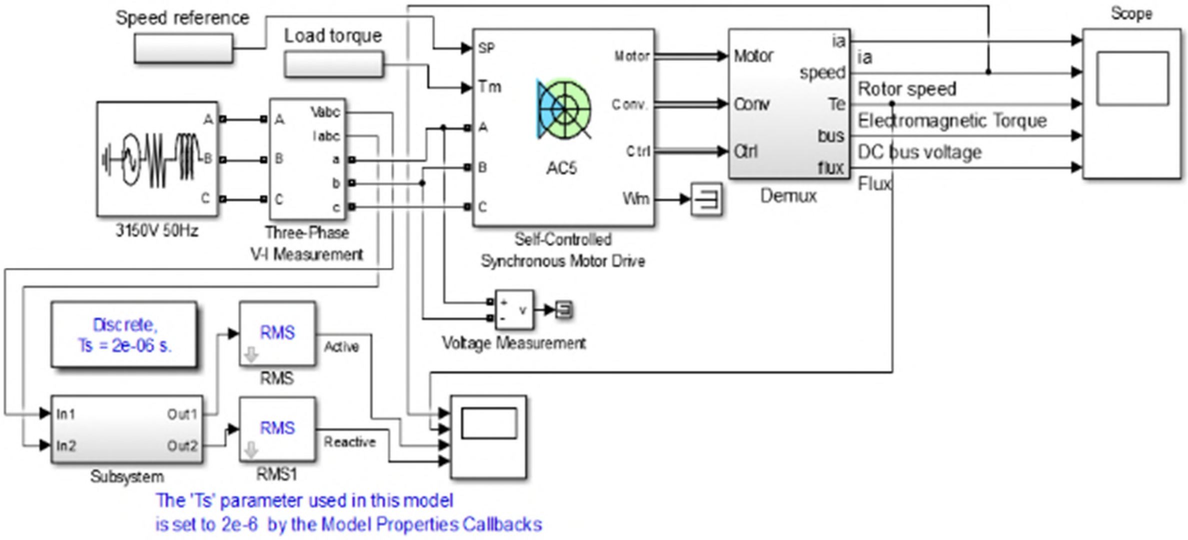

Fig. 10. Diagram of the drive model with the FC-SM.

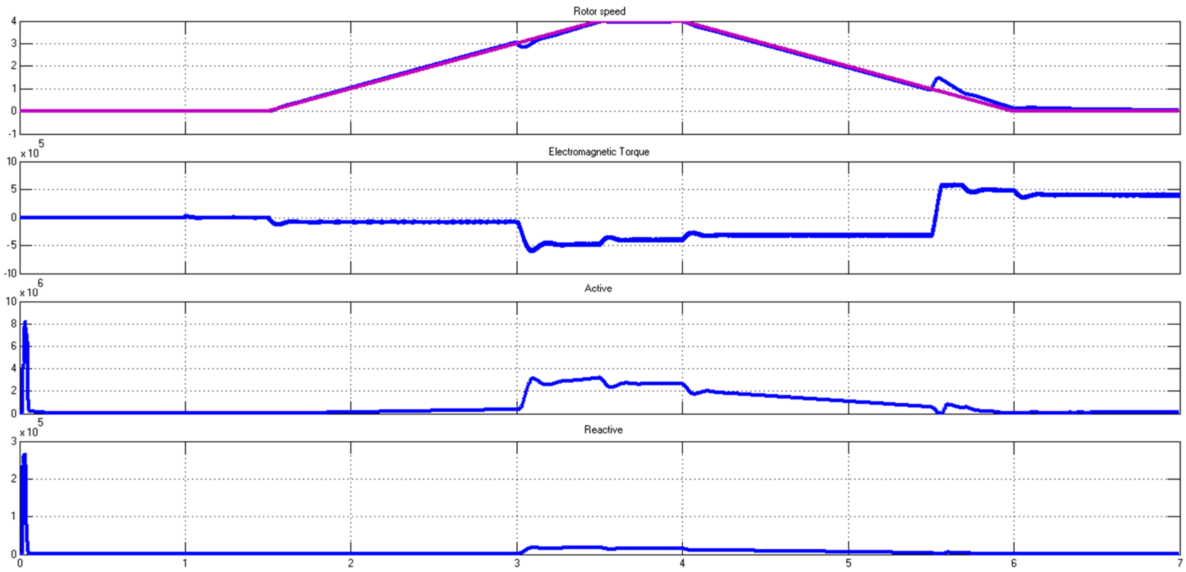

Fig. 11. Oscillogramme of rotation speed, active and reactive power of the FC-SM.

4 Conclusions

The research investigates into specific features of applying active rectifiers to frequency-controlled drives of underground mine hoists. Corresponding models are developed and studied to compare and analyze two types of control over transistor switches of the active rectifier. Analysis of the active rectifier mode enables determining advantages and disadvantages of these control systems and formulating requirements to improving parameters of the active rectifier. The structure of the control system of the frequency convertor is also analyzed, this indicating a potential control over torque controllers, the motor flux, the level of consumed reactive power and the power factor value.

Application of the research results will allow determining structures and methods of adjustment of control systems of the active rectifier in the frequency-controlled drive of underground mine hoists. The scope of further research will involve improvement of energy efficiency of active rectifiers and reduction of their impact on the grid.

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Study and modelling of droop-controlled islanded mesh microgrids

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Abstract. The active and reactive power sharing of distributed generation sources (DGs) connected to isolated microgrids with a single point of common coupling (mono-PCC) to which the loads are also connected has already been the subject of several studies. A high penetration rate of DGs based on renewable energies has as a logical consequence the development and implementation of mesh and more complex multi-PCC microgrids. In this paper, a developed droop control method for synchronization and power sharing between different DGs connected to a mesh islanded multi-PCC microgrid with many distributed generation sources (DGs) and different type of loads (including active load (CPL)) randomly connected to different PCCs is applied. Then, a state model of the entire mesh microgrid is developed integrating the generators with their controllers, power lines, droop algorithms and dynamic loads. This model is then used to study the asymptotic stability and robustness properties of the system. The simulation results confirm the effectiveness of the applied strategies for the synchronization of the different DGs to the microgrid while ensuring an efficient active and reactive power sharing. also, they confirm the validity of the developed state space model of the system.

1 Introduction

Microgrids powered by clean renewable energy through distributed power generation units are one of many solutions to reduce greenhouse gas emissions [1]. The intermittency of renewable energies can lead to some serious microgrid instability problems. therefore, one of the challenges is to synchronize and connect all distributed generators to an isolated microgrid while ensuring "plug and play" functionality and respecting the active and reactive power sharing between the different distributed generation units [2-4].

Strategies based on Droop control is currently the most used methods for power sharing and synchronization in literature strategy [5-9]. Those strategies were proven to be effective in microgrids with a single point of common coupling (mono-PCC) like in [10].

Unlike in mono-PCC microgrids those strategies for synchronization and power sharing are less efficient when they are applied on a mesh multi-PCC microgrids, with many distributed generation sources (DGs) and different type of loads randomly connected to different PCCs. And that's firstly because of the strong couplings between active and reactive powers injected by the DGs in different microgrid PCCs introduced by the line feeders and also due to the complex nature of the mesh microgrid.

Limited researches have focused on solutions that concern the active and reactive power sharing in mesh microgrids [10-12]. In [10] the authors propose the use of bi-directional communication. In [11] a variable Droop control strategy with virtual impedance correction loop and [12] using a modified Droop control strategy by adding a decoupling term in order to remove the coupling phenomenon between active and reactive power.

Another problem is the possible unstable behavior of the microgrid due to the interaction between the DGs and loads, especially the ones supplied trough tightly regulated power converters. These loads behave as constant power loads (CPL) and may cause the system instability [13-15].

In this paper, a mesh microgrid constituted by several PCCs to which are connected multiple DGs and different type of loads including an active load CPL is considered. The different PCCs are interconnected with power supply lines, modeled by RLC circuits inspired by an IEEE 9-bus test feeder Fig. 2. Like as in [12], a modified droop control and synchronization strategies, adapted to the considered multi-PCC mesh microgrid is applied in order to ensure an accurate power sharing and to provide the "plug and play" function. The microgrid voltage and frequency are imposed by the first DG connected. For other DGs an adapted synchronization strategy is proposed and applied before its interconnection to the microgrid.

To study the stability of the mesh microgrid and the robustness of its control, a state model of the entire mesh microgrid is developed considering the generators with their decentralized controllers integrating modified droop

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algorithms, power lines and several loads including a CPL.

The simulation results confirm the effectiveness of the applied strategies and the validity of the developed mathematical model.

2 Power sharing strategies in mesh multi-PCC islanded microgrids

Classical Droop control strategy in (1) and (2) can be efficient for power sharing in mono-PCC microgrids in Fig.1 if and only if the microgrid lines impedances were ignored. Therefore, a developed Droop control strategy in (3) and (4) from [11] that was proven efficient for power sharing in mono-PCC microgrids is applied on the mesh multi-PCC islanded microgrid in Fig.2.

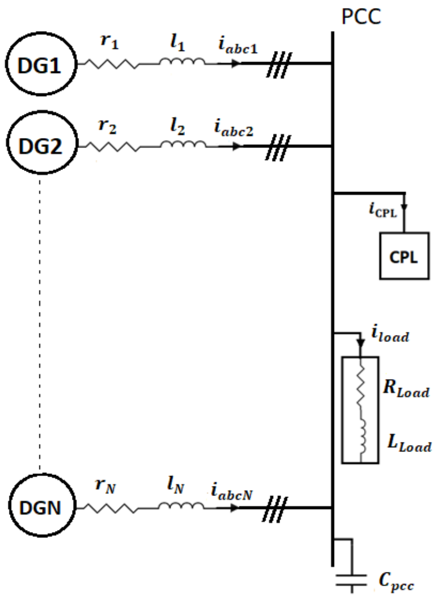

Fig. 1. Mono-PCC microgrid.

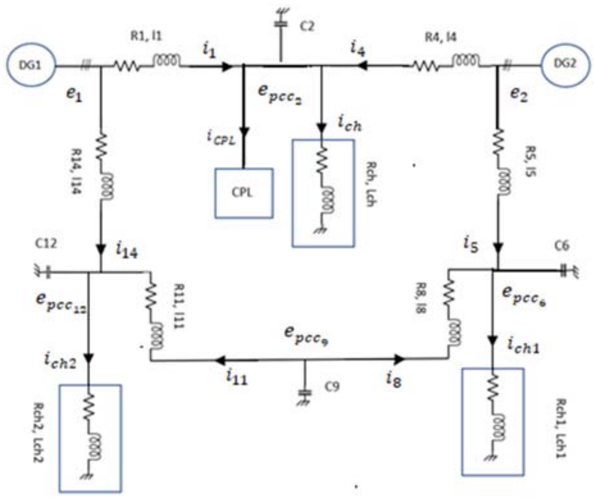

Fig. 2. Mesh multi-PCC microgrid.

$$\omega_i = \omega_n - m_i(P_i - P_{in}) \quad (1)$$
$$V_i = V_n - n_i(Q_i - Q_{in}) \quad (2)$$

$$With: \quad m_i = \frac{\Delta_\omega}{P_{in}}, \quad n_i = \frac{\Delta_V}{Q_{in}}$$

Classical Droop control in (1) and (2) sets for each DG, the frequency and the voltage amplitude at the associated PCC. Where P_i and Q_i are the measured values of the active and reactive power of the i^{th} DG, P_{in} and Q_{in} are their nominal values, ωn and V_n are the nominal values of the pulse and voltage of the i^{th} DG, Δ_ω and Δ_V are the permissible variations of the pulse and voltage, and m_i and n_i are the droop control coefficients.

$$\delta_i = \int \big(K_a(\delta_{in} - \delta_L) - m_i(P_i - P_{in})\big).dt \quad (3)$$
$$V_i = \int \big(K_e(V_{in} - V_L) - n_i(Q_i - Q_{in})\big).dt \quad (4)$$

The proposed angular droop aims to indirectly control the voltage at the PCC and its phase to be equal to the nominal values (i.e. V_{in} and δ_{in}). The added integrators can minimize the static error between the return signal and the corresponding nominal values. By choosing identical K_a and K_e for each generator, a precise active and reactive power sharing is achieved that no longer depends on the system impedance

It can be observed in Fig.3 that the proposed strategy in (3) and (4) ensure a perfect active power sharing while Fig.4 prove that the applied strategy does not guarantee an efficient reactive power sharing due to the complexity of the microgrid.

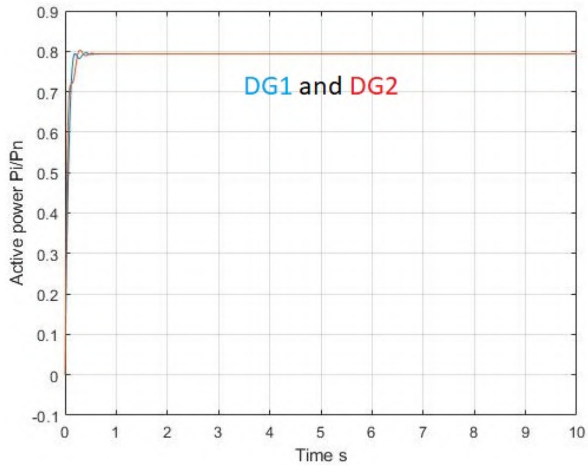

Fig. 3. Evolution of the DGs active powers (both DGs are connected to the microgrid at 0s).

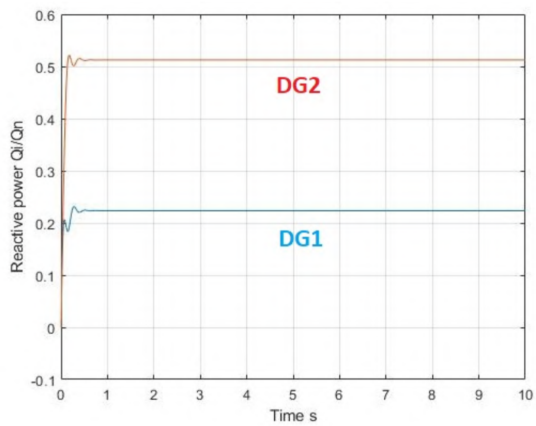

Fig. 4. Evolution of the DGs reactive powers (both DGs are connected to the microgrid at 0s).

In multi-PCC microgrids, each line connecting the i[th] PCC to the j[th] PCC has a non-negligible inductance $\lambda_{i,j}$ and a resistor $\rho_{i,j}$. Due to this phenomenon, the line voltage drop between these two PCCs creates a coupling between the active ($P_{i,j}$) and reactive ($Q_{i,j}$) powers exchanged [12], according to the following formula (5):

$$\Delta V = \rho_{i,j} I_{i,j} \cos\varphi + j\lambda_{i,j}\omega I_{i,j} \sin\varphi = \frac{\rho_{i,j}P_{i,j} + j\lambda_{i,j}Q_{i,j}}{V_i} \quad (5)$$

With φ the phase shift between the voltage V_i and the current $I_{i,j}$.

Based on the strategies developed in [12] to obtain an efficient reactive power sharing in this type of multi-PCC microgrids, the voltage equation is modified by adding a decoupling term (see equation (7)) removing the coupling phenomenon between active and reactive power. This non-linear coefficient, called J_i, is estimated using a PI regulator, forcing the cancellation of the ε_i error defined in (8).

In steady state, when the error ε_i tends towards zero, the reactive power is shared between the DGs.

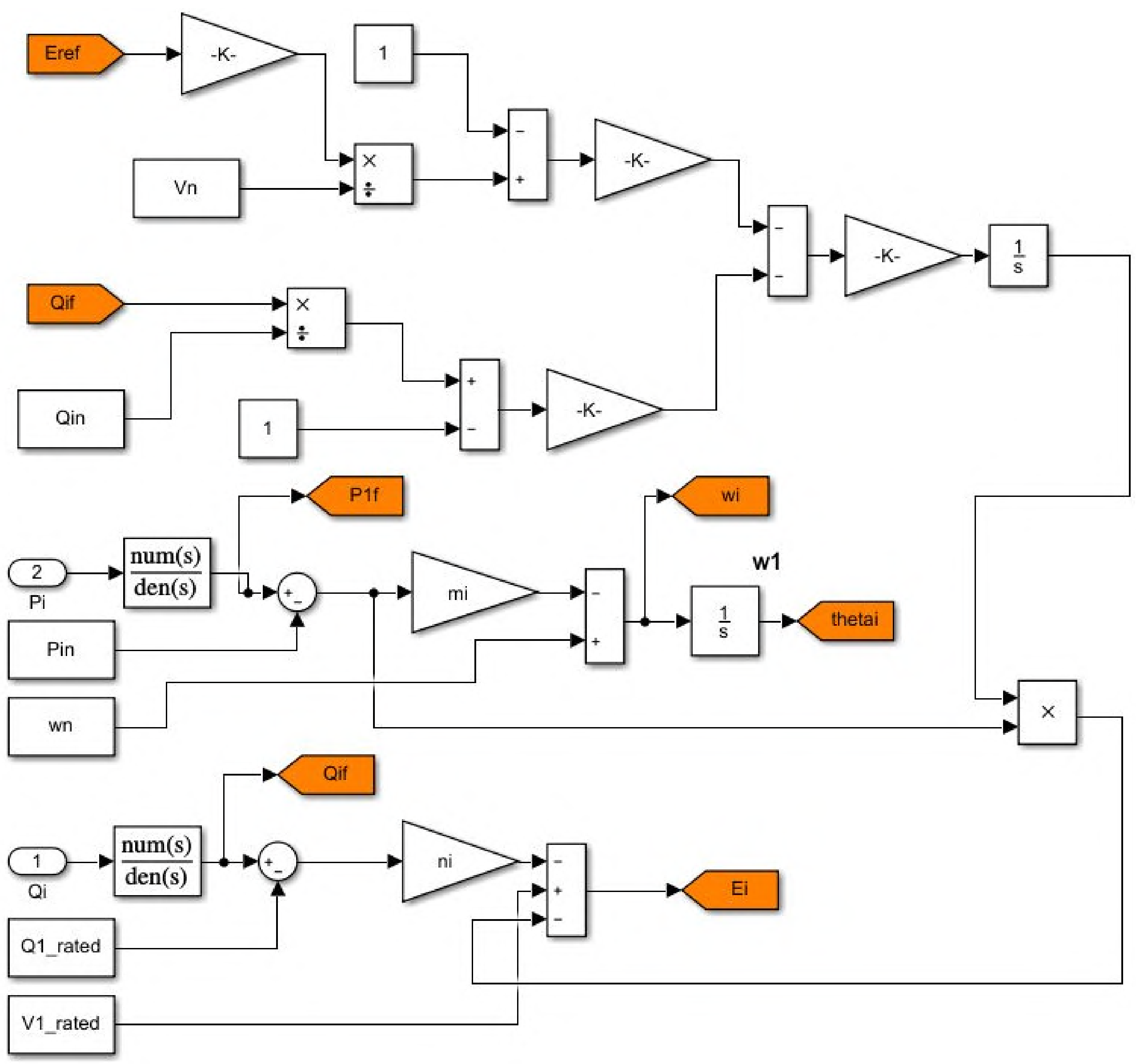

Fig. 5. Primary control.

This approach allows the primary control of the voltage of the i[th] DG Fig.5, regardless of the operating point of the loads. It should be noted that V_{ref} in Fig.5 and equation (7) is a reference potential corresponding to one of the PCC voltages in the studied mesh Microgrid serving as a pilot node and its nominal voltage is called V_n.

$$\omega_i = \omega_0 - m_i(P_i - P_{in}) \quad (6)$$
$$V_i = V_0 - n_i(Q_i - Q_{in}) - J_i(P_i - P_{in}) \quad (7)$$

With: $J_i = K_P\varepsilon_i + K_I \int \varepsilon_i dt$

$$\varepsilon_i = [-\left(\frac{V_{ref}}{V_n} - 1\right) - \left(\frac{Q_i}{Q_{in}} - 1\right)] \quad (8)$$

In the absence of information on V_{ref} the coefficient J is set to 0 and we return to the classical droop in (1) and (2).

3 Synchronization strategy in mesh multi-PCC islanded microgrids

Due to the complexity of the mesh multi-PCC microgrid and the intermittency of renewable energy, DGs frequently connect and disconnect from the microgrid which make the integration of a fast and an efficient synchronization strategy an obligation. The big challenge here is to propose a synchronization strategy that is at the same time efficient and doesn't affect the power sharing between the DGs already connected to the microgrid.

To show the effect of the lack of synchronization in mesh multi-PCC islanded microgrid, modified droop control in (3) and (4) is applied to the mesh microgrid.

It can be seen in Fig.6 that the strategy in (3) and (4) as explained in section 2 does ensure a perfect active power sharing but at 5s it can be remarked that an unacceptable disturbing active power peak occur due to the lack of synchronization.

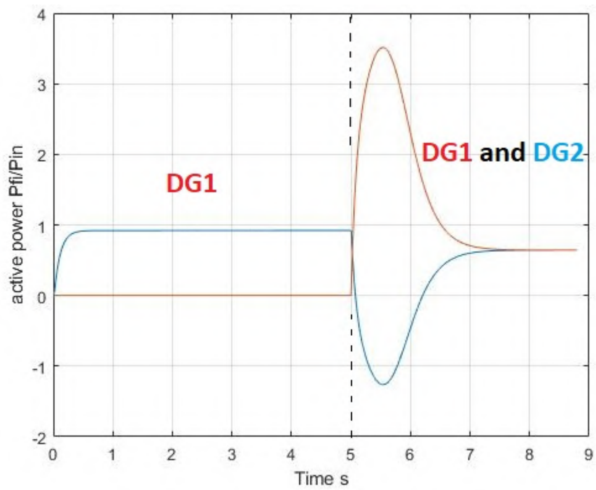

Fig. 6. Evolution of the DG active powers (first DG supplies the microgrid up to 5s, the second DG is connected to the microgrid at 5s).

The same power peak occurs in the DG's reactive powers.

To remove those unacceptable power peaks, a fast and an efficient synchronization of the i^th DG to the i^th PCC should be applied before their interconnection. Therefore, the voltage amplitude V_{pcci}, pulsation ω_{pcci} and phase θ_{pcci} of the i^th PCC must be approximately equal to those of the i^th DG ($V_{DGi}, \omega_{DGi}, \theta_{DGi}$). To achieve this objective, the errors between the amplitudes, pulsations and phases of both sides (the i^th DG and the i^th PCC) are forced to zero by adding only during the synchronization interval pure integral controllers to the i^th DG Droop control as shown in equations (9) and (10) [12]

$$\omega_i = \omega_0 - m_i(P_i - P_{in}) + K_{ai}\int(\omega_{pcci} - \omega_{DGi}) - K_{bi}\int(\theta_{DGi} - \theta_{pcci}) \quad (9)$$

$$V_i = V_0 - n_i(Q_i - Q_{in}) - J_i(P_i - P_{in}) - K_{ei}\int(V_{DGi} - V_{pcci}) \quad (10)$$

4 System modeling

Due to the dynamic interaction between the DGs and the loads, the stability of the microgrids is strongly influenced. Therefore, for a future study of system stability and robustness, a complete mathematical modeling of the system is provided in this section.

4.1 State-space model of a distributed generator (DG)

In order to formulate the equations describing a DGi, an equivalent synoptic diagram is shown in Fig. 7.

- Power calculation

As shown in Figure 7, the measured output voltages and currents are used to calculate the instantaneous active and reactive powers using the equations (11):

$$\begin{cases} P_i = e_{di} * i_{di} + e_{qi} i_{qi} \\ Q_i = e_{qi} * i_{di} - e_{di} * i_{qi} \end{cases} \quad (11)$$

- Low-pass filter

To obtain the average values P_{fi} and Qf_i The instantaneous powers P_i and Q_i pass through a first order low-pass filter in (12), with ω_f representing its filter cut-off frequency.

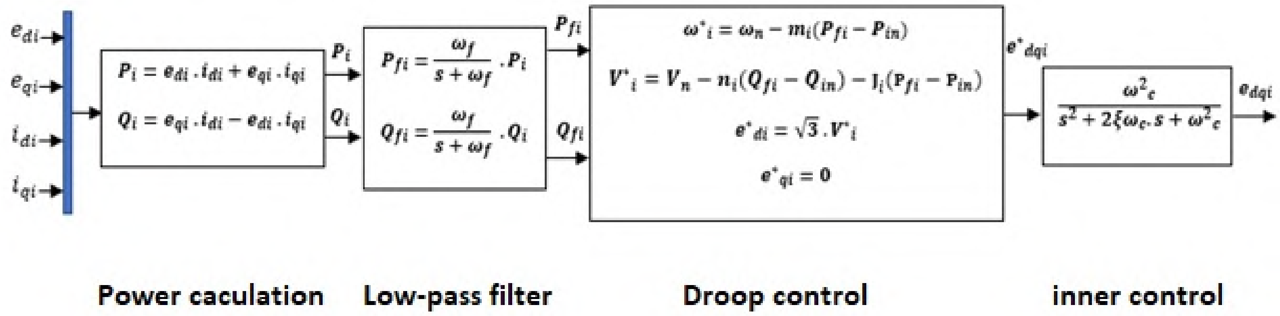

Fig. 7. Equivalent synoptic diagram describing a Droop controlled DGi.

$$\begin{cases} \frac{d}{dt} P_{fi} = \omega_f \left(P_i - P_{fi} \right) \\ \frac{d}{dt} Q_{fi} = \omega_f \left(Q_i - Q_{fi} \right) \end{cases} \quad (12)$$

- Droop control

The third bloc applies the modified Droop control strategy in (6) and (7)

- Inner control

The fourth bloc models the delay imposed by the Voltage Source Inverter (VSI) controlling the ith DG output voltages by means of a second-order filter. This filter which has a faster dynamic compared to the external droop control loop allows the output voltages ith DG ($e^{*}{}_{i_{dq}}$) following their voltage references ($e_{i_{dq}}$). The transfer function of this forth bloc is defined in (13):

$$\frac{e_{i_{dq}}}{e^{*}{}_{i_{dq}}} = \frac{\omega^2{}_c}{s^2 + 2\xi\omega_c . s + \omega^2{}_c} \quad (13)$$

4.2 Microgrid structure and modelling

In this section the microgrid used for modelling is the one presented in section 2. The considered Microgrid is composed of two DGs powering three classical inductive loads, modeled by serial R-L circuits, and a CPL load. They are interconnected by RLC power lines to present a mesh multi-PCC microgrid.

In order to study the considered microgrid having 2 DGs, the state equations are given using a common reference frame for expressing the different variables. The used d-q reference frame is defined in a way that its d-axis is oriented toward the first DG voltage vector V_1 (Fig.8). In steady state, the frequencies of the system are the same (i.e. $\omega_i = \omega_j = \omega_{com}$).

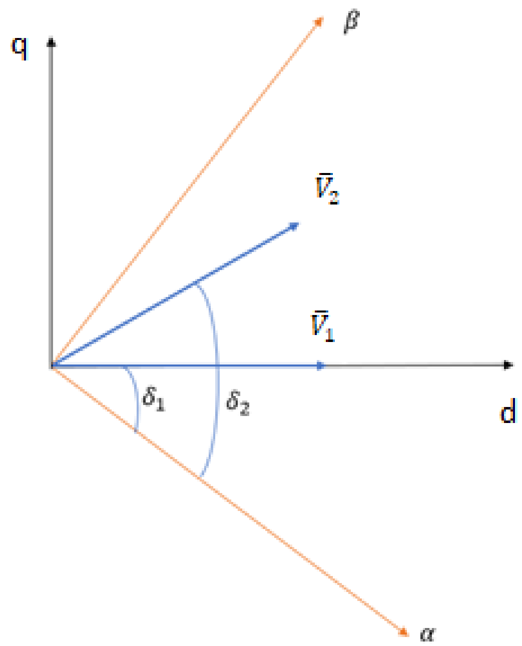

Fig. 8. Reference Frames $\alpha - \beta$ and $d - q$.

Knowing that the phase voltages of DG1 and DG2 (connected to PCC1 and PCC2) have the RMS values of $\boldsymbol{V_1}$ and $\boldsymbol{V_2}$, the $\boldsymbol{\alpha - \beta}$ components of $\bar{\boldsymbol{V}}_{\boldsymbol{1}}$ and $\bar{\boldsymbol{V}}_{\boldsymbol{2}}$ are obtained using Concordia transformation $\boldsymbol{T^t_{32}}$:

With: $T^t_{32} = \sqrt{\frac{2}{3}} . \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}$

$$\text{DG1}: \begin{cases} \begin{pmatrix} e_{d1} \\ e_{q1} \end{pmatrix} = P(-\delta_1) . \begin{pmatrix} V_{\alpha 1} \\ V_{\beta 1} \end{pmatrix} \\ \begin{pmatrix} e_{d1} \\ e_{q1} \end{pmatrix} = \begin{pmatrix} \cos\delta_1 & \sin\delta_1 \\ -\sin\delta_1 & \cos\delta_1 \end{pmatrix} . \begin{pmatrix} \sqrt{3}. V_1 . \cos\delta_1 \\ \sqrt{3}. V_1 . \sin\delta_1 \end{pmatrix} \\ \begin{pmatrix} e_{d1} \\ e_{q1} \end{pmatrix} = \begin{pmatrix} \sqrt{3}. V_1 \\ 0 \end{pmatrix} \end{cases} \quad (14)$$

$$\text{DG2}: \begin{cases} \begin{pmatrix} e_{d2} \\ e_{q2} \end{pmatrix} = P(-\delta_1) . \begin{pmatrix} V_{\alpha 2} \\ V_{\beta 2} \end{pmatrix} \\ \begin{pmatrix} e_{d2} \\ e_{q2} \end{pmatrix} = \begin{pmatrix} \cos\delta_1 & \sin\delta_1 \\ -\sin\delta_1 & \cos\delta_1 \end{pmatrix} . \begin{pmatrix} \sqrt{3}. V_2 . \cos\delta_2 \\ \sqrt{3}. V_2 . \sin\delta_2 \end{pmatrix} \\ \begin{pmatrix} e_{d2} \\ e_{q2} \end{pmatrix} = \begin{pmatrix} \sqrt{3}. V_2 . \cos(\delta_2 - \delta_1) \\ \sqrt{3}. V_2 . \sin(\delta_2 - \delta_1) \end{pmatrix} \end{cases} \quad (15)$$

- Network model

Equations (16) present a network model of N supply lines, connecting N DGs to N randomly placed common coupling points (PCC) of a microgrid.

$$\begin{cases} \frac{d}{dt} i_{d_i} = \frac{1}{L_i} \Delta e_{d_{jk}} - \frac{r_i}{L_i} i_{d_i} + \omega_{com} i_{q_i} \\ \frac{d}{dt} i_{q_i} = \frac{1}{L_i} \Delta e_{q_{jk}} - \frac{r_i}{L_i} i_{q_i} - \omega_{com} i_{d_i} \end{cases} \quad (16)$$

With:

$$\Delta e_{d,q_{jk}} = \left(e^{*}{}_{d,q_j} - e^{*}{}_{d,q_k} \right), \; e^{*}{}_{d,q_j} \in \left\{ e_{d,q_j}, e_{pcc}{}_{d,q_j} \right\}$$

- Load model

The loads considered in this work are serial passive R-L loads and an active CPL (Fig. 2). The next equations (17) are written for all PCCs except the ones connected to the DGs for which the voltages are imposed by their droop controllers.

$$\begin{cases} \frac{d}{dt} e_{pccd_i} = \frac{1}{C_{pcci}} \left(\sum i_{Di} - i_{CHdi} - i_{CPLqi} \right) + +\omega_{com} . e_{pccq_i} \\ \frac{d}{dt} e_{pccq_i} = \frac{1}{C_{pcci}} \left(\sum i_{Qi} - i_{CHqi} - i_{CPLdi} \right) - \omega_{com} . e_{pccd_i} \end{cases} \quad (17)$$

$$\begin{cases} \frac{d}{dt} i_{CHdi} = \frac{1}{L_{CHi}} \left(e_{pccd_i} - Rch_i . i_{CHdi} \right) + \omega_{com} . i_{CHqi} \\ \frac{d}{dt} i_{CHqi} = \frac{1}{L_{CHi}} \left(e_{pccq_i} - Rch_i . i_{CHqi} \right) - \omega_{com} . i_{CHdi} \end{cases} \quad (18)$$

With Rch_i and Lch_i representing the resistance and inductance of the RL load. i_{CPLdi} and i_{CPLqi} are the input current of the CPL load.

The active CPL_i connected to PCC_i is supposed to absorb the active and reactive powers P_{CPLi} and Q_{CPLi}. They are related to the d-q components of the current absorbed by CPL_i (i_{CPLid} and i_{CPLiq}) by the next relation:

$$\begin{cases} e_{CPL_{DQi}} = \begin{pmatrix} e_{pccd_i} & e_{pccq_i} \\ e_{pccq_i} & -e_{pccd_i} \end{pmatrix} \\ i_{CPL_{DQi}} = (e_{CPL_{DQi}})^{-1} . \begin{pmatrix} P_{ci} \\ Q_{ci} \end{pmatrix} \end{cases} \tag{19}$$

5 Simulations results

To validate the efficiency of the strategies proposed in sections 2 and 3 for power sharing and synchronization, the multi-PCC mesh microgrid (Fig. 2) is modeled using the Simscape toolbox of Matlab/Simulation. DG1 and DG2 are formed with two controllable voltage sources Fig. 9, connected to PCC1 and PCC2 and controlled with the modified droop strategies described by equations (9) and (10). The main parameters of different element of the microgrid and its control are listed in table 1.

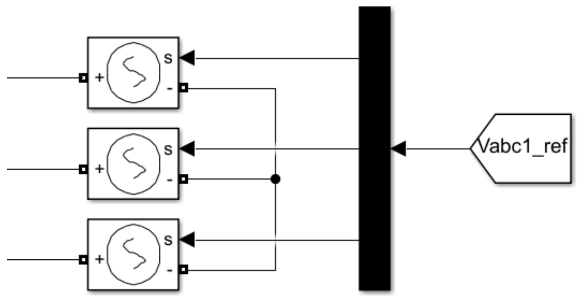

Fig. 9. Controllable voltage source.

Table 1. Parameters of the considered microgrid.

Lines	Resistance (Ω)	Inductance (mH)	capacitance (µF)	Points of connections
Line 1	0.63	7.14	205	Bus 8- Bus 7
Line 2	2.55	11.4	230	Bus 5- Bus 7
Line 3	0.63	7.14	205	Bus 8- Bus 9
Line 4	2	7	180	Bus 9- Bus 6
Line 5	1.7	7.6	153.4	Bus 4- Bus 5
Line 6	1.7	7.6	153.4	Bus 4- Bus 6
Sources and loads	Active power (MW)	Reactive power (Mvar)	Phase to pahse voltage (kV)	Point of connection
Source 1	3	0.9	20	Bus 7
Source 2	2	0.9	20	Bus 9
Load 1	1.5	0.35	20	Bus 5
Load 2	1.2	0.25	20	Bus 6
Load 3	1	0.25	20	Bus 8

These simulations are performed to validate the efficiency of the synchronization and power sharing strategies proposed in relations (9) and (10). The first DG imposes at 0 s the frequency of the microgrid as well as the voltages of the different PCCs. The second DG is synchronized during the interval [4 s ~ 5 s], and connected to the microgrid at 5 s. Fig.10 and Fig.11 show the evolution of voltage amplitude and phase angle of both the ith PCC $(V_{pcci}, \theta_{pcci})$ and the ith DG (V_{DGi}, θ_{DGi}) before and during the synchronization and after the interconnection of the ith DG. It can be seen that the synchronization is fast and it can be achieved in less than 1s.

To prove that it is efficient and doesn't affect the power sharing Fig.12 and Fig.13 show the evolutions of active and reactive powers. It can be remarked in Fig.12 and Fig.13 that the active and reactive power sharing are ensured in steady state without being affected by the synchronization procedure. In addition, power peaks are cancelled during the transient state following the interconnection of the second DG to the microgrid. It should be noted that these performances are maintained with a higher number of DGs, even if the results are not presented.

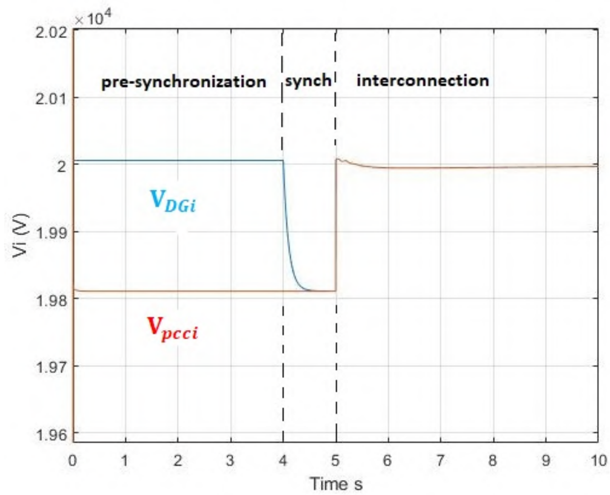

Fig. 10. Evolution of DG2 and PCC2 voltage amplitudes.

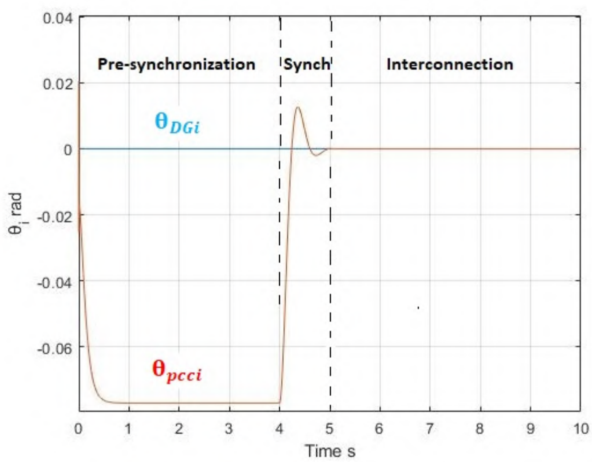

Fig. 11. Evolution of DG2 and PCC2 phase angles

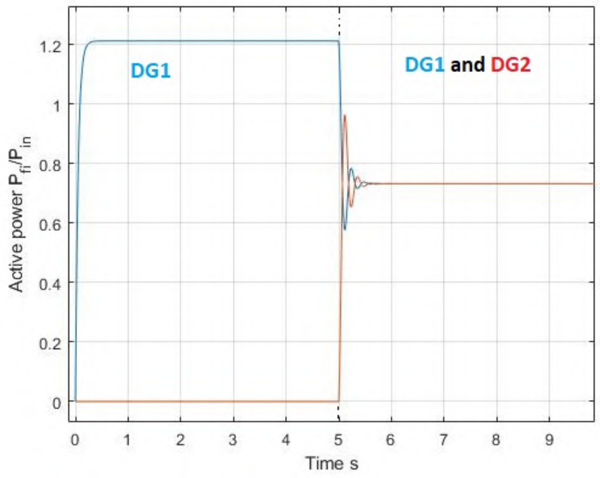

Fig. 12. Evolution of the DG active powers (first DG supplies the microgrid up to 5s, the second DG is connected to the microgrid at 5s).

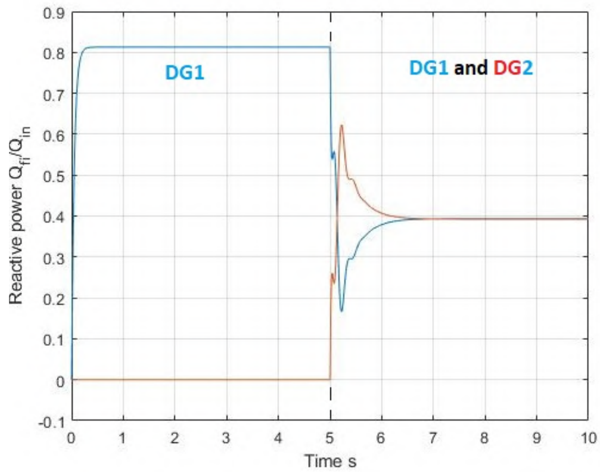

Fig. 13. Evolution of the DG reactive powers (first DG supplies the microgrid up to 5s, the second DG is connected to the microgrid at 5s).

To validate the developed model in section 4. A simulation is performed by applying the modified droop in (9) and (10) at the same time and under the same conditions on the Simscape model and the mathematical model in Matlab.

Figs. 14 and 15 show the evolution of the active and reactive powers of the two models on the same figure at the same time.

It can be seen that the evolutions of active and reactive powers in the two models are the same, which shows the validity of the model proposed in section 4.

5 Conclusion

An improved Droop control strategy is proposed to ensure a controlled active and reactive power sharing in an islanded multi-PCC meshed microgrid. Only the RMS voltage measurement at a pilot node of the microgrid is necessary for its implementation. A synchronization technique is also introduced for the connection of the DGs to the microgrid. The proposed technique allows a correct connection without important power overflow during transient states. Moreover, the proposed droop control strategy with its synchronization technique is compliant with a "plug and play" function and does not require a priori knowledge of the microgrid structure and parameters. A mathematical model of the complete system has been proposed in order to perform stability and robustness studies. The developed modified droop control strategy can be adapted and used for power sharing in grid-connected mesh microgrids. The developed and validated state-space model can be the base for many future studies in mesh microgrids.

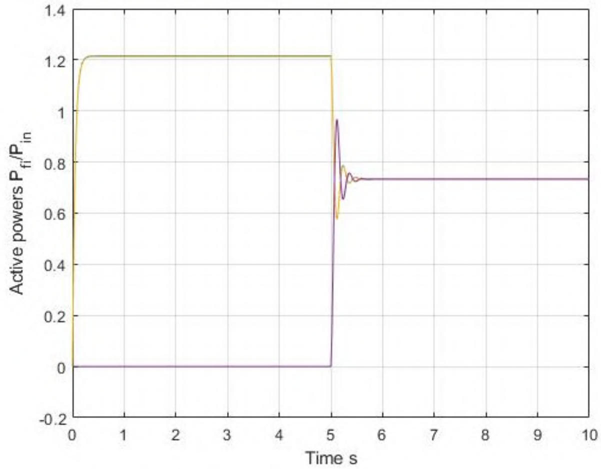

Fig. 14. Evolution of the DG active powers (Simscape model/mathematical model (first DG supplies the microgrid up to 5s, the second DG is connected to the microgrid at 5s).

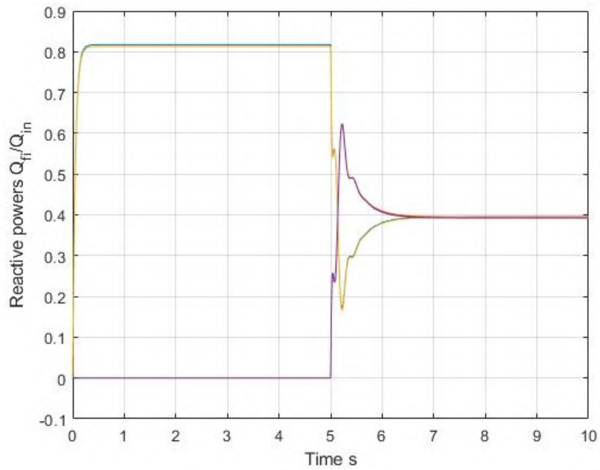

Fig. 15. Evolution of the DG reactive powers (Simscape model/mathematical model) (first DG supplies the microgrid up to 5s, the second DG is connected to the microgrid at 5s).

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Economic feasibility of wind and photovoltaic energy in Kuwait

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Abstract. The worldwide environmental concern and awareness created a way towards the generation of pollution-free wind and solar renewable energies. Wind and Photovoltaic (PV) power plants of each 10 MW capacity located in the Shagaya area, west of Kuwait, were compared after one year of operation. The wind power plants recorded high capacity factors resulting in a yearly power production of 42.59 GWh, 21% higher than expected (contractual 31.160 GWh). It will reduce the emission of CO_2 throughout the projected lifetime of 25 years by 118,303 tons. CAPEX (capital Expenditure) and OPEX (operation expenditure) were taken into consideration throughout the life of the plants along with investment costs resulting in a levelized cost of electricity (LCOE) for wind of 0.015 KWD/kWh or 0.046 USD/kWh, compared to 0.027 KWD/kWh or 0.082 USD/kWh for solar PV (44% lower than PV). Offshore, Boubyan Island, Northern Kuwait territorial waters, were found to be the foremost appropriate for wind energy generation, with Wind Power Density of more than 500 Watt/m^2 in summer which is ideal for the high energy demanding season in Kuwait. The LCOE for offshore wind energy was 27.6 fils/kWh, compared to 39.3 fils/kWh for thermal power plants.

1 Introduction

A move towards pollution-free renewable energy, particularly wind power and solar energy generation, has generated global concern and environmental awareness. Wind energy potential analysis requires thorough statistical evaluation of wind characteristics such as mean wind speed and frequency distribution [1-2].

The Shagaya area, west of Kuwait, hosts the first renewable energy power plant that combines three different technologies in the Arabian Gulf area. Wind energy, photovoltaic and consecrated solar power (CSP). Dust storms play a big role in renewable energy technology performance and efficiency. Depending on the area and the climate, some areas have more sand storms than others. In the Shagaya location, wind is fairly high. As this location is an open desert location, sand storms are very common and have different effects on the two technologies in question, wind and photovoltaic. The wind turbines in the Shagaya power station were optioned with a high temperature package that allows more air flow to pass through the nacelle, ultimately allowing the dissipation of heat, however, this means more dust in the air filters of the nacelle, which in turn could cause blockage of the air flow and hence increasing the nacelles components (gearbox and hydraulic systems etc.) temperature. This may affect the operation availability and allowable down time where energy may not be produced.

When it comes to photovoltaic (PV) cells, dust may cause calcification on the top surface of cells. This may reduce the cell's efficiency if not immediately cleaned. Water in the desert is also scares and very hard to come by. With all the above mentioned effects on the performance of renewable energy technologies in question in open desert climates, economic feasibility of the technologies may determine the choice of renewable energy technology that would be more favourable for such climates [3].

The main aim of this paper is to compare the economic feasibility of wind and Photovoltaic (PV) power plants, each of 10 MW capacity located in the Shagaya area, west of Kuwait, after one year of operation. The annual power production, CAPEX (capital Expenditure) and OPEX (operation expenditure) were taken into consideration for the designed life span of these plants along with Investment costs resulting in one figure, known as LCOE (levelized electricity cost). From this analysis, it is possible to understand which one is better (wind power or PV based power production) for country like Kuwait with high annual temperature variation (5 to 52 degree C) and with high suspended dust concentration in air.

1.1 Mean monthly wind speed and expected annual power production

The Shagaya area is situated on the western side of Kuwait with 280 meters above mean sea level. This is causing airstream over the location to be compressed. This area is exposed year round to higher wind velocities than the urban areas of Kuwait. Based on the meteorological data in Shagaya Wind Farm, the average monthly wind speed is around 7.8 m/s, as shown in Table 1.

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Table 1. Average monthly wind speed and the Monthly (gross) power production in Shagaya wind farm during the first year of operation/

Month	Average wind speed (m/s)	Power production (Kwh)
Aug-17	8.0	4,179,365
Sep-17	6.9	3,822,571
Oct-17	7.2	3,174,254
Nov-17	6.7	2,770,897
Dec-17	7.8	3,948,152
Jan-18	7.3	3,330,362
Feb-18	7.0	2,876,305
Mar-18	7.3	2,692,287
Apr-18	7.2	2,624,838
May-18	6.3	2,506,604
Jun-18	10.2	5,192,837
Jul-18	11.1	5,471,524

This 10 MW wind power plant consists of 5 turbines, each of 2.0 MW capacity. It has recorded an annual power production of 42.59 GWh gross total power (contractual 31.160 GWh) which is 21% higher than expected. As for the PV of 10 MW capacity, expected annual energy production is estimated to be 18.85 GWh gross total.

1.2 Wind farm capacity factor

Fig. 1 below shows the monthly calculated capacity factor obtained during the first year of operation for the wind farm. June and July of 2018 are near record numbers ever recorded worldwide by industry standards, 68%-70%. The wind speed is comparatively high and it is sustained during these months. This has resulted in high capacity factor. In this figure, the five different colors for each month indicate the capacity factor of each 2 MW wind turbines.

Based on the capacity factor evolution observed, the Capacity Factor for the Shagaya wind farm is expected to be above 40%. Note that the standard capacity factor for on-shore wind farms are, on average, 25-35%. Comparing the first month of operation, July of last year with July of this year (2018), Fig. 2, there is a great difference in performance as that first 6 months are dedicated to adjust and improve wind farm performance. Therefore, availability was low (below the contractual, 95%) during the first few month as can be seen in Fig. 2. With these information, the aim of this paper is to reveal the economics of wind and PV power generation based on one year power production from the wind mills and PV plants of 10 MW capacity in Kuwait.

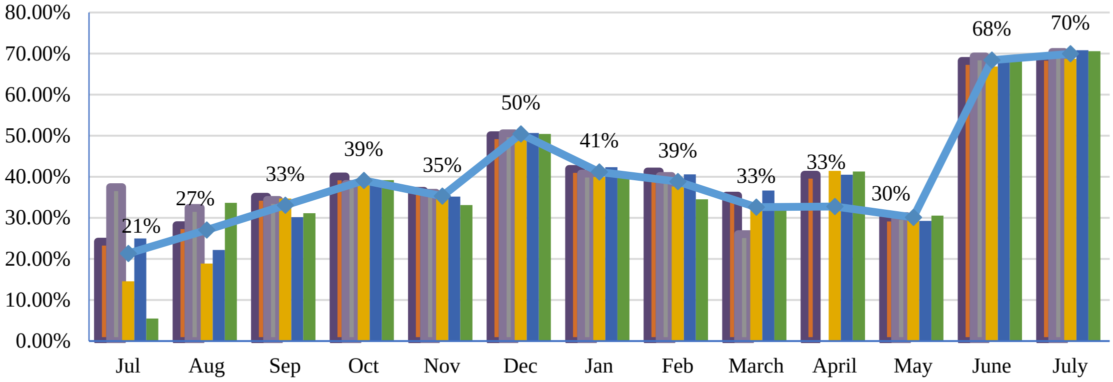

Fig. 1. Monthly Capacity Factor.

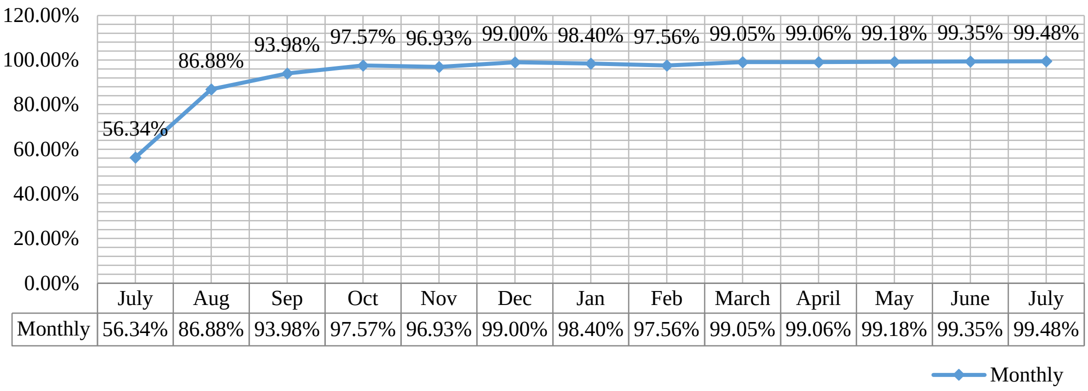

Fig. 2. Kuwaiti 10 MW Wind Farm - Monthly Average Availability.

2 Methods

The present work is focused on the economic analysis based on actual power generation for 1 year from wind and PV plants of each 10 MW installed in Kuwait. The economic analysis results are projected based on Levelized Cost of Electricity (LCOE). The purpose of this is to encourage investment in projects, which promote the most efficient use of a nation's resources. As the economic analysis is done from the point of view of the national economy, inflation, customs, duties, and other factors, which distort market prices are not taken into consideration. The objective of the economic analysis is to calculate the cost of electricity supply of these options for the Kuwaiti national economy.

2.1 Economic analysis approach

LCOE is derived by dividing the present value of the project costs at economic prices by the present value of the quantity of power generation. It thus represents the specific energy generation cost over the entire project life cycle. Mathematically, the LCOE is described as follows:

$$LCOE = \frac{\sum_{t=0}^{n} \frac{C_t}{(1+i)^t}}{\sum_{t=0}^{n} \frac{E_t}{(1+i)^t}} \quad (1)$$

Where:
- C_t is the project costs incurred in year t
- E_t is the power generation in year t
- i is the economic discount rate
- n is the number of years in the period under consideration.

After calculating the LCOE, a subsequent step will assess the financial feasibility of the WTG project. In the future situation with these projects, wind or PV energy replaces energy that in the absence of these projects would otherwise have to be generated by conventional (thermal) power plants. The energy produced by the projects thus serve to avoid the costs of thermal generation of the equivalent amount of energy. The benefit derived from this avoided cost consists solely of the energy benefit, which comprises the avoided operating costs of the alternative, i.e., fuel costs and variable operation and maintenance costs. Furthermore, CO_2 emissions are foregone as a consequence of this avoided fuel consumption. The benefit through capacity replacement is evaluated with the average specific CAPEX of the Ministry of Electricity and Water (MEW) planned thermal power plants to be built until 2023 and counts for USD 1,650/kW (1,146 EUR/kW). The benefits accruing to the project include the following:

- Inescapable fuel utilization
- Foregone variable operation and maintenance costs
- Environmental benefits (CO_2 savings)
- Replacement of conventional generation capacity.

These benefits materialize because the implementation of these projects effectively offset energy that would otherwise have to be produced by thermal power plants.

Within the context of the economic analysis, the generation in thermal power plants would be calculated with the following assumptions:

- Average electrical efficiency: 42%. This corresponds to the average electrical efficiency of the planned conventional power plants in the medium term in Kuwait.
- Fuel price: USD 13.59 2010/GJth. Average annual increase: 1.8%.
- Fuel specific CO_2 content: 15.3 kg CO_2 /GJth, according to IPCC.
- Price of CO_2 emissions: USD 10/t CO_2. This price reflects current market prices for emission allowances in international carbon stock markets.

2.2 Project costs

In general the investment costs for wind farms comprise the following items:

- Purchase price for wind turbines (WTGs) and PV cells, ex-works.
- In the case of wind energy, purchase price for WTG towers, in case it is excluded from the aforementioned item.
- Purchase price for MV (step-up) transformer, in case it is excluded to the aforementioned items.
- International and local transportation.
- Supervisory Control and Data Acquisition System (SCADA), in case it is excluded from the aforementioned items.
- Civil works (control room and substation building, administration, workshop and other buildings).
- Access roads (in most cases a width of 8 m) and cable trenches.
- Foundation works (in case it is excluded in the turbine price and PV price).
- Electrical works (grounding, cabling, substation, transformers).
- Engineering and installation supervision (consultancy services, construction supervision, as well as project management).
- Miscellaneous (computer and network, working table and accessories, printers, fax, phone lines, security, purchase of land, etc.).

2.3 Operation and maintenance costs

Operational expenditures for the wind and therefore the PV farms arise from the following:

- Fees for O&M Contract
- Spare Components
- Insurances
- Administration

2.4 Net present value

The Net Present Value Approach (NPV) is a decision tool generally used to measure the long-term financial costs and benefits of a project by considering the money's time value. The time value of money essentially indicates that at some point in the future, a dollar earned today is worth more than a dollar earned, since the dollar received today can be spent to gain interest. The potential net cash flows of a project are discounted by a rate called discount rate to measure the time value of a project, which is a percentage representation of how much more a dollar is worth to the project funded today than next year, which may indicate other variables such as the project's perceived danger which expected escalation variables over the estimated NPV era. The time value of cash depends on a variety of variables, including net cash flows, the period of estimation of the NPV and the discount rate[5]. NPV

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estimates find the current value of the potential net cash flow of a project in today's dollars, enabling that amount to be compared with the amount of money needed to execute the project. Cash Flow is a project 's income minus the project's expense for a given year.

$$NPV = C_0 = -I_0 + \frac{CF_1}{1+i} + \frac{CF_2}{(1+i)^2} + ... + \frac{CF_t}{(1+i)^t} = -I_0 + \sum_{t=1}^{n} \frac{CF_t}{(1+i)^t} \qquad (2)$$

Where,

- I_0 is the Investment in time t=0
- CF_t is the cash out - flow in t
- t is the period (year)
- $0 \leq t \leq n$
- i is the discount rate

2.4 Future value of money

The financial ROR is an indicator to measure the financial return on investment of an income generation project. It is obtained by simply rearranging the time value of money equation,

$$FV = PV\ (1+i)^t \qquad (3)$$

Where,

- FV is the future value of money
- PV is the present value of money
- t is the period (year)
- $0 \leq t \leq n$
- i is the discount rate and effectively in this case ROR

2.5 Payback period

The payback period is simply the time required to recover the initial investment at the beginning of the project.

3 Economic analysis results

The economic output of the wind project was focused on MEW's reference fuel price scenario. The Net Present Value (ENPV) is positive because of the relatively low CAPEX and OPEX of the WTG project and the relatively high energy production, indicating that the investment is profitable for the Kuwaiti economy. This can also be seen in the Rate of Return (ROR), which is 8.5 percent and thus greater than the 7.0 percent basic discount rate.

4 Solar photovoltaic (PV) vs wind energy

The current Shagaya wind farm powers 450 houses, at the current annual household consumption of 94,500 kW/h/yr compared to 199 homes for PV. Reducing local and global emissions throughout the projected lifetime of 25 years by 118,303tons of CO_2, 2.3 times higher than that of PV. As for potential power producing companies, the Shagaya wind energy power plant provides investors with 8.5% rate of return with a 5.36 year payback period. A comparison between the Levelized Electricity Cost (LCOE) of wind energy generation with the LCOE of photovoltaic power plants is essential. Fig. 3 below compares PV to On-shore wind energy. For the Shagaya wind energy power plant, Simplified LCOE obtained for Shagaya wind farm is 0,015 KWD/kWh, that represents an LCOE of 0,046 USD/kWh(1), compared to 0,027 KWD/kWh or 0,082 USD/kWh(1) for solar PV. Thus the LCOE value for wind energy is 44% less than that of PV.

Exchange rate considered: 1 KWD=3.2988 USD.

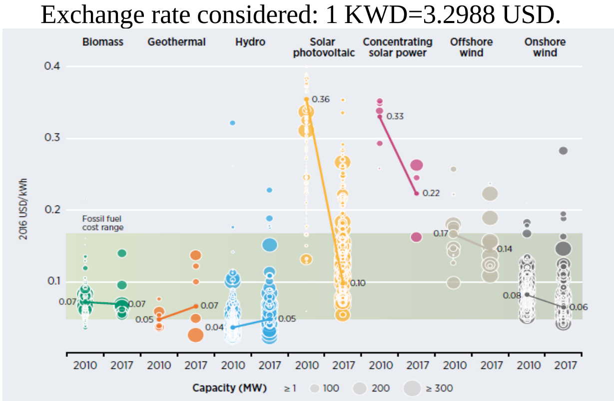

Fig. 3. Comparison of LCOE according to the technology implemented. Renewable power generation costs in 2017, [6].

Table 2. Depositional rates of dust fallout within major dust storm trajectories in the world from upwind to downwind.

Zone-Location	Country	Ref.	Tons.km^{-2}.yr^{1}
A long Niger River	Mali	7[7]	913-10446
Northern Diarnena	Chad	[8]	142
Kano	Nigeria	9[9]	137-181
Southern Chad	Chad	[10]	109
Nouadhibou	Mauritania	[11]	80
Smara	Western Sahara	[12]	111
Agadir	Morocco	[13]	114
Sidi Ifni	Morocco	[14]	145
Tan Tan	Morocco	[15]	175
Dakhla	Mauritania	[16]	191
Boujdour	Western Sahara	[17]	219
Libya	Libya	[18] [16]	155
Negev Desert	Palestine	[19]	57-217
Crete	Greece	20	10-100
Fahal	Oman	[21]	89
Riyadh	Saudi Arabia	[22]	392
Dead Sea	Palestine	[23]	45
Khur Al-Zubir	Iraq	[24]	75.92
Um Qasr	Iraq	[24]	193.47
Kuwait	Kuwait	[26]	370
Xilingele	Mongolia	[24]	292
Shapotou	China	[25]	372
Tokyo	Japan	[26]	3.5
Adelaide	Australia	[27]	5-10
Namoi valley	Australia	[27]	16.9-58.2

The Fig. 3 below compares the LCOE of various renewable energy technologies worldwide. It can clearly been seen that the simplified LCOE of wind energy is approximately 50% lower than expected LCOE values for solar photovoltaic, PV plants. For decision makers, a comparison between the Levelized Electricity Cost

(LCOE) of wind energy generation with the LCOE of photovoltaic power plants is essential. Also, table 2 shows that deposited dust in Kuwait is one of the highest compared to regional and global scales. These amounts of deposited dust will surely act as a major challenge for the solar energy. Therefore, wind energy is the alternative and proper solution for future power generation in Kuwait.

From table 2, it is found that the dust deposit arte in Kuwait is about 370 Tons.km^{-2}.yr^{1}. This dust deposits on PV surface is found to reduce the efficiency of PV power generation. It is also found that the calcification is as hard as the PV surface itself. This makes the surface cleaning difficult.

4 Conclusion

Wind and Photovoltaic (PV) power plants of each 10 MW capacity was installed in the Shagaya area, west of Kuwait. This wind power plants recorded high capacity factors and has resulted in a yearly power production of 42.59 GWh, 21% higher than the contractual value of 31.160 GWh. A detailed economic analysis is carried out based on the actual capital Expenditure, operation expenditure and is taken for the complete life time of these installed plants. Based o this analysis, it is found that the levelized cost of electricity (LCOE) for wind is 0.015 KWD/kWh (0.046 USD/kWh), compared to 0.027 KWD/kWh (0.082 USD/kWh) for solar PV (44% lower than PV).

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Determining the parameters of a shunting locomotive taking into account the environmental component

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Abstract. The article considers the issues of determining the main technical and economic indicators of the shunting locomotive during its modernization by a hybrid power plant. The analysis of scientific and practical works on the impact of railway transport on the environment and increase the efficiency of shunting locomotives due to design changes, which are aimed at reducing emissions. A model has been developed to determine the rational ecological and energy characteristics of a shunting locomotive, which has been modernized by technical means for energy saving taking into account the ecological component. A procedure, algorithm and program for calculating locomotive parameters have been developed. The main parameters of the shunting locomotive of the ChME3 type at modernization by its hybrid power plant taking into account an ecological component are defined and the estimation of expediency of such modernization is given.

1 Introduction

With the growing trend of human mobility and increasing freight traffic, vehicles face the problem of shortage of primary energy resources. To date, the analysis of the locomotive fleet of Ukraine has shown the urgent need to update it, which can be done in two ways: the purchase of new locomotives, the price of which is very high, or the modernization of the existing rolling stock.

In recent years, active work has been carried out to modernize locomotives on railways and industrial enterprises of Ukraine. The need to increase the efficiency of rolling stock operation motivates the search for innovative solutions during the modernization process. Diesel locomotives need to be more efficient and better adapted to alternative energy sources, the use of which solves the issue of shortage of primary energy resources and increases the environmental performance of diesel traction.

2 Literature review and problem statement

The issue of ecology in transport is given much attention in the works of scientists [1-7]. Thus, in [3] an analysis of various aspects of the impact of rail transport on the environment was conducted, in addition, examples of the negative impact of rail transport on the environment and human health are given.

Studies [4] on reducing the environmental load have shown the need to create a new comprehensive scheme for the treatment of waste oils and technological sludge of railways, the implementation of which will increase the efficiency of recovery and resource conservation, increase the environmental friendliness of oil circulation.

The authors in [5] considered the impact of rail transport on the environment. Ways to reduce the eco-destructive load of transport on the environment are given, the necessity of transition of railway transport to electric traction is also conditioned. As a result, the procedure for calculating the economic damage from the impact of railway transport on the environment is proposed, thus necessitating the introduction of an indicator that takes into account the mode of operation of locomotives at different power, which affects the mass of emissions.

The analysis conducted in [6] showed the relevance of improving the environment and improving the efficiency of natural resources. Thus, the preconditions for the development of "green" logistics in railway transport are identified, in addition, environmental issues in Ukraine are considered, which are the most relevant at present in the existence of problems that hinder the development of "green" logistics.

In [7] the results of researches of determination of bacteria of group of Escherichia coli in ballast of a railway track are published. As a result of which, conclusions were made about the level of pollution of railway ballast and described ways to radically solve this problem.

The issues of modernization of shunting locomotives with hybrid power plants were considered by scientists of the Ukrainian State University of Railway Transport in [8-10]. They provide methods for determining the main characteristics of a locomotive with a hybrid power plant,

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but the environmental component is not sufficiently taken into account.

According to research by scientists and transport workers, shunting locomotives run idle for more than 50% of the time. The specific emissions of pollutants are the largest. Therefore, the introduction of modern power plants, especially those that have the technical means to save energy, in the modernization of locomotives, is a topical issue in terms of ecology.

But, unfortunately, some scientific issues of the use of hybrid transmissions in the modernization of locomotives, taking into account the environmental component, the choice of energy storage and the region of operation of these scientists or not considered at all, or were not fully considered. Therefore, based on the analysis, the purpose of the study was formulated and tasks were set to achieve it.

3. Objective and tasks

The purpose of the work is to increase the efficiency of modernized shunting locomotives by improving their design with modern technical means and technologies for energy saving and improving environmental performance. To achieve the goal of the work it is necessary to solve the following tasks:

- - to analyze scientific and practical works on the impact of railway transport on the environment and increase the efficiency of shunting locomotives due to design changes that are aimed at reducing emissions;
- - to develop a model for determining the rational ecological and energy characteristics of the shunting locomotive, which is modernized by technical means for energy saving
- - to determine the main parameters of the shunting locomotive type ChME3 during the modernization of its hybrid power plant taking into account the environmental component and to assess the feasibility of such modernization.

4 Equations and mathematics

As a result of the analysis of different types of schemes of hybrid power plants taking into account features of shunting locomotives and conditions of their operation for shunting work the scheme which power chain is presented in figure 1 was chosen.

In General, the power of the hybrid power plant *Nгеу* is presented as follows,

$$Nгеу = f(Ndg, Nne, Ene, limi,j, Mpred, Vpred, Kzav, Uzag\ I, Kvzr) \qquad (1)$$

where *Ndg* - diesel power, kW; *Nne* - energy storage capacity, kW; *Ene* - energy consumption of the energy storage, kJ; *limi* - restrictions on the length of the energy storage, m; *j* - the number of elements of energy storage; *Kzav* - locomotive load factor.

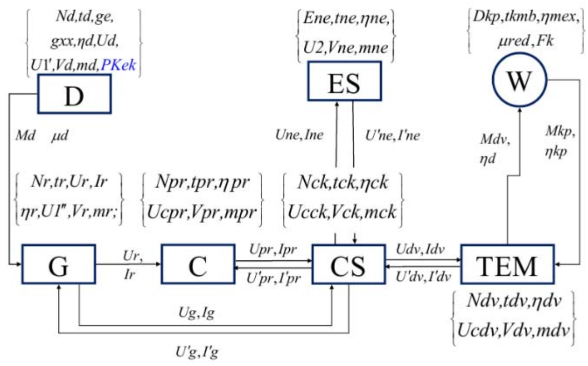

Fig. 1. Functional diagram of the power circuit of a shunting locomotive with a hybrid transmission.

Based on the European experience of environmental taxation, the target function for determining the technical and economic indicators of the locomotive included compensation for environmental losses, in addition to those previously taken into account, the cost of energy storage and maintenance and repair costs. It should also be borne in mind that the parameters of the energy storage can be affected by its limitations in terms of mass and size parameters. In General, the objective function is described as follows:

$$\begin{cases} Czag=f(C0,\ C1,\ C2,\ C3,\ C4,\ C5) \rightarrow min, \\ \Delta Vlim= f(Ene,\ l_{ne},\ b_{ne},\ h_{ne},\ j) \rightarrow min. \end{cases} \qquad (2)$$

where C0 – the cost of an old diesel generator, UAH.; *C1* – cost of a diesel generator, UAH.; *C2* – cost of energy storage devices, UAH; *C3* – fuel costs after modernization, UAH.; *C4* – maintenance and repair costs, UAH; *C5* – costs of environmental penalties, UAH; *ΔVlim* – underutilized free space of the locomotive to be engaged in energy storage, m^3; - respectively the length, width and height of one element of the energy storage, m. The costs of environmental penalties are determined by the formula, UAH:

$$C5 = \sum(C5i \cdot \sum gik \cdot \tau k \cdot T10pm \cdot Kf \cdot KT), \qquad (3)$$

where $T^{10}_{рт}$ – total operating time of the locomotive for 10 years, hours.

The target function, taking into account the constraints on energy storage, power plant and environmental emissions, will be explicitly presented as follows,

$$\begin{cases} Czag \ = \ C0 \ + \ A{\cdot}Nд2 + B{\cdot}Nд + C \ + \\ +\left[\sum_{i=1}^{n}\left(Nf_i \cdot ge0 \cdot \Delta\tau/3600\right) - \sum_{i=1}^{n} G_{i,j}\right] \cdot \mathrm{ct}- \\ -(1-k(Neng_j))Cб + \\ + \ \sum(C_{5i} \cdot \ \sum g_{ik} {\cdot} \tau_k {\cdot} T^{10}{}_{pm} {\cdot} Kf \cdot K_T) \rightarrow \ min, \\ \Delta Vlim = \ kv{\cdot}Ene \ \rightarrow \ min \end{cases} \qquad (4)$$

where *A, B, C* – coefficients that characterize the diesel power plant; Nд – power of a diesel power plant, kW;

u2 – specific cost of energy storage, UAH / kWh; *ct* – fuel cost, UAH / kg; *ge0* – specific fuel consumption by diesel of the base locomotive, kg / kW·h; *Gi,j* – fuel consumption by hybrid locomotive, kg; where *Cб* – costs for maintenance and repair of the base locomotive, UAH.; *k(Nengj)* – the ratio of expenditure on maintenance and repair of the hybrid locomotive to the base, depending on the selected power diesel generator set; k_v – coefficient of underutilization of free space of the locomotive to be engaged in energy storage, m^3 / MWh. The coefficient is chosen depending on the type of locomotive, the overall dimensions of the elements of the energy storage and its required energy consumption.

Parameter limits were set for the model: $Nf_j \in [0 \ldots Nf_{max}]$, $Neng_j \in [0 \ldots Nf_{max}]$, $Nust_j \in [0 \ldots Nf_{max}]$, $E_{1,j}=Eo=0$, $Ene \in [0 \ldots Em_{max}]$, $Ene \in [0 \ldots Ev_{max}]$, де Em_{max}, Ev_{max} – maximum values of energy consumption by mass and volume for a certain shunting locomotive.

To determine the technical and economic characteristics of the shunting locomotive with a hybrid power plant, an appropriate procedure was developed (Figure 2), which consists of seven stages.

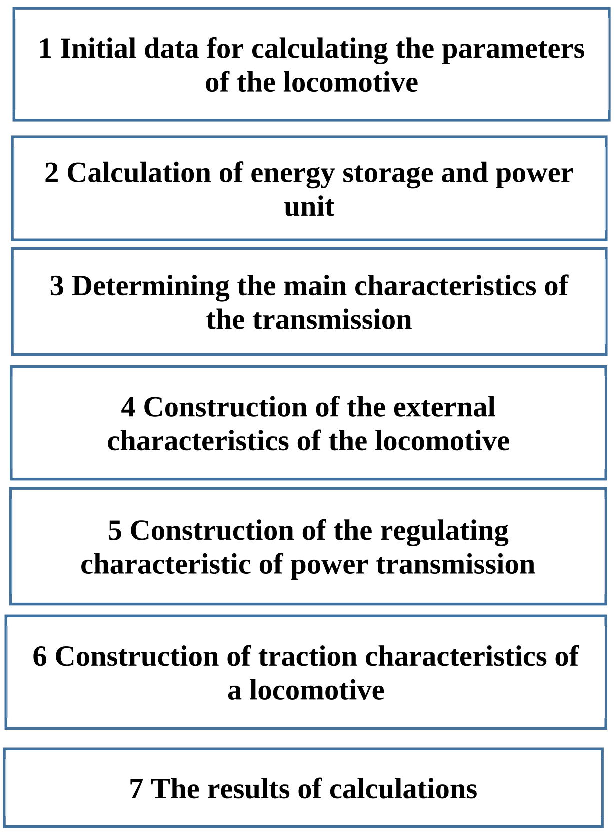

Fig. 2. Procedure for determining the technical and economic performance of shunting locomotive with hybrid power transmission.

At the first stage the values of necessary parameters for calculation are defined. Then the calculation of the energy storage is performed. In the third stage, the main parameters of the hybrid transmission are determined. After that, the construction of the external characteristics of the traction generator, the characteristics of the electric transmission and the traction characteristics are performed.

On the basis of the developed procedure the algorithm of the program of calculation of technical and economic indicators of the shunting locomotive with hybrid transfer of power was made.

To determine the main parameters of power transmission of a shunting locomotive with a hybrid power plant for operation in shunting motion, the model described in [11] was improved.

The initial data for determining the parameters of the energy storage and power plant of the locomotive, taking into account the works [12-14] are: power of the power plant Nf_i, кВт, which is determined during the time interval $\Delta\tau$, c, and a matrix of energy storage parameters is introduced in the form of a matrix *kne* and mass storage limits *Mpred*, kg; and volume *Vpred*, m^3, provided they are placed on the locomotive.

The proposed model differs from the existing ones in that when using an energy storage device, its power *Nne* is used for traction of engines to 3 the position of the driver's controller. Charging it is performed, if necessary, at 6 the position of the driver's controller. When using a power of more than 4 the position of the driver's controller, the shunting locomotive begins to operate according to the usual scheme. If necessary, the power of the energy storage *Nne* added to the power of the diesel generator *Ndg* and total power *Ntey* supplied to traction engines, kW,

$$Ntey = Nne + Ndg. \qquad (5)$$

As a result of calculation of this block we receive: dependence *Ene(Neng)* the required energy consumption of the energy storage, MWh, and the power of the locomotive power plant, kW, as well as the limit parameters of the energy consumption of these storage in the form of a matrix *Enelim*, MJ, and the optimal power values of the diesel generator *Nopt*, kW and energy consumption of the energy storage *Eopt*, MWh.

As a result of the analysis of works [2; 15-20] the initial data for definition of the basic parameters of electric transfer of the locomotive are expressed through an array *Mpoch*:

$$Mpoch = \{Ne\ , kdod, \eta g, Ps, \psi kr, \eta vu, \eta ed, \eta sl, c\}, \qquad (6)$$

where *Ne* – locomotive power, kW;
kdod – percentage of costs for ancillary needs, %;
ηg – efficiency of the generator;
Ps – coupling weight of the locomotive, kN;
ψkr – thrust coefficient on the calculated lift;
ηvu – efficiency of the rectifier;
ηed – efficiency of the electric motor;
ηsl – efficiency, taking into account losses in the power circuit;
c – number of traction motors, pcs.

The result of the calculation of this block is the mass *Mrzr*:

$$Mrzr = \{\Delta N, Nd, Pg, \eta en, Fkr, vp, Ped, Pde\}, \qquad (7)$$

where ΔN – power auxiliary needs, kW;

Nd – потужність дизеля, яка віддається на тягу, кВт;
Pg – diesel power, which is given to traction, kW;
ηen – efficiency of power transmission;
Fkr – the calculated thrust force determined from the condition of realization of the thrust coefficient on the calculated lift, kN;
vp – speed on the calculated rise, km / h;
Ped – power at the terminals of the traction motor, kW;
Pde – power on the shaft of the traction motor beforehand, kW.
An array of parameters was used to construct the external characteristics of the traction generator:

$$M_{TT} = \{Ugmax, Cgu, CgI\}, \tag{8}$$

where *Ugmax* – maximum voltage of the traction generator, kW;
Cgu – voltage control factor of the traction generator;
CgI – current control coefficient of the traction generator.
The result of the construction of this unit is the construction of the external characteristics of the traction generator *U(I)* with all restrictions.

To build the control characteristic of the power transmission is also added *vmax* – maximum speed of the locomotive, km / h. The result of the calculation of this block is the construction of graphs and dependence *Ig(v)* and *Ug(v)* generator current and voltage from the speed of movement.

To construct the traction characteristics of the locomotive, the dependence of the efficiency of the electric transmission on the current is introduced. As a result, dependence is built *F(v)* with limitation on current and coupling.

Based on the proposed algorithm, a program for calculating the technical and economic characteristics of a shunting locomotive with a hybrid power transmission using a software package was developed Mathcad,

The verification of the developed model for adequacy was performed on the basis of the choice of parameters of the locomotive ChME3.

The parameters of the locomotive were calculated and its characteristics were constructed. In Figure 3.5. shows the traction characteristics of the locomotive ChME3: real and built on the model. Current and clutch restrictions are also applied to the characteristics.

Figure 3 shows that the characteristics are almost identical. But there is a need to determine the difference between them. For this purpose, the absolute error of the traction characteristic according to the formula was determined:

$$\Delta(v) = \left|Fp(v) - F(v)\right|, \tag{9}$$

where *Fp(v)* – traction characteristics of the locomotive ChME3, built on the model;
F(v) – real traction characteristic of the ChME3 locomotive.

From the analysis of which it turns out that the maximum error is about 6.3%, which is satisfactory for calculations.

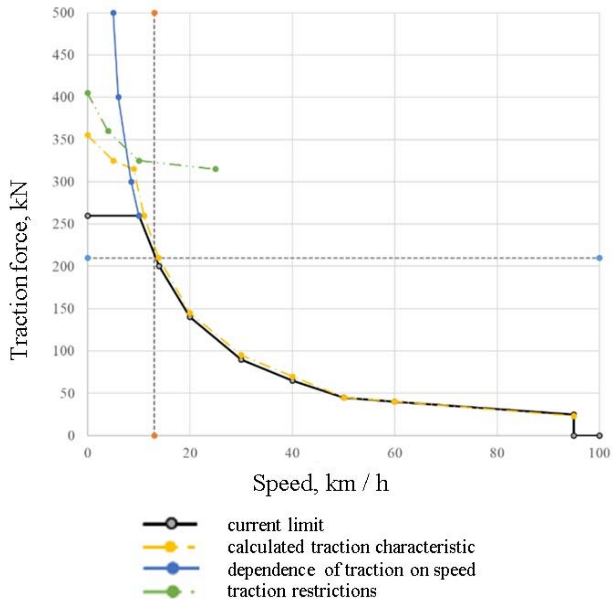

Fig. 3. Traction characteristics of the locomotive ChME3 basic and calculated and its limitations.

Based on the absolute error, the relative error of the traction characteristic is calculated by the formula,

$$\delta(v) = \frac{\Delta(v)}{F(v)} \cdot 100\%. \tag{10}$$

Figure 4 shows the change in the absolute and relative errors of traction from velocity in the construction of the traction characteristics of the locomotive ChME3.

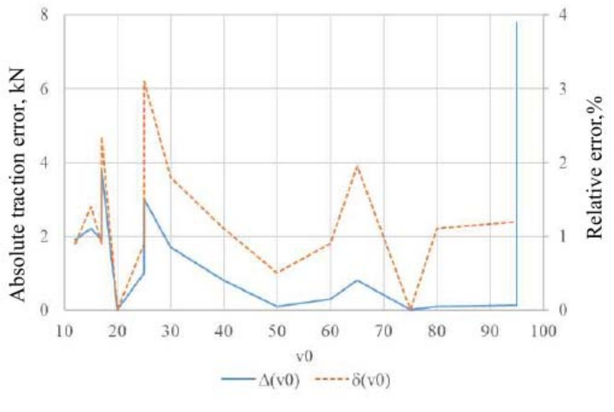

Fig. 4. Dependences of absolute and relative error in determining the thrust force as a function of speed

Based on the developed model, the main technical and economic parameters for a six-axle shunting locomotive are determined, taking into account the selected modern energy-saving technologies.

According to scientific research and operation of serial six-axle shunting locomotives, taking into account the limitations (mass and dimensions and provided that the free space of the locomotive is limited), the maximum energy consumption of various energy storage devices was calculated. The capacity of the energy storage is selected so that it is sufficient for the operation of the locomotive, which is equivalent to its operation at 1 to 3 positions of the driver's controller. The power dependences of the hybrid locomotive power plant for each position of the locomotive driver's controller are constructed.

The total costs associated with the upgrade are calculated *Czag*, UAN. It is determined that taking into account the restrictions imposed on the energy storage device, the minimum modernization costs are observed for the power of the diesel generator of 360 kW and the energy consumption of the energy storage device of about 600 kWh. Calculations of parameters of the modernized shunting locomotive with the hybrid power plant for performance of shunting works by the locomotive are executed.

The calculations of life cycle costs of modernized locomotives by a hybrid power plant (two options) and the base locomotive ChME3 showed the following. The costs of emission fines in the base locomotive ChME3 are more than 40% higher than in the locomotive with the base engine and energy storage and almost 75% higher than in the modernized locomotive with a new power plant and energy storage.

Similarly, the life cycle costs for modernized locomotives have shown that it is advisable to perform a deep modernization of the shunting locomotive with a new diesel and energy storage. But at lower costs, ie the installation of only energy storage and repair of the base diesel, there will also be a positive effect, the costs will be lower by 12%.

According to the results of calculations, the appropriate parameters of the modernized shunting locomotives at the energy capacity of the energy storage of 600 kWh are selected, the optimal power of the diesel generator will be within: for shunting operation 250 kW; for export - 800 kW; for work on a hill - 300 kW. According to the results of traction calculations for export work, fuel consumption of the hybrid locomotive was reduced to 30% compared to the base.

The life cycle of a hybrid locomotive based on ChME3 and a basic locomotive for a period of 20 years - the time from modernization (or overhaul) of the locomotive to its complete decommissioning. Thus, when using a hybrid locomotive based on ChME3, during operation the total economic effect of one locomotive will be UAH 3.5 million.

The efficiency of the shunting locomotive is proposed to be determined taking into account the technical, economic and environmental components according to the formula

$$K_{ef} = K_1 \cdot \sum_{i=1}^{i=s} k_n \varphi(i) \Big/ \sum_{i=1}^{i=s} \varphi(i) + K_2 \cdot LLC_{TB} / LLC_{TG} + \\ + K_3 \cdot \sum_{z=1}^{n} A'_z m_{бz} \Big/ \sum_{z=1}^{n} A'_z m_{гz} \qquad (11)$$

where *kn* – the ratio of numerical parameters of the new development to the parameters of existing objects for rational categories and irrational categories; $\varphi(i)$ – function that normalizes the weight of the parameters in the ranked sequence; i – shunting locomotive parameter number; LLC_{TB}, LLC_{TG} – life cycle cost of the basic *locomotive* and the modernized, respectively, UAH.; $A'z$ – indicator of the relative activity of impurities of the z-th type; $m_{бz}$, $m_{гz}$ – average annual masses of pollutant of the z-th type, which enter the atmosphere in year t during operation, respectively, of the basic locomotive and modernized, kg / h per section; K_1, K_2, K_3 – weights of efficiency components. At the same time $\sum_{i=1}^{3} \mathrm{Ki} = 1$. The weights of the components of efficiency are determined by the expert method depending on the presented tasks. This factor when using a locomotive in shunting operation for the base locomotive is equal to K_e=1, for an upgraded diesel locomotive with a basic diesel engine and an energy storage capacity of 600 kWh equal to K_e=1,13, and for the upgraded new diesel with a capacity of 250 kW and this energy storage equal to K_e=1,4. This confirms the efficiency of modernization of six-axle shunting locomotives with a hybrid power plant of the proposed type.

Conclusions

Based on the results of theoretical and experimental studies, the following conclusions were made.

1. Analysis of the directions of work of scientific organizations, rolling stock manufacturers and works of scientists shows that to solve the problem of determining the technical and economic indicators of locomotives with hybrid power plant requires a comprehensive approach that should link the technical parameters of the locomotive, performance and cost indicators taking into account the environmental component. To substantiate the choice of technical and economic indicators of locomotives with hybrid transmission, an approach based on mathematical modeling was taken. He allowed to justify the choice of the main technical and economic indicators of the modernized locomotive at the lowest cost of the life cycle when using it in shunting work.
2. The functional scheme of the power circuit of a shunting locomotive with a hybrid power plant is proposed, which allowed to determine the functional connections between the elements of power transmission with a hybrid drive.
3. A model has been developed to determine the rational design and energy characteristics of an upgraded shunting locomotive with a hybrid power plant. The functional dependences of the power of the diesel generator set on the energy consumption of the energy storage for shunting operation of the locomotive are obtained.
4. It is proposed to determine the efficiency of shunting locomotive modernization by an appropriate coefficient, which takes into account the technical level of the locomotive, life cycle costs and environmental component with the appropriate weights. This factor when using a locomotive in shunting operation for the base locomotive is equal to K_e=1, for an upgraded diesel locomotive with a basic diesel engine and an energy storage capacity of 600 kWh equal to K_e=1,13, and for the upgraded new diesel with a capacity of 250 kW and this energy storage equal to K_e=1,4. This confirms the efficiency of modernization of six-axle shunting

locomotives with a hybrid power plant of the proposed type.

5. The procedure for the designation of technical and environmental indicators of locomotives for a specific core structure can be used for similar applications in other types of transport.

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Models of the optimal distribution of fertilizers and vehicles in grain production

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Abstract. The paper considers models of optimal distribution of fertilizers and vehicles in grain production. To ensure the delivery of fertilizer to the destination for the chemical treatment agriculture, the optimal distribution of fertilizers in grain production was solved. On the basis of optimal models, the needs of vehicles for servicing these works are determined. As calculations show, the cost of acquiring machines and operating costs can be reduced by 20-30% due to the correct selection and use of equipment. This made it possible to distribute mineral fertilizers between farms in accordance with the characteristics of their soils. With the help of ground equipment, mineral fertilizers are applied, chemical pest and plant disease control is carried out, weed vegetation is destroyed in grain crops. The optimal plan for the use of machine and tractor fleet can only be determined using optimization methods, since the composition of machines and tractors and their possible use have such a large number of options that it is almost impossible to simply sort them out and select the best. Further, the algorithm and the solution to the problem of optimal distribution of vehicles in grain production are considered.

1 Introduction

One of the most important works in the transport system of the grain processing industry is to ensure the delivery of fertilizers to the destination for the chemicalization of agriculture. In this regard, in determining the transportation of fertilizers, it is necessary to solve the problem of optimal distribution of fertilizers between grain crops, individual farms, as well as districts, oblasts.

The need for mineral fertilizers considerably exceeds the possibilities of their production, therefore the problem of developing methods for their most rational use is of extremely great not only sectoral, but also national economic importance. The increase in yield and the amount of net income in agriculture largely depend on the rational distribution of organic and mineral fertilizers between crops and farms.

All currently known methods for solving the problem of fertilizer distribution, taking into account computer-aided implementation programs, can be divided into two groups: 1) based on iterative models; 2) optimization. In the first case, the algorithm of the preferred saturation method is used, in the second – the simplex method. Iterative models make it possible to select the most rational of them through targeted analysis and evaluation of plan variants; the use of optimal methods ensures the selection of the best solution for the given conditions of the problem. Despite the differences in the methods of solution, the formulation of the problem has much in common. In both cases, a plan for distributing a limited fertilizer pool is sought, ensuring maximum efficiency in their use.

The effectiveness of fertilizers is expressed in yield increase, which can be measured in physical and monetary terms. Moreover, the increase in value terms can be commensurate with the costs associated with its receipt, that is, with the costs of purchasing, transporting, storing and applying fertilizers. Based on these indicators, net (conditional) income per 1 ha of sowing from mineral fertilizers is calculated.

The optimization criterion for the distribution of fertilizers is taken as the maximum gross yield of grain crops obtained through their use, or the maximum conditional net income obtained as the difference between the value of the gross yield increase from mineral fertilizers and the costs associated with their use.

In the previously described models for the optimal distribution of mineral fertilizers, practically the same indicators are used as constraints: size of sown areas, limits of mineral fertilizer funds, planned production volumes (increase) of production, doses of mineral fertilizers, increase in yield of grain crops as a result of using mineral fertilizers. However, these models do not always take into account the presence of local fertilizers, soil types, agrochemical characteristics, the effect of fertilizers, as well as the conditions for the preservation and improvement of soil fertility. These factors are taken

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into account when solving the problem of determining the rational distribution of mineral fertilizers.

Consequently, the statement of the problem can be formulated as follows: determine a plan for the distribution of mineral fertilizers between grain crops and farms, which would provide the maximum conditional net income.

The optimal distribution plan for fertilizers should take into account: the presence of fertilizers on the farm; the area of fields of crop rotations (areas) with different agrochemical characteristics; the priority of fertilizing for the main crops and crops grown on land-reclamation lands. It follows that the constraints of the problem are:

– balances on the use and availability of mineral fertilizers;

– conditions on the areas of grain crops in the context of individual areas that differ in agrochemical characteristics;

– conditions for ensuring the planned production volumes;

– conditions for the preservation and improvement of soil fertility in the farms;

– conditions for ensuring the priority of crops grown on land-reclamation lands.

Currently, insufficient knowledge of soils and agroecosystems as objects of modeling creates the greatest difficulty in developing complex mathematical models of renal fertility. Therefore, the creation of models of soil fertility is still at the stage of modeling the dynamics of its elements.

In the work of Z.O. Zhadlun [1] developed economic and mathematical models of the vital nutrition of plants.

When constructing and studying mathematical models of the optimal distribution of fertilizers, the following objective conditions are taken into account that affect the yield of grain crops:

soil type and agrochemical characteristics (acidity, provision of mobile phosphorus and potassium compounds);

weather conditions are average for 5 years;

predecessors based on the data of production experiments, based on the structure of the sown area;

level of agrotechnology, which took place in the production experiments. It is accepted as advanced and accessible to all households.

At present, a large number of economic and mathematical models in agricultural production have been developed [2-6], in which there are three main areas:

– development and solution of economic and mathematical problems of on-farm analysis;

– development and solution of economic and mathematical problems at the level of agro-industrial associations and individual units of agricultural production;

– development and solution of economic and mathematical problems of industry analysis.

At present, the tasks of the first direction are the most developed and implemented, since the information necessary for them is more accessible and reliable. The objectives of this direction include: optimization of the use of mineral and organic fertilizers; optimization of crop development plan; optimization of the production structure of the grain enterprise, etc.

The second direction, which has arisen in connection with the organization of agro-industrial associations, includes the tasks of optimizing not only the production of grain production, but also its industrial processing within the associations.

The third direction is connected with the development and solution of problems of development of individual links of the grain processing industry at the level of the oblast, krai and republic. The main objective of this direction is the optimal placement and specialization of grain production by regions, as well as the optimization of purchases of grain products by farms, regions, regions and republics [6].

2 Material and methods

Taking into account the above features, a mathematical model of the optimal distribution of fertilizers can be formulated as follows:

Find the maximum net income

$$\left(\sum_{e\in E}\sum_{j\in J}\sum_{q\in Q}G_{ejq}X_{ejq}+\sum_{e\in E}\sum_{j\in J}\sum_{q\in Q}G^{1}_{ejq}Y_{ejq}\right)- \quad (1)$$

$$-\left(\sum_{e\in E}\sum_{j\in J}\sum_{q\in Q}C_{ejq}X_{ejq}+\sum_{e\in E}\sum_{j\in J}\sum_{q\in Q}C^{1}_{ejq}Y_{ejq}\right)\rightarrow \max$$

under restrictions

on the distributed fund of mineral and organic fertilizers

$$\sum_{e\in E}\sum_{j\in J}h_{eju}X_{ejq}+\sum_{e\in E}\sum_{j\in J}h^{1}_{eju}Y_{ejq}\le F_{qu}, q\in Q, u\in U \quad (2)$$

on conservation and improvement of soil fertility in farms

$$\left(\sum_{e\in E}\sum_{j\in J}h_{eju}X_{ejq}+\sum_{e\in E}\sum_{j\in J}h^{1}_{eju}Y_{ejq}\right)- \quad (3)$$

$$-\left(\sum_{e\in E}\sum_{j\in J}h_{eju}X_{ejq}+\sum_{e\in E}\sum_{j\in J}h^{1}_{eju}Y_{ejq}\right)\ge B_{qu}, q\in Q, u\in U$$

to fulfill the minimum required volume of gross production of grain products by farms

$$a_{ejq}X_{ejq}+Y_{ejq}\ge P_{ejq} \quad (4)$$

to the maximum possible amount of increase in production

$$Y_{ejq}\le M_{ejq} \quad (5)$$

on fertilized crop areas by crops

$$X_{ejq}\le S_{ejq} \quad (6)$$

on non negativeness of variables

$$X_{ejq}\ge 0,\ Y_{ejq}\ge X_{ejq}\ge 0,\quad Y_{ejq}\ge 0,\ e\in E;\quad j\in J;\quad q\in Q; \quad (7)$$

Where, E - many types of soil, fields;

e – soil type, field e $\in$E ;

J – a variety of crops;

j – grain crop index, j $\in$J ;

Q – a set of farms - grain production;

q – farm index, q $\in$Q ;

U – many types of fertilizers;

u is the type of fertilizer, u $\in$U ;

a $_{ejq}$ – average yield (base) *j*-th culture on th *e*-th soil of the *q*-th farm;

h_{eju} – the rate of application of the u-th type of fertilizer per unit area under the j-th crop on j-ts soil;
h^1_{eju}– the rate of application of the *u*-th type of fertilizer per unit of yield increase under the *j*-th crop on the *e*-th soil;
Z_{eju} – removal of the u- th type of nutrient (fertilizer) per unit area at the baseline yield of the j- th crop on the *e*-th soil;
Z^1_{eju} – removal of the u- th type of nutrient with the unit of the prefix of the harvest of the j- th crop on the *e*-th soil
F_{qu} – the fund of fertilizers allocated for the q-th farm containing u-th nutrient;
B_{qu} – the value characterizing the preservation of the balance of the u-th nutrients in the q-th household:

$$B_{qu} = \sum_{ujq} \left(B^{(1)}_{ujq} + B^{(2)}_{ujq} + B^{(3)}_{ujq} \right), \qquad q \in Q,\ u \in U,$$

$B^{(1)}_{ujq}$ – the number of u-th fertilizers delivered by the j-th crop with the gross q-th farm gain obtained due to other factors, except fertilizers;
$B^{(2)}_{ujq}$ – the number of u-th fertilizers, which characterizes the difference in the effect of organic and mineral fertilizers of the j-th crop in the q-th farm;
$B^{(3)}_{ujq}$ – the amount of biological nitrogen entering the soil (it is included in the calculation of the nutrient balance only for nitrogen);
S_{ejq} is the allowable sown area of the j-th crop on the e-th soil in the q-th farm;
P_{ejq} – the minimum required for the planned task of the production of j-th culture on the e-th soil in the q-th economy;
M_{ejq} – the maximum amount of the gross increment of the j-th crop on the e-th soil of the q-th farm;
G_{ejq} is the assessment of the production of the j-th crop on the *e*-th soil in the q-th farm per unit of sown area (in purchase prices);
G^1_{ejq}– evaluation of the unit of yield increase of the j-th crop on the *e*-th soil in the q-th farm (purchasing systems);
C_{ejq} is the cost per unit area for the j-th crop on the *e*-th soil in the q-th farm, associated with the use of fertilizers;
C^1_{ejq} – costs per unit of yield increase from the use of fertilizers for the j-th crop on the *e*-th soil in the q-th farm;
X_{ejq} – the size of the used area under the j- th crop on the soil on the q-th economy;
Y_{ejq} – the value of the increase in gross output for the j-th crop on the e-th soil in the q-th farm from the entire area.

The model of the problem (1) – (7) reminds one of the most frequently encountered generalizations of the transportation problem – the so-called distribution problem. In [2-6] provides an overview of methods for solving such problems. Recently, at the Institute of Cybernetics named after V.M. Glushko. NAS of Ukraine developed a number of new more efficient gradient type algorithms [7], which can be applied to the solution of distribution problems.

Recommended rates of application of mineral fertilizers for crops and yield, obtained at each site when applying the recommended dose of fertilizers are determined according to the zonal agrochemical station. Application rates are determined based on the use of organic fertilizers. For example, the doses of mineral fertilizers can be determined by calculation using the formulas [8]:

for phosphate and potash fertilizers

$$D = (100 * B - P * K_{P} - P' * K_{r}) / K_{y}$$

for nitrogen fertilizers

$$D = (100 * B - P * K_{r}) / K_{y}.$$

Where D – the dose of fertilizer, kg dv;

B – removal of nutrients with the planned yield, kg ae.;

P – the content of mobile compounds of phosphorus and potassium in the soil, kg dv per 1 ha (determined by multiplying their amount in milligrams per 100 g of soil by 30, since 1 mg of phosphorus and potassium per 100 g of soil corresponds to 30 kg per 1 ha);

P' is the nutrient content of organic fertilizers applied per 1 ha, kg;

K_p – the utilization of mobile substances of phosphorus and potassium from the soil, %;

K_y – the utilization of nutrients from fertilizers in the first year, %;

K_r – the utilization of nutrients from the manure in the year of application, %.

The implementation of the model (1) – (7) on a computer technique will be considered using a specific example.

3 Results and discussion

Distribute the fund of mineral fertilizers for applying them to grain crops in such a way as to obtain the maximum conditional net income. The total sown area is 2750 hectares. It is planned to cultivate winter wheat, corn for grain, sunflower, corn for green fodder. Funds of mineral fertilizers (in kg of active ingredient) were allocated for these areas: nitrogen – 167400, phosphate – 196200, potash – 136200. Planned to produce 12000 centner grains, sunflower – 10600 centner, green mass of corn – 170000 centner.

The optimal distribution of mineral fertilizer funds by crop is given in Table 1.

In the obtained optimal plan, the fertilized areas with basic yield were: winter wheat – 1000 hectares, corn for grain – 700 hectares, sunflower – 220 hectares, corn for green fodder – 439 hectares. The increase in corn yield was 3,500 c.

Table 1. Optimal distribution of mineral fertilizer by crop.

Fertilizers	Dedicated fertilizer and active substance funds	Distribution of mineral fertilizers and active ingredients by crop				
		Winter wheat	Corn for grain	Sunflower	Corn for green fodder	Total
Nitrogen	1674	400	588	354	332	1674
Phosphoric	1962	450	704	432	376	1962
Potash	1362	400	385	279	288	1362

An economic analysis of the use of fertilizers showed that the mineral fertilizers available on the farm, with their optimal distribution, make it possible to increase the net income of crop production by 14,6%.

Thus, in solving the optimization problem, factors describing the effect on yield were more fully taken into account than in traditional planning. This made it possible to distribute mineral fertilizers between farms in accordance with the characteristics of their soils.

Receiving sufficiently high and stable yields of grain crops is impossible without the use of chemical agents, the introduction of which can be carried out using the machine-tractor fleet. In this case, there is a need for a coordinated solution of the tasks of the machine-tractor park and the achievement of maximum efficiency from its use in grain farming.

With the help of ground equipment, mineral fertilizers are applied, chemical pest and plant disease control is carried out, weed vegetation is destroyed in grain crops.

Each chemical work (technological operation) can be performed using different types of machine and tractor fleet. To perform the same operation, an unequal number of ground equipment with different performance and operating costs will be required. Therefore, it is necessary to choose the best option for the use of machine and tractor fleet, which will ensure the implementation of a given amount of chemical work in a timely manner at the lowest cost.

The optimal plan for the use of machine and tractor fleet can only be determined using optimization methods, since the composition of machines and tractors and their possible use have such a large number of options that it is almost impossible to simply sort them out and select the best.

Consider the problem of optimal use of machine and tractor fleet.

The mathematical model of the problem has the following form [8].

Find a solution that minimizes total costs.

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{k} C_{ijk} t_k x_{ijk} + \sum_{i=1}^{m}\left(\max_k \sum_{j=1}^{n} x_{ijk}\right)\alpha_i \qquad (8)$$

under restrictions

$$\sum_{i=1}^{m} P_{ijk}\, x_{ijk} = d_{jk} \quad j=\overline{1,n}; \qquad k=\overline{1,K}, \qquad (9)$$

$$x_{ijk} \geq 0,\ i=\overline{1,m};\ j=\overline{1,n}; \qquad k=\overline{1,K}, \qquad (10)$$

Where i is the index of the type of ground equipment, $i=\overline{1,m}$;

j is the index of the type of chemical works, $j=\overline{1,n}$;

k – the index of the type of the calendar period, $k=\overline{1,K}$;

d_{jk} – changeable amount of chemical work of the j-th species, which must be performed in the calendar period k, ha;

P_{ijk} – replaceable productivity of ground equipment of type i performing the j-th type of work in the *k*-th calendar period, ha / h

C_{ijk} – replaceable costs for performing work of the j-th type by the i-th type of ground-based equipment in the k-th calendar period, independent of the annual load of machines, tenge;

α_1 – the coefficient of annual deductions of the i-th type of ground equipment;

t_k – the duration of the k-th calendar period;

x_{ijk} is the number of the used ground equipment of type i, the j-th type of work in the k-th calendar period.

In the more general case, the model (8) – (10) can be supplemented with an inequality of the form

$$\sum_{j=1}^{n} x_{ij} + x_{m+1} = b_i,\ i=\overline{1,m},$$

where x_{m+1} – underused power of ground equipment; b_i – the total power of the ground equipment of the i -th type (in terms of reference hectares)

That is, the total power of ground equipment should be sufficient to perform all types of work. However, the mathematical content of the model will not change.

The first component of the objective function (8) takes into account the costs associated with the operation of ground equipment; This includes the cost of fuel and lubricants, salary, the cost of repairs, maintenance and storage of ground equipment.

The second term takes into account the deductions associated with the specified payback period of the machines. Equation (9) reflects the requirement that all chemical works were carried out in agrochemical terms, inequality (10) requires non-negativity of variables.

Thus, the task is described using a convex non-differentiable (piecewise linear) objective function (8) and linear constraints (9), (10).

In the model (8) – (10) it is assumed that the values C_{ijk}, P_{ijk}, d_{jk} are deterministic, however, studies show that these values cannot be considered as predetermined, since they can vary significantly under different conditions. Therefore, the model (8) – (10) does not reflect the conditions associated with the random nature of the quantities, and it becomes necessary to consider models of stochastic programming that take into account the probabilistic nature of the initial information.

We construct a mathematical model of the problem, assuming random variables d_{jk}, i.e. the amount of work that due to fluctuations in natural and climatic conditions in advance cannot be accurately predicted.

Assume that plan X is taken before actual values d_{jk} become known. After they become known, equality (9) is corrected by values y^+_{jk}, y^-_{jk} determined as follows:

$$y^+_{jk} = d_{jk} - \sum_{i=1}^{m} P_{ijk}\cdot x_{ijk};\ y^-_{jk} = 0,$$

if $\quad d_{jk} \geq \sum_{i=1}^{m} P_{ijk}\cdot x_{ijk};$

$$y^+_{jk} = 0;\quad y^-_{jk} = \sum_{i=1}^{m} P_{ijk}\cdot x_{ijk} - d_{jk};$$

if $\quad d_{jk} \langle \sum_{i=1}^{m} P_{ijk}\cdot x_{ijk}.$

Where y^{+}_{jk} – the amount by which the actual volume is more than planned, if we denote by h^{+}_{jk} additional costs per unit of work, then the total cost of additional work is

$$\sum_{j=1}^{n}\sum_{k=1}^{k} t_k h^{+}_{jk} y^{+}_{jk};$$

y^{-}_{jk} – the amount by which the actual amount of work was less than planned; set a penalty for unused equipment per unit of work by h^{-}_{jk}, then the total losses will actually be

$$\sum_{j=1}^{n}\sum_{k=1}^{k} t_k h^{-}_{jk} y^{-}_{jk}$$

$\sum_{j=1}^{n}\sum_{k=1}^{k} t_k \left(h^{+}_{jk} y^{+}_{jk} + h^{-}_{jk} y^{-}_{jk}\right)$ on average were minimal.

Then we come to the problem of stochastic programming.

Find a plan X that minimizes total costs,

$$\min F(x) = \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{k} C_{ijk} x_{ijk} t_k + \sum_{i=1}^{m}\left(\max_k \sum_{j=1}^{n} x_{ijk}\right)\alpha_i + M\left\{\min \sum_{j=1}^{n}\sum_{k=1}^{k} t_k \left(h^{+}_{jk} y^{+}_{jk} + h^{-}_{jk} y^{-}_{jk}\right)\right\} \tag{11}$$

under restrictions

$$y^{+}_{jk} - y^{-}_{jk} = d_{jk}(W) - \sum_{i=1}^{m} P_{ijk} x_{ijk}, \tag{12}$$

$$y^{+}_{jk} \ge 0; \quad y^{-}_{jk} \ge 0, \tag{13}$$

$$x_{ijk} \ge 0,\ i = \overline{1,m}; \quad j = \overline{1,n}; k = \overline{1,K}. \tag{14}$$

where $d_{jk}(W)$ is a random realization of d_{jk}.

This is a non-linear two-stage stochastic programming problem.

To solve this problem, we use the iterative random search method proposed in [9].

According to this method, at each iteration for fixed X_{ijk} and $d_{jk}(W)$, we solve the problem dual to the following problem of the second stage:

$$\Phi(x, d(w)) = \min \sum_{j=1}^{n}\sum_{k=1}^{k} t_k (h^{+}_{jk} y^{+}_{jk} + h^{-}_{jk} y^{-}_{jk}) \tag{15}$$

under conditions

$$y^{+}_{jk} - y^{-}_{jk} = d_{jk}(W) - \sum_{i=1}^{m} P_{ijk} x_{ijk} \tag{16}$$

$$y^{+}_{jk} \ge 0,\ y^{-}_{jk} \ge 0, \quad j = \overline{1,n};\ k = \overline{1,K}. \tag{17}$$

The dual problem has the form: to find

$$G(x, d(w)) = \max \sum_{j=1}^{n}\sum_{k=1}^{k} \lambda_{jk}(x, d(w)) \cdot (d_{jk}(w) - \sum_{i=1}^{m}\{P_{ijk} x_{ijk}) \tag{18}$$

under conditions

$$\lambda_{jk}(x, d(w)) \le h^{+}_{jk} t_k \tag{19}$$

$$-\lambda_{jk}(x, d(w)) \le h^{-}_{jk} t_k \tag{20}$$

Require that the relation be satisfied

$$h^{+}_{jk} + h^{-}_{jk} \ge 0.$$

Then the solution of the effective problem (18) – (20) is simply:

$\lambda_{jk}(x, d(w)) \le h^{+}_{jk} t_k$ if $d_{jk}(w) - \sum_{i=1}^{m} P_{ijk} x_{ijk} \rangle 0,$

$\lambda_{jk}(x, d(w)) = -h^{-}_{jk} t_k$ if $d_{jk}(w) - \sum_{i=1}^{m} P_{ijk} x_{ijk} \langle 0,$

$\lambda_{jk}(x, d(w))$ – any number on the segment (h^{-}_{jk}, h^{+}_{jk}), if

$$d_{jk}(w) - \sum_{i=1}^{m} P_{ijk} x_{ijk} = 0$$

Consider a random vector with components

$$\xi_{ijk} = C_{ijk} t_k + F_x(x) - P_{ijk} \lambda_{jk}(X, d(w)) t_k,$$

where $F_x(x)$ is the gradient of $\sum_{i=1}^{m}(\max_k \sum_{j=1}^{n} x_{ijk})\alpha$ function expression (11).

As shown in [10], the expectation of the vector ξ coincides with the vector of the generalized gradient of function (11), and the sequence $\{x^{(s)}\}$, whose components

$$X^{(s+1)}_{ijk} + \max\left\{0, x^{(s)}_{ijk} - \rho_s \left[C_{ijk} t_k + F_x(x) - P_{ijk} \lambda_{jk}(x, d(w)) t_k\right]\right\}$$

(ρ_s is a step size, $d(w^{(s)})$ is an arbitrary realization of the vector $d(w)$ in the s-th iteration), converges with probability 1 to the minimum of function (11) with

$$\rho_s \rangle 0, \sum_{s=0}^{\infty} \rho_s = \infty, \sum_{s=0}^{\infty} \rho_s^2 \langle \infty.$$

Thus, we propose the following algorithm for solving problem (11) - (14) by the method of random search. Let the value be obtained at the s-th step $X_{ijk}^{(s)}$ (the initial plan $X_{ijk}^{(0)}$ is specified).

1. Choose a random implementation $d_{jk}(w^{(s)})$ in accordance with the given distribution law.

2. Calculate the value

$$L^{(s)} = d_{jk}(w^{(s)}) - \sum_{i=1}^{m} P_{ijk} x^{(s)}_{ijk}$$

3. At $L^{(s)} \rangle 0,\ \lambda^{(s)}_{jk} = h^{+}_{jk} t_k$;

at $L^{(s)} \langle 0,\ \lambda^{(s)}_{jk} = h^{-}_{jk} t_k$;

at $L^{(s)} = 0,\ \lambda^{(s)}_{jk} = h^{+}_{jk} t_k$;

4.Find

$$X^{(s+1)}_{ijk} = \max\left\{0, x^{(s)}_{ijk} - \rho_s \left[C_{ijk} t_k + F_x(x) - P_{ijk} \lambda_{jk} t_k\right]\right\}.$$

4 Conclusion

To ensure the delivery of fertilizers to the destination for the chemicalization of agriculture, the problem of optimal distribution of fertilizers in grain production has been solved. Based on optimal models, the needs of vehicles for servicing these works are determined. As the obtained calculations show, the cost of purchasing machines and operating costs can be reduced by 20-30% due to the correct choice and use of equipment.

We have developed a complex of economic and mathematical models for the use of vehicles (machine and tractor fleet and agricultural aviation) in the chemicalization of grain crops in a deterministic and stochastic setting. The developed models, in contrast to the previously known ones, are built in accordance with the principles of targeting and taking into account the peculiarities of the development of regions.

The method of determining the need for a machine-tractor park of the economy involves the following main steps:

– identification of typical farms in a given zone or area;

– development of technological maps of crop cultivation and the determination of the optimal composition of the machine-tractor park for typical farms of the zone or area;

– development of standards requirements in the technique for groups of farms characterized by selected typical farms;

– determination of the composition of the machine and tractor fleet of any agricultural object, characterized by this typical farm.

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Perspectives for usage of adsorption semiconductor sensors based on Pd/SnO_2 in environmental monitoring of carbon monoxide and methane emission

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Abstract. Nanosized semiconductor sensor materials based on SnO_2 with different palladium contents were obtained via zol-gel technology with the use of ethylene glycol and hydrate of tin (VI) chloride as precursors. Morphology and phase composition of nanosized sensor materials were studied by X-ray diffraction and TEM methods. Catalytic activities of the Pd/SnO_2 nanomaterials in the reaction of H_2 and CO oxidation were investigated. Adsorption semiconductor sensors based on Pd/SnO_2 nanomaterials were made by their calcination up to 620 ^{0}C in air and the sensors were found to be highly sensitive to presence of CO and CH_4 in air ambient. Higher responses to CO of Pd-containing sensors in comparison with their responses to CH_4 were confirmed by higher reaction activity of CO in catalytic oxidation reaction. Differences in sensitive properties of the sensors to methane and carbon monoxide were explained by features of the catalytic reactions of methane and carbon monoxide oxidation occurring on surfaces of the gas sensitive layers of the sensors.

1 Introduction

Nowadays, a significant degradation of environment due to an increase in harmful substances emissions from industry, multiple technogenic accidents and uncontrolled usage of the existing resources of the planet is one of the global problems of humanity. It should be noted that such ecological situation is due to the pollution of almost all components of the environment (air, water reservoirs and soils). In particular, such gases as CO, CH_4, H_2S, NO_2, CO_2, NH_3, SO_2 etc. presented in air can lead not only to local significant air pollution by toxic gases, but also to climate change throughout the planet. Therefore, control over the emission of such gases in the air is one of the necessary challenges, the solution of which will prevent further deterioration of the environment.

Among harmful gases presented in air control of natural gas and carbon monoxide is crucially needed. Natural gas is widely used in chemical industry and is one of the main energy sources. On the other hand, natural gas can combine with air explosively that leads to human's deaths and economical loses. Since methane is the main component of the natural gas detection of CH_4 allows to monitor the natural gas leakages. Besides, methane is also known to be one of the most dangerous greenhouse gases (Fig.1) and, thus, control of the methane emission in atmosphere is important for reduction of global warming.

Carbon monoxide is widely used in industry also, e.g. in synthesis of aldehydes, methanol, phosgene, in oil industry, in metallurgy etc. But the main part of carbon monoxide emission falls on incomplete combustion of carbonaceous substances. In particular, vehicles, coal and wood burning, portable and back-up generators emit large amount of CO in environment (Table 1).

Table 1. Sources of CO emissions.

Concentration	**Source**
5–15 ppm	Near properly-adjusted gas stoves in homes, modern vehicle exhaust emissions
<1000 ppm	Car exhaust fumes after passing through catalytic converter
5000 ppm ppm	Exhaust from a home wood fire
30000–100000ppm	Undiluted warm car exhaust without a catalytic converter

Carbon monoxide emission hazard is attributed mainly to ability of CO molecules almost irreversibly bounded with iron in human blood (with hemoglobin cells) that leads to decrease in its ability to transport oxygen. Deficit of oxygen leads to different symptoms including headache and dizziness (Table 2). If the CO concentration is high enough human death can be occurred. Carbon monoxide is colorless and odorless gas that make detection of its presence in air crucially needed, especially in household where burning of different organic or carbon-reached compounds is present.

It is known that gas analytical devices based on sensors are promosing to determine the content of

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methane and carbon monoxide in air. It should be noted that nowadays a variety of the sensors are being widely developed [1], and they are intended for usage in various branches of science, technology and industrial production. The main areas of the sensors application are [2-8]: control over volatile combustion products in industry, analysis of exhaust gases from automobile transport, quality control of food products, diagnostics of some diseases, studies of cell transformations of living organisms, determination of drugs purity in pharmacology and environmental monitoring.

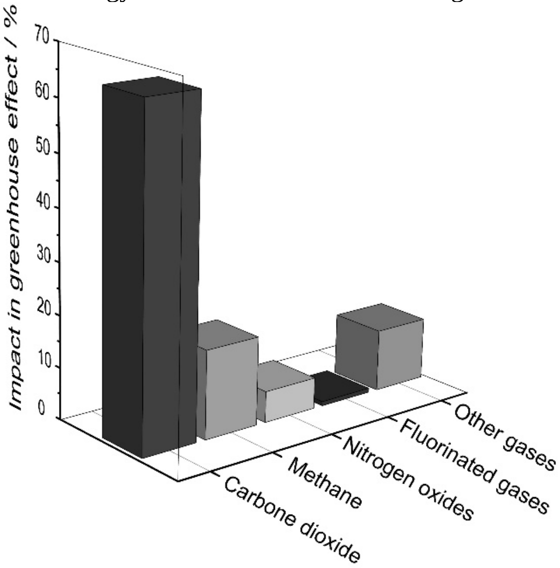

Fig. 1. Impact of different gasses in greenhouse effect.

Table 2. Influence of different CO concentrations on human.

Concentration	Effect
35 ppm	Headache and dizziness within six to eight hours of exposure
400 ppm	Frontal headache within one to two hours
800 ppm	Dizziness, nausea, and convulsions within 45 min; insensible within 2 hours
1600 ppm	Headache, increased heart rate, dizziness, and nausea within 20 min; death in less than 2 hours
6400 ppm	Headache and dizziness in one to two minutes. Convulsions, respiratory arrest, and death in less than 20 minutes.
12800 ppm	Unconsciousness after 2–3 breaths. Death in less than three minutes.

The gas sensors are widely used to detect leakages of toxic and explosive gases and monitor their content in air of both domestic premises and industrial production [9]. Cheap and reliable, with low power consumption, such sensors are widely used. Requirements for them are growing and, in particular, the main characteristics of the sensors - sensitivity, selectivity, response time, relaxation, gas measurement range, stability etc. should be improved [10]. The adsorption semiconductor sensors are perspective to determine presence of both carbon monoxide and methane in air due to combination of their high sensitivity to reducing gases and operational characteristics [11-13]. But the adsorption semiconductor sensors have poor sensitivity to methane and carbon monooxide [14] because of their chemical inertness and thus low oxidation rates of CH_4 and CO by oxygen, chemisorbed on the gas sensitive layer of the sensor.

To create highly sensitive adsorption semiconductor sensors intended to detect toxic and explosive gases leakages it is very important to develop new more sensitive functional nanomaterials [9, 15]. It is known that the main semiconductor material of a sensitive layer of such sensor is tin dioxide due to its chemical and thermal stability [16, 17]. However, it has low sensitivities to gases [18]. One of the effective ways to improve variety functional properties of materials, including their sensitivity, is to use them in a nanosized state [19-21]. In particular, the usage of nanosized semiconductor as the gas sensitive material can lead to increase in the sensor response to reducing gases (such as carbon monoxide and methane) through increase in contribution of surface processes into bulk properties (conductivity) of the semiconductor [14, 22].

Another way to increase the sensor responses to carbon monoxide and methane is introduction of catalytically active additives into the gas sensitive layer of the sensors [23]. Palladium, platinum, gold, oxides of transition and rare earth metals can be such active components [24, 25]. Among the known catalysts for oxidation of carbon monoxide and methane, palladium is one of the most effective [26].

Therefore, development of new nanosized semiconductor gas sensitive materials based on tin dioxide containing catalytically active components, in particular, palladium, should be considered as promising in order to obtain highly sensitive adsorption semiconductor sensors intended to detect carbon monoxide and methane.

The aim of this work is creation of palladium-containing nanosized materials based on tin dioxide for development of the adsorption semiconductor sensors to carbon monoxide and methane.

2 Experimental techniques

Initial SnO_2 was synthesized by a sol-gel technique. The reagents ($SnCl_4 \times 5H_2O$ and ethylene glycol) were mixed under stirring and excess of ethylene glycol was evaporated in two steps corresponding to a gel formation (120 ^oC) and xerogel formation (150 ^oC). The crystalline SnO_2 was obtained after high temperature treatment (up to 600 ^oC) of the xerogel [12].

For the sensors creation the initial powder of SnO_2 was mixed with a binder (10% carboxymethylcellulose solution in water) to form a paste that was applied on a ceramic sensor plate between platinum measuring electrodes [13]. Palladium was introduced into a gas sensitive layer by a wet impregnation technique using water solutions of $PdCl_2$. After impregnation the plates were dried at 90 ^oC and then calcinated up to 620 ^oC in

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air. Gas sensitive materials and catalysts were prepared by the same procedure as the sensors.

In the sensor materials added palladium content were determined by X-ray fluorescence analysis with the energy dispersion X-ray spectrometer ElvaX EXS - 01.

Morphology of the gas sensitive materials was studied by transmission electron microscopy (TEM) using the SELMI PEM-125K electron microscope (accelerating voltage was equal to 100 kV).

X-ray diffraction (XRD) analysis of the materials was conducted by using a Bruker D8 Advance with CuKα radiation. Estimation of the XRD particle sizes was performed by a Scherrer equation: [27]:

$$D = k{\cdot}\lambda \,/\, \beta{\cdot}cos\theta \,, \qquad (1)$$

where D is the XRD particle size; k is a constant close to unity (for our calculation value 0.9 was taken); λ is the wavelength of CuKα radiation (λ= 1,5418 Å); β is a true broadening of a diffraction peak ($\beta = \Delta - b$, where Δ is an experimental broadening and b is an instrumental broadening); θ is a Bragg angle.

For stabilization of the electric characteristics of the sensors they were periodically treated by 930 ppm CH_4 for 30 seconds per 1 hour. During the procedure the temperature of the gas sensitive layer was 405 ^oC. A ratios R_0/R_{CO} and R_0/R_{CH4} were taken as measures of the sensor responses to CO and CH_4, correspondingly, where R_0 is a value of the sensor electric resistance in air, R_{CO} is a value of the sensor electric resistance in the presence of 1000 ppm CO and R_{CH4} is a value of the sensor electric resistance in the presence of 930 ppm CH_4. The used gas mixtures were certified at the Ukrainian Center of Certification and Metrology. Carbon monoxide- air and methane–air mixtures with lower CO and CH_4 concentrations (less than 1000 and 930 ppm, correspondingly) were obtained through dilution generators.

The values of the sensor signals in air and in the presence of carbon monoxide or methane were measured in a special electric stand [13]. The sensors were sequentially connected to load resistors. The sensor electric resistance was calculated according to the Ohm's law by the next formula:

$$R_s = R{\cdot}(U_{p.s.} - U_r) \,/\, U_r \qquad (2)$$

where $U_{p.s.}$ is a value of voltage supplying by power source at the gas sensitive layer (V); U_r is a value of voltage at the load resistor (V) that depends on the gas composition surrounding the sensor (CO or CH_4 content); R is a known value of electric resistance of the load resistor (Ohm); R_s is a value of the sensor electric resistance (Ohm) in air (R_0) and in the analyzed gas mixture (R_{CO} or R_{CH4}).

Catalytic activities of the Pd/SnO_2 nanomaterials were studied in flow-type reactors using gaseous mixtures 1000 ppm CO or 930 ppm CH_4 with air. Analysis of the gas mixture components was carried out by a chromatographic method using a chromatograph Shimadzu GC-14. The weight of the analyzed catalyst was 200 mg. The temperature of 100% CO or CH_4 conversion (T_{100}) was taken as a measure of the catalytic activity of the samples.

3 Results and discussion

3.1 Morphologies of the sensor materials

It was shown that the initial tin dioxide consists of particles with predominantly spherical shape with an average size 10-11 nm estimated by TEM (Table3). High temperature treatment of the sensor material based on the initial SnO_2 without any dopants results in an increase in its particle size up to 19-20 nm (Table3). Introduction into the sensor material a low amount of palladium is enough to prevent the semiconductor particles enlargement during sintering up to 620 °C. Therefore, for all studied gas sensitive materials with palladium additives the average particle size observed by TEM was 14-15 nm (Table3).

Table 3. Particles sizes calculated from TEM and XRD data for initial SnO_2 and different sensor materials (s.m.).

Materials	TEM size / nm	XRD size / nm
Initial SnO_2	10 – 11	6.7
SnO_2 (s.m.)	19 – 20	20.1
0.31 wt.% Pd/SnO_2 (s.m.)	14 – 15	12.8
1.41 wt.% Pd/SnO_2 (s.m.)	14 – 15	12.4

TEM observation of semiconductor gas sensitive materials revealed their nanoscale nature (Fig. 2). The semiconductor nanoparticles for Pd/SnO_2 are spherical shaped with particle distribution range from 6 to *c.a.* 30 nm (Fig. 3). It should be noted that particles size in sensor materials are larger in comparison with initial SnO_2 (Table 3). This fact can be explained by particles agglomeration and enlargement during high temperature treatment during formation of gas sensitive layer of the sensors [28].

According to the XRD data the cassiterite phase (Fig.4) was detected for Pd-containing sensor materials (ICDD PDF-2 Version 2.0602 (2006), card no. 00-041-1445). Calculated parameter of SnO_2 unit cell (Fig.4) was: a=b= 4.7382 Å, c= 3.1882 Å. For Pd doped materials no phases corresponded to palladium compounds were found even for materials contained up to 3.31 wt.% Pd. No electron diffraction attributed to palladium containing spices also was observed for all studied Pd/SnO_2 materials. The absence of diffraction from Pd-containing particles (metallic Pd, PdO, etc.) for both XRD and electron diffraction methods can be explained by high palladium dispersion on tin dioxide surface and/or probably due to large number of defects in palladium species [27].

Calculation by the Scherrer equation shows different SnO_2 particle sizes for the sensor materials without any additives and the Pd-containing samples (Table 3). The XRD sizes for them are quite smaller than corresponding TEM sizes (12-13 and 14-15 nm respectively). This may be caused by additional defects on the tin dioxide surface [29].

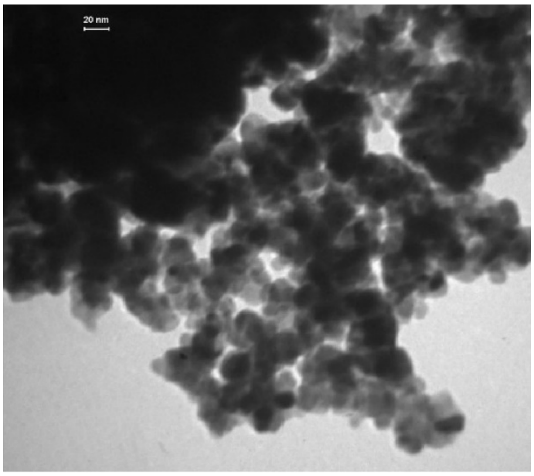

Fig. 2. TEM image of the 1.41 wt.% Pd/SnO_2.

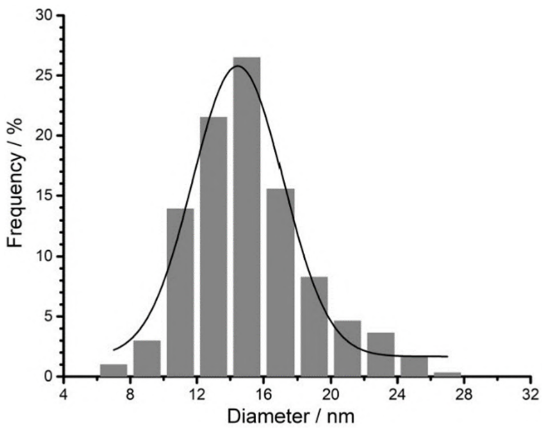

Fig. 3. Histogram of the particles distribution calculated through analysis of TEM data for the samples 1.41 wt.% Pd/SnO_2.

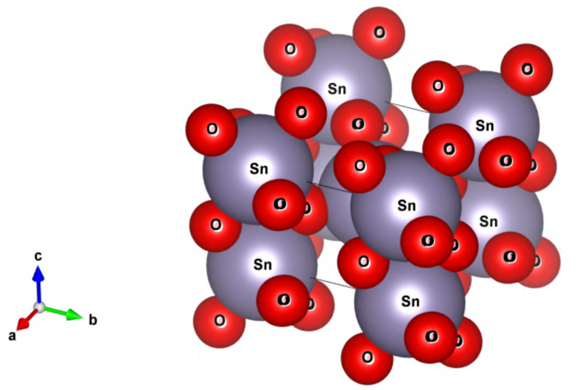

Fig. 4. Crystal structure of tin dioxide calculated by using the XRD data.

3.2 Gas sensitive properties of the sensors

The changes of the values of the sensor electrical resistances in air on the dopant content have an extreme character for both Pd-containing sensors (Table 4). The initial decrease in the electrical resistances in air for the sensors with a low Pd content (0.09-0.23 wt.%) can be attributed to formation of more quantity of oxygen vacancies in tin dioxide crystal structure due to palladium introduction. Such changes can occur at the high temperature treatment process of the sensor formation. It leads to increasing surface charge carriers concentration.

Further increase in dopant content leads to increasing the electrical resistance (Table 4) that can be caused by formation of an interface between the palladium particles and tin dioxide support. The interface consists of active centers for the oxygen chemisorption [30]. Therefore, the increase in the electrical resistance with an increase in the palladium content (from 0.23 wt.% to 1.41 wt.%) is caused by the increase in amount of oxygen chemisorbed on the longer interface between the catalytically active additive and tin dioxide. Further increase in the palladium content leads to the enlargement of the particles of the catalytically active additives and to their aggregation. As a result, the length of the interface begins to decrease and the amount of chemisorbed oxygen decreases too. This leads to decrease in the electrical resistances of the sensors with a large content of the catalytically active Pd additives (Table 4).

Table 4. Electrical resistance in air of the sensors based on Pd/SnO_2 at different operation temperatures.

Sensor resistance / kOhm							
T / °C	**Pd content / wt.%**						
	0.09	**0.31**	**0.62**	**1.41**	**2.28**	**2.42**	**3.31**
405	206	296	392	416	469	395	271
380	218	357	625	681	739	569	399
350	217	372	852	963	1005	720	507
325	211	354	1001	1243	1311	809	542
295	192	290	977	1428	1355	828	523
260	152	200	790	1276	928	592	434
225	106	99	397	660	609	377	240

For the sensors based on Pd/SnO_2 a change in the responses to CH_4 on palladium content correlate with the change in the electrical resistances at the various sensor operation temperatures (Table 5). The highest responses to methane and the highest values of the electrical resistances in air are observed for the same sensor composition (based on 1.41 wt.% Pd/SnO_2) (Table 4). Such correspondence indicates to a common reason that determines both the value of R_0 and γ to methane. This reason is the amount of oxygen chemisorbed on the interface Pd-SnO_2. The electrical resistance in air depends on the number of electrons localized on the chemisorbed oxygen. On the other hand, the response of the sensor is determined by the rate of the reaction that also depends on the amount of chemisorbed oxygen [14].

It was established that the dependences of the Pd-containing sensor responses (γ) to 1000 ppm CO on palladium content are extremal (with maximum at 0.228 wt.% Pd) for all studied operation temperatures (Fig. 5). The highest response was observed at 380 °C ($\gamma = 13.5$ for the sensor based on 0.228 wt.% Pd/SnO_2). The shift of maximal CO response value in comparison with response to methane for the sensors with lower Pd loading can be explained by differences in catalytic activities of Pd/SnO_2 gas sensitive nanomaterials in oxidation reactions of CO and CH_4.

It was found that introduction of Pd into SnO_2 materials leads to increase in their catalytic activities in both CO and CH_4 oxidation reactions. Maximal differences of temperatures of CO and CH_4 total conversions (ΔT_{100}) for nanomaterials Pd/SnO_2 in comparison with nanosized SnO_2 are equal to 240 and 185^0C, respectively. It was found that Pd/SnO_2 materials are much more active in CO oxidation reaction in comparison with CH_4. For the catalyst 2.3wt.% Pd/SnO_2 temperature of total conversion is equal to 110 ^0C in CO oxidation reaction and 415 ^0C in CH_4 oxidation reaction. Such difference in catalytic activity may be due to the chemical inertness of methane molecules. Since the optimal operating temperatures of the sensors (when their significant response values are observed) are quite high. It should be noted that optimal operation temperatures are much higher than the temperature of 100% CO conversion on the corresponding Pd/SnO_2 materials, it can be assumed that a significant amount of products of the CO oxidation reaction occurred on the surface of palladium clusters will prevent access of reagents (CO and O_2) to the interface Pd-SnO_2, that is responsible for the formation of the responses of the sensors. This leads to the shift of the maximal response of the sensors to CO in the area of the sensors with the lower palladium content. For these sensors, due to the higher rate of CO oxidation, the effect of blocking the interface of Pd-SnO_2 interface by CO oxidation products is much greater compared to sensors based on Pd/SnO_2 materials with palladium content higher than 0.228 wt.%, though the additional introduction of palladium increases the interface as evidenced by the increase in the electrical resistance of the sensors (Table 4). It should be noted that the final exclusion of oxygen chemisorbed at the interface Pd - SnO_2 from the formation of the sensor response to CO occurred probably for the sensors with Pd concentration > 1 wt.%. This leads do decrease in response of such sensors to the level of the sensors based on undoped tin dioxide (Fig. 5).

Table 5. Response to 930 ppm CH_4 in air of the sensors based on Pd/SnO_2 at different operation temperatures.

T / °C	Sensor response						
	Pd content / wt.%						
	0.09	**0.31**	**0.62**	**1.41**	**2.28**	**2.42**	**3.31**
405	3.0	9.2	10.1	9.7	9.0	8.9	6.1
380	2.2	8.1	11.5	12.0	11.3	10.7	7.8
350	1.6	6.4	11.1	12.4	11.1	10.5	7.8
325	1.3	4.6	8.4	10.1	8.7	8.4	6.4
295	1.0	3.0	5.3	7.0	5.7	5.4	4.2
260	1.0	1.7	2.7	3.6	2.5	2.4	2.5
225	1.0	1.2	1.3	1.6	1.6	1.3	1.4

The temperatures of CH_4 total conversion are higher in comparison with the sensor operation temperatures. This results in include of the full interface Pd-SnO_2 length in the formation of the sensor responses to methane. This assumption is in consistent with the fact that the maximal responses to methane and values of electrical resistances in air are observed for the sensors with the same palladium content (Tables 4, 5).

The response time and relaxation time of the optimal CO and CH_4 sensors based on Pd/SnO_2 obtained in this work and characteristics of the sensors known in the literature are presented in Table 6. As it can be seen, the dynamic characteristics and response values of the sensors with 0.228 wt.% Pd to CO and 1.41wt.% to CH_4 obtained in this work are better than literature data.

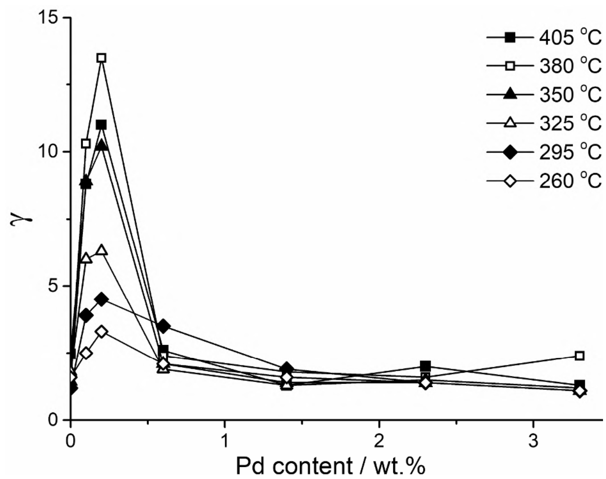

Fig. 5. Responses to 1000 ppm CO of the sensors based on Pd/SnO_2 on palladium content at different operation temperatures of the sensors.

Table 6. Sensor responses and dynamic characteristics of the developed sensors and known in the literature

Sensitive layer content of nanosysytems	Gas concent-ration, ppm	Sen-sor res-ponse	Tem-pera-ture, °C	Res-ponse time, sec	Re-co-very ti-me, sec	Refe-rences
Sensors to CO						
SnO_2 porous nanosolid	4000	9.2	300	28	252	[31]
0.2mol%Pd/ 1mol%Fe/SnO_2	3000	1.3	350	100	50	[32]
7%PdO/SnO_2 / CuO	2000	1.32	200	7	10	[33]
5%Pd/SnO_2/ graphene na-nocomposites	1600	1.1	26	120	120	[34]
0.228wt% Pd/ SnO_2	1000	13.5	380	5.5	15.2	this work
SnO_2/MoO_3	300	2.4	300	1430	1524	[35]
2.8 wt%Al/ ZnOnanorods	100	1.6	350	480	240	[36]
SnO_2/Au multilayered hetero-structure	100	3.07	300	58.6	77.7	[37]
Co_3O_4 nano-structured	25	2.1	200	120	600	[38]
Sensors to CH_4						
SnO_2 porous nanosolid	4000	9	440	112	3222	[31]
SnO_2-rGO-PdPt	1000	1.7	150	50	270	[39]
1.41wt% Pd/ SnO_2	1000	12.4	350	6	10	this work
SnO_2 nanoparticle	500	1.5	-	24	36	[40]

For the sensors with maximum responses that based on the materials 0.228% Pd/SnO_2 for CO and 1.41% Pd/SnO_2 for CH_4, the dependences of their signal values in the presence of different CO and CH_4 concentrations in air correspondingly were studied. It was found that the sensors can measure CO in the range of 20 -1000 ppm and CH_4 in the range of 50 - 930 ppm. It should be noted that the studied dependences are practically linear in these ranges of measured concentration. These results indicate to possibility of using the obtained sensors to measure with good dynamic characteristics presence of CO and CH_4 in a wide concentration range in air.

4 Conclusions

The synthesized nanosized material based on SnO_2 with palladium additives allowed to create adsorption semiconductor sensors with enhanced response intended to measure different concentrations of CO and CH_4 in air. The sensors containing 1.41 wt.% palladium demonstrate the highest response to CH_4 at 350 °C and the sensors containing 0.228wt.% palladium exhibit the maximum response to CO at 380^0C. The higher sensitivities of the sensors to CO compared to CH_4 is explained by the mechanism of the sensor response formation, which is based on the occurring the catalytic oxidation reaction of gases on the surface of the sensors with involving of chemisorbed oxygen adsorbed from air on the semiconductor surface. The sensors obtained in the work have good dynamic properties and a wide range of carbon monooxide and methane detection, that is necessary to provide fast analysis of the environment using sensor gas analyzers based on the created sensors.

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Technological, agronomical and economic efficiency of new organic and organo-mineral soil amendments

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Abstract. The intensification of crop production coupled with current declining soil fertility needs proper plant nutrition management and improved effectiveness of fertilizer use. Sustainable practices providing new soil amendments could be a useful tool to improve soil fertility and crop productivity causing economic benefits. The technology of processing local raw materials (leonardite, bentonite, and molasses) was developed to produce new soil amendments with optimal physical and chemical properties and to meet the needs of a particular crop in the nutrients. The best ratio of components was proved in a model experiment with an estimation of the full cost of final organic and organo-mineral soil amendments. In a field experiment, the effect of new soil amendments on available nutrients in Chernozem Podzolic and corn yield was studied. Two doses and methods of application (banding and broadcasting) of new soil amendments were compared taking into account its economic efficiency. Development of technologies to improve fertilizing properties of local organic materials, compliance to recommended doses, and methods of soil inputs application could increase the efficiency of crop production emerging environmental and economic benefits.

1 Introduction

With a growing world population food security has become a global concern. Soil protection in response to increasing food demand is a great challenge, which, in turn, may contribute lasting benefits for climate change mitigation and biodiversity conservation [1, 2]. The importance of fertilizers in raising soil fertility and food production is undoubtedly high. International Fertilizer Association declares that fertilizers play an important role in achieving several of the Goals of the 2030 Sustainable Development Agenda and contribute to Goals: 1 (No Poverty); 2 (No Hunger); 9 (Sustainable Industrialization); 13 (Climate Change); and 15 (Life on Land). Fertilization is essential element of all quality systems in primary production, such as Integrated Production, Good Agriculture Practice or Sustainable Agriculture Initiative [3]. On the one hand, our modern society would not exist without the invention of the Haber–Bosch process and synthetic nitrogen (N) fertilizers, which have become significant factor for increasing agricultural productivity worldwide [4]. On the other hand, the high rate application of synthetic nitrogen requires strategies to mitigate associated environmental damage, such as eutrophication of waters, greenhouse gases emission, soil degradation [5].

To minimize these environmental problems related to the use of chemical fertilizers, organic fertilizers are of increased interest as an alternative source of nutrients for crops. Organic fertilizers have long since been known to increase the organic matter content of the soil, therefore stimulating flourishing of beneficial soil organisms, which, in turn, improves nutrient mobilization and decomposition of toxic substances. They release nutrients slowly and contribute to the residual pool of organic N and phosphorous (P) in the soil, improving the exchange capacity of nutrients [6, 7].

Organic fertilizers serve as both fertilizers and soil amendments. It is known that application of organic amendments is an effective tool to improve soil structure, increase soil water retention as well as to buffer the soil against acidity, alkalinity, salinity, pesticides and heavy metals. Organic amendments have an increasing impact on aggregate stability and organic carbon content in macro- and micro-aggregate scale [8].

Locally available organic materials are an essential source of carbon and nutrients for arable soils. The most

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common soil organic amendments are animal manure and compost, but also peat moss, wood chips, straw, sewage sludge, sawdust *etc.* Meanwhile, several organic by-products coming from manufacturing processes such as residues from sugar extraction, biochar, distillery waste, biosolids from paper mill can be applied to soil [9].

Sound organic materials management contributes to environmental, economic and social benefits [10]. A socially inclusive and low-carbon economy is achieved by tapping into waste as a resource and increasing the use of secondary materials. Organic amendments are gaining popularity on the market within the European Union, if they come from approved or registered enterprises or plants [11]. The significance of production new soil amendments has become even clearer considering the escalating prices of chemical fertilizers. Involvement of local raw materials for the production of fertilizers is an important issue in agriculture today.

Integrated use of organic materials and chemical fertilizers is beneficial in increasing available nutrients content and organic carbon content in soil [12, 13]. Scientifically based application of organo-mineral amendments stimulates biological activity, improves soil structure, water retention and preserves soil fertility. Organo-mineral amendments provide essential nutrients [14], enhance soil physicochemical properties [15] and re-establish microbial populations [16].

Weak market and low application rate of organic amendments lead to a gap between the actual and potential crop yields. The lack of policy and institutional support in a changing technological environment may lead to negation of organic amendments efficiency by farmers before any economic or environmental benefits would appear. Increasing interest arises in production of organic amendments that can improve soil fertility, stabilize soil organic carbon and allow a sufficient release of mineral nutrients to sustain crop yields.

2 Materials and methods

There is an insufficient availability of organic materials in Ukraine connected with decreasing livestock production (in three times since 1992). That is why the role of alternative soil amendments is constantly increasing in Ukraine. As the main component of new soil amendments, a leonardite was chosen. Leonardite moisture content is 55.8 %, ash content 9.0 %, content of total nitrogen 0.06 %, phosphorus 0.001 %, potassium 0.02 % in dry matter, pH 5.3. To assess the role of organic fertilizer as source of humus, the data on its organic matter composition is necessary. Leonardite contains 48.3 % of carbon, while in pyrophosphate extract was determined carbon content 5.7 %.

To increase the degree of humification of leonardite and to improve its agrochemical characteristics different materials were used: bentonite, $FeSO_4$ and molasses. Model experiment was conducted to determine the best ratio of these components for production high-quality soil amendment with optimal physical and chemical properties.

The effectiveness of new soil amendments was studied in field experiment (table 1). Research was conducted on the experimental field «The impact of different levels of biologization of agriculture on soil fertility» (at State Enterprise «Experimental Farm Grakivske» NSC ISSAR, Kharkiv oblast, v. Novy Korotich). Geographic coordinate: 49°58'12.4"N 36°01'31.7"E. Natural-climatic zone – Forest-Steppe. Climate – temperate continental, sum of positive temperatures about 2400-2900 °C. The average annual precipitation is 465-680 mm. Soil of the experimental field - Chernozem Podzolic, low-humus heavy loamy formed on loess loam with humus content by the Tyurin method 4.1%; total nitrogen content - 0,21%; phosphorus by the method of Chirikov - 111 mg kg^{-1}; potassium by the method of Chirikov - 90 mg kg^{-1}.

Table 1. Field experiment design.

Treatment	Abbreviation	Total N fertilization (kg N ha^{-1})	Method of application
Without fertilizer	WF	0	-
Mineral fertilizer	MF	30	Banding
		60	Broadcasting
Organic amendment	OA	30	Banding
		60	Broadcasting
Organo-mineral amendment	OMA	30	Banding
		60	Broadcasting

The three-replicate trials was set up according to the randomized complete-block design. The elementary plot size was 4 sq. m. Maize (Zea mays) was cultivated. Soil samples were collected after harvest.

Analytical research was carried out in the certified laboratories. Total nitrogen content was determined by Kjeldahl method. Phosphorus and potassium content in soil amendments were determined by sample mineralization during heating with sulfuric acid followed by photometric determination. Mineral nitrogen (NH_4-N + NO_3-N) in soil was determined by modification of the method of NSC ISSAR named after O. N. Sokolovsky: nitrogen extraction from the soil using potassium sulfate then nitrates determined photometrically with disulfophenol acid, and ammonium with Nessler's reagent. Available phosphorus and potassium in soil was determined by the Chirikov method, extracting P_2O_5 and K_2O by 0.5M acetic acid with a ratio of soil to a solution 1:25 followed by photometric determination. All measurements were performed in triplicate. Analysis of variance was performed using Statistica 10 software.

Calculation of cost of soil amendments production to assess the economic efficiency of their use was carried out taking into account the methodological approach and standards given in papers [17-19]. Evaluation of the economic efficiency of soil amendments and mineral

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fertilizers was carried out using the author's scientific and methodological approach, which provides an assessment of the impact on effective fertility (crop yield) and profitability of agricultural production [20]. In the calculations were used the following: the average cost of NPK 16% fertilizer - 11440 UAH/t; the average cost of organic soil amendment – 2984 UAH/t; the average cost of organo-mineral soil amendment – 5243 UAH/t; average costs NPK 16% fertilizer application – 1350 UAH/t; average costs of soil amendments application – 125 UAH/t.

3 Analysis and discussion

3.1 Production of new organic and organo-mineral amendments

Leonardite is an oxidized lignite, which has not completed process of coalification. It has high content of carbon (about 50 %) and considerable aromaticity. Leonardite and humic substances derived from leonardite used in many sectors agriculture [21, 22].

To increase humic substances content in leonardite and to improve its agrochemical characteristics were used different components (figure 1). Catalysts of the process of humic substances synthesis can serve variable-valent metals, such as iron; a bentonite was used as matrice to their synthesis. Bentonite is a complex mineral ($Si_8Al_4O_2(OH)_4 \times nH_2O$) and it include amorphous silicon which is an center for the formation of organo-mineral complexes due to the polyvalence of this element. It is also used to improve soil quality and to prevent leaching of fertilizers from a soil [23]. Molasses (sugar refinery waste) were used as the binder during granulation of new soil amendments.

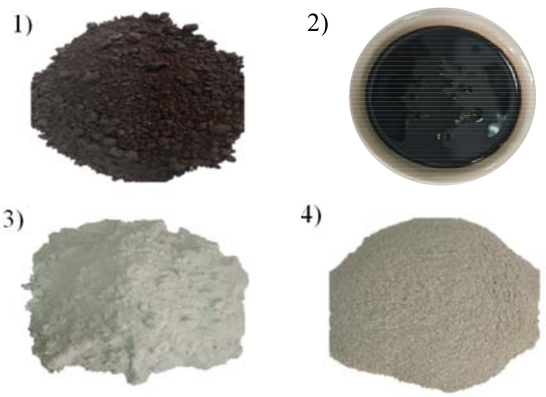


Fig. 1. The initial components for new soil amendments production: 1) leonardite; 2) molasses; 3) $FeSO_4$; 4) bentonite.

Bentonite increases the strength of granules and as well as molasses make the granules denser. In addition, due to high hydrophilicity of bentonite its particles intensively absorb moisture that leonardite contains. The following technological scheme of production of soil amendment was developed (figure 2).

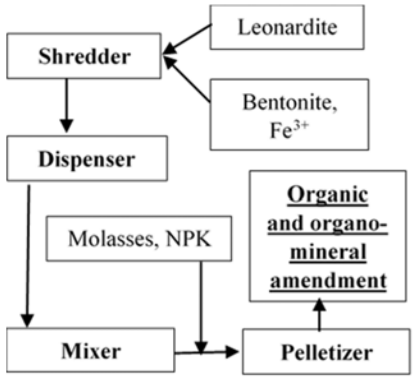


Fig. 2. The scheme of technological process of production of organic and organo-mineral amendments.

Granulation of amendments allows obtaining homogeneous granules of spherical forms, reducing consolidation of a product and preventing the destruction of a product during transportation. The technological solution for production organo-mineral amendment (OMA) involves the combination of organic compounds and mineral fertilizers in organo-mineral form (figure 3). The period of nutrients releasing from organo-mineral mixtures into a soil is longer compared to organic materials. The organo-mineral amendment production could be adapted to meet different specific needs (soil type, particular crop requirements for nutrients *etc.*).

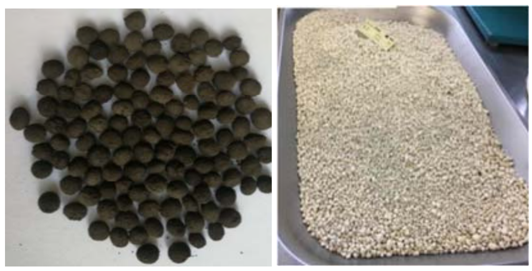


Fig. 3. Final organic soil amendment (left side of figure) and organo-mineral soil amendments (right side of figure).

In model experiment, it was proved that the best ratio of components for production of organic amendment with optimal physical and chemical properties is leonardite:bentonite:molasses:$FeSO_4$ in the mass ratio 1:0.5:0.5:0.01; to produce organo-mineral amendment the best mass ratio of components is leonardite:bentonite:molasses:$FeSO_4$:NPK 16 % fertilizer - 1:0,5:0,7:0,01:0,7.

Nutrients ratio in finished organic amendment (OA) is N:P:K = 1:0.1:2.7, while organo-mineral amendment have a balanced composition for particular crop and soil and promote a balanced crop nutrient uptake. OMA contents nutrients in ratio – N:P:K = 1:0.86:0.95 (according to the corn need).

Expert calculation showed that the estimated cost of 1 ton of organic soil amendment is 3134 UAH, and organo-mineral amendment - 5393 UAH (table 2).

Table 2. Calculation of the estimated cost of organic and organo-mineral amendment, 2020.

Cost	Cost per 1,000 tons, thousand UAH		Structure of production costs, %	
	OA	OMA	OA	OMA
The cost of raw materials	2876.5	5135.2	96.4	97.9
Remuneration	8.8	8.8	0.3	0.2
Fuel	17.2	17.2	0.6	0.3
Amortization	29.2	29.2	1.0	0.6
Current repairment	41.9	41.9	1.4	0.8
Other expenses	10.4	10.4	0.3	0.2
Production cost	2984.0	5242.7	X	X
Selling expenses	150	150	X	X
Total cost	3134.0	5392.7	X	X
Full cost of 1 ton, UAH	3134	5393	X	X

3.2 The effect of new organic and organo-mineral amendments on soil chemical indicators and crop yield

Soil pH plays a central role in many chemical properties and biological soil processes including solubility and availability of nutrients and trace metals. Soil pH value under different types and methods of application of organic and organo-mineral amendments do not change compared to the control, where no amendments was ever applied. Only high dose of organic soil amendment led to an increase in pH value of Chernozem Podzolic (table 3).

Nutrients in synthetic fertilizer are soluble and immediately available to the plants. Therefore, the effect of mineral fertilizer is fast, while from soil amendments nutrients slowly released into soil that makes them have prolong effect. Nutrients are easily lost from soils through fixation, leaching or gas emission and can lead to reduced fertilizer efficiency.

Nitrogen is one of the most important inputs in crop production and the main limiting factor for productivity in agroecosystems. It was found that the application of soil amendments significantly affects the nitrogen regime of chernozem podzolic with both broadcasting and band application, promotes the accumulation of mineral nitrogen (NH_4-N + NO_3-N) in the soil that increases proportionately with the application doses. The broadcasting application of organic and organo-mineral amendments increases the mineral nitrogen content by 0.7 mg/100 g (7 % compared to the control) and 2.0 mg/100 g (19 % compared to the control). Ammonium-nitrogen is accumulated in 1.2–1.4 times more intensive under broadcasting application of soil amendments than under banding. The amount of NO_3-N provided by new soil amendments was less than the amount provided by mineral fertilizer.

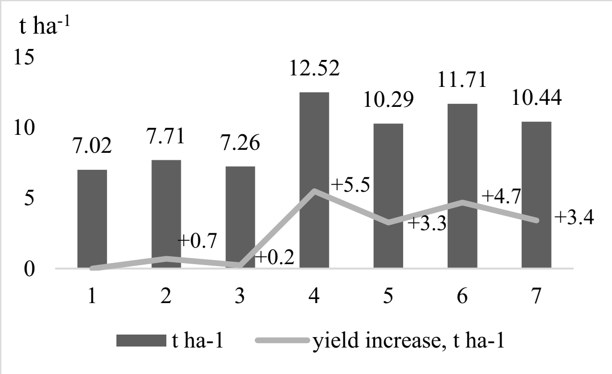
Table 3. Effect of new soil amendments on available nutrients content in the 0-20 cm layer of chernozem podzolic.

Treatment	pH	NH_4-N, mg kg^{-1}	NO_3-N, mg kg^{-1}	P_2O_5, mg kg^{-1}	K_2O, mg kg^{-1}
Without fertilizer	6.1	59.0	45.0	70.0	120.0
MF banding	6.1	57.7	75.4	67.5	112.5
MF broadcasting	6.1	86.3	74.7	72.5	130.0
OA banding	6.1	56.1	43.5	67.5	117.5
OMA broadcasting	6.2	59.4	51.5	70.0	125.0
OA banding	6.1	55.8	46.5	67.5	120.0
OMA broadcasting	6.1	59.2	64.5	67.0	127.5
LCD_{05}	0.1	3.2	5.8	3.1	6.7

Phosphorus is the second most limiting nutrient in crop production. Unfortunately, the reserves of phosphate rock are finite; estimates of the reserve suggest that at the current rate of use this resource will become exhausted within some hundreds of years [24]. Phosphorus is abundant in soil; however, the concentration of plant available P in the soil solution is generally low [25]. New soil amendments do not have significantly effect on the content of available phosphorus in the soil. However, the application of new soil amendments (organic amendment as well as organo-mineral one) caused an increase in the content of available potassium in Chernozem Podzolic compared to the control.

Potassium is also an essential and unsubstitutable nutrient for plants. Although most soils are rich in K minerals, its availability to plants is relatively little. Hence, the demand for K fertilizer is increasing worldwide [26]. After broadcasting application of organic and organo-mineral amendment, the potassium content was increased by 0.5 mg/100 g (4%) and 0.8 mg /100 g (7%) compared to the control. Meanwhile, another study found the effects of leonardite applications on nutrient contents in soil were statistically significant [22].

With a growing world population, food security require appropriate management greater demand of fertilizers to increase yield per unit land. Corn is one of the most important food crops in the world and demand for maize is constantly increasing. Studies showed the increase of corn yield under the band application of organic and organo-mineral amendments by 5.5 and 4.69 t ha^{-1} compared to the control, respectively (LSD_{05} = 2.09) (figure 4).



Note. 1 – without fertilizer; 2 – mineral fertilizer (banding); 3 – mineral fertilizer (broadcasting); 4 – organic amendment (banding); 5 – organic amendment (broadcasting); 6 – organo-mineral amendment (banding); 7 – organo-mineral amendment (broadcasting)

Fig. 4. Effect of new organic and organo-mineral amendments on corn yield.

3.3 Economic efficiency of new organic and organo-mineral amendments

The results of calculation of economic efficiency of application of organic and organo-mineral amendment showed (table 4) that the total cost of band application of organic soil amendment was 15545 UAH/ha, meanwhile the cost of broadcasting method of their application - 31090 UAH/ha; for organo-mineral soil amendment these indicators were equal to 4026 and 8052 UAH/ha, respectively.

Table 4. Model calculation of cost indicators of application of new soil amendments, 2020.

Treatment	The rate on 1 ha, t physical mass	The cost of fertilizers, UAH/ha	Application costs, UAH / ha	Total costs, UAH / ha
MF broadcasting	0.375	4290	506	4796
MF banding	0.188	2151	254	2405
OA broadcasting	10.000	29840	1250	31090
OA banding	5.000	14920	625	15545
OMA broadcasting	1.500	7864	188	8052
OMA banding	0.750	3932	94	4026

Respectively, 96 and 97 % of the total costs for the use of both soil amendments belong to their value. Differences in costs are due to different application rates as well as different production costs of soil amendments. The use of soil amendments is much more expensive compared to the total cost of NPK 16% fertilizer.

Conditional additional income from band application of organic soil amendment was 23580 UAH/ha, while broadcasting application of OA characterized by conditional additional loss of 6950 UAH per hectare (table 5). At the same time, band application of organo-mineral soil amendment can provide conditional additional income 28898 UAH/ha, and broadcasting application of OMA - 16076 UAH/ha. Therefore, the conditional level of profitability of band application of organic amendment can reach 158% and band application of organo-mineral amendment - 204.4-734.9%, while the broadcasting application of organic soil amendment was unprofitable (as well as the application of NPK 16%).

Table 5. Model calculation of indicators of economic efficiency of application of new soil amendments, 2020.

Treatment	Cost of additional income, UAH/ha	Additional profit (loss), UAH/ha	Level of profitability (loss), %
Without fertilizer	-	-	-
MF broadcasting	1680	-2610	-60.8
MF banding	4830	2679	124.5
OA broadcasting	22890	-6950	-23.3
OA banding	38500	23580	158.0
OMA broadcasting	23940	16076	204.4
OMA banding	32830	28898	734.9

Note. The calculations take the average realization price of corn (October 2020) at the level 7000 UAH/t.

As a result, it was defined a higher economic efficiency of the application of organo-mineral soil amendment, compared to organic one, because application of OMA characterizes by the conditional additional income and the level of profitability which is significantly higher than similar indicators for OA. Moreover, the application of organic soil amendment was found to be economically inefficient.

It should be noted that the calculations are based on one-year data and need to be clarified on the basis of at least three-year field experiments. It is clear that in case of other price of harvested corn, as well as in case of cultivation of another crop, the economic efficiency may be completely different. Therefore, future research would be related to an effectiveness of new soil amendments for production of various crops.

4 Conclusions

1. Large use of synthetic inputs and soil fertility decline have emerged as major impediments to sustainable

agricultural production causing a large pressure on the environment. Soil amendments are an environmentally friendly alternative to recover soil fertility and they might offer the potential for sustainable agriculture through adaptation against climate change and lifting farmers out of poverty. Proposed technological scheme makes the production of soil amendments more efficient and effective. New soil amendments based on local raw materials and their efficient use is an option of maintaining soil quality and increasing crop production per unit of land from economic and environmental perspectives.

2. In model experiment on production of new soil amendments from local raw materials, it was proved that the best ratio of components is leonardite:bentonite:molasses:$FeSO_4$ in the mass ratio 1:0.5:0.5:0.01 to produce organic amendment with optimal physical and chemical properties. Moreover, soil amendments could be produced to meet the needs of particular crop in the nutrients though addition of NPK in calculated doses.

3. Correct dose and method of fertilizer application plays an important role in its efficient use. The results of field trial indicated that the application of new soil amendments can provide significant benefits for crop yield and provide an impact on accumulation of main nutrients in a soil. Band application of organo-mineral amendment increased corn yield, available N content in soil but had no effect on P_2O_5 and K_2O. Meanwhile, broadcasting application of organo-mineral amendment enhanced available potassium content in a soil. The plot with the broadcasting application of mineral fertilizer showed the highest nutrients concentrations; while it had the smallest yield increase compared the control plot, where no amendment was applied.

3. The higher economic efficiency of application of organo-mineral soil amendment in comparison with organic soil amendment is established. Thus, conditional additional profit of band application of organo-mineral soil amendment is by 22.6 % higher compared with organic soil amendment. Estimated level of profitability of organo-mineral amendment band application is in 4.7 times higher than profitability of organic amendment.

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Woody artificial plantations as a significant factor of the sustainable development at mining & metallurgical area

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Abstract. The relevance of our research is determined by the need to find practical measures that will be aimed of the sustainable development formation and maintenance at mining and metallurgical areas by used of artificial woody plantation. The main objective of this work was on the standpoint of the ecosystem approach to consider the artificial woody plantations as a significant factor for sustainable development paradigm implementation at Kryvyi Rih mining and metallurgical district (Central Ukraine). During 2015-2020, by classical methods were studied the natural forest ecosystems and the artificial forest plantations, which are located in contrast ecological and environmental conditions. Numerous scientific papers about sustainable development have also served as materials for our work. At Kryvyi Rih mining and metallurgical district the leading characteristics of artificial woody plantations have a clear ecological and environmental conditionality. It is proved that in artificial woody plantations of this district tree species are in a state of stress. Therefore, these species lose stability due to the constant influence of adverse environmental factors of natural and anthropogenic genesis. The authors assume that the biogeochemical parameters of trees fallen can be considered one of the promising markers that determine the vitality / healthy of tree species and forecast the development of artificial woody plantations. It has been suggested that the artificial woody plantations at Kryvyi Rih mining and metallurgical area should acquire the status of one of the key factors that determine the sustainable development of this district and Ukraine as a whole. In practice, to achieve this goal, the following steps must be taken: (i) artificial woody plantation assessment, (ii) ecological and environment conditionality of artificial woody plantation current state ascertainment, (iii) sustainable model of artificial woody plantation development, (iv) sustainable management of artificial woody plantation, (v) sustainable development of artificial woody plantation. In the near future, it is recommended to optimize the Kryvyi Rih forest cover by 8-10%. The first step in streamlining and preliminary assessment of the artificial forest ecosystems sustainability is the use of biogeochemical indicators of the chemical circulation system relationship "Leaf precipitation - soil" as markers and predictors of the artificial forest current state in Kryvyi Rih District.

1 Introduction

Practices of the natural forest ecosystems and artificial forest plantations sustainable management are implemented in the World already over century. The international experience history of their service is changing as a result of growing interest to traditional paradigms forest resources policy. The greatest achievements are among the countries of the European Union [13]. Thus, currently in Europe the activities of many institutes are aimed at the most efficient forest use for both present and future generations. Ministerial Conference on the Protection of Forests in Europe is pan-European political tool for forest management [4, 26].

Since 1990, the cooperation of European countries has intensified their policies. These activities were aimed at: (i) consolidating funds for modern forest use, (ii) combating illegal logging, (iii) developing an approach to the assessment of ecosystem services and (iv) increasing attention to the social aspects of forestry and to the role of forests in a green economy [3, 5, 6, 8].

However, in most cases, current environmental activities are aimed primarily at sustainable development and to solving the problems of forest ecosystems and woody plantations. Meanwhile, forest stands can be very factors for sustainable development at industrial areas. This is most relevant for such areas where there is a strong anthropic impact on the environment, including mining and metallurgical areas [9, 12, 14, 17].

Last years the scientific community is actively searching for ways to implement the paradigm of sustainable development in practical measures. Scientists propose: (i) improving the optimal conditions for land use planning and conservation, (ii) developing strategic steps for sustainable development, (iii) calculating the amount of environmental compensation and (iv) community development planning [28, 30,31]. In our opinion, the change for approaches in achieving sustainable development in certain industrial areas (including mining and metallurgical areas) should be aimed at measures involving the use of natural forest ecosystems and artificial tree plantations [19, 21].

It should be noted that in many countries around the world (at the national / regional / local level) various institutions (scientific / public, state / municipal / private) are actively researching natural forest ecosystems and artificial woody plantations. In particular, the scientific field of these studies is: (i) assessment of the natural artificial forests resilience, (ii) elucidation of their cultural and aesthetic value, (iii) establishment of compensation mechanisms for damage. Also analyzed: (i) the state of forest ecosystems, as a complex of trees, shrubs, grasses, bacteria, fungi, protozoa, arthropods and other invertebrates, (ii) parameters of geochemical cycles of oxygen, carbon dioxide, water, minerals and dead organic matter. At the same time, researchers claim that in forest ecosystems the natural changes can never reach equilibrium, but is constantly changing in time and space [10, 11, 13, 23].

In general, natural forest ecosystems and artificial woody plantations have recently been well analyzed in numerous scientific publications. There are also numerous ones on various aspects of sustainable development. However, practical measures to implement sustainable development in a separate industrial area (for example, in the mining and metallurgical district) have in fact been left out of the attention of researchers.

The objective of this paper was to considered the artificial woody plantations as a significant factor for sustainable development paradigm implementation at Kryvyi Rih mining and metallurgical district.

2 Materials and methods

This study was conducted in the artificial woody plantations, which are located at Kryvyi Rih mining and metallurgical district (Central Ukraine). The study area is located between 47°53'54" and 48°8'52" north latitude and 33°19'52" and 33°33'38" west longitude (Figure 1).

During 2015-2020, we studied the natural forest ecosystems and the artificial forest plantations, which are located in contrast environmental conditions.

We studied all types of artificial woody plantations: (i) woody stands of city parks, (ii) woody stand of health protection zones, (iii) woody stands of city protection forest and (iv) woody stands of river protection forest. The natural forest ecosystems from of Gurivsky forest were used as control.

A forest woodland inventory was made a random sampling scheme. The 34 research plots (25*25 m) were established in natural forest ecosystems and in artificial woody plantations. Field data were collected through direct enumeration and measurement of all trees in every plot. In each plot, all woody stems of diameter at breast height (dbh) > 10 cm were recorded and: (i) their diameter at 1,3 m above ground (in two perpendicular directions by a caliper); (ii) their height (by a hypsometer) and (iii) their vitality were measured [16, 29].

For each research plot the following dendrometric parameters were computed: tree-density of the stand, basal area of the tree and volume of the tree [16, 29]. For each research plot the vitality of stand also was computed [1].

All data were submitted to descriptive statistics and analysis of variance (ANOVA). The statistical analysis was performed using the program SPSS for Windows. For all statistical analysis, significance was considered $P < 0,05$ [20].

Numerous scientific papers about sustainable development have also served as materials for our work. In their study, classical scientific methods were used: analysis and synthesis, induction and deduction, analogy and formalization, abstraction and concretization, classification and modeling.

3 Results and discussions

3.1 Current state of artificial woody plantations

The artificial woody plantations in the Kryvyi Rih mining and metallurgical district were planted in the 30-60s of the 20th century. In that historical period, afforestation was carried out as part of Soviet government state program to transform nature. For this purpose, significant financial and human resources were used.

In Kryvyi Rih district the artificial forests are characterized by significant variances in their structural and functional organization. It should also be noted that these artificial forests are located in areas with contrasting ecological & environmental condition.

Summing up the soil factors actions (fertility and moisture) and the air pollution actions, four ecological locations were identified: 1) environmentally friendly area (Background), 2) relative environmentally friendly area (Buffer 1), 3) relative environmentally not friendly area (Buffer 2) and 4) environmentally not friendly area (Impact).

Natural forest ecosystems of Gurivsky forest are located in environmentally friendly area. These ecosystems have a natural origin and are 110-160 years old (table 1). In their floristic composition, the dominant species are English oak, Norway maple and European ash. The natural origin of the Gurivsky forest ecosystem led to the presence of a full complete vertical structure. In this composition were detected Emergent, Canopy Understory Shrub and Herb layers. It was established that at Natural forest ecosystems of Gurivsky forest the values of stand density varied from 1100 to 1300 trees * ha^{-1}, stem heights were 17-19 m, stem

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diameters were from 19 to 21 cm, stand basal area were from 44 to 48 $m^{2*}ha^{-1}$, stand volume were from 500 to 550 m^3*ha^{-1}. It should be noted, that the vitality of the stand were very high and indicated to healthy forests of these ecosystems. In general, the characteristics of the Gurivsky forest were typical for the floodplain forests of Ukraine [15, 18, 25].

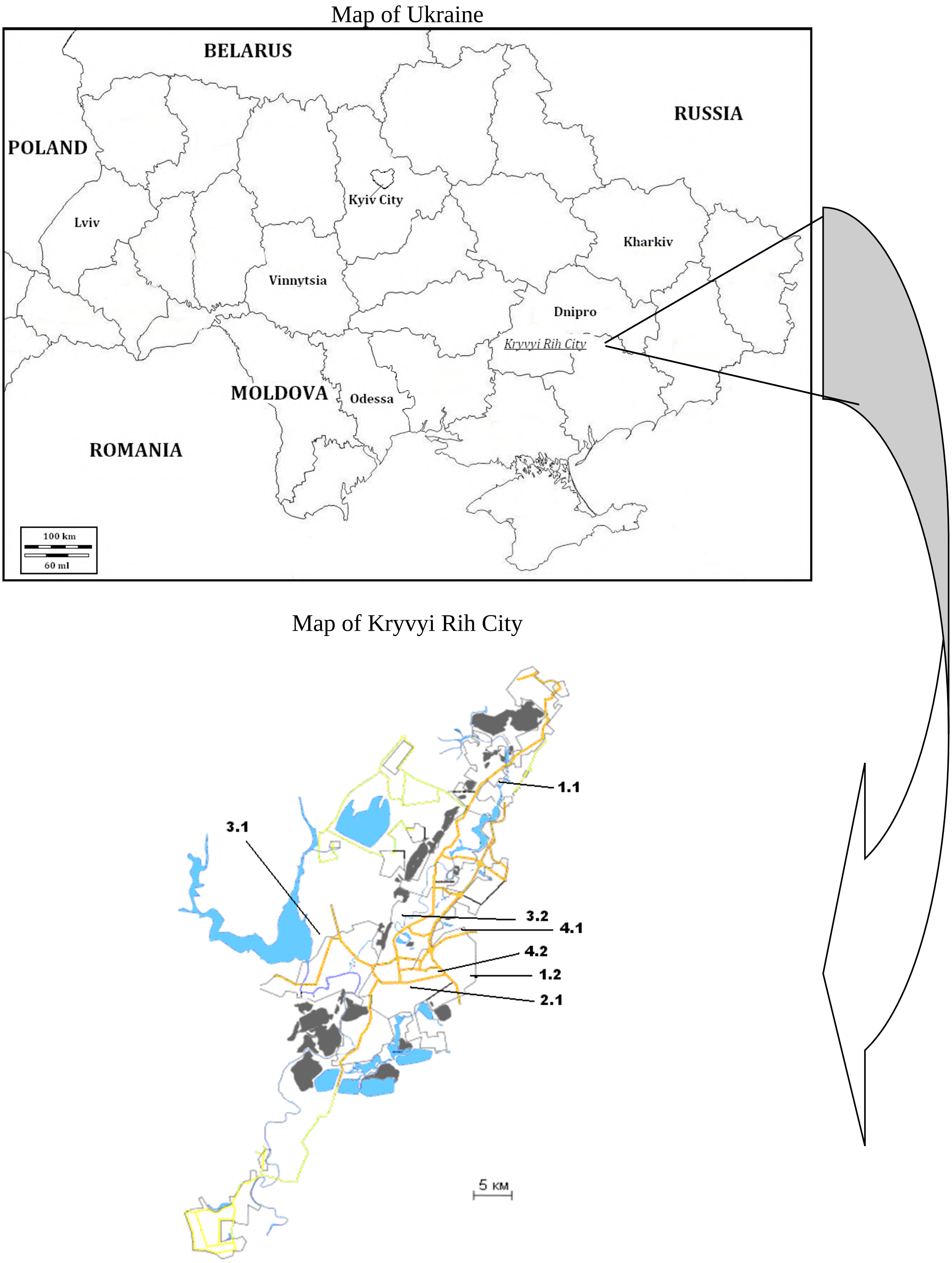

Fig 1. Location of study areas
1. – City parks (1.1 – Veseloternivsky arboretum, 1.2 – Dovgintsivsky arboretum);
2. – Health protection zones (2.1 – protection zones of PJSC "ArcelorMittal Kryvyi Rih");
3. – River protection forests (3.1 – Karachuny forest tract, 3.2 – Dubki forest tract);
4. – City protection forests (4.1 – Lisove forest tract, 4.2 – Sotsmisto forest tract)

Table 1. Characteristics of artificial woody plantations at Kryvyi Rih mining and metallurgical district.

Indexes	Location of forest sites			
	Background	Buffer 1	Buffer 2	Impact
Name of study areas				
Forest tract	Gurivsky natural forest	Veseloternivsky arboretum, partially Karachuny forest tract, Dubki forest tract	Dovgintsivsky arboretum, partially Karachuny forest tract, Lisove forest tract	Protection zones of PJSC "ArcelorMittal Kryvyi Rih", Sotsmisto forest tract
Ecological conditions of stand area				
Fertility and soil moisture	Fertile and sufficiently moist soils	Fertile and sufficiently moist soils	Relatively fertile and insufficiently moist soils	Relatively fertile and insufficiently moist soils
Levels of the air pollution	Very low	Low	Moderate	High
Biological stand parameters				
Origin of stand	Natural	Natural, artificial	Artificial	Artificial
Age of stand, years	150-170	50-120	40-80	50-90
Dominant species	English oak (*Quercus robur* L.) Norway maple (*Acer platanoides* L.) European ash (*Fraxinus excelsior* L.)	English oak (*Quercus robur* L.) European ash (*Fraxinus excelsior* L.), European white elm (*Ulmus laevis* L.) Ashleaf maple (*Acer negundo* L.)	English oak (*Quercus robur* L.) European ash (*Fraxinus excelsior* L.) Ashleaf maple (*Acer negundo* L.) Littleleaf linden (*Tilia cordata* L..)	English oak (*Quercus robur* L.) European ash (*Fraxinus excelsior* L.) Ashleaf maple (*Acer negundo* L.) Norway maple (*Acer platanoides* L.) Black cottonwood (*Populus nigra* L.)
Vertical structure of the stand				
Emergent layer	Available 100 %	Available 100 %	Available 100 %	Available 100 %
Canopy layer	Available 100 %	Available 100 %	Available 75 %	Available 100 %
Understory layer	Available 100 %	Available 75 %	Available 75 %	Available 75 %
Shrub layer	Available 100 %	Available 75 %	Available 25 %	Available 25 %
Herb layers	Available 100 %	Available 100 %	Available 75 %	Available 0 %
Dendrometric parameters of the stand				
Density, trees/ha	1100-1300	800-900	1400-1500	1400-1500
Height, m	17-19	15-17	12-14	10-12
Diameter, cm	19-21	24-26	16-18	14-16
Basal area, m^2/ha	44-48	34-38	30-34	26-32
Volume, m^3/ha	500-550	300-350	200-250	150-250
Vitality of the stand				
Levels of the vitality	High (healthy forests)	High (healthy forests)	Moderate (partially healthy forests)	Moderate (partially healthy forests)

Artificial woody plantations of the Veseloternivsky arboretum, river protection forests (Karachuny and Dubki forest tracts) are located in relative environmentally friendly area (Buffer 1). These plant communities grow on fertile and moist soils under low level of air pollution (table). In these woody plantations the dominant species are English oak, European ash, European white elm and Ashleaf maple. The age of these plantations is 50-120 years. It is important to note that the vertical structure of these plantations was not formed at all locations. On some forest sites understory and shrub layers were absent. In Buffer 1 area the dendrometric parameters of artificial woody plantations were slightly different from the control (F>Fcritical, p<0,05). Thus, the values of stand density varied from 800 to 900 trees $*ha^{-1}$, stem heights were 15-17 m, stem diameters were from 24 to 26 cm, stand basal area were from 34 to 38 $m^{2*}ha^{-1}$, stand volume were from 300 to 350 m^3*ha^{-1}. In relative environmentally friendly area the vitality of the stand was high and indicated to healthy forests of these woody plantations. In general, biological and dendrological characteristics of artificial woody plantations from Buffer 1 are typical for other artificial forests of Ukraine [15, 18, 25].

Artificial woody plantations of Dovgintsivsky arboretum and River protection forests (Karachuny forest tract (partially)) are located in relative environmentally not friendly area (Buffer 2). These plantations develop on relatively fertile soils with insufficient moisture under moderate level of air pollution (table). The age of the plantation varies from 40 to 80 years. English oak, Red oak, European ash, Ashleaf maple, Scots pine and Littleleaf linden are Dominant species. There is also an insufficiently formed vertical structure: trees of the emergent layer, with partially identified canopy and understory layers, shrub and herb layers is weakly expressed (table).

In these artificial woody plantation, the values of stand density varied were 1400-1500 trees $*ha^{-1}$, stem heights were 12-14 m, stem diameters were 16-18 cm, stand basal area were 30-34 $m^{2*}ha^{-1}$, stand volume were 200-250 m^3*ha^{-1}. These values differ significantly from the control measurements in the natural ecosystems of the Gurivsky forest (F>Fcritical, p<0,05). The vitality of the stand was not high and indicated to partially healthy forests of these woody plantations.

Health protection zones (protection zones of PJSC "ArcelorMittal Kryvyi Rih") and city protection forests (Lisove and Sotsmisto forest tracts) are located in environmentally not friendly area (Impact). These woody plantations develop mainly on relatively fertile soils with little moisture under high level of air pollution (table). The age of these plantations is 50-90 years. English oak, European ash, Ashleaf maple, Norway maple and Black cottonwood are dominant species (table).

In artificial woody plantation from environmentally not friendly area there is no complete vertical structure. Only emergent and canopy layers are present in all forest sites. While other layers (understory, shrubs and herb) are absent in forest sites. It was established that at these woody plantation the values of stand density varied from 1400 to 1500 trees $*ha^{-1}$, stem heights varied from 10 to 12 m, stem diameters varied from 14 to 16 cm, stand basal area varied from 26 to 32 $m^{2*}ha^{-1}$ and stand volume varied from 150 to 250 trees m^3*ha^{-1}. These values are very different from the control (F>Fcritical, p<0,05). The vitality of the stand was very low and indicated to partially healthy forests of these woody plantations.

In general, at Kryvyi Rih mining and metallurgical district the leading characteristics of artificial woody plantations have a clear ecological and environmental conditionality.

It is known that in all industrial regions, which are located in the steppe zone of Ukraine, tree species in artificial woody plantations grow and develop under the combined stress of moisture deficiency and anthropic pollution. In such negative ecological conditions, tree species are characterized by (i) inhibited growth (ii) suppressed physiological state, (iii) accelerated old aging processes and (iv) reduced environmental efficiency. Analysis of recent papers shows that the real vitality of the stand and healthy of trees in artificial woody plantations is unknown, due to their botanical features. That is why the development of rapid methods of early diagnosis of the vitality / healthy of tree species in artificial woody plantations in the steppes of Ukraine and the industrial area is becoming very important.

In our opinion, the biogeochemical parameters of trees fallen can be considered one of the promising markers that determine the vitality / healthy of tree species and forecast the development of artificial woody plantations [7].

At one time, even V.I. Vernadsky [27] taught that trees fallen leaves are "thin, the uppermost layer of soil, full of life". But it is still unclear what chemical elements in fallen leaves can be considered the most informative for diagnosing vitality / healthy of tree species at artificial woody plantations.

Our research proves the reliable 29 correlation coefficients (from possible 70 ones) of the alkaline earth metals content in trees fallen leaves and the vitality of the stand from artificial woody plantations. In 15 cases these correlation coefficients confirm the presence of a direct relationship ($r^2 > 0$). That is, in the case of increasing values of alkaline earth metal content in fallen leaves, there is an increase level of the stand vitality.

In contrast, for the other 14 cases, an inverse correlation was observed ($r^2 < 0$). Based on the correlation strength assessment between the alkaline earth metals content in fallen leaves and stand vitality at the artificial woody plantations certain patterns have been established. At the same time various communications between the certain indicators were followed: (i) in 15 cases there was a weak connection ($0.3 < |r^2| < 0.5$), (ii) in 12 cases there was a medium connection ($0.5 < |r^2| < 0.7$), (iii) in 2 cases there was a strong connection ($0.7 < |r^2| < 0.9$). No cases of strong correlation were found within the calculation matrix ($|r^2| > 0.9$). This phenomenon requires additional reflection.

The obtained results confirm the hypothesis that the stand vitality of the emergent and canopy layers is the most sensitive to the alkaline earthmetals content in trees fallen leaves.

In general, at Kryvyi Rih mining and metallurgical district for 30-60 years numerous and large artificial woody plantations were created. At present, these plantations have reached their peak of development. Their leading biological and dendometric characteristics have a clear ecological conditionality. For woody plant species, soil moisture deficiency and atmospheric repetition pollution are significant environmental factors. In some cases, negative phenomena in artificial woody plantations are observed. At the same time, these plantations can become a "green framework" for future sustainable development Kryvyi Rih mining and metallurgical district.

3.2 Artificial woody plantations and sustainable development of the Kryvyi Rih district

For the last 40 years, the concept of sustainable development has been considered the only possible strategy for further interaction between man and his natural environment. Currently, there are more than 60 different definitions of the "sustainable development" concept. However, in our opinion, the most successful is the definition that was voiced in 1992 in Rio de Janeiro. According to him, "sustainable development of mankind" is understood as such a development that allows satisfying the needs of the present generation and does not jeopardize the ability of future generations to meet their needs.

In the practice of the sustainable development concept implementing, two main directions can be distinguished: resource-economic and socio-philosophical. In the first case, attention is focused on economics and ordering of natural resource consumption. The second direction involves the further development of the sustainable development concept, substantiation of the philosophical basis of this idea, as well as the search for ways and methods of forming an environmental ("ecological") culture for mankind.

Over the past 20-25 years, a significant number of recommendations for the implementation of sustainable development have been developed. Without diminishing the importance of all the aforementioned directions of sustainable development implementation ideas in modern realities, it should be noted that until now, the biosphere aspect of this concept has not been fully considered. Although it is generally accepted that the biosphere, as a phenomenon of our planet, forms unique conditions where only humanity can exist. At the same time, the existence of the biosphere and its stability are determined by natural forest ecosystems and artificial woody plantations.

In general, the concept of sustainable development is considered as the fundamental paradigm and the dominant vector for the further development of modern forestry. However, in the overwhelming majority of cases, the theoretical aspects of this concept development in relation to the forest were considered in scientific papers. The issues of sustainable development of forests and forestry are also actively discussed. While the applied aspects concerned exclusively the "greening" of forestry and grasslanding, optimization of land use systems, conservation of biodiversity, the study of ecological forest services, etc.

In our opinion, artificial woody plantations can be an important factor for the further sustainable development of the Kryvyi Rih area. In practice, to achieve this goal, the following steps must be taken: (i) artificial woody plantation assessment, (ii) ecological and environment conditionality of artificial woody plantation current state ascertainment, (iii) sustainable model of artificial woody plantation development, (iv) sustainable management of artificial woody plantation, (v) sustainable development of artificial woody plantation (Fig. 2).

<u>Artificial woody plantation assessment</u> intends consistent analyze of the plantation area and the plantation stand. Plantation area assessment has a purpose to study soil characteristics and to analyze the levels of soil and air pollution. Plantation stand assessment has a purpose to get a comprehensive understanding of stand with a vision of biology, dendrology and ecology. Moreover, special attention should be paid to the dendrometric characteristics of the stand and the viability of the stand. These parameters manifest the environmental prospects of the stand at natural forest ecosystems and artificial woody plantations. It should also be noted that the biogeochemical indicators of leaf litter are promising indicators of the forest stand.

<u>Current state of artificial woody plantation</u> is ecologically environmentally conditioned. Therefore, it is so important to identify this conditionality and also develop a model for this conditionality. Moreover, in this model, ecological markers and ecological predictors will be the "active center". In our understanding, ecological markers will manifest the current state of the stand, and ecological predictors will manifest the future state of the stand.

<u>Sustainable model of artificial woody plantation</u> should reflect the optimal floristic composition and spatial structure of future artificial woody plantations. We believe that by choosing adapted tree species and rationally placing tree species on the ground, it is possible to create very promising woody plantations. Such woody plantations will be maximally adapted to the climate, soil and environment of the area. Such tree plantations will be maximally adapted to the climate, soil and environment of the Kryvyi Rih area.

<u>Sustainable management of artificial woody plantation</u> has two directions. The first direction involves the improvement of already existing artificial woody plantations. The second direction involves the creation of new artificial tree plants. By our opinion, these two directions should be based on sustainable model of artificial woody plantation. In this case, the improved plantings and the created plantations will be as stable and efficient as possible.

In the leading countries of the world Issues of ensuring the stable development of natural forest ecosystems and artificial tree plantations are considered in conjunction with ensuring the balanced implementation of environmental and natural resource relations. In this case, the criteria and indicators of sustainable use of forests are a combination of simultaneous: 1) conservation of biological diversity; 2) maintaining the economic potential of forest ecosystems as a source of resources; 3) maintaining the viability of ecosystems that are affected by anthropogenic impacts, man-made pollution, changes in climatic conditions; 4) conservation and maintenance of soil and water resources on the territory of forest ecosystems; 5) ensuring the implementation of functionalities in the prevention of regional climate change in the region; 6) support and strengthening of long-term multiple socio-economic benefits from natural and artificial forests to meet the needs of society, strengthening the recreational and tourist potential of forests, as well as opportunities to meet cultural, social and spiritual needs in the process of forest use; 7) legal, organizational and economic framework for forest conservation and sustainable management in the relevant field. Ukraine is one of the least forested countries in Europe. At the same time, Ukraine has the smallest specific area of forests, both natural and artificial, per 1 ha of its territory compared to other European countries (only 0.178 ha per 1 ha).

In general, an important measure to achieve sustainable development in the Kryvyi Rih mining and metallurgical area is the streamlining of a few existing natural forest ecosystems and the creation of new artificial tree plantations. As is known, artificial tree plantations are able to improve the microclimate of certain areas due to the positive impact of trees on the environment. Due to the influence of tree plantations, the amount of precipitation increases by 5-25%, and the total river runoff increases by 15-20%. Such results are extremely relevant for water-deficient conditions. In addition, natural and artificial forests reduce levels of

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soil and groundwater pollution, prevent the spread of water and wind erosion. When creating artificial woody plantations at Kryvyi Rih area taking into account the levels of soil pollution by heavy metals and their biogeochemical features is very important [2, 7, 22, 24].

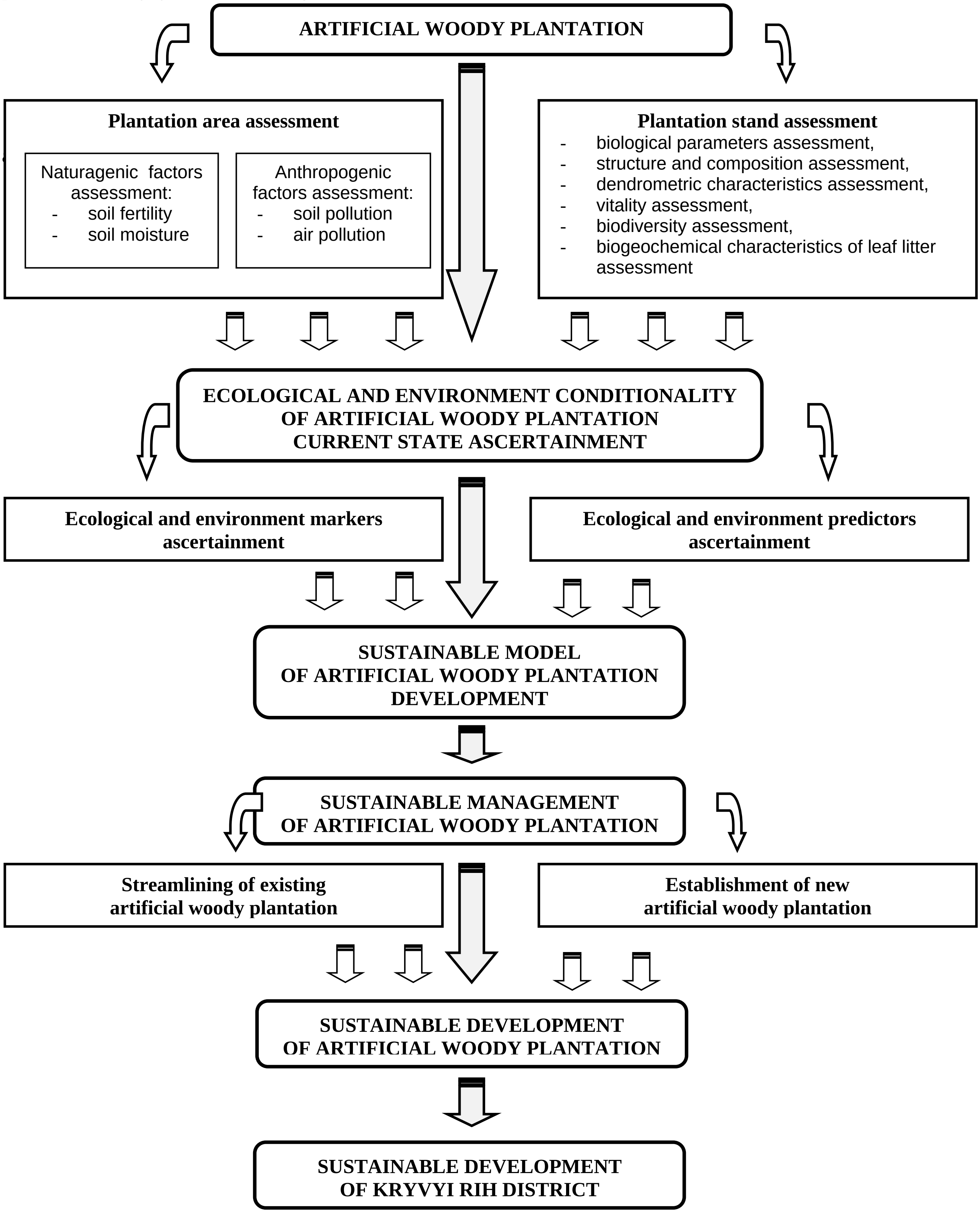

Fig. 2. Conceptual model of artificial woody plantations implementation in sustainable development at Kryvyi Rih district.

4 Conclusions

At Kryvyi Rih mining and metallurgical district for 30-60 years numerous and large artificial woody plantations were created. These plantations have reached their peak of development. Their leading characteristics have a clear ecological conditionality. For woody plant species, soil moisture deficiency and atmospheric repetition pollution are significant environmental factors. In some cases, negative phenomena in artificial woody plantations are observed. At the same time, these plantations can become a "green framework" for future sustainable development Kryvyi Rih mining and metallurgical district.

Artificial woody plantations can be an important factor for the further sustainable development of the Kryvyi Rih area. In practice, to achieve this goal, the following steps must be taken: (i) artificial woody plantation assessment, (ii) ecological and environment conditionality of artificial woody plantation current state ascertainment, (iii) sustainable model of artificial woody plantation development, (iv) sustainable management of artificial woody plantation, (v) sustainable development of artificial woody plantation.

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Population structure and symbiotic relationships of the invasive species *Sinanodonta woodiana* (Lea, 1834) in water bodies of Ukraine

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Abstract. Understanding the process of penetration and distribution of the invasive species *Sinanodonta woodiana* is important for predicting associated changes in biodiversity and the structure of freshwater communities. The biomass, density, age and sex structure of mollusk populations were analyzed. An increase in the size of Chinese pond mussels was noted after the introduction: the shell length of individuals from a pond (Romanivka village, 2017) was 24,2% more than of mollusks from the Velyka Repida river (Matroska village, 2004), and in 2019 it increased by another 14,7% (by 42,5% compared to the shell length of the mollusks from the Velyka Repida river). The body weight of *S. woodiana* from the river was 125,3 g, while in the pond there was a 2,13-fold increase in body weight in 2017, with a further increase in this indicator by another 23,6% in 2019 and another 37,7% in 2020. The relative number of *S. woodiana* and native species *Unio pictorum* and *Anodonta anatina* in 2017 was 26,3%, 47,4% and 26,3%, in 2020 – 64,0%, 16,0% and 20,0% respectively. Ciliates of the genus *Conchophthirus* and *Trichodina*, *Aspidogaster conchicola*, *Helobdella stagnalis*, larvae of *Chironomus* sp. are in a symbiotic relationship with *S. woodiana*. The most common *Conchophthirus* sp. – in 21,6% of individuals. Further spread of *S. woodiana* to the cold regions of Ukraine and the formation of new populations in the already developed regions should be expected.

1 Introduction

There is a problem of colonization of territories by invasive species in many countries these days. This is one of the largest environmental problems of our time, which is associated with active processes of biotic globalization.

Invasive species in new habitats, as a rule, do not have natural enemies to control their numbers, which contribute to their rapid spread and a sharp increase in numbers in the newly populated area. Invaders, directly and indirectly, affect native species in natural ecosystems. An invasive species has a direct impact, entering into a relationship of interspecific competition with local species for resources of the same type. As a result, it can suppress or completely displace native species, which leads to a simplification of the structure of the community and a decrease in its resistance to external influences. An indirect influence is associated with a change in the system of evolutionarily formed complex relationships of local organisms with the habitat. The spread of an invasive species in new habitats leads to the disruption of the established biocenotic relationships between native species. An invasive species can bring its symbionts from their native range, where they were originally distributed, and can also acquire local symbionts in a new range [1–5]. Penetrating new regions, it enters into relationships with local species, negatively affecting the size and structure of their populations, resulting in a reduction in natural biodiversity.

The bivalve freshwater mollusk *Sinanodonta woodiana* (Lea, 1834) is an invasive species that was introduced into freshwater bodies of Europe in the middle of the last century and continues to colonize new territories. Its original range is in East Asia. However, from the second half of the twentieth century, a rapid expansion of the range of *S. woodiana* began. Due to its ecological features and wide morphological variability [6], this species of unionid mollusks is actively spreading further, as indicated by the constantly growing number of new sites in which *S. woodiana* is found [7–9]. Although this mollusk was previously considered a thermophilic species, it is found both in reservoirs with a changed (due to the discharge of heated waters) and with a constant water temperature. Depending on the temperature of the aquatic environment, only the density of the settlement and the biomass of this species change. Thus, the population density of *S. woodiana* in favorable conditions of existence usually ranges from several to tens of individuals per square meter. In fish ponds, which do not receive heated waters, the population density of the Chinese pond mussel is relatively low – about 4 individuals per m^2 [10].

Understanding the process of penetration and distribution of an invasive species is important in

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predicting the associated changes in biodiversity and biocenosis structure. However, at present, information on the symbiotic relationship of *S. woodiana* in the biocenoses of European freshwater bodies, where the mollusk enters, is scarce [11–14].

Our study aimed to study the structure of populations of the species *S. woodiana* introduced into the water bodies of Ukraine and its symbiotic relationship with local species of freshwater fauna of Ukraine.

2 Material and methods

2.1 Study area and sampling

The material was the authors' collections from the Velyka Repida river (Matroska village, Izmail Raion, Odessa Oblast) (geographic coordinates – N 45°33'43"; E 28°77'70") in July 2004. Also, the collection of material was carried out in July–August 2017, 2019 and 2020 from a pond in Romanivka village (Berdychivsky Raion, Zhytomyr Oblast) (geographic coordinates – N 49°89'22"; E 28°48'80"). A total of 94 specimens of *S. woodiana* were examined.

The mollusks were collected by hand at a depth of 0,7–2,5 m. The density of their settlement was determined by the site method. The biomass was calculated by weighing live mollusks together with the liquid of the mantle cavity, followed by recalculating the mass per unit of bottom area. The species identification of mollusks was carried out according to generally accepted literary sources [15; 16]. The age of the animals was determined according to the lines of winter growth arrest. The sex of the mollusks was determined by a smear made from the gonad fluid after its opening. Statistical analysis of the data was performed using descriptive statistics and independent samples t-test.

2.2 Symbiont detection

The mollusks underwent a complete parasitological dissection with the preparation of temporary preparations of symbionts. The animals inhabiting *S. woodiana* were initially searched for on the surface of the mantle, oral lobes, gills, in the mantle fluid, and then inside internal organs such as the gonads, pericardium, and kidneys.

The prevalence of symbionts was determined as the percentage of infected hosts with a specific species or group of symbionts. The intensity of invasion is an arithmetic mean of the number of parasites per one infected individual of the host. Abundance index – the average number of a particular species or group of parasites in all host individuals (including uninfected ones).

Determination of the systematic affiliation of symbionts was carried out using keys and scientific articles devoted to the taxonomy of the corresponding groups [17–20].

The study of the morphological organization of local species of freshwater fauna was carried out visually by the movement of objects in a drop of water, at magnifications of 40–400 times based on a biological microscope ULAB XY-B2. The observation was accompanied by photographing using an IS Capture digital camera designed for observation, photographing and video projection of transparent objects in transmitted ordinary light.

3 Results and discussion

3.1 Population structure of *S. woodiana*

For the first time in the Ukrainian part of the Danube river basin, the Chinese pond mussel was recorded in 1999 [21], where the species probably entered from Romania, spreading downstream of the Danube. The Velyka Repida river is a left tributary of the Danube, where the collection of mollusks was carried out in 2004 and 2005 (Matroska village, Izmail Raion, Odessa Oblast).

The entry of *S. woodiana* into a pond in the Romanivka village (Berdychivsky Raion, Zhytomyr Oblast), most likely, occurred in 2005 as a result of the release of mollusks glochidia during their temporary maintenance (for two summer months in special cages-baskets) under conditions natural reservoir. Chinese pond mussels, collected from the Velyka Repida river, got into the pond.

The population density of *S. woodiana* in the Velyka Repida river was 1,8 ind./m^2, the biomass was 227,1 g/m^2 (Table 1). In the pond, the density of this mollusk during the study ranged from 0,3 to 4,0 ind./m^2, and the biomass – from 133,5 to 1354,8 g/m^2.

Table 1. Changes in quantitative indicators of *S. woodiana* and its populations

Year	Shell length, mm (M±SD)	Weight, g (M±SD)	Median age	Population density, ind./m^2	Biomass, g/m^2
Velyka Repida river, Matroska village					
2004	106,2± 8,9	125,3± 25,7	4,3	1,8	227,1
Pond, Romanivka village					
2017	131,9± 6,8	267,0± 41,6	3,6	0,5	133,5
2019	151,3± 4,2	330,1± 35,1	3,9	4	1354,8
2020	158,6± 4,2	454,4± 35,3	3,9	0,3	145,4

The lower values of these indicators for mollusks from the pond in Romanivka village in 2017 and 2020 may be associated with more severe winter conditions in the north of Ukraine since the water temperature has a direct effect on the growth rate, reproduction and distribution of this species. However, in 2019, we saw a surge in the number of Chinese pond mussels in the local population from a pond in the Pyatygirka river.

Like any invasive species at the stage of conquering new territories, individuals of *S. woodiana* actively reproduce, spread, and, easily winning interspecific competition with native bivalve mollusks for environmental resources, grow rapidly from year to year.

The average shell length of individuals living in the Velyka Repida river was 106,2 mm, whereas, after introduction into the pond, mollusks significantly increased in length. Thus, the average shell length of individuals collected in 2017 was 24,2% more ($p<0,01$) than that of mollusks from the Velyka Repida river, and in 2019 increased by another 14,7% (by 42,5% compared with the length of the shell of the Chinese pond mussels from the Velyka Repida). The average shell length of specimens collected in 2020 remained almost unchanged, but the average mass (with shell) continued to grow. Thus, the mass of *S. woodiana* from the river was 125,3 g, while in the pond, a 2,13-fold increase in body weight was noted in 2017 ($p<0,01$). In 2019, in mollusks collected from the same local population, this indicator increased by another 23,6% (Table 1), and in 2020, Chinese pond mussels also increased their body weight by another 37,7%. Although the average age of individuals in this local population in 2019 and 2020 increased slightly to 3,9 years compared to 3,6 years in 2017, the increase in shell length and body weight was faster. This process is especially noticeable when studying the growth of these parameters in age groups. So, if 2-year-old individuals collected in 2017 and 2019 weigh the same, then by the age of 6 year the body weight gain is more noticeable in individuals collected in 2019 (5,6 times) compared to 2017 (3,9 times). These data indicate that the Chinese pond mussel, thanks to its modification variability, is adapting better and better to new conditions of existence every year.

The age structure of *S. woodiana* populations was studied according to the ratio of age groups – young individuals (1–3 years): average age (4–6 years): older group (7 years and older). In populations from two areas, individuals aged from 2 to 8 years were found, in particular, from the Velyka Repida river, 3–8-year-old mollusks were found, and from a pond in Romanivka village – 2–7-year-olds. The age structure consists of representatives of all age groups: the ratio of age groups is 0,8 : 1 : 0,2 for mollusks from the Velyka Repida river and 0,9 : 1 : 0,04 for Chinese pond mussels from the pond. In both populations of mollusks, the most numerous is the middle age group (from 4 to 6 years old). Young individuals account for a slightly smaller percentage of the total collection. Thus, in the river, 3-year-old mollusks represent 39,5% of the population of the studied group (Fig. 1), and in the pond, 2- and 3-year-old individuals – 45,1%. The smallest is the older group (2,0–9,3%). We did not find 1-year-old individuals in two local populations, and 2-year-olds were found only in the Velyka Repida river. The presence of a large number of young individuals in the studied populations of *S. woodiana* indicates its active reproduction.

In the sex-age structure of *S. woodiana* from the Velyka Repida river, the most numerous group among all age groups are 3-year-old males, from the pond – an equally large number of 3- and 4-year-old males and females (Fig. 2). The number of females and males of other age groups is much less.

The sex-age structure in the Velyka Repida river more reflects the invasive nature of the *S. woodiana* species. The presence of a large group of 3-year-old males suggests a growing population in this collection site. In the pond, all age groups are represented relatively evenly, which indicates the sufficient viability of this population and the transition of the Chinese pond mussels from conquering the territory to stable existence in this water body.

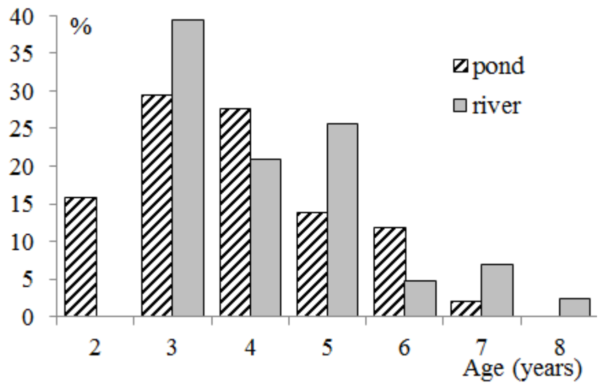

Fig. 1. Age structure of *S. woodiana* population from surveyed biotopes (the ratio of individual age categories to the total number of individuals, %).

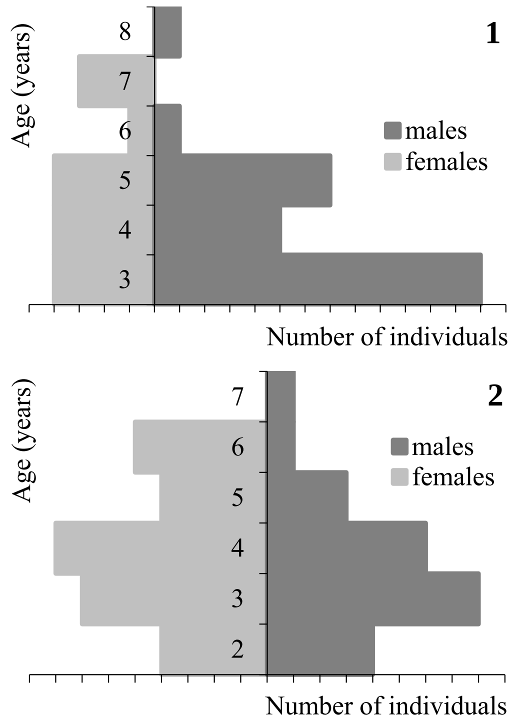

Fig. 2. Sex-age structure of *S. woodiana* population from the studied water bodies: 1 – Velyka Repida river, Matroska village; 2 – pond, Romanivka village.

The sex structure of the population from the Velyka Repida river was dominated by males (female : male ratio is 0,6 : 1). Whereas in the sex structure of the studied group from the pond, females quantitatively prevailed over males (1,2 : 1). This may indicate active reproduction of the invasive species in a new place. Also, almost all females from the pond during the period of collecting the material had a gill pregnancy (85,7%), that is, all age groups of mollusks, including 2-year-old individuals, participated in reproduction. The smallest female with glochidia in the gills had a shell length of

9,3 cm. That is, even with a slow growth rate of mollusks at the beginning of their life in a reservoir with a natural temperature regime in northern Ukraine, they are capable of reproduction at 2 years of age.

It is known that individuals of *S. woodiana* reach sexual maturity already in the first year of life with a shell length of about 30 mm [22], while the native *Anodonta* species reach maturity at 2 years or later [23]. This feature of the reproductive biology of the Chinese pond mussel gives a significant competitive advantage over the local unionid mollusks.

3.2 Advantages of *S. woodiana* in freshwater biocenoses and its impact on their biodiversity

One of the key factors in the success of a species invasion is its tolerance to environmental stress. There is ample empirical evidence that invasive species can better tolerate adverse conditions than native species. Thus, researchers have studied the resistance of *S. woodiana* to thermal stress and trace metallic zinc pollution stress. The higher tolerance of this mollusk in stress tests was associated with a significant decrease Rhodamine B accumulation, indicating more efficient multixenobiotic resistance mechanism; with significantly higher INT reduction capacity; with less pronounced changes in the activity of stress-related enzymes (glutathione-S-transferase, catalase) and neurotoxicity biomarker (cholinesterase) [24].

We noted a high variability in the shape and color of shells in *S. woodiana* from the two studied biotopes. The shape of the shells of individuals of the initial population from the Velyka Repida river is most often rounded (the shape of the lower edge of the shell corresponds to a regular semicircle), however, it can be elliptical and irregularly rhombic (the lower edge of the shell forms an obtuse angle). The mollusks from the pond in Romanivka village do not have a rounded shell. The specimens here are usually elliptical, although a third of the specimens have an irregular rhombic shape. An egg-shaped form is occasionally found.

The color of the periostracum of 2/3 of the mollusks of the progenitor population (the Velyka Repida river) is bright green. The rest of the individuals are olive-colored with a small amount of yellow or brown. All individuals from this biotope have pink stripes along the growth lines and vertical green rays. The general background of the periostracum of half of the mollusks from the pond is yellow-green, the second half of the Chinese pond mussels have a darker olive-brown color. The latter variants, as a rule, have a proportion of gray color against the general background of the shell. In all specimens, areas of the periostracum along the growth lines, especially in the lower part, are colored red, and vertical green rays are visible on the shell.

So, the color of shells from the Velyka Repida river is light, bright, while the color of the mollusks from the pond is dominated by a dark general background, which is probably associated with living in very turbid water. Specimens from the Velyka Repida river are more similar in shape and color to typical *S. woodiana*, while specimens from the pond in Romanivka village resemble mollusks of the genus *Anodonta*. Such a wide morphological variability of individuals of the Chinese pond mussel is its specific feature, which allows *S. woodiana* to adapt better to different habitats.

Since an invasive species readily adapts to new living conditions, it can rapidly increase the density of the newly formed population and, as a result, threaten native species. We observed such relationships in the investigated pond between *S. woodiana* and two other species of unionid – *Unio pictorum* Linnaeus, 1758 and *Anodonta anatina* Linnaeus, 1758, which form joint malacofauna. The relative number of *S. woodiana* and native species *U. pictorum* and *A. anatina* in 2017 was 26,3%, 47,4%, and 26,3%, respectively. In 2020, the ratio of these species in the malacofauna changed and amounted to 64,0%, 16,0% and 20,0%, respectively. However, much earlier, before the Chinese pond mussel appeared in the pond, there were more other mollusks of the Unionidae family: the population density of *U. pictorum* was 2,1 ind./m^2, and *A. anatina* – 1,5 ind./m^2. That is, after the introduction of the Chinese pond mussel, the number of local species of unionid mollusks significantly decreased: from 3,6 ind./m^2 (in 2005) to 0,2 ind./m^2 (in 2020).

Thus, *S. woodiana* is a large species of bivalve mollusks, which actively assimilates the environment in a new habitat, multiplies intensively, and rapidly increases in size and weight. Due to these features, it can be an attractive settlement site (microbiota) for various freshwater symbionts.

3.3 Symbiotic relationship of *S. woodiana* in new biocenoses

Among the wide variety of interconnections of living organisms in ecosystems, such a type of interspecific relations as symbiosis is distinguished. A symbiotic relationship is a type of close interspecies relationship in which at least one of the species benefits from it. The forms of symbiosis are quite diverse [25]. So, one of the forms is commensalism, in which one of the partners (commensal) imposes on the other (the owner) the regulation of his relations with the external environment and thus receives a certain benefit, without bringing the owner either harm or benefit. Also, a form of symbiosis is parasitism – a form of interspecific relations in which one organism (parasite) exists at the expense of another (the host), repeatedly using it: feeding on its blood, tissues or digested food, and also using it as a temporary or permanent habitat.

Various forms of biological connections between species serve as regulators of the number of living things in a community, determining its stability.

Among the organisms found in association with *S. woodiana*, one can distinguish the group of truly symbiotic organisms for which association with the host is obligatory throughout the life cycle (ciliates of the genus *Conchophthirus* and *Trichodina*, *Aspidogaster conchicola* Baer, 1827) and the group of free-living organisms, which, as a rule, accidentally enter the mantle cavity of the mollusk, but can live there permanently

(*Helobdella stagnalis* Linnaeus, 1758, larvae of *Chironomus* sp.).

Thus, we found the genus *Conchophthirus* (Oligohymenophorea: Conchophthiridae) typical ciliates to unionid, which are found in aboriginal species from similar biotopes. These ciliates are widespread and occur exclusively in freshwater bivalve mollusks [26]. Ciliates were identified on the gills and in the mantle fluid from the mantle cavity of the *S. woodiana*, where they live and actively move. The prevalence of *Conchophthirus* sp. in the mantle cavity of the Chinese pond mussels was 21,6%. The body of these ciliates is flat, elliptical, with a mouth near the middle of the body. They have dense cilia over the entire surface and an average length of about 100 microns. Sometimes it can attach to host tissues, especially gills and oral lobes, without causing harmful effects on these tissues. Host age has no effect on invasion by the ciliate *Conchophthirus* sp. Individuals of age categories from 2 to 6 years old were infected.

We found a parasitic ciliate of the genus *Trichodina* (Oligohymenophorea: Trichodinidae) on the gills of *S. woodiana* (Fig. 3). The prevalence is insignificant – 5,9%. The intensity of the invasion of the Chinese pond mussels was 3,7 specimens per individual. Ciliates of the genus *Trichodina* from the mantle cavity of mollusks *S. woodiana* have also been identified and described by Chinese researchers [27].

The obligate parasite *A. conchicola* (Trematoda: Aspidogastridae) is widespread and occurs in all species of the Unionidae family. It has a direct life cycle, which allows it to successfully and quickly enter the symbiocenosis of a species new to the ecosystem. The parasite can complete its life cycle without leaving the mollusk. Adults mature in the pericardial cavity and kidneys, in which they remain to live. In most cases, there were no lesions associated with the vital activity of *A. conchicola*. However, it can damage host tissue through suction and feeding. Local cellular changes are possible, such as necrosis, metaplasia. Mollusks can encapsulate aspidogasters (encapsulation reaction or granuloma) if they invade tissues [28, 29].

In the examined mollusks, the level of invasion with aspidogasters is low. Thus, the prevalence of these parasites is 13,7%, and the intensity of invasion is 2 specimens. The abundance index is only 0,3 ind. Aspidogasters were found in the pericardium in 71,4% of the invaded individuals and in the kidney – in 42,9%. Host age does not significantly affect helminth infection. So, individuals of almost all age categories from 3 to 7 years old were infected. However, 2-year-olds were not infected with *A. conchicola*.

Among the facultative symbionts, we identified the two-eyed flat leech *H. stagnalis* (Clitellata: Glossiphoniidae), which was localized in the mantle cavity of *S. woodiana*. Its body length was 6–10 mm, width was 1–3 mm. The body is short, wide, and flattened dorsally. The front half of the body can stretch strongly. The body is grayish-white, with a large number of brown spots on the dorsal side. A distinctive feature of the species is a brown lenticular plate on the back between the 12th and 13th rings, which is visible through a microscope. Also, this leech has only one pair of eyes that are quite large. The prevalence of this symbiont was 9,8%. The two-eyed flat leech belongs to the organisms of macrozoobenthos, as it lives in stagnant and flowing water bodies on plants and stones, to which it attaches with the help of suckers. It prefers small stagnant overgrown reservoirs. It is α-mesosaprobe. The two-eyed flat leech is very mobile and can swim.

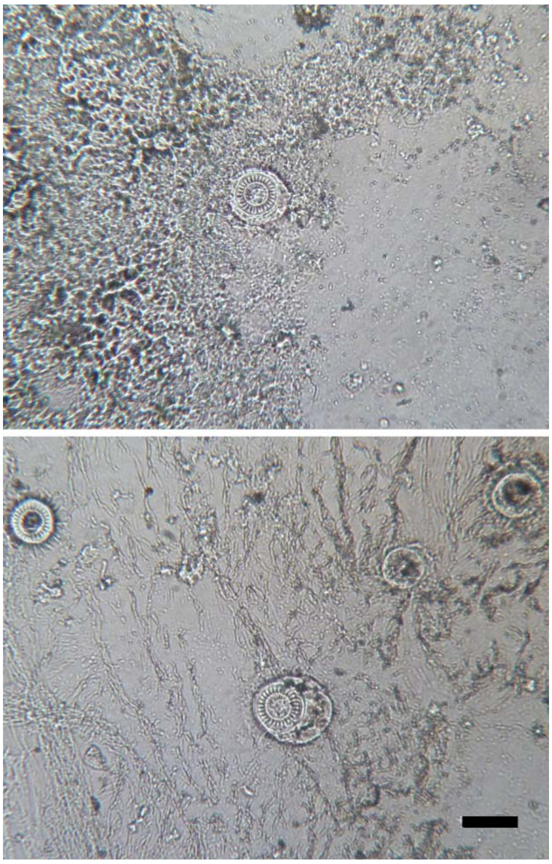

Fig. 3. *Trichodina* sp. found in the mantle cavity of *S. woodiana* (×200). Scale bar: 200 μm.

We found larvae of *Chironomus* sp. (Insecta; Chironomidae) between the external gills and the mantle. The prevalence in the studied mollusks is insignificant – 3,9%. The intensity of symbiont is minimal – 1 specimen per individual. Taking into account the low values of the prevalence and intensity of colonization of the Chinese pond mussels by these organisms, it is possible that they accidentally entered their mantle cavity. However, getting into the mantle cavity, they can exist in association with the mollusk for a long time (this assumption is supported by the fact that the identified above-mentioned free-living organisms were alive and active at the time of the dissection).

So, 45.1% of the studied individuals of *S. woodiana* from the pond in Romanivka village was inhabited by symbionts. Mixed invasions were observed in 17,4% of individuals. Other mollusks were inhabited only by representatives of one taxonomic group.

As for the prevalence of symbionts, depending on the age of the mollusk, in 2-year-old specimens of the Chinese pond mussel this indicator is the smallest (12,5%)

among the age groups, and only one symbiont was found in them – the ciliate *Conchophthirus* sp. (Fig. 4). Almost all symbionts described in the article are found in 3-year-old mollusks and their prevalence in this age group is 53,3%. Only the larvae of *Chironomus* sp. identified in 4-year-old and older individuals. The prevalence of symbionts in 4-year-old *S. woodiana* and older age groups is 42,8–66,5%.

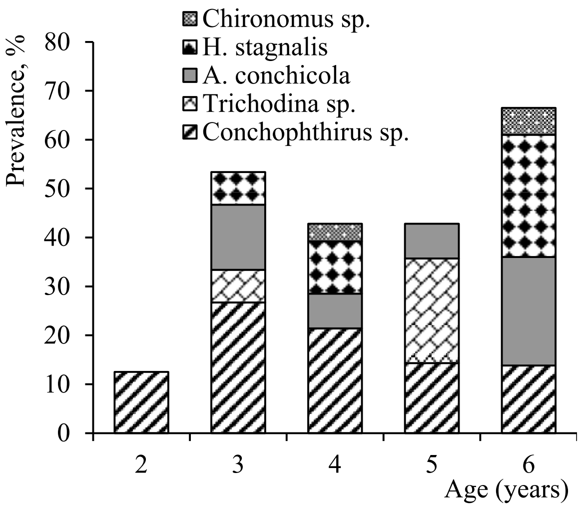

Fig. 4. Prevalence of symbionts in *S. woodiana.*

The large bivalve mollusks *S. woodiana* are an attractive habitat for various freshwater symbionts. This is possible due to the biological characteristics of the species (a large body size and significant biomass in the ecosystem) and its ecological features (resistance to water pollution and oxygen deficiency) [30]. Such hosts provide the best opportunities for symbionts for nutrition, mobility, protection from anxiety, and reduce the risk of predation.

4 Conclusions

It was determined that even significant climatic differences between the invasive part of areas (a reservoir with a natural temperature regime in northern Ukraine) and the native part do not create a barrier for the spread of *S. woodiana*. The low water temperature does not limit the spread of the Chinese pond mussel, which indicates the significant ecological plasticity of this species and the ability to survive and spread in conditions of sufficiently low temperatures. The high percentage of females with gill pregnancy indicates that the development of mollusk larvae under new conditions is close to normal. The presence of a large number of young individuals in the age structure of the population indicates the active reproduction of local populations.

The Chinese pond mussel easily conquers new habitats, where it enters into a variety of biocenotic relationships with local species of freshwater fauna, thereby confirming the stability of its existence in new conditions. Our results show that *S. woodiana*, a species alien to Ukraine, can be inhabited by various groups of symbionts living in Europe. Among the local symbionts in mollusks from a pond in Romanivka village, we noted ciliates *Conchophthirus* sp., two-eyed flat leech *H. stagnalis*, larvae *Chironomus* sp. that enter commensalism with mollusks, *Trichodina* sp. and *A. conchicola*, which are parasites of the mollusk. Also, the Chinese pond mussel enters into a relationship of interspecific competition (like any invader species) with local mollusks of the Unionidae family, significantly reducing their numbers. That is, *S. woodiana* can, directly and indirectly, influence the natural biota of the aquatic habitat in the invasive part of the range.

Further spread of *S. woodiana* to the cold regions of Ukraine and the formation of new populations in the already developed regions should be expected.

In the future, we consider it expedient to monitor the state of the *S. woodiana* population from the pond in Romanivka village, to study the annual changes in the age and sex structure, the features of the growth rate of the shell of mollusks and the influence of the invader on the native species of unionid mollusks.

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Long-term assessment, modeling and forecast of salinity conditions of reclaimed mine dumps of Western Donbass

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Abstract. The neutralization of toxic mine rocks with additional of soil and loess like loam mass leads to a significant decreasing of salts migration at the contact zone. The mathematical model was working out follow general principle where mine rock is pollution source, but soil and loess like loam take place as volumetric filter for water-soluble salts. MathCAD file with commands for solving the problem forecasting the process of vertical salinization of reclaimed minelands was developed. The prospect for the numerical model using up to the most accepted range of values with experimental data shown. The irrigation of reclaimed minelands in the Western Donbass possible in the case of the dilution of the mine waters of aquifers with the Samara river water.

1 Introduction

Rainfall, evaporation, rock weathering, saltwater intrusion, or chemical contamination can cause the salt source for soil salinization in abandoned and reclaimed minelands [1]. Modelling is a suitable alternative technique that saves time and cost for the environment monitoring [2]. Meantime the performance of the models should base on long-term monitoring data. The fate of chemical substances in the soil is complex and dynamic, depending on such factors as clay level, soil pH, hydraulic conductivity, structure, and many others [3]. From the general convection-dispersion function describing solute transport in porous media, several numerical and analytical models have evolved [4, 5]. These include the finite difference approaches. HYDRUS, SALTMOD, PESTFADE, UNSATCHEM, SODIC and SWAP have been widely used as seasonal models to consider the interaction between soil-water and water-soluble salts [6-8]. HYDRUS-2D demonstrates the relevance of numerical modelling in evaluating the water and salt dynamics under drip irrigated horticultural trees [9]. DRAINMOD-S was useful either for the design of a new drainage system and long-term impacts assessment on the groundwater table and soil salinity [10]. All hydrogeological processes: filtration, mass transfer and moisture transfer are those that have a limit and steady state. Pessimistic options have prospects. They calculate theoretically and prevent in advance [11]. Field experiments established 30-40 years ago in reclamation stations in areas affected by mine works require additional research to justify the choice of a mitigation technology or rock deposits replacement in a way that would guarantee the least negative consequences for the environment. It is necessary to introduce a procedure of environmental impact assessment (EIA) for the recommended technologies of reclamation of disturbed lands [12]. The EIA methodology involves the identification of impacts, the choice of mitigation technology, following modeling and forecasting its positive effect.The main objective of our research was to substantiate decisions to create favorable ecological and reclamation conditions on reclaimed mine dumps in the Western Donbass.

2 Materials and methods

The data on salinization of two land reclamation profiles in 1987, 1995, 2003, 2008 and 2018 obtained in the conditions of the Pavlograd experimental station of the DSAEU. The station founded in 1976 in the floodplain of the Samara River in order to examine the best restoration measures. Typical abandoned site shown in the figure 1.

Other example connected with intention to create dachas for mining workers in Pavlogradsky district just in reclaimed minelands (Fig.2). The scheme for reclamation of disturbed land based on the study of the effectiveness of capping the mine dumps with different layers of black-soil mass (chernozem) both with and without a shielding layer of loess - like loam. The following models of artificial land reclamation profiles were used to look into the peculiarity of upward migration of toxic salts from the mine dumps: 1 Mine rock (MR) + 50 cm of the top black soil (50BS); 2. MR + 50 cm of the loess-like loam (50LLL) + 50BS. Soil and rock samples taken along both

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profiles, mixed thoroughly, air-dried and sieved through a 2-mm diameter stainless steel screen.

Fig. 1. Abandoned mining site in Western Donbass.

Fig. 2. Small dacha in reclaimed minelands in Western Donbass.

Soil pH and EC measured using a soil-to-water ratio of 1:1. pH and EC distribution in two land reclamation profiles are shown in fig 3.

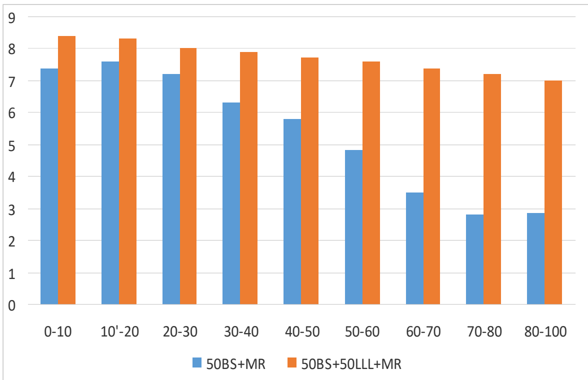

Fig. 3. pH distribution in two artificial profiles.

The differences in pH and EC profile distribution between two profiles demonstrate the negative impact of underlying toxic mining rocks caused with weathering in space and time. The applied model of the moisture-salt transfer process based on the theory of physicochemical hydrodynamics of porous soils. Mass transfer processes are described by differential equations of motion and conservation of matter mass of the second order in partial derivatives of elliptic and parabolic types according to this theory. One - dimensional versions of these equations used for solving practical problems. This process describe by the equation of movement and of mass of matter mass keeping:

$$D\frac{\partial^2 c}{\partial x^2} - V\frac{\partial c}{\partial x} = m_0\frac{\partial c}{\partial t}, \qquad (1)$$

where C – soil salinity, %; D – hydrodispersion coefficient; x – spatial coordinate; t – time; V – infiltration rate, m/day; m_0 – topsoil moisture, %. This is due to the fact of the salt transfer in the aeration zone takes place mainly in the vertical direction.

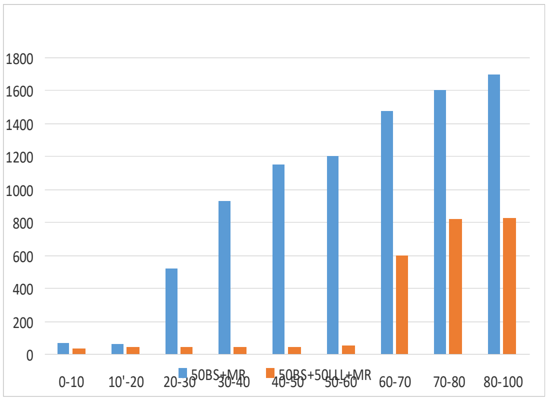

Fig. 4. EC distribution in two artificial profiles, units.

A special MathCAD file created to predict the process of vertical salinization of the topsoil. Commands to solve the simulation problem to this file written. It is enough to substitute the original data into this file. The program itself will calculate the result. Constants and procedures are on the first two sheets of the MathCAD document. They changed under the conditions of introduction of new initial parameters. It is necessary to indicate the depth of the artificial soil profile, modeling time, step in space and time correctly. The operator: = to set the value of the variable used. The name of the variable to the left of it written. Variable value: *upper_border*:=0 and *lower_border*:= 1 is written on the right. Sign (dot) used to separate integer and fractional part in number. Variables *upper_border* and *lower_border* used to establish border boundaries. Value *upper_border* always set to zero. The dimensions along plot are in meters. Variable *dx* used to change the size of the soil layer. The size of the soil layer is set as 10 cm in the section of global constants. This value changed as follows: *dx: =0.1* when the size of the reclamation layer differs. The variable *t* to change the simulation time used. Simulation time in days is measured. The number of year's t: = translated into the number of days. The number of simulation steps (periods into which the simulation time is divided) must also be set. The number of steps from 10 to 16 recommended. It is possible to use other values as well. The variable steps: = 32 used to set the number of steps. The variable *n* used to find the number of steps in space. It calculated automatically by the command:

$$n := \frac{(lower\_border - upper\_border)}{dx}.$$

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This command can not be deleted. The most important step in future modeling is to enter the initial salinity values. The character C denotes salinity. It inserted in a slightly different way than all other data since salinity is not one value. Character *C* selected in toolbar in the menu after entering C: = Item "Insert - Matrix". It is necessary to select the number of horizontal and vertical values in the window that appears. The number of values horizontally is always set to 1. A step plus one vertically should indicate the height of the soil profile. A blank for entering salinity data of the soil profile will appear on the screen. The results are displayed on the screen using the command res= after that. Name *res* used in the previous command (or  - on the toolbar) used to construct the surface of the results Command "Insert - Graph – Surface Plot". 3D a surface with three coordinates (y (*C*) is the salinity of the soil, z (t) is time, x is the spatial coordinate, dm) appears on the screen.

3 Results

The choice of measure to neutralize potentially toxic rocks related to the ratio of precipitation and evaporation at each site. Evaporation is a negative component of the water balance. Evaporation involves a complex water vapor between the ground surface and the atmosphere. Its value depends on the depth of groundwater, lithological composition of the rocks, vegetation cover and complex climatic factors. The maximum evaporation for the Dnipropetrovsk province is 800 – 820mm [13]. The ratio between precipitation and evaporation is 0.5. The rate of vertical moisture - salt transfer preliminarily estimated by the balance method according to the formula (2):

$$\boldsymbol{V} = \frac{\boldsymbol{P-(E-W)}}{\boldsymbol{1000T}}, \qquad (2)$$

where P - precipitation, mm, E – evaporation rate, mm, W – water accumulation (moisture removal with plant biomass), T – grass vegetation period, days. The coefficient of water consumption (W) varied depending on the type of plant – from 450 to 550 m^3/t. In subsequent calculations, the formula used to calculate the hydrodispersion coefficient (3):

$$D = V \cdot \frac{x}{2 \cdot ln\left(\frac{C_2}{C_1}\right)}, \qquad (3)$$

where V – velocity of vertical moisture transfer, m/day; C_2 – salinity at a point with the coordinate of the mine dump (x, m), C_1 – mineralization depending on the surface of the dump. The mathematical model was refined in the second stage by solving multivariate forecast problems to the best coincidence of the calculated values with the experimental data. The use of such an approach in the mathematical model of vertical salt transfer along profile of the dump of mine rocks allowed taking into account the surface runoff. Equation (1) proved for this to the form of boundary differences:

$$D\left(\frac{C_{i+1}^{\tau+1}-2C_i^{\tau+1}+C_{i-1}^{\tau+1}}{(\Delta x)^2}\right) - V\frac{C_{i+1}^{\tau+1}-C_i^{\tau}}{\Delta x} = m\frac{C_i^{\tau+1}-C_i^{\tau}}{\Delta t} \qquad (4)$$

where τ – time grid point number; i – spatial grid point number. The boundary condition of the 3rd kind Dankwerts - Brenner [14] was given at the upper bound:

$$[C(0,t) - C_n] \cdot V = D\frac{\partial C(0,t)}{\partial x} \qquad (5)$$

Boundary condition of the 1st kind (C_0 = const) was set at the lower limit. Consider more carefully the boundary condition at the upper bound. Write the formula (5) in another form:

$$(V_2 - V_1)(C_n - C_0) = D\frac{\partial C}{\partial x} \qquad (6)$$

After giving the equation in the form of finite differences and opening the brackets in the left part of the formula we get the following formula:

$$V_2C_n - V_2C_0 - V_1C_n - V_1C_0 = D\frac{C_0 - C_1}{\Delta x}. \qquad (7)$$

We proceeded from the position that the third component in the left part was equal to zero, because the evaporation of salts from the soil surface under natural conditions does not occur. The boundary condition in this case takes the following form:

$$DC_0 + \Delta x V_2 C_0 + \Delta x \cdot V_1 \cdot C_0 = D \cdot C_1 + \Delta x \cdot V_2 \cdot C_n, \qquad (8)$$

where V_1 – ascending flow rate of the substance, m / day;
V_2 –downward flow rate of the substance, m / day;
C_p –mineralization of precipitation, %
C_0 –salinity on the top soil, %;
Δx –step along the spatial coordinate, m

The vertical transfer rate was calculated as the speed difference V_2-V_1 taking in account that this boundary pre-condition is used. The salinity forecast scenarios was made for the two- and three layers reclamation profiles during a period of three decades (Fig. 5 and 6).

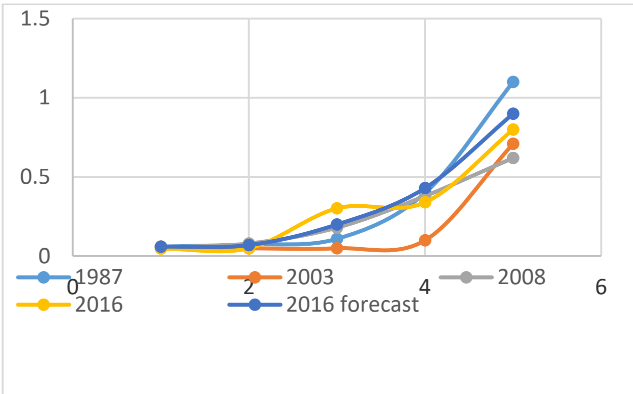

Fig. 5. Estimation and forecast of salinization of the two-layers profiles, %.

The results of the forecasts for one of the two recommended reclamation profiles are in good agreement with the data of experimental observations for 1987, 2003, 2008 and 2016. The analysis of changes in the content of water-soluble salts at the contact of the lower layer of the soil with the mine rock in the trial MR + 50cm Black Soil indicates a slow decrease in the soil mineralization. The tendency of slow increase in salinization of the upper soil layers of the artificial reclaimed profile is recorded. At the same time, the comparison of soil salinization data in the options MR + 50cm Black soil and MR+ 50 cm Loess Like Loam + 50 cm Black Soil testifies in favor of the three - layer reclamation profile. The same conclusion made after trend analyse analysis of water-soluble salts vertical migration in technogenic edaphotops of reclaimed mine dumps [15].

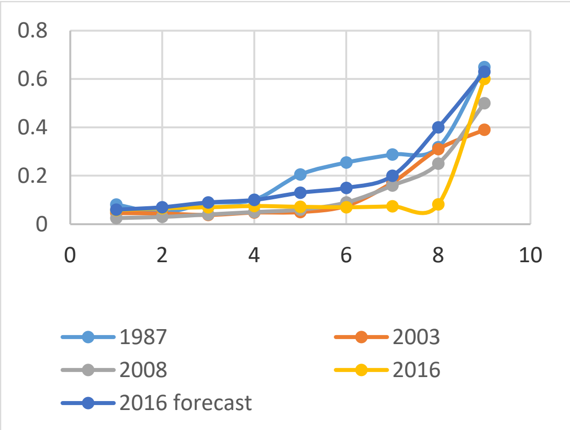

Fig. 6. Estimation and forecast of salinization of the three layers profiles, %.

It is obviously also that there is a certain pattern of growth of the content of soluble salts in the layers in the chernozem, which was dumped on the mine rock, approaching the mine rock. The topsoil looks like a volumetric filter of soluble salts migrating from the lower layer of mine rock. Thus, the salt concentration on the surface will be lower the larger the soil layer. This observation led to the theoretical assumption that the mine rock is a source of salinization, and black soil as volumetric filter for salts migration and absorption by the soil. Therefore, the obtained experimental data allowed building a mathematical model of the generalized dependence of the content of soluble salts in the layer of black soil of different heights, poured on top of the mine rock. The database grouped by the distance of a certain layer, starting from the mine rock, and the corresponding values are plotted on a scatter plot (Fig.7).

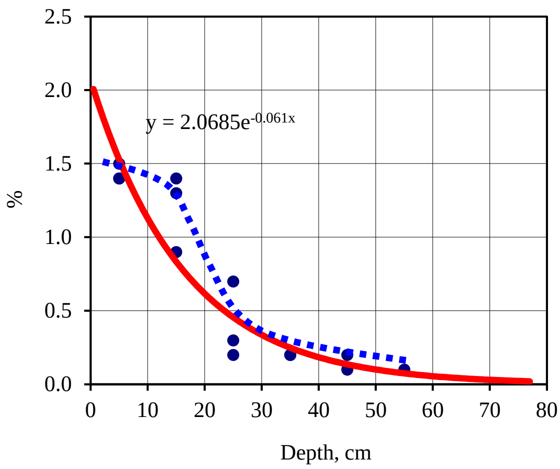

Fig. 7. Dependence of the content of soluble salts on the thickness of the soil layer.

The trend in the form of an exponent represent by a solid line. The possible real dependence presented by a dotted line. The smoothing of the discrete series of values performed by the exponent described above-mentioned assumption. Quantitatively, the molecular diffusion of substances described by first and second laws of the Fick. Under the above conditions, the differential equation of mass transfer of pollutants looks like the equation of diffusion of matter everywhere per unit area (Fick's first law):

$$j = -D\frac{dC}{dx}, \text{ mg/cm}^2, \tag{9}$$

where C is the mass concentration of the flow of the transferred substance through the selected plane, mg / m^3; x is the current coordinate in the direction of flow, m; D is the diffusion coefficient, m^2 / s.

Therefore, according to the law of diffusion, the salts drift into the region with a lower concentration. This process written in the form of an equation for a steady state in the soil in which there is no time factor, namely:

$$\frac{dC}{dl} = -k \cdot C, \tag{10}$$

where C is the concentration of the migrating substance, mg / m^3 or%; l is the thickness of the layer of loose soil), m (cm); k is the filtration coefficient of dissolved salts in the soil, m^{-1}. Analytical solution of equation (10) with initial conditions, for (salt concentration at the boundary of the soil with the mine rock) has a general form

$$C = C_0\, exp(-k \cdot l). \tag{11}$$

Since the nature of salt migration influenced by various factors, the real dependence of the salt content describe by a second-order differential filtration equation. For practical conditions, in our opinion, it is sufficient to apply a simplified version of the exponential dependence, which represent in an approximate normalized form (12):

$$C = C_0\, exp(-0{,}05 \cdot l), \tag{12}$$

where l - the salt content in the topsoil adjacent to the surface of the mine dump or at a depth selected for the initial level of reference in the soil, %. According to the properties of the exponent, a decrease in the salinity of chernozem in *e* times, ie 2.7 times, will be observed at a layer thickness of 20 cm. Almost zero concentration will decrease at a layer thickness of black soil at (3-4) 1 / k , i.e. 3-4 times larger, namely - 60-80 cm.

Verification of this model and its subsequent identification for chernozem was performed three times on the basis of experimental data obtained in the Pavlograd reclamation hospital every eight years. The results of the distribution of salt content in soil samples taken in the reclaimed profiles of the two-layer variant are presented in Figure 8.

As we can see, the content of soluble salts in chernozem depends not only on the soil layer, but also on the period from the beginning of reclamation. In this case, over time, there is an increase in the maximum concentration of salts (curve 2 in Fig. 8), coming from the lower layers of the rock to the chernozem, and then, over the years - a gradual decrease (curve 3).

The calculations showed that in real conditions, when the mode and duration of salinization are unknown, it is possible to use a model that takes into account all available experimental data.

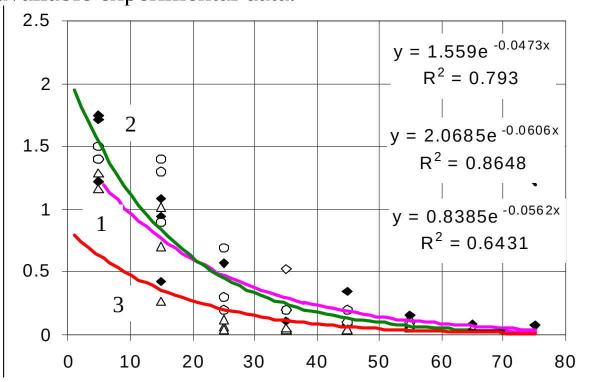

Fig. 8. Profile distribution of salt content (y,%) depending on the thickness of the layer (x, cm) of black soil.

This dependence represented in the form (11), where the coefficient k is approximately in the range of 0.05-0.06 m – 1, and the value will depend on the level of the initial salt concentration in the rock. The introduction of a 50 cm layer of loess-like loam in the option 50BS + 50LLL + MR led to a significant decreasing of the chemical weathering process of underlying mining rocks (Fig. 9).

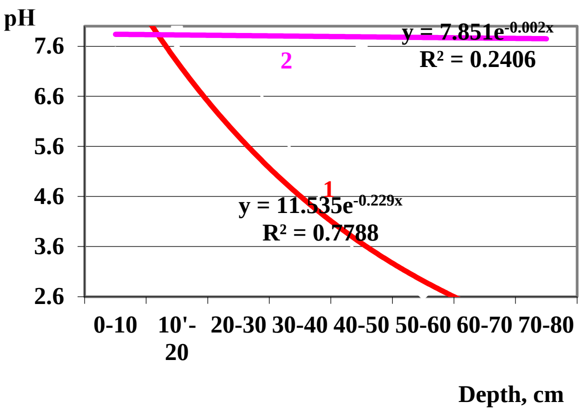

Fig. 9. Modeling of pH distribution along two land reclamation profiles: 1-50BS+MR; 2-50BS+50LLL+MR.

Therefore, pH stabilization in the trial 50BS + 50LLL + MR is possible in the range of 7.6-7.7. Estimation of quality of waste mine waters of the Western Donbass has shown that a certain part of weakly mineralized waters can be suitable for irrigation under conditions of dilution of mine water of artificial ponds by water of the Samara river (Fig. 10).

The results of the calculation of salt migration for the trial with dilution shown in Fig. 11.

The forecast of the salt regime of the reclaimed mine dump with systematic irrigation in the option with water dilution of the irrigation source up to 1.6 g / dm^3 was performed for a period of 5, 10, 20 years in the steady state for the initial salinity of 0.6 and 0.8%. The process characterized by a constant content of salts of the topsoil with slow salinization of the upper part of the mine rock heap. The calculation of the required amount of gypsum as an ameliorant performed by the formula:

$$\ldots\ldots\ldots\ldots \quad R = E \cdot \left[Ca^{++} - C^{++}{}_f\right] \cdot N, \ldots \qquad (13)$$

where R – ameliorant dose, t / ha; E – the equivalent of ameliorant, which is equal to 1 mg - eq Ca^{++}; Ca^{++}– the amount of Ca, which is equal to 43.4mg-eqv/dm^3; N – irrigation rate, thousand m^3 / ha. The dose of gypsum for case study of the Samara river as a source for topsoil irrigation is following:

$$R = E \cdot \left[Ca^{++} - C^{++}{}_f\right] \cdot N =$$
$$8.6 \cdot [16.6 - 11.1)] \cdot 1000 = 0.5 ton / ha$$

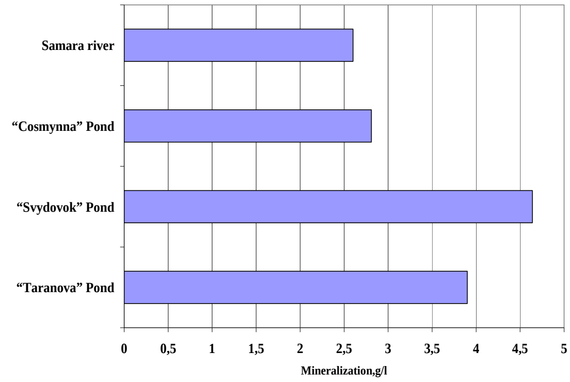

Fig. 10. Water mineralization in river and mine ponds.

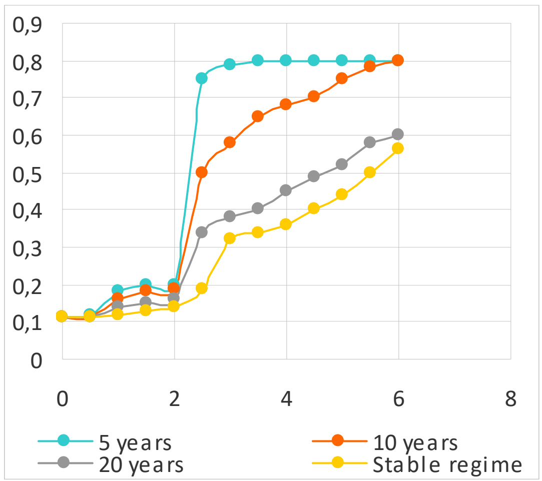

Fig. 11. Dynamics of salt transfer on a reclaimed mine dump with irrigation, %.

The implementation of the environmental protection measures recommended for production took place as follows. On the one hand, some reclaimed territories transferred to the balance of private farms in Pavlograd district. At the same time, a certain share of reclaimed areas given to several horticultural societies with a total area of more than 100 hectares. All of them are located in the floodplain of the Samara River.

The calculations proved that in any case of reclaimed mine dump salinization of the top soil is inevitable. It is necessary to create a flushing mode to prevent it. Irrigation carried out with the minimum norms.

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4 Discussion

The main problem in identifying the optimal scheme of land reclamation in the coal mining regions is the prevention man-made pollution of artificial landscapes [16, 17]. Given the trend of transition from land use as arable land to the state of natural meadows, the latter type of nature management of reclaimed land in the Western Donbass seems less risky for the development of soils vertical salinization.

The solution of the migration problem for reclaimed mine dumps in the steady state with the maximum values of the initial salinity of dump rocks (0.8-1.0%) should be considered as an extreme negative option, leading to intensive accumulation of salts in the soil.

Analysis of vertical migration of salts with the depth of the reclaimed profile showed that none of the options with a top layer of chernozem 30, 50 and 70 cm did not provide complete stabilization of the distribution of pH and water-soluble salts. Predictive calculations based on the theory of migration proved the possibility of salinization of the topsoil without irrigation due to the pulling of salts by the upward flow of moisture.

Therefore, stable and favorable ecological and reclamation conditions created with the use of systematic irrigation. Three types of irrigation regimes used in different natural and climatic zones of Ukraine: compensatory, evaporating and washing [11]. Conditions for the application of compensation and evaporation regimes are more typical for the Central Donbass, where mine rocks are not saline.

The flushing regime of irrigation of reclaimed dumps is more suitable, as they are everywhere to varying degrees saline. Irrigation by brackish water is a possible solution to alleviate freshwater shortages [18]. The simulated results were helpful to provide a basis for assessing the environmental effect under long-term brackish water irrigation.

During long term, salts leaching under the effects of rainfall can contaminate groundwater [19-20]. On the other hand, the salinization phenomenon in the topsoil can be cyclic, and the effect of salinity on crops attenuated with proper management that involves appropriate irrigation for salt leaching [21-23]. This risk reduces in the case of special irrigation strategy. This requires lower irrigation doses and the use of a drip irrigation system associated with proper management practices such as increasing irrigation frequency.

5 Conclusion

Slow salinization of the topsoil described for the three-layer reclamation profile. The introduction of a carbonate-containing layer of loess like loam is a reliable geochemical barrier to counteract the process of vertical migration of water-soluble salts from the surface of the mine dump. Creating a leaching regime with a downward flow of moisture is a guarantee to prevent the development of the process of soil salinization. In this case, irrigation carried out with minimum standards. Irrigation with ponds-accumulators water diluted by water of the Samara River can be tolerable to the grass and induces a low topsoil salinization risk in the artificial land reclamation profile**.** Given the trend of transition from land use as agricultural land to the state of natural meadows and plantations for second generation energy crops cultivation, the latter type of nature use of reclaimed land in the Western Donbass is less risky.

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Removal of Cr(VI) from wastewater by silver-loaded natural clinoptilolite

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Abstract. Presence of hexavalent chromium, Cr(VI), in water is an important environmental and human health problem. Natural zeolites are widely accepted as non-expensive adsorbents for sustainable remediation, however they are not effective in removing metals in anionic form. The paper presents study on use of silver (Ag) modified natural clinoptilolite to immobilize Cr(VI) ions from model and real neutral to slightly alkaline wastewater. Increasing the initial pollutant concentration increases the removed amount (80 % removal from model wastewater in 45 min at initial concentration of 30 mg Cr(VI)/L). The pseudo-second order kinetic equation best describes the Cr(VI) immobilization by the Ag-modified zeolite, which is indicative for the chemical nature of the rate-limiting step of the process. The data obtained are best fitted to the Freundlich adsorption isotherm. The Ag-modified clinoptilolite removes in 30 min over 80 % of Cr(VI), over 75 % of Cu(II) and over 70 % of Zn(II) that present simultaneously in an industrial wastewater. Due to its ability to remove Cr(VI) species, in combination with some heavy metal ions, some organic pollutants and exhibited antibacterial activity, silver loaded clinoptilolite seems to be a possible multifunctional reagent in the water and wastewater treatment and deserves further investigation.

1 Introduction

Hexavalent chromium, Cr(VI), appears in water due to natural and anthropogenic reasons. Oxidation of the chromium presenting in the igneous geologic formations is the natural source [1]. However, it is estimated that more than 70 % of Cr that is found in the environment comes from anthropogenic sources, such as nonferrous metals production (minerals beneficiation, metals smelting and refining), metals finishing and corrosion protection, paper and pulp mills, urban wastewater, etc. The effluents from these industries contain Cr(VI) at concentrations ranging from parts of the tenth to hundreds of mg/L [2]. It is established that both trivalent and hexavalent compounds of chromium are persistent in water [1]. Chromium (VI) is relatively mobile in water because its salts are more soluble than those of Cr(III) [3]. In natural waters Cr(VI) exists mainly as chromate (CrO_4^{2-}) or hydrogen chromate ($HCrO_4^{2-}$) ion [4].

The acute Cr intoxication via water ingestion in humans include severe gastrointestinal disorders, respiratory, liver and kidney injury, and cardiovascular collapse due to severe hypovolemia. The lethal dose is estimated at around 1 g of potassium dichromate ($K_2Cr_2O_7$) [5]. The exposure of human volunteers to Cr(VI) at a single dose of up to 4 mg and to Cr(III) or Cr(VI) at 5 mg in drinking water was not found to cause any adverse effect [2]. No apparent evident clinical changes or health effects were observed in humans who took Cr(VI) via drinking water at doses of between 0,03 and 4 mg per kg body weight (bw) per day for at least 3 days [2, 6]. However, gastrointestinal disorders including diarrhoea, abdominal pain, indigestion, and vomiting were associated with the chronic oral exposure of the general population in China to Cr(VI) through consumption of well water containing 20 mg Cr(VI)/L (considered to be equivalent to 0,57 mg Cr(VI)/kg bw per day). In addition, the oral exposure to Cr(VI) has been found to aggravate dermatitis of sensitive individuals [5].

Some *in vivo* studies showed that oral exposure to Cr(VI) was carcinogenic in rats and mice. The lowest-observed-adverse-effect levels in male and female rats and mice were 0,38 and 1,79 mg Cr(VI)/kg bw per day respectively [7]. Chromium (VI) shows broad genotoxicity that, together with its multispecies and multisite carcinogenicity, represents a strong evidence for a classification of Cr(VI) exposures through drinking water as probably to be carcinogenic to humans [3].

A guideline value of 50 μg/L drinking water is proposed by WHO and the EU for total Cr on the basis of the measurability by the available analytical methods, achievability by nowadays treatment technologies, and the data from toxicology studies [4, 8]. The proposal of the European Commission is this value to be reduced to 25 μg/L in 10 years after the new directive on the quality of water intended for human consumption will be enforced [9].

Different technologies have been applied and /or studied for removal of Cr (VI):

- Reduction coagulation filtration (RCF) - where Cr(VI) is reduced to Cr(III) by addition of ferrous salts or stannous chloride, followed by precipitation of $Cr(OH)_3$,

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the latter process very often aided by addition of ferric coagulants and the final step is filtration [10.]

- Ion exchange - column strong-base or weak-base anion exchange removed 95% of the Cr(VI) ions thus achieving levels below 5 μg/L [11].

- Membrane technologies, such as nanofiltration, reverse osmosis [12] and electrodialysis [13] have been successfully tested at laboratory level for Cr(VI) removal from model wastewater.

- Microbiological removal - activated sludge has been proved at laboratory level to be effective in reducing Cr(VI) to Cr(III) and precipitating the latter within biomass. However, the microbial methods may not be suitable for drinking-water and surface water treatment as chromium removal efficiency decreased with the increase of DO and Cr(VI) initial concentration and the best results were obtained under anaerobic conditions [14].

Each of the methods described above has its own advantages and disadvantages in dependence of the Cr(VI) concentration and the presence of other pollutants resulting in inadequate removal, the high initial and/or operational costs, toxic metals sludge generation and the need of its safe disposal.

Sorption is widely accepted as a suitable method for removing pollutants presenting in relatively low concentrations in the wastewater [15]. Conventional adsorbents such as activated carbon have been widely studied for their ability to remove chromium from water [16].

Recently efforts have been placed in nanomaterials by studying and searching for low-cost and environmentally friendly adsorbents. Activated carbon -based nanocomposites, carbon nanotubes and composites based on them, and graphene-based materials have been studied for their ability to remove Cr(VI) from wastewater by sorption. Metal oxides and metals-based nanomaterials as well as polymer-based nanomaterials have also been investigated for Cr(VI) sorption [17]. However, future studies are needed to investigate the cost-effectiveness and practical applicability of the nanomaterials usage.

Natural and non-expensive adsorbents are intensively searched for in order to reduce the treatment costs and the environmental load of the adsorption process and to ensure a sustainable environmental management.

Zeolites are abundant and relatively cheap aluminosilicate materials. They are non-toxic, thermally and chemically stable - features that render them good materials for pollutants removal by adsorption processes. Their building blocks are SiO_4 or AlO_4 tetrahedral structures, connected in different ways that leads to formation of different crystalline lattice structures and ensuring high specific surface area of these materials. The isomorphic framework substitution of silicon (+4) by aluminium (+3) causes appearance of a charge deficit that is accountable for the need of charge-balancing cations, in order to keep the neutrality of the zeolitic network. Alkaline (Na^+, K^+) or alkaline-earth metals (Mg^{2+}, Ca^{2+}) are the common charge-balancing cations. The mobility of these ions ensures the ion-exchange capability of zeolites for removing cationic species from different effluents [18].

However, due to the negative charge on their surface, zeolites possess very low to negligible affinity for the exchange of anions. In order to use their excellent physical properties, combined with their low price and environmentally friendless, researchers have conducted and are carrying out many studies to tailor zeolites in order to give them the ability to remove anions [19 - 21].

Generally, the following processes have been and are being applied: i) zeolites surface modification with surfactants that ensure availability of positive charge on the zeolite surface, ii) zeolites surface modification with metal ions that form insoluble compounds with the pollutants, and iii) zeolites grafting by using molecules with affinity for negative ions [20].

While the efforts on zeolites modification with surfactants started in the 90-ties of the previous century, the studies on modification with metal ions aiming at immobilization of anions have been developed in the recent 10-15 years [22 - 26].

Faghihian and Bowman [23], who were experienced also in the zeolite modification with surfactants, stated that the metal-modified zeolite showed higher Cr(VI) uptake compared to the surfactants-modified.

In addition, the application of metal-modified zeolites exhibits an advantage of easy preparation - by simple ion-exchange process. In some cases the zeolite could be initially used to immobilize other pollutant, such as lead ions and then already loaded material to be used for removing Cr(VI) [27].

Furthermore, it would be good if the sorbent is able to simultaneously immobilize some heavy metal cations together with Cr(VI) anions - a feature that is expected to be possessed by the metal-modified zeolite if its CEC is not entirely utilized. In the treatment of water, an additional advantage would be the possible bactericidal action of the material used. Zeolite loaded with silver ions (Ag^+), both further reduced or without reduction, showed antibacterial action against *Escherichia coli* and other microorganisms [28 - 31]. Last but not the least, silver loaded zeolite proved to be effective in the removal of an organic pollutant (xanthate) from model and clarified wastewater from flotation of zinc-lead ore [32].

The above described suggests that zeolite loaded with Ag^+ ions could be used as a multifunctional reagent in the treatment of waters contaminated with cations, anions and organic pollutants, e.g. wastewater from various industrial activities or of groundwater intended to be brought to domestic water quality. Since the number of studies using Ag^+-modified zeolites for removing anionic pollutants is relatively low [23, 33], in our opinion, a study on their ability to remove anions deserves the efforts.

2 Materials and methods

Natural zeolitic rock from Rhodopes region of Bulgaria was used. It was milled, the fraction 0.09-0.325 mm was separated by sieving and it was utilized in the experiments. The XRD analysis of the washed material has revealed that it contained 73% clinoptilolite. The classical silicate analysis was applied to determine the chemical composition of the material that was (in wt. %):

SiO_2 – 70,29, Al_2O_3 – 10,90, CaO – 2,97, MgO – 0,51, K_2O – 3,41, Na_2O – 0,46, Fe_2O_3 – 0,28, MnO – 0,04, TiO – 0,06, P_2O_3 < 0,05, SO_3 < 0,05, LOI – 10,99. The theoretical cation exchange capacity (TCEC) was found to be 215 meq/100 g zeolite. Silver ions (Ag^+) were loaded on the zeolite by placing it in contact with 0,1 M $AgNO_3$ solution at solid to liquid ratio = 1 : 20 for 6 hours, pH = 6 and magnetic stirring. Silver-loaded zeolite was washed with distilled water until negative reaction for Ag^+ in washings was reached. The amount of Ag^+ uploaded on zeolite (in this case 79 mg Ag/g zeolite) was calculated by using the data on the solution concentration before and after its contact with zeolite. More information on the zeolite modification and on the characterization of the metal-loaded zeolite can be found in our previous work [31, 32].

Stock solutions containing 1000 mg/L of Cr(VI) were prepared by dissolving K_2CrO_4 in distilled water. This solution was diluted with distilled water as required to obtain the solutions with different concentrations of Cr(VI) thus modelling polluted water. The solution pH was adjusted by adding 0,1 M HCl and 0,1 M NaOH solutions and measured by a laboratory pH meter. Concentrations of metal ions were determined by ICP-AES analysis after separating the solid and liquid phases by centrifugation (800 rev/min).

Experiments were conducted batch-wise: 0,5 g of zeolite, contacting with 50 mL of Cr(VI) bearing solution, was stirred with magnetic stirrer for corresponding time. Our preliminary studies showed as optimum the ratio 100 mL of wastewater to 1 g of zeolite (volume to mass – v: m) and the zeolite particles' size of 0,09-0,325 mm. Solutions containing Cr(VI) in the range from 5 to 30 mg/L (at pH 6) were deployed in the experiments aimed at studying the process kinetics, the impact of initial concentration of the pollutant and determining the adsorption isotherm. The impact of solutions pH value on the Cr(VI) immobilization was studied under the following conditions: concentration - 10 and 20 mg/L Cr(VI); contact time – 30 min and pH value of solutions to be treated 4, 6 and 8.

Table 1. Some parameters of the studied wastewaters

Water sample, Parameter	Sample 1	Sample 2	Sample 3
Ca^{2+}, mg/L	11,6	2,0	73,1
Mg^{2+}, mg/L	3,6	2,4	8,2
Na^+, mg/L	90,3	49,9	26,2
K^+, mg/L	0,7	1,9	3,3
HCO_3^-, mg/L	125,9	97,1	237,1
CO_3^{2-}, mg/L	6,0	18,0	-
SO_4^{2-}, mg/L	109,1	70,4	66
Cl^-, mg/L	12,4	7,8	7,2
Cr (VI), mg/L	16,8	23,2	33,8
Cu, mg/L	8,3	7,4	31,2
Zn, mg/L	19,3	8,8	61,2
pH	8,3	8,5	7,2
Cond., μS/cm	442	297	557

Desorption experiments were made in order to check how strongly Cr ions were immobilized by the silver modified zeolite. One g of preloaded zeolite (by its equilibration with solutions containing 20 mg/L Cr(VI)) was placed in contact for 8 h with 100 mL of distilled water and then the water was analyzed. The separated zeolite was dried and reused under the following conditions: 20 mg/L Cr(VI), pH 6, v: m = 100, 30 min.

In other series of experiments Ag^+-loaded zeolite was placed in contact for 30 min at v: m = 100 with samples of industrial wastewater that was partially treated in an enterprise - Table 1.

Data obtained were processed with the aid of EXCEL program.

3 Equations used

The pollutant removal from the initial solution, was calculated using the equation (1):

$$Removal,\ \% = [(C_o - C_t) / C_o] \times 100 \quad (1)$$

where C_o is the initial and C_t is the pollutant concentration (mg/L) at time t (min).

The quantity of immobilized pollutant q_t (mg/g) was calculated according to equation (2):

$$q_t = (C_o - C_t) \times V / m \quad (2)$$

where C_o and C_t - as mentioned above, m is the mass of the adsorbent (g) and V is the volume of the solution, contacting with the adsorbent (L). When equilibrium is reached the relation gives the amount q_e, (mg/g) of pollutant immobilized per unit mass of the adsorbent at equilibrium:

$$q_e = (C_o - C_e) \times V / m \quad (2')$$

and C_e is the pollutant concentration at equilibrium (mg/L).

Experimental data have been fitted to the equations describing the pseudo first order (PFO) - (3), the pseudo second order (PSO) - (4) and the Elovich - (5) kinetic models [34]:

$$\ln (q_e - q_t) = \ln q_e - k_1 \times t \quad (3)$$

$$t / q_t = 1 / (k_2 \times q_e^2) + t / q_e \quad (4)$$

$$q_t = (1/\beta) \times \ln (\alpha \times \beta) + (1/\beta) \times \ln t \quad (5)$$

where t, q_e and q_t are as described above, k_1 is the PFO rate constant [time^{-1}, 1/min] and k_2 is the PSO rate constant of adsorption [concentration^{-1} x time^{-1}, g/(mg x min)], α - the Elovich initial adsorption rate [concentration x time^{-1}, mg / (g x min)], β [concentration^{-1}, g/mg] - Elovich desorption constant.

Only data from the initial 20 min (that are not very close to the equilibrium) were considered, in order to avoid incorrect conclusions [35].

Isotherms equations that are most often tested in the literature for describing the adsorption from liquid phase, namely, Freundlich (6) and Langmuir (7) isotherms (used in their linear form) [17, 36], were checked for their ability to describe the adsorption equilibrium:

$$\log q_e = \log K_F + 1/n \times \log C_e \quad (6)$$

$$C_e / q_e = 1 / (K_L \times q_{max}) + C_e / q_{max} \quad (7)$$

where q_e, and C_e - as described above, K_F - Freundlich constant $[(mg/g)/(L/mg)^{1/n}]$, K_L is the Langmuir equilibrium constant (L/mg) - related to the free energy of adsorption and the reciprocal of the concentration at which half saturation of the adsorbent is reached, q_{max} (mg/g) is the maximum adsorption capacity, calculated by using equation (7).

Temkin isotherm (8) that takes into the account the adsorbent–adsorbate interactions and the Redlich–Peterson isotherm (9) featuring both Langmuir and Freundlich isotherms and describing sorption on heterogeneous surfaces were also checked (in their linear form) [17, 36] for their ability to describe the process:

$$q_e = B \ln A + B \ln C_e \quad (8)$$

$$\ln (C_e / q_e) = \beta \times \ln C_e - \ln k_R \quad (9)$$

where A [L/mg] - equilibrium binding constant that relates to the maximum binding energy, B = R x T / b is related to the heat of adsorption, R - gas constants ([J/(molxK)], T - temperature [K], b - the Temkin isotherm constant [J/mol], k_R - the Redlich-Peterson constant [L/mg] and β - dimensionless heterogeneity factor, q_e, and C_e - as described above.

4 Results and discussion

Results for Cr(VI) removal from model water as function of time at different initial pollutant concentrations are presented in Figure 1.

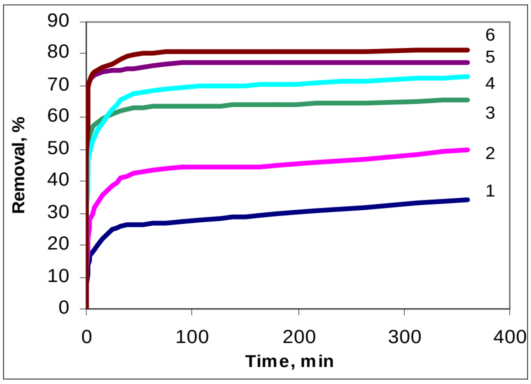

Fig. 1. Removal of Cr(VI) as function of time at different initial concentrations: 1 - 5 mg Cr(VI)/L, 2 - 10 mg Cr(VI)/L, 3 - 15 mg Cr(VI)/L, 4 - 20 mg Cr(VI)/L, 5 - 25 mg Cr(VI)/L, 6 - 30 mg Cr(VI)/L, pH 6, v : m = 100

As it can be seen from the Figure 1, the major part of the Cr(VI) removal occurred in the initial 25-30 min. That is why contact time of 30 min has been chosen in experiments aimed at studying the possible differences in Cr(VI) removal, due to influence of initial pH value of solution as well as the Cr(VI) removal from the real wastewater.

The immobilized amounts of Cr(VI) are of the same order of magnitude as the values described by other works for metal-exchanged (with best results for lead ions) forms of different aluminosilicate minerals, including natural clinoptilolite [25, 27]. However, use of Ag^+-loaded zeolite is more environmentally friendly, compared to Pb-loaded, and the additional advantage is the antibacterial activity of the material.

As it can be seen in the Figure 1, increasing the initial concentration of Cr(VI) increases both the removal (%) and the absolute removed amount of pollutant (mg/g). Similar influence of the initial pollutants concentration was found for the Cr (VI) removal by Martínez and co-authors [37].

The experimental data fitting to equations (3) - (5) showed that Cr(VI) ions immobilization is best described by the PSO kinetic equation, for which the coefficients of determination (R-squared) were the highest, followed by the Elovich model - Table 2. Similar order of kinetics models suitability is found for describing the adsorption of other noxious (arsenic) anions from aqueous solutions by use of manganese ferrite nanoparticles [34].

Table 2. The R^2 value for the studied kinetic models of Cr(VI) removal from model wastewater

Initial concentration, mg/L; Models	Pseudo-first order	Pseudo-second order	Elovich
5	0,993	0,994	0,982
10	0,945	0,999	0,996
15	0,960	0,999	0,997
20	0,986	0,999	0,994
25	0,989	0,999	0,998
30	0,992	0,999	0,995

Generally, kinetics description by the pseudo-second-order equation indicates that the rate-limiting step of immobilization process is of chemical nature. The removal process depends on the concentration of the dissolved pollutant in the solution and the available fraction of active sites of the adsorbent [38]. Most probably, the explanation lies in the formation of low soluble Ag_2CrO_4 on the adsorbents surface.

Another way to check the model adequacy is to compare experimental and calculated with the model values for the quantity of immobilized pollutant - Table 3 (data at 25th min). As it can be seen from Table 3, the PSO kinetic model quite satisfactory describes the process, the relative error for the calculated adsorbed amount is less that 10 % at all initial concentrations of Cr(VI).

The Elovich equation is generally applied to describe satisfactory kinetics of chemisorption for systems with heterogeneous adsorbing surfaces [34]. The relatively high values of R^2 obtained also for the Elovich equation implies the surface heterogeneity of the used modified clinoptilolite.

Table 3. Comparison of q_{exp} and q_{model}, calculated with PSO model.

Initial concentration, mg/L	q_{exp}, mg/g	q_{model}, mg/g
5	0,187	0,206
10	0,396	0,427
15	0,939	0,956
20	1,257	1,311
25	1,846	1,862
30	2,286	2,380

Experimental data fitting to the isotherm equations (6) - (9) showed that the process is well described by the Freundlich isotherm - Table 4.

Table 4. The R^2 value for the studied isotherm models of Cr(VI) removal from model wastewater.

Model	Freundlich	Langmuir	Temkin	Redlich–Peterson
R^2	0,995	0,897	0,937	0,985

In addition, the amounts $q_{e,}$ (mg/g) of pollutant immobilized per unit mass of the adsorbent at equilibrium, calculated using that model are near to the experimentally found (the relative error for the calculated adsorbed amount is less that 10 % for all studied initial concentrations) - Table 5. The process description by the Freundlich isotherm indicates that sorption occurs on heterogonous surfaces, and the obtained value n < 1 implies on the chemical nature of the bonding [17, 36].

Table 5. Comparison of q_{exp} and $q_{e,calc.,}$ calculated with Freundlich model.

Initial concentration, mg/L	$q_{e,exp}$, mg/g	$q_{e,calc.,}$, mg/g
5	0,256	0,2605
10	0,508	0,5329
15	1,0005	0,9106
20	1,461	1,3835
25	1,908	1,9929
30	2,415	2,5004

The immobilization process description by the PSO and Freundlich models has been reported also by other authors for Cr(VI) removal from waters by surfactant modified zeolite [19, 21].

Results showing the impact of wastewater initial pH value on Cr(VI) removal efficiency are presented in Table 6. As it can be seen from Table 6, the Cr(VI) removal is increased at higher pH value. Similar trend was observed for clinoptilolite modified with barium and zinc [27]. The findings could be attributed to the presence of different species of Cr(VI) at different pH values, and their affinity to silver and the stability of the formed surface species [17].

Results from desorption experiments showed that about 2 % of Cr(VI) were immobilised.

Table 6. Influence of wastewater initial pH on the Cr(VI) removal, in %, for 30 min

Initial Cr(VI) concentration / pH	4	6	8
10 mg/L	2,4	40,4	43,0
20 mg/L	3,6	65,6	82,4

When the zeolite was reused, the Cr(VI) removal in 30 min was 43,8 % implying for the possible use of the zeolite in more than one cycle.

Results from experiments with industrial wastewaters are presented in Table 7.

Considering the complicated water matrices (compared to the model waster - i.e. solutions prepared with distilled water), surprisingly good results for the Cr(VI) removal were found. Having in mind the parameters of the studied water samples (Table 1), as well as the observed influence of the initial pollutant concentration and the initial pH value (found for model waters - Figure 1 and Table 6), the good results could be ascribed to the impact of those factors.

Table 7. Pollutants removal from wastewater, in %, for 30 min

Water , pollutant	Sample 1	Sample 2	Sample 3
Cr (VI)	80,54	95,98	91,03
Cu(II)	95,1	86,6	76,7
Zn(II)	78,3	71,4	69,8

An additional positive result is the immobilization of copper and zinc ions, which is not unexpected and could be related to the unused entirely sorption capacity of the zeolite at its loading with silver ions.

5 Conclusions

Modification of natural Bulgarian zeolite - clinoptilolite by its loading with silver ions renders it able to immobilize Cr(VI) from practically neutral to slightly alkaline industrial wastewater.

Increasing the initial pollutant concentrations in the model wastewater (in the studied range) increases the removed amount (reaching 80 % in 45 min at initial concentration of Cr(VI) = 30 mg/ /L).

The kinetics of Cr(VI) immobilization by the Ag-modified zeolite is best described by the pseudo-second order kinetic equation that is indicative for the chemical nature of the rate-limiting step of the Cr(VI) immobilization.

The data obtained are best fitted to the Freundlich adsorption isotherm.

The silver-loaded clinoptilolite removes in 30 min over 80 % of Cr(VI), over 75 % of Cu(II) and over 70 % of Zn(II) that present simultaneously in industrial wastewater.

In conclusion, we can say that due to its ability to remove Cr(VI) species in combination with some heavy metal ions and some organic pollutants, as well as the exhibited antibacterial activity, silver loaded clinoptilolite deserves further investigation as a multifunctional reagent in the wastewaters treatment.

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The formation of the leaf surface area and biomass of the miscanthus giganteus plants depending on the sewage sludge rate

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Abstract. The case study to determine the peculiarities of Miscanthus giganteus aboveground biomass formation depending on sewage sludge and composts rate carried out in the Precarpathian region of Ivano-Frankivsk province on sod-podzolic soils. The largest area of the leaf surface of miscanthus is formed in the trials where fresh sewage sludge was applied in the rate of 20 - 40 t/ha. The leaf surface area increases from 19 up to 24.0 cm2/plant, and the yield of raw mass of plants at the level of 23.5 - 25.1 t/ha due to increasing rates of sewage sludge application. The highest indicators of net photosynthesis productivity were found in the period of intensive growth, which amounted to 7.78 g/m²/day and in the maturation period of 7.56 g/m²/day in the trial SS - 40 t/ha + $N_{10}P_{14}K_{58}$. The amount of dry mass of miscanthus plants significantly depends on the height of the shoot and the leaf surface area of the plants. The use of compost based on sewage sludge and straw in a ratio of 3: 1 at a rate of 30 t/ha contributes to the dry weight of miscanthus plants at the level of 15 t/ha.

1 Introduction

The three main land-use groups in EU are: built-up areas, forest and agricultural land including mixed crop-livestock, pasture/livestock grazing, permanent crop production systems and bioenergy crops [1]. The biomass of energy crops occupies an important place in solving the problem of replacing traditional energy sources with alternative ones. Oil crops (82% of the land used for biodiesel fuel production) took first place in EU countries in 2015 [2]. The rest area for the production of ethanol crops (11%), biogas (7%), and heat generation (1%) used. Dedicated energy crops are mainly perennial grasses (miscanthus or switchgrass) and short rotation coppice such as willow or poplar. Poland, France, Germany, Spain, Romania, Sweden and the United Kingdom are the largest energy crops producer countries of the total European acreage [3-5]. For instance, withdrawn in 2009 short rotation plantations scheme was granted in Poland at national level for such energy crops as willow, poplar, Miscanthus and Sida hermaphrodita [6].

According to European experts, the area of land available for growing energy crops in 2020 will increase up to 20.5 million hectares, and in 2030 - up to 26.2 million hectares. Today 8 million hectares are unproductive in Ukraine [7]. Growing energy crops on marginal lands makes sense to estimate the use of some wastes. These wastes considered as fertilizers available to promote high yields [8]. Meantime the question about the fertilization impact on energy crops availability as biofuel is still an open debate [9, 10].

A wide range of feedstocks is available in abundance for biofuel production in industrialized countries using municipal solid waste [11]. The use of biomass residues, municipal and agri-waste as primary resource for biofuels is a promising proposal to reduce technogenic load connected with the waste disposal. Biomass is the biodegradable fraction of products, wastes, and residues of biological origin from agriculture (including plant and livestock), forestry, and related industries, including fisheries and aqua culture, as well as the biodegradable fraction of industrial and household waste [12]. Municipal sewage sludge considered as potential source of macroelements, which recovered during the production of energy crop biomass [13 - 16]. It is composed of a wide range of organic matter (OM), microorganisms, macro- and micro-nutrients, non- organic and organic micro pollutants [17] All these components indispensable for proper functioning of plants in optimum quantities and proportions for fertilization purposes [18]. However,

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sewage sludge also contains heavy metals, polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) [19-21]. The combination of different methods and the modification of chemical immobilizing agents both improved the fixation effect on heavy metals [22]. It allowed introducing municipal sewage sludge for growing crops at arable lands a dose of not more than 10 tons/ha for three years according to the Ukrainian state standard [23]. Large doses are possible in the case of mineland reclamation after three years monitoring, calculation of heavy metals uptake with energy crops yield and forthcoming life cycle assessment availability of municipal sewage sludge and other soil amendments application [24]. Fertilization at certain stages of the energy grass lifespan can maintain plantation production performance even in the later years of cultivation [25]. Agronomic and energy efficiency analysis to evaluate the effects of sewage sludge applied at rates equivalent to 100 and 160 kg N ha^{-1} on the production of giant miscanthus made [26]. Energy efficiency was 43–52% higher when giant miscanthus plants with sewage sludge rather than mineral fertilizers supplied. The highest energy value of biomass yield was in the treatments with 20MgDM$ha^{-1}$of sludge application [27]. The knowledge about the effect of large doses of sewage sludge on the energy crops longterm plantations is insufficient [28, 29]. Perennial herbaceous plants are considered to be promising for cultivation. Miscanthus as a relatively new energy crop for Ukraine requires additional study on the efficiency of cultivation in different soil and climatic conditions [30 - 32]. Miscanthus × giganteus can produce a high yield of aboveground biomass at relatively low input costs [33, 34]. Miscanthus can improve soil structure and levels of organic matter in marginal lands [35] and use for both liquid and solid biofuels production as raw material [36]. The crop characterize by extensive root/rhizome growth. This process can reduce soil compaction and allow a greater water buffering capacity [37]. The use of sewage sludge could not only increase yield but also positively affect biological and physico – chemical properties of soil profile [38]. It is known also that the intensity of organic matter accumulation depends on the size of the leaf surface, which is determined by the biometric parameters of plants and largely depends on their nutrition requirements [39, 40]. Miscanthus leaves take great importance for the formation and intensity of biomass accumulation [41]. During the season of plant vegetation, the shape and size of the leaf surface varies considerably [42, 43]. That is why it difficult to conduct biometric measurements. The aim of our research was to determine the dependence of the size of the leaf surface area and miscanthus biomass on different rates of sewage sludge and compost made on its basis.

2 Materials and methods

The field experiment was carried out during 2016 - 2019 in the sod-podzolic gley medium loamy soil at the territory of the Maidan village situated in Tysmenytsia district of Ivano-Frankivsk province. The scheme of field experiments included the following options: 1. Without fertilizers - control; 2. $N_{60}P_{60}K_{60}$; 3. $N_{90}P_{90}K_{90}$; 4. Sewage Sludge (SS) - 20 t/ha + $N_{50}P_{52}K_{74}$; 5. SS - 30 t/ha + $N_{30}P_{33}K_{66}$; 6. SS - 40 t/ha + $N_{10}P_{14}K_{58}$; 7. Compost 20 t/ha + $N_{50}P_{16}K_{67}$; 8. Compost 30 t/ha + $N_{30}K_{55}$.

The sewage sludge and straw mixed in ratio 3: 1 to prepare compost. Leaf area was determined by scanning 20 plants in each trial. After the measurement, the sheets were cut into pieces up to 25 cm long. The cutted parts of one sheet were folded into a transparent envelope (stationery file) in such a way that the individual pieces did not touch each other. After that, files with parts of the sheet were scanned. The same resolution was provided for all scanned images.

The analysis of the scanned images was performed using the Area S 2.1 program [44, 45]. The net productivity of photosynthesis was determined as the accumulation of dry matter per day per unit area of leaves. Measurements were performed during the growing season and determined the average. Net photosynthesis productivity defined as the accumulation of total plant biomass (every 20 days during the growing season) relative to the average leaf area over the same period.

Crop accounting performed by the method of continuous mowing of biomass in the accounting area and weighing the green mass to determine the dry matter content 3 times. The dry matter content determined by thermostatic weight method at a temperature of 105 ° C.

3 Results

During the four years of research, the average height of miscanthus plants in the field experiment varied from 1.85 m to 2.95 m (Table 1). The height of plants increased by 14 and 23% in the trials 2 and 3 respectively compared to the control. The additional height growth in three next options (4-6) was fixed in combination SS – 40 t/ha + N_{10} $P_{14}K_{58}$. During the application of compost based on sewage sludge and straw best result on height, number of plant stems and output of dry biomass was obtained in trial 8 (30 t / ha + $N_{30}K_{55}$). The number of plant stems increased with the amount of applied fertilizers based on sewage sludge at the rate of 20 - 40 t/ha (options 4 - 6) from 6 to 13 pieces/m^2 compared to the control (option 1). Application of sewage sludge and straw compost at the rate of 20 - 30 t/ha (options 7 - 8) led to the number of stems increasing up to 16 - 22 pcs/m^2 higher than at the control. The dependence of the leaf surface area on the height of miscanthus plants established using the method of correlation analysis (Fig. 1).The plant height and the leaf surface area were in the control variant 1.85m, and 11.5cm^2/plant correspondingly. The application of mineral fertilizers in the dose $N_{60\text{-}90}P_{60\text{-}90}K_{60\text{-}90}$ (options 2 and 3) increased the height of plants by 0.26 - 0.44 m, and the leaf surface area - by 2.0 - 2.5 cm^2/plant. The sewage sludge at the rate of 20 - 40 t/ha (options 4 - 6) impact on the plant height and leaf surface area was 2.24 - 2.72 m, and 18.5 - 23.8 cm^2/plant respectively.

Table 1. Miscanthus productivity parameters depending on sewage sludge rate application.

№	Trials	Height of the main shoot, m	Number of stems, pcs/m^2	Dry biomass yield, t/ha	Moisture content in biomass, %	The output of dry biomass, t/ha
1	Control	1.85	16	22.1	21.4	10.0
2	$N_{60}P_{60}K_{60}$	2.11	20	23.0	27.8	10.4
3	$N_{90}P_{90}K_{90}$	2.29	25	23.8	29.2	11.0
4	SS – 20 t/ha + N_{50} $P_{52}K_{74}$	2.24	22	23.5	26.1	10.6
5	SS -30 t/ha + $N_{30}P_{33}K_{66}$	2.56	26	24.4	28.7	11.7
6	SS – 40 t/ha + N_{10} $P_{14}K_{58}$	2.72	29	25.1	31.6	12.2
7	SSCompost– 20 t/ha + $N_{50}P_{16}K_{67}$	2.81	32	26.0	32.4	12.8
8	SSCompost– 30 t/ha + $N_{30}K_{55}$	2.95	38	26.9	32.9	13.0
	LSD $_{0.05}$	0.5	1.0	0.3	1.2	0.2

However, the leaf surface area of miscanthus plants was 6.1 - 8.4 cm^2/plant more than the leaf area of plants of the control variant in case of applying compost based on sewage sludge at the rate of 20 - 30 t / ha (options 7 and 8). The correlation dependence of the leaf surface area on the height of miscanthus plants described by the following multiple regression equation:

$$y = 7.1678 + 0{,}0143x,$$

where y – is the area of the leaf surface, cm^2/plant; x – plant height, m. It was determined that the leaf surface area of miscanthus plants depends on the height of the plant. This dependence can be considered as close, because the coefficient of determination is $R^2 = 0.69$, and the correlation coefficient r = 0.74.

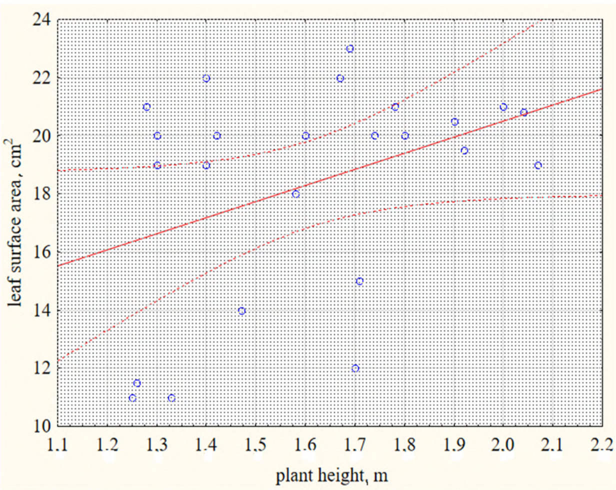

Fig. 1. Correlation dependence of leaf surface area on the height of miscanthus plants, average for 2016–2019.

The leaf surface area of miscanthus plants significantly depends on the number of stems and the height of shoots (Fig. 2).

The height of the dewlines was 2.24 - 2.72 m, the area of the leafy surface was apparently 18.5 - 24.0 cm^2/dewline, and the number of dewlines - 11.3 - 12.7 pcs/m^2 for the siege of sewage waters near the rate 20 - 40 t/ha (options 4 - 6).

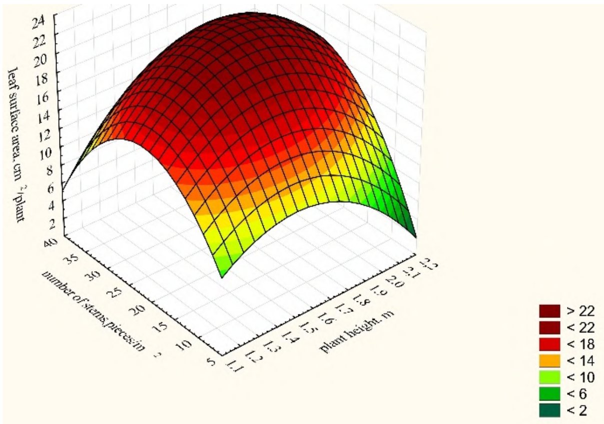

Fig. 2. Dependence of the leaf surface area on the number of stems and the height of the miscanthus shoot, average for 2016 - 2019.

The fallowness of the area of the leafy top of the number of stalks and the height of the pagoon of the muscanthus can be described by the following simple regression:

$$c = 1729.6509 - 14.683x - 75.8414y - 0.017x^2 + 1.2845xy - 2.5305y^2$$

where: c - the area of the leaf surface, cm^2/ plant; x - height of the growth, m ; y - the number of stems, pcs / m^2.

Miscanthus belongs to the plants of the C_4 group of photosynthesis, which are able to intensively accumulate the sun energy during the vegetation period [46]. This plant is highly resistant to diseases and pests [47]. About 95% of the total plant biomass is formed in the process of photosynthesis. The dynamics of accumulation of dry plant biomass reflects the intensity of its assimilation process [48]. The power of the assimilation apparatus and the duration of its operation is a decisive factor in the productivity of photosynthesis [49]. The dynamics of the formation of the photosynthetic apparatus in miscanthus is similar to other taller plants. [50]

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The net productivity of photosynthesis (NPP) of miscanthus plants varies according to the surface area of the leaves (Table 2).

The introduction of 20 - 40 t/ha of SS and mineral fertilizers (options 4 - 6) impact on NPP at the initial growth was 3.64 - 3, 73 g/m^2 per day. The NPP at the initial growth increased and amounted to 3.65 - 3.69 g/m^2 per day with the application of composts based on sewage sludge (options 7 - 8). Meantime the NPP at the initial growth was 3.65 g/m^2 per day with the application of mineral fertilizers at the rate of $N_{90}P_{90}K_{90}$ (option 3).

Table 2. Net productivity of photosynthesis of miscanthus plants depending on fertilizer application rates, g/m^2 per day.

No	Trials	Initial growth	Intensive growth	Maturation
1	Control	3.55	7.45	7.30
2	$N_{60}P_{60}K_{60}$	3.61	7.58	7.39
3	$N_{90}P_{90}K_{90}$	3.65	7.63	7.45
4	SS 20 t/ha + N_{50} $P_{52}K_{74}$	3.64	7.61	7.40
5	SS 30 t/ha + $N_{30}P_{33}K_{66}$	3.68	7.69	7.47
6	SS 40 t/ha + N_{10} $P_{14}K_{58}$	3.73	7.78	7.56
7	Compost 20 t/ha + $_{0}P_{16}K_{67}$	3.65	7.60	7.38
8	Compost 30 t/ha + $N_{30}K_{55}$	3.69	7.65	7.44
	LSD $_{0.05}$	0.01	0.03	0.01

The NPP at the intensive growth of plants was the highest during the introduction of sewage sludge and was7.61 - 7.78 g/m^2 per day (options 4 - 6), which is 0.11 - 0.33 g/m^2 per day more than in control (option 1). The NPP at the intensive growth decreased by 0.1 - 0.4 g/m^2 per day with the application of composts (options 7 - 8) compared to the sewage sludge options 4 – 6 data.

The NPP during maturation remained the highest with the introduction of sewage sludge at the rate of 40 t/ha + $N_{10}P_{14}K_{58}$ and amounted to 7.56 g/m^2 per day. According to the obtained research results, the photosynthetic activity of plants in different vegetation periods remained the largest in the variants where sewage sludge was applied.

The net productivity of photosynthesis depended on the leaf surface area of miscanthus plants (Fig. 3).

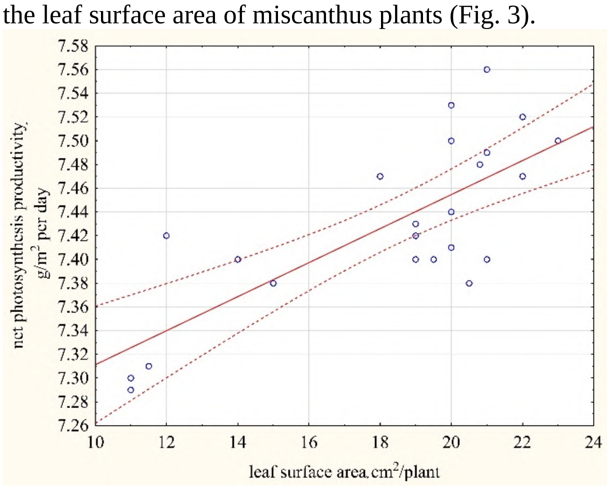

Fig. 3. Dependence of net productivity of photosynthesis on the leaf surface area of miscanthus plants, average for 2016 - 2019.

The net productivity of photosynthesis of miscanthus plants significantly depends on leaf surface area of miscanthus plants. The dependence of the net productivity of photosynthesis on the leaf surface area of the miscanthus plant described by the following regression equation:

$$y = 6.821 + 0.0556x$$

where: y is the area of the leaf surface, cm^2/plant; x – net productivity of photosynthesis, g/m^2 per day. The coefficient of determination R^2 was 0.79, i.e. the closeness of the connection can be considered as significant. There is a positive relationship between the net productivity of photosynthesis of miscanthus plants with the leaf surface area and the rate of fertilizer application. The dry mass yield of miscanthus plants depends on the height of the shoot and the area of the leaf surface of the plants (Fig. 4).

The dependence of the amount of dry mass of miscanthus plants on the height of the shoot and the area of the leaf surface can be described by the following equation:

$$c=12.1185-0.1587x+2.3991y-0.00766x^2+0.3554xy-0.71084y^2$$

where: c is the yield of dry mass of the plant, t/ha; x is the area of the leaf surface, cm^2/plant; y - plant height, cm. The multiple coefficient of determination (R^2 = 0.74) indicates a close correlation between these indicators.

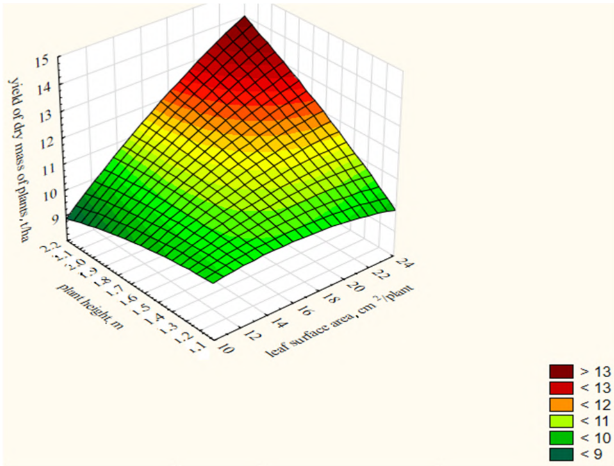

Fig. 4. Dependence of the accumulation of the dry weight of the miscanthus plant on the height of the shoot and the area of the leaf surface.

Thus, the highest productivity of miscanthus is achieved in the trials 7-8, where plants have the largest (24.0 cm^2/plant) leaf area. The coefficients of multiple regression are significant, since the actual value of the t-criterion exceeds the theoretical one by 5% of the significance level (Table 3).

According to the obtained results, the value of the regression coefficients for the yield of dry mass of plants (F_f = 196.32> $F_{0.05}$ = 1.22) is -26,356 with a standard error of 62.9 and the materiality criteria tf (t $_{0.05}$ = 1.33) is equal to 7.2. Thus, the value of the regression coefficients for the leaf surface area (F_f = 66.254> $F_{0.05}$ = 1.22) is -87.4178 with a standard error of 25.1 and a materiality criterion ($t_{0.05}$ = 1.33), which equal to 3.5.

Table 3. Coefficients of multiple regression of the dry weight and the leaf surface area of the miscanthus plant.

The yield of dry mass of the plant (F_f=196.32> $F_{0,05}$=1.22)			
Regression coefficients	**Values of regression coefficients**	**Standard error Sb**	**Significance criteria t_f ($t_{0.05}$ =1.3)**
c	-26.356	62.92730	7.204340
bx	0.7865	0.160104	10.63481
by	48.766	10.07493	5.173311
Leaf surface area (F_f=66.254> $F_{0.05}$=1.22)			
c	-87.4178	25.0682	3.48704
bx	4.1611	2.2231	1.87171
by	39.3230	7.7302	5.08694

4 Discussion

The dependence of the dry mass of the plant on the shoot height and the leaf surface area based on several biometric parameters. The genetic and physiological mechanisms underlying biomass production of the *Miscanthus* species awaits further investigation [51]. It was described also highly significant dependence of the number of stomata on the leaf surface and age [52]. The morphometric analysis confirmed higher growth performance of the fertilized trials [53]. Our case study results are consistent with other conclusions that the yield, specific leaf area and leaf area index of Miscanthus stimulated by N fertilization [54]. The greatest impact on the leaf surface of miscanthus in our field experiment has the height of the plant, the number of stems, which, in turn, depending on the application of fertilizers.

The yield of dry mass of plants depends on the area of the leaf surface and the height of the plant. Miscanthus requires intense sunlight during the growing season to form the optimum leaf area and accumulate sufficient organic matter [55].

The net photosynthetic productivity of miscanthus plants in our research was closely related to the leaf surface area. This dependence characterized by high density (R^2 = 0.79).

5 Conclusions

It was found that the greatest impact on the leaf surface of miscanthus has the height of the plant and the number of stems, which, in turn, depend on the application of fertilizers. The yield of dry mass of plants depends on the area of the leaf surface and the height of the plant. The largest area of the leaf surface of miscanthus is formed in the trials where fresh sewage sludge was applied in the rate of 20 - 40 t/ha. The leaf surface area increases from 19.0 up to 24.0 cm^2/plant with increasing rates of SS application. The highest indicators of net photosynthesis productivity were found in the period of intensive growth, which amounted to 7.78 g/m²/day and in the maturation period of 7.56 g/m²/day in the trial 6 (SS - 40 t/ha + $N_{10}P_{14}K_{58}$). The amount of dry mass of miscanthus plants significantly depends on the height of the shoot and the leaf surface area of the plants. Multiple coefficient of determination (R^2 = 0.74) indicates a close correlation between these indicators. The use of compost based on sewage sludge and straw in a ratio of 3:1 at the rate of 30 t/ha contributes to the dry weight of miscanthus plants at 15 t/ha.

The studies were performed on sod-podzolic soils, which are characterized by relatively low organic matter content, low antidegradation resistance, unsatisfactory agrophysical and agrochemical properties. Thus, the conducted research can serve as a model experiment and be extrapolated to such soils, which are marked by manifestations of degradation of various degrees. In addition, the problem of environmentally safe disposal of sewage sludge is gaining global scale and needs to be addressed. The performed researches partially give the answer to the decision of this problem. One of the ways to solve it is to use sewage sludge as fertilizer for energy crops. Therefore, the studies can be of practical value for use in different regions on other types of soils, which are characterized by varying degrees of degradation processes, which will increase the ecological sustainability of agroecosystems.

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Forecasting of the number of bird collisions with turbines in the territory of Pre-Azov region wind park using the route census method

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Abstract. The information system has been designed to ensure the analysis of information on the monitoring results of the wind power plant (WPP) territory using the route census method. The database contains 48 fields, reflecting the monitoring results of birds' behavior in the territory of WPP and processing the initial data: year, month and day of observation, a number of birds of this species, flight altitude, flight speed, direction of flight, coordinates of the bird registration point on the Google-map, average number of birds flying over the territory of the wind park at a given time, coordinates of the points of intersection of the bird flight path with the perimeter of the wind park or observation site, the length of bird flight path over the observation site, and other parameters. The analysis of distribution of birds in the territory of the "Primorsk-1" WPP according to the types of migration (forage, transit, nesting, and ground), direction of flight and altitude characteristics has been carried out. The total number of registered birds was 8927 specimens of 72 species, of which 802 specimens of 11 species were referred to the transit type, 2511 specimens of 32 species – to the forage type, 5614 specimens of 60 species were on the ground (ground type). Most birds (63%) belong to the ground type. 28% of birds were registered in the forage group, 9.0% of birds were flying in transit. The greatest activity of birds is manifested in the autumn migration season, when the transit group accounts for 77% of all annual transit flights. The proportion of birds of forage and ground types, registered in autumn, is 68% and 74%, respectively, of the total number of birds registered in autumn. In the group of ground birds, the overwhelming majority of specimens belong to the period of autumn migration (4141 birds or 74%). The least number was observed in the winter season (317 birds or 5.6%). The author proposes a mathematical model for analyzing birds' interaction with turbines using the results of monitoring the territory of wind power plants by means of route census method. The model makes it possible to obtain information on the probability of different species of bird collisions with wind wheels and the number of collisions with turbines, depending on the flight characteristics of birds, parameters of wind parks and observation conditions in different seasons. In the risk zone of birds' interaction with turbines, only specimens of one species, Buteo buteo, were observed. The calculated probability of one bird collision when passing through the wind wheel is 0.19. The anticipated number of bird collisions with turbines during one year of the "Primorsk-1" wind park functioning is in the range of 5.6÷6.7 specimens.

1 Introduction

The intensive development of wind energy has a certain impact on the environmental situation, especially noticeable in cases where wind power plants are located in places where bird communities are concentrated. The negative impact of wind turbines on ornithofauna is of global concern [9] [13] [24] [26]. According to the data [17], eleven wind power plants at the Spanish station in Navarro 20.6 vultures and several thousand of small birds are killed by one turbine annually. Only in two regions of Spain in the period from 1993 to 2016 the number of dead birds of 170 species and bats were 10,017 specimens [23]. Winkelman [27] reports that mortality rates of large birds on the coast are estimated at 2.4-56.2, and for passerines at 2.1-63.8 specimens/ turbine/year. In the territory of the wind power plant in the United States, 140.000-328.000 birds [18] and 0.5÷1.6 million bats [8] die annually.

The territory of most of the used and projected wind power plants in Ukraine is located on the Azov and Black sea coasts. In 2020, the energy company DTEK completed the construction of the second stage of the Primorsky wind park in the Zaporozhye region next to the operating 200 MW Botievo WPP. Earlier, in May, the first stage of the station, which is located near the city of Primorsk, was launched (Primorsk Wind Park, 2020). Migratory bird complexes of the Azov-Black Sea ecological corridor are characterized by a great diversity in species composition, large-scale in numbers in Eastern Europe and they are significant in the number of rare and endangered species, which are protected by the Bonn Convention and the Agreement on the Conservation of

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Migratory Birds on the Afro-Eurasian Transcontinental Routes [6]. Therefore, the study of transcontinental migration flows is extremely important for assessing possible negative impact of wind power plants on the behavior of birds in the territory of wind power plants and adjacent zones.

The foundations of the analysis and, in particular, the anticipation of the state of the birds' biodiversity in the studied territories are the results of long-term monitoring. The methodology for the anticipation of the number of bird collisions with wind turbines is described in the recommendations of the Scottish Natural Heritage Foundation (Scottish Natural Heritage, 2014). The reliability of these recommendations has been confirmed by many researchers [16] [20] [15] [21]. The recommendations of the Scottish Natural Heritage Foundation provide for monitoring at several stationary sites belonging to the wind power plants. The size of the selected sites, as a rule, does not exceed 10÷20% of the total area of the wind park.

The deployment of wind power facilities in one of the most powerful migration routes in Eastern Europe predetermines the need to study the state of biodiversity in the territories of the wind power plants. Project work to substantiate the impact of WPP on the ornithological bird complexes within Primorsk district of Zaporozhye region was carried out in 2011-2017 [1] [6] using the recommendations of the Scottish Natural Heritage fund. Based on the data obtained, the analysis of the possibility of bird death due to their collision with the rotor blades at the "Primorsk-1" wind power plant was carried out [4].

An alternative way to obtain information is the route census method, adapted by Siokhin V.D. and Gorlov P.I. in relation to collecting data necessary to anticipate the impact of wind power plants on the environmental situation [3] [7]. The route census method allows collecting information on the behavior of birds from almost the entire territory of the wind power plant, therefore, in this scientific work, this method is used as a main one. The obtained statistical data processing is not possible without the involvement of modern computer technology. In the scientific works [1] [4] [6] [21] [25] information systems and ornithological databases have been created to ensure the storage and analysis of the results of bird calculations in the Pre-Azov region in 2015-2020. The given research work is devoted to the development of these studies in relation to the monitoring of bird complexes in the territory of "Primorsk-1" wind park using the route census method.

2 Aim and methodology of research work

1. Research work aim. The aim of the research work is to anticipate the interaction of birds with the turbines of the "Primorsk-1" WPP, based on the analysis of the results of monitoring the territory of the "Primorsk-1" wind park, which was carried out in 2018 using the route census method. To achieve the aim, the following objectives were formulated:

• development of information system to ensure the analysis of information, based on the results of monitoring the WPP territory using the route census method

• identification of birds distribution according to the direction of migration and altitudes in the territory of the "Primorsk-1" station,

• design of a mathematical model for anticipating birds' interaction with turbines, based on the results of monitoring the wind park's territory using the route census method,

• anticipation of the number of bird collisions with turbines in the territory of the "Primorsk-1" wind park.

2. Methodology for monitoring the territory of WPP. The monitoring time was chosen so as to cover all periods of bird's life: winter period 2018.01.25, 2018.02.16, spring migration season 2018.03.10, 2018.03.20, 2018.04.11, nesting period 2018.05.05, 2018.05.23, autumn migration season 2018.09.15, 2018.09.29, 2018.10.13. The observations were made in the morning and evening hours lasting approximately 3 hours each with a total observation time of 63 hours. The scheme of one of the route census, related to the observations of 2018.03.20 and linked to the Google map for the northeastern part of the territory of the "Primorsk-1" wind park, is shown in Fig. 1.

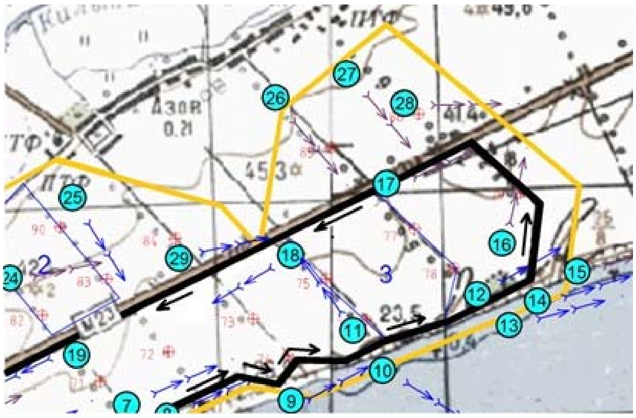

Fig. 1. Scheme of route census 2018.03.20 in the territory of the wind park "Primorsk-1".

The territory of the wind park is an irregular polygon with sixteen vertices; in Fig. 1 its boundary is painted in yellow color. The observer was moving by car at a speed of less than 10 km/h. The vehicle's trajectory is represented on the map by the segments, painted in black color, the direction of movement is indicated by black arrows. At first, the movement was carried out along the sea coast in a northeast direction. As the observer was moving, he registered several groups of birds in positions with numbers 9÷15, which are circled in Fig. 1.

For each group of registered specimens, the flight altitude, number of birds of a certain species and direction of migration, which is indicated by arrows on the map, were registered. For example, at the position, marked with the no.9, at 10:00 am, 6 specimens of Podiceps cristatus of the forage type, flying in a northeastern direction at an altitude of 10m, were registered. This mode is typical for birds that constantly inhabit the wind park's territory or the buffer zones. Approximately 500m from the eastern border of the wind power plant, the direction of the route has changed first to the north, then to the north-west. Here at 11.00 a.m. in position no.16 at an altitude of 10m, a flock of 14 specimens of Motacilla alba was found. This group of birds was flying in a northeastern direction. Then the route continued in a southeastern direction, where various specimens were observed at positions no.17-19. After reaching the southeastern part of the wind park territory, the route turned north, passed along its northern part, turned south and returned to its western boundaries.

Route census method covered about 75% of the wind power plant’s territory, which is several times larger than the area of sites that are usually involved in the method ("Scottish Natural Heritage", 2014). The monitoring results, obtained by the route census method, contained the following data on the behavior of birds in the WPP territory: season, month, day and hour of registration; place of registration, linked to a Google map; number of birds; bird species; flight direction; type of stay in the territory of WPP (transit, forage, ground); flight altitude. An example of the monitoring results, using the route census method, is presented in table. 1.

Table 1. Monitoring results of number of n-birds of forage type in the territory of "Prymorsk-1" wind park 2018.01.25 NE – north-east, S – south, SW – south-west.

No	Time	Sprcies	N	Type of migration	Altitude (m)	Direction
1	11.00	Sturnus vulgaris	25	forage	7	NE
2		Buteo lagopus	1	forage	30	S
3		Larus cachinnans	18	forage	15	NE
4	12.00	Larus cachinnans	21	forage	10	NE
5		Fringilla coelebs	20	forage	5	SW
6	14.00	Larus cachinnans	7,3,2,2	forage	10	SW
7		Larus cachinnans	1,1,5,3,4,4	forage	10	SW
8	16.00	Buteo lagopus	1	forage	30	SW
Total		5 species	118			

Similar tables contained the results of the registration of migratory flows of birds, which were carried out in 2018.

3. Methodology for processing observation results. The processing of monitoring results should provide information on the behavior of birds in the territory of WPP according to the basic characteristics, which are necessary to anticipate the impact of wind power plants on ornithocomplexes [3] [6] [21] [25], namely:

• a number of birds of the observed species in the territory of the wind park in different seasons of the year,
• distribution of birds by altitude,
• time, spent by birds in the risk zone (RZ) of collision with wind turbines,
• probability of bird collision with the turbine blades when it is in RZ,
• anticipated number of bird-turbine collisions.

The probability of a collision of a bird of the j species with turbine blades when it is flying through the danger zone of a wind park is [11] [12]:

$$P_j = p_j(r,\phi) r dr d\phi / \pi R^2 , \qquad (1)$$

where

$p_j(r,\varphi)$ - probable density of a bird collision,
r - distance from a bird to the turbine center,
φ - angle of turbine blade rotation,
R - radius of the turbine wind wheel.

The danger zone (ZD) is a part of the area of the entire wind power plant, where the rotating turbines are located. The cubage of the danger zone is

$$V_{Zd} = M\pi R^2 d \cos(\gamma), \qquad (2)$$

where

M – a number of turbines in the station territory,
d - average value of the width of the wind wheel blade,
γ - blade wedge angle between its chord and the plane of rotation of the wind wheel.

Let n_{jZd} birds of j-species are flying through ZD. Then the number of their collisions with the turbine blades is identified by the formula

$$n_j = f n_{jZd} P_j, \qquad (3)$$

where

f - coefficient of evasion, which determines the ability of the bird to change the direction of flight near the wind wheel and, thus, to avoid collision with it; the most probable value of the coefficient f is in the range 0.05÷0.005 (May, Hoel, & et al, 2010; Furness, 2015),

P_j, - probability of collision of birds of j-species, flying through the turbine, is identified by formula (1).

Let us introduce the concept of risk zone (RZ) of interaction of birds with rotors. Under RZ we mean a part of the space in the interval of altitudes $\delta H = H_2 - H_1$ between the lower $H1$ and upper $H2$ levels of the turbine wind wheel on the observation site with the area S_{Rz}. The cubage of the risk zone V_{Rz} is

$$V_{Rz} = \delta H S_{Rz}. \qquad (4)$$

Let during the monitoring of T_{Rz} i-groups of birds of j-species were taken into account in the number of n_{ij}, each of which was in RZ during t_{ij}. The total number of birds of j-species n_{jDz}, flying through RZ during the operation of the station is (Band, W., 2000; Osadchyi V. et al. 2019)

$$n_{jDz} = \frac{V_{Dz}T_{Lc}}{T_{Rz}V_{Rz}}\sum_i n_{ij}l_{ij}, \quad (5)$$

where

$l_{ij}=t_{ij}v_j$ - length of the bird's trajectory at the observation site,

t_{ij} - time of bird's flight over the observation site with a speed vj,

T_{Lc} - duration of bird's life cycle during the wind park functioning for some time.

Substituting the values of V_{Dz} and V_{Rz} from formulas (2), (4) into (5), we obtain

$$n_{jDz} = \frac{M\pi R^2 \cos(\gamma) d T_{Lc}}{T_{Rz}\delta H S_{Rz}}\sum_i n_{ij}l_{ij}. \quad (6)$$

According to formulas (3) and (6), the number of collisions of birds of *j*-species with turbine blades is identified by the formula

$$n_j = \frac{M\pi R^2 \cos(\gamma) d T_{Lc} f P_j}{T_{Rz}\delta H S_{Rz}}\sum_i n_{ij}l_{ij}. \quad (7)$$

The value of the integral (1) is estimated by the formula [21]:

$$P_j=[\pi R_0^2+6(R-R_0)L_{2j}/\pi+3(R-R_0)d+3(R-R_0)^2\omega t/2]/(\pi R^2), \quad (8)$$

where

L_{2j} - wingspan of the bird,

ω - angular speed of turbine rotation,

R_0 - radius of the rotor sleeve where the blade is attached,

T - time of flight of *j*-species bird through the rotor with speed v.

The time of flight t is identified by the formula

$$t= (d\sin(\gamma)+L_{1j}))/v, \quad (9)$$

where

L_{1j} - length of the bird.

The distance from the ground to the bottom of the rotor is $H1$=48m, to the top – $H2$=182m. The blade length is 67 m, the width at the widest point is 4.1m, maximum rotation speed of the wind wheel is 14 rpm. The shape of the observation site can be represented as a circle with an area of about 1 km^2, in the center of which the observer is located.

3 Results of work

1. *Description of the developed information system Birds2*. The designed program ensures the storage and processing of data, obtained during monitoring the wind park's territory using the route census method. The program code is based on *Windows Forms* technology in the *Microsoft Visual Studio Community 2019* software development environment. Initiating the program execution displays the main window. In its upper part there are three tabs "Database", "Calculation", "Request", which provide switching the execution of commands between program blocks. When you start the program, the "Database" tab is displayed by default. It contains the *dataGridView* element with the original data.

Information is loaded into the spreadsheet automatically from the database file of *Microsoft Access "birds2.mdb"*, which is located in the folder with the executable file *"Birds2.exe"*. The spreadsheet contains information on the results of monitoring the behavior of birds in the territory of the wind power plant and processing the obtained data. It consists of 48 fields:

1. Code – serial number of the record in the database.
2. Date – year, month and day of observation.
3. No. – number, corresponding to the entry on the Google map.
4. Time – time of observation.
5. *t* – duration of observation in hours for the selected observation day.
6. Species – birds belonging to definite species.
7. Number – number of birds.
8. Type of migration – the way of birds' movement and their presence on the observation site (transit, forage, nesting).
9. Altitude (m) – flight altitude in m.
10. Speed (km/hour) – bird's flight speed in km/h.
11. Direction – flight direction (N - north, NE - northeast, NW - north-west, W - west, SW - southwest, E - east, SE - south-east, S - south).
12. *tg* - tangent of the angle between the direction of flight and the abscissa axis.
13. *t* u (km) - coordinates of the bird registration point on the Google-map on the abscissa axis in km.
14. *v* (km) - coordinates of the bird registration point on the Google-map along the ordinate in km.
15. *x1÷x16* - sixteen coordinates on the abscissa axis in km for the points of intersection of the bird's flight path with all lines that pass through the sides of the polygon that are the boundaries of the wind power plant.
16. *y1÷y16* - sixteen coordinates on the ordinate axis in km for the points of intersection of the bird's flight path with all lines that pass through the sides of the polygon that are the boundaries of the wind power plant.
17. Number - the number of sides of the polygon, which are intersected by birds' flight paths at the entrance and exit of the wind power plant.
18. Length of flight - the average number of birds, flying over the territory of the wind park at a given time.

When the program starts, the display shows the original information, contained in the data file. In the lower left corner of the spreadsheet, information is displayed about the number of records contained in the spreadsheet in the "Database" tab. The spreadsheet is viewed by scrolling the mouse wheel or moving the slider in the horizontal and vertical directions in the lower and right parts of the window using the arrow keys "left", "right", "up", "down".

The coordinates of the points of intersection of the bird's flight path with the boundary of the wind park territory are determined automatically using a specially created calculation block. The color of the active (highlighted) line determines the type of migration: blue indicates the type "forage" or "transit", green indicates the type "ground".

In the lower right part of the main window there is a button "Calculation". Pressing this button you start the process of calculating the number of birds of the transit type of flight (*Ktr*), forage type of flight (*Kforage*), ground type (*Kground*) and the total number of birds (*Ksum*). The *K* index denotes a calculated parameter that characterizes the average value of the number of birds present in the wind park at a given time. The value of K could be obtained based on the results of photographing the territory of the wind park from a flying vehicle. If *M* birds are found in m photographs of this kind, then the value of the parameter *K* is equal to the ratio *M/m*. To calculate the value of *K*, a special program block is drawn up.

The calculation results are displayed on the screen in the form of a message window.

Next to the "Calculation" button is the "Map" button. It opens a new window designed for viewing a Google map, indicating the boundaries of the wind power plant in yellow color, the route of observation and places of observation of birds. To display the map on the screen, you must press the "Select file" button in the upper right corner of the window. A dialog box will appear on the screen, in which you should specify the path and select the file with the "jpg" extension for viewing. A map will appear in the center of the screen. Under the button "Select file" there is an element "label", which reflects the coordinates (km) of the mouse cursor on the map.

Clicking the left mouse button at a certain point on the map is resulted in the appearance of a red cross under the cursor. The coordinates of the marked point will be displayed above the "Add coordinates" button. This button copies the coordinates to the *"u(km)"* and *"v(km)"* fields of the spreadsheet located in the "Database" tab of the main window. The selected coordinates are copied to the active (selected) table row. Information in the active line is displayed in the lower part of the "Map" window (entry code, entry date and number that corresponds to the designation of the entry on the map). The "Map" window is also used for the initial filling in the *"u(km)"* and *"v(km)"* fields.

In the second tab of the main window "Calculate" there is a spreadsheet that reflects the data, calculated on the basis of the entries of the first spreadsheet in the "Database" tab for a specific direction and altitude of birds' flight. Namely:

- a number of bird species;
- a total number of birds;
- a number of birds of forage type, transit type and nesting type;
- an average number of birds in the territory of the wind park at a given time.

At the bottom of the tab the information about dates of various types is displayed:

- a date or dates that were requested in the "Request" tab;
- a date or dates that meet the conditions of the request;
- a date or dates that meet the conditions of this request and are referred to the entries with the "forage" and "transit" flight types.

Calculations are carried out on the basis of a request for the entries using the third tab "Request", where the forms that ensure the fulfillment of the conditions for selecting data from the spreadsheet from the tab "Database" are displayed. The choice is made according to four parameters:

- species of birds;
- flight date;
- direction of flights;
- type of flights.

Sample request provides a selection of all registered birds of a transit type in the territory of the wind park that were flying in 2018.09.15 in a western direction. The choice of initial data is carried out using the forms in the headings "All values" or "Selectively". "Selectively" mode defines a list of selected parameters from the existing options. Installation of one or several arbitrary options is allowed.

After setting the request, you have to leave the "Request" tab and go to the "Database" or "Calculate" tab. The program automatically performs all actions in accordance with the request. Information from the database that meets the set request is displayed in the "Database" tab, and a number of birds is displayed in the lower right corner of this tab. After the user leaves the "Request" tab, the data from the "Calculation" tab are automatically recalculated in accordance with the new information from the "Database" tab.

2. *Distribution of birds by types of migration and altitudes*. The total number of registered birds was 8927 specimens of 72 species, of which 802 specimens of 11 species were of the transit type, 2511 specimens of 32 were of the forage type, 5614 specimens of 60 species were of the ground (terrestrial type). 4 birds *Buteo buteo* were registered in the risk zone of the collision with turbines (RZ). The quantitative characteristics of birds of various types according to the season are given in table 2.

Table 2. Distribution of birds by type of migration.

Type of migration	Winter season	Spring migration	Nesting season	Autumn migration	Total
Transit	0	128	53	621	802(9,0%)
Forage	277	375	162	1697	2511(28%)
Ground	317	592	564	4141	5614(63%)

As it can be seen from table 2, a majority of birds (63%) belongs to the ground type. In the forage group 28% of birds were registered, the remaining 9.0% of birds were flying in transit. The greatest activity of birds is manifested in the autumn migration season, when the transit group accounts for 77% of all annual transit flights. The proportion of birds of forage and ground types, registered in autumn, is 68% and 74%, respectively, of the total number of birds registered in autumn. Data on the number of species and number of birds of the ground type in different seasons are given in table 3.

Table 3. Distribution of birds by type of migration.

Season	Winter season	Spring migration	Nesting season	Autumn migration
Number of species	13	25	35	43
N	317	592	564	4141

Of the total number of ground type birds, the largest part of them belongs to the period of autumn migration (4141 or 74%). The least number was registered in the winter season (317 birds or 5.6%).

Analysis of migratory flows showed that only 277 specimens of six species of the forage group were flying by in winter. At an altitude of up to 10 m, 66% of birds were registered, in the range of altitude (11÷25) m – 32%, in the range of altitude (26÷50) m – 2%. There were no birds in the risk zone.

The spring migration period was distinguished by a higher diversity of species. The forage group included 375 birds of 22 species, the transit group – 128 birds of 6 species. In RZ, at an altitude of 100m, two forage-type *Buteo buteo* birds were found. In the range of altitude (26÷50) m, one bird was registered, in the range of altitude (11÷25) m – 40 birds (8%), the remaining 460 specimens (91%) were flying at an altitude of up to 10m.

During the nesting period, 162 birds of 10 species of the forage group and 53 birds of one species *L.melanocephalos* of the transit group were counted in flight. No birds were found in RZ. At an altitude of up to 10m, 134 (62%) birds were flying by, in the range of altitude (11÷25) m – 40 (8%), in the range of altitude (26÷50) m – 70 specimens (32.5%).

The total number of migratory birds in the autumn period was 2318, belonging to 26 species. Out of these, 1697 specimens of 21 species belonged to the forage group, 621 specimens of 8 species – to the transit group. 1591 (68.6%) birds were flying at an altitude of up to 10m, in the range of altitude (11÷25) m – 173 (7.5%), in the range of altitude (26÷50) m – 350 (15.1%) birds. In RZ, at an altitude of 150m, 2 (0.1%) *Buteo buteo* birds of the forage type were found, 202 (8.7%) specimens were flying above 150 m.

Thus, out of 72 species in RZ, only one species, *Buteo buteo*, was registered in the amount of 4 birds. During the monitoring period, 16 representatives of this species were registered, most of which were outside the RZ.

Designed program differs from other information systems, described in the scientific works [1] [21] by the ability to identify a number of characteristics of birds of the transit type, which are necessary for the anticipation of their collision with turbine blades:

• coordinates of points of bird's flight path intersection with the perimeter of the wind park or observation site,

• length of the bird's flight path over the territory of the wind park,

• average number of birds flying over the territory of the wind park at a given time.

3. *Anticipation of the interaction of birds of the species Buteo buteo with turbines*. The results of monitoring the territory by the route census method provide information only about the altitude and direction of flight. Bird migration trajectories are characterized by a great diversity. An example of flight trajectories of specimen, registered in the territory of the "Primorsk-1" wind park, during the autumn migration is shown in Fig. 2.

Fig. 2. Sample flight trajectories of specimens, registered in the territory of the "Primorsk-1" wind park during the autumn migration.

At low altitudes, birds usually fly along curved trajectories such as (4), (5) in Fig. 2. The vast majority of birds, registered in RZ and above it, were flying along straight lines (1), (2), (3), (6), (7). In order to estimate the length of rectilinear trajectories l_{ij} in formula (7), we represent the shape of the observation site as a circle of radius r with area $SRz = \pi r2$, in the center of which the observer is located. The SRz value is about 1 $km2$. In this case, the viewing radius r is 560 m. The length of the bird's flight path in the observation site was 880 m. The flight speed was taken to be vj=11,6 m/sec.

The tij value in this case is 75.9 sec.

To anticipate the interaction of birds with turbines according to formula (7), we need information on the duration of the bird's life cycle during the year of the wind park functioning. Two cases may arise here:

• a number of bird collisions with turbines is identified in each season separately, taking into account the results of monitoring by seasons,

• a number of bird collisions with turbines is identified during a year, taking into account the total monitoring results for one year.

In both cases, the same formula (7) is used, but due to different values of the parameters TLc (duration of the bird's life cycle) and $TRisc$ (duration of monitoring time), the results will not be the same. With a sufficiently large statistical sample of birds in the RZ, the first case should be preferred. The corresponding data on the value of TLc in different seasons with duration of TRz in relation to one year of wind park "Primorsk-1" functioning are presented in Table. 4. The duration of a conventionally bright day ΔTRz when calculating TLc was taken equal to 8 hours for the winter season, 10 hours for the autumn season, and 12.5 hours for the spring and nesting seasons.

Calculations were carried out for the following values of WPP parameters and characteristics of Buteo buteo birds: maximum blade width d=4.1 m, maximum angular rotation speed of the wind wheel ϖ=14 rpm, wind wheel radius R=67 m, hub radius $TR0$=3 m, angle between the chord of the blade section and the plane of the wind wheel $T\gamma$=300, bird length $L1j$=0.54 m, wingspan $l2j$=1.2 m, flight speed 11.6 m/s. The probability of a bird collision with the blades, calculated by the formula (8) in the case of its flight through the wind wheel, is 0.19.

The number of collisions during one year of WPP functioning, calculated by the formula (7) for the collision probability Pj=0.19, taking into account the data in Table 4, equals 3.7 for the spring and 3.0 for the autumn migration season. The total number of collisions was 6.7.

Table 4. Duration of observations TRz, a number of conditional light days ΔTRz in the season and a phase of the life cycle of birds TLc in hours.

Cycle of observation	TRz, hour	TRz, sec	ΔTRz	TLc, days	TLc, hour
Migration in spring	13	46800	12,5	85	1062,5
Nesting	22	79200	12,5	90	1125
Migration in autumn	15	54000	10	100	1000
Winter season	13	46800	8	90	720
Total	63	226800		365	3907,5

Monitoring the territory of the wind park has shown that birds of the species Buteo buteo are found at different altitudes in all seasons. The total number of Buteo buteo birds that were found in the territory of the wind park at all altitudes was 16. One bird was registered outside the RZ in winter, seven – during the spring migration period (2 in the RZ and 5 outside it), three – during the nesting season and five – in autumn (2 in RZ and 3 outside). It can be assumed that, theoretically, in the risk zone of interaction with turbines, birds could appear not only in spring or autumn, but also in winter and nesting periods. Therefore, the registered number of birds in RZ can equally be attributed to any season. In this case, the same formula (13) is valid, but due to the different duration of the bird's life cycle TLc and the duration of the monitoring time $TRisc$, the results will not be the same. The calculated number of collisions during one year of WPP functioning turned out to be 5.6 specimens, which practically coincides with the calculated value in the first case.

Combining the latest data with previously obtained results, which take into account seasonal differences, we can assume that the most reliable anticipation is the range of values 5.6÷6.7. It is interesting to compare the obtained assessment of the interaction of birds with turbines with the anticipation made in 2017 (Osadchyi V. et al.) which was based on the results of WPP monitoring, carried out in accordance with the recommendations of the Scottish Natural Heritage Foundation, 2014. The anticipated number of collisions per one year of WPP functioning according to the data of the mentioned above research work was about 6.5 birds. the observer is located.

4 Conclusions

The Birds2 information system has been developed to ensure the analysis of information, based on the results of monitoring the wind park's territory using the route census method. The program code is compiled on the basis of Windows Forms technology in the Microsoft Visual Studio Community 2019 software environment. The main database contains 48 fields, reflecting the results of monitoring of birds' behavior in the wind park and processing the initial data: year, month and day of observation, an identifier that binds coordinates of the registered bird to the point on the Google-map, time of observation day, observation duration for the selected observation day, bird species, number of birds of this species, type of movement and presence of birds in the observation site, flight altitude, flight speed, direction of flight, coordinates of a point of registration of birds on a Google map, average number of birds flying over the territory of the wind park at a given time and other parameters.

The designed program differs from previously developed information systems in the research works [1] [21] by the ability to identify a number of characteristics of birds of the transit type, which are necessary to anticipate their collision with turbine blades:

• coordinates of points of intersection of the bird's flight path with the perimeter of the wind park or observation site,

• length of the bird's flight path over the territory of the wind park,

• average number of birds, flying over the wind park's territory at a given time.

The analysis of the distribution of birds in the territory of the "Primorsk-1" wind power plant is carried out according to the types of migration (forage, transit, nesting, ground), direction of flight and altitude characteristics. The total number of registered birds was 8927 specimens of 72 species, of which 802 specimens of 11 species were of the transit type, 2511 specimens of 32 species were of the forage type, 5614 specimens of 60 species were on the ground (ground type). Most birds (63%) belong to the ground type. In the forage group 28% of birds, 9.0% of birds were flying in transit. The greatest activity of birds is manifested in the autumn migration season, when the transit group accounts for 77% of all annual transit flights. The proportion of birds of forage and ground types, registered in autumn, is 68% and 74%, respectively, of the total number of birds registered in autumn. In the group of ground birds, the overwhelming majority of specimens belong to the period of autumn migration (4141 or 74%). The least was registered in the winter season (317 birds or 5.6%).

A mathematical model has been developed for analyzing the interaction of birds with turbines using the results of monitoring the territory of wind power plants using the route census method. The model makes it possible to obtain information on the probability of collisions of different species of birds with wind wheels and number of collisions with turbines, depending on the flight characteristics of birds, parameters of wind parks and observation conditions in different seasons. In the risk zone of birds' interaction with turbines, 4 birds of the same species Buteo buteo were registered. The probability of a single bird's collision, when passing through the wind wheel, is about 0.19. The calculated number of collisions of birds with turbines during one year of "Primorsk-1" wind park functioning is within the range of 5.6÷6.7 specimens.

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Study of influence of alkaline component type on pH value and properties of alkali activated concretes containing basalt rock

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Abstract. The paper discusses the questions of alkalinity changes in alkali activated cement-based materials at different stages of hardening. It was shown that use of alkali activated cement with dry alkaline component ("all-in-one system") in the presence of basalt rock leads to the immediate decrease of pH value and strength drop of the material. On the other hand, using alkaline component in the form of alkaline solution provides almost normal hardening of systems. Taking into account obtained results a methodology of changes in concrete mix design was proposed. In general, for different cement systems under study pH value varies from 8.5 to 12 reflecting on the materials structure formation processes and strength gain. Shrinkage of the systems was within the ranges 0.3…0.6 mm/m at 28 days age and 0.3…0.5 mm/m for different systems. Absence of expansion witnesses about compensation of ASR results and normal structure developments processes in the material comparing to OPC.

1 Introduction

Nowadays a question of widening of raw materials base became very sharp [1-2], including materials for cement and concrete production [3-5]. Permanent rising of prices on traditional high-quality aggregates leads to the search of chipper ones, but at the same time the less qualified materials [6-8]. Between aggregates in this category there is a high possibility to have active grains (active silica) [9-1], able to participate in reaction with cement matrix and leading to the problems [12-14], some times – technogen accidents [15-17].

Problem of alkali-silica reaction (ASR) of aggregates in concretes is also critical from the point of view of absence of such tests in the quality assurance procedures of the most concrete and concrete constructions manufactures and determination of alkaline corrosion appearance is possible only at the stage of exploitation of construction, when it is to late to provide any actions.

Problem of loses in quality of aggregates and rise of their activity taoks a top rate [18-20]. The point is that shift to the coal use in the portland cement clinker manufacture results in increasing of Na and K compounds in the cement [21-23]. That fact together with increasing of aggregates activity provides appearence of destructive processes in concrete directly in exploitation period [24-26]. In the body of concrete appears reactions «alkalis – active silica » (ASR) [27-29], leading to the formation in the hardened concrete pores new formations, exceeding volume of the pore [30-32]. These formations further leads to the internal stresses in the concrete and may lead the increased leaching of the hardened stone and development of destructive processes [33-35].

Results of the studies [36-38] shows that there are some ways to ASR development in concrete by using active mineral aggregates [39-41], which makes it possible to regulate and control ASR processes development, appearing because of thise reaction and make it constructive [42-44]. The most effective systems in this case are alkaline cements [45-47], which make it possible to change ASR process mechanics from destructive to constructive, shifting in time moment of to the initial stages of structure formation and thus not creating possibility to have destructive processes [48-50].

At the same time, provided investigations studies mostly use of alkali activated cements by two component technology (alkaline component is in the liquid form). Such systems are effective enough, but application of this technology is complicated and far from the ideal [46, 47]. The modern technologies in construction requires application of alkali activated cements in the dry state, « all-in-one » system), which are simply mixed with water.

The problem of such cement application together with active aggregates is that alkaline solutions (by the old technology) have much more alkalis in the system [49], and in the single component cement present alkalis content could be not enough for compensation of negative influence of active aggregate. Use of the extra alkalis on the other hand in dry cement system also is dangerous because of possibility of high leaching rates of material an development of destructive processes [51].

The aim of the study to investigate changes in pH value for different cement systems and to study optimal alkaline component content in the cement system.

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2 Raw materials and methods

To investigate the processes of inner corrosion of the slag alkaline concrete the basalt rock has been selected as aggregates. Quartz sand was taken for reference. Chemical composition of the rocks is given in Table 1.

Table 1. Chemical composition of rocks

Oxide	Oxide content, % by mass, in aggregate
	Basalt
SiO_2	50.42
Al_2O_3	14.0
Fe_2O_3	6.14
FeO	8.37
TiO_2	2.66
MnO	0.243
CaO	8.04
MgO	5.56
P_2O_5	0.316
K_2O	0.71
Na_2O	2.27
SO_3	0.07
Σ, %	99.57

For a complex estimation of durability of the slag alkaline concretes with alkali-reactive aggregates, the strength kinetics was investigated, for which a standard procedure was used.

Ground granulated blast furnace slag with a specific surface 450 m^2/kg (by Blaine) was used in the experiments. Chemical composition of the slag is shown in Table 2.

The graded aggregates were in used in the experiments. The quantities of aggregate retained on the No 2.5 mm, 1.25 mm, 0.63 mm, 0.315 mm and 0.14 mm-sieves were 20 % by weight of each.

The beam specimens (25×25×254 mm) made of slag alkaline concretes of equal consistency with a flow of 170+/- 5 mm, according to procedure specified by the DSTU B V.2.7-186, were prepared using a vibrating table. The cement to aggregate ratio was taken as 1: 2. Used as alkaline component were the Na_2CO_3 in dry state and soluble glass with density 1250 kg/ cub m.

Alkalinity of the hardening systems (pH) was determined after 1, 2, 3, 4, 5 i 24 hours of hardening by measuring properties of 10% water solution at pH-meter PL-700al (pH/ORP/Conductivity/TDS/Salt/DO/Temp).

As a reference material was taken OPC Grade 42.5 with a specific surface 320 m^2/kg by Blaine.

Also for reducing alkaline corrosion value of concrete the active mineral admixture was taken (represented by metakaolin) in the quantity 10% (MK).

Length of the specimens was measured using a pointer-type indicator with a scale factor of 0.01 mm.

Between 2 to 4 hr. before the next measurement the specimens were removed from the thermostat and allowed to cool in the environment with T=20+/-2 ºC.

Table 2. Chemical composition of blast furnace slag

Oxides	Oxide content, % by mass
	No 1
SiO_2	38.6
Al_2O_3	6.50
CaO	48.50
MgO	5.40
MnO	-
FeO	0.36
SO_3	1.99
TiO_2	-
P_2O_5	-
K_2O	-
Na_2O	-
Σ, %	101.35

Linear deformations of the slag alkaline concretes were compared with those of the reference specimens made with sand. The linear deformations of the slag alkaline concretes made with alkali- reactive aggregates were studied using a basic blastfurnace slag as the most typical representative reflecting peculiarities of the processes of hardening [51].

3 Results and discussion

Traditionally during mix design of alkali activated cements alkaline solutions of sodium silicates and carbonates are using as an alkaline component. In our case, to determine limit points of alkali activated cements were studied of the cements using soluble glass (SS) with density 1250 kg/m^3 with silicate modulus 2.6.

Variation of pH value for different cement compositions in paste are shown in Table 3 and at the Figure 1.

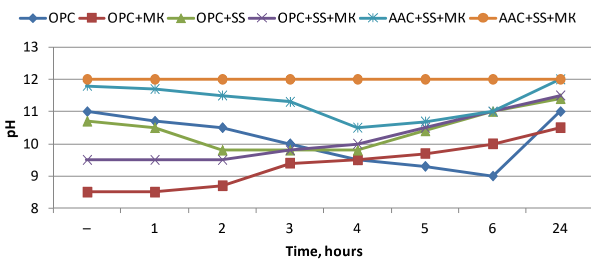

Fig. 1. Variation of pH value depending from content of the alkaline component, represented by alkaline solution.

Analysis of the results shows that at initial stages the highest pH value have alkali activated cement using soluble glass, regardless metakaolin admixture.

Use of OPC also provides high alkalinity of media (pH=11). However, it has regularity to rapidly decrease in time and at the age of 6 hours it is pH=9.Then at 1 day age is returns to pH=11. Such behavior could be explained in that way: high alkalinity at initial stage provided by calcium hydroxide further decreasing via reaction with active SiO_2, which is leaching from the aggregate. Then, reaching limit point in the system, content of soluble silica in the media is reducing and content of portlandite is rising because of continuation of clinker minerals reaction continuation. This creates proper conditions for hardening and strength gain and this is explaining absence of negative influence of active aggregate on material exploitation properties at initial stages of hardening and exploitation.

Table 3. Variation of pH value in alkali activated cements using alkaline solutions as alkaline component and referenced materials.

Time, Hrs	pH					
	AAC	AAC+MK	AAC +SS	AAC +SS+MK	AAC +SS+MK	AAC+SS+MK
–	11.0	8.5	10.7	9.5	11.8	12.0
1	10.7	8.5	10.5	9.5	11.7	12.0
2	10.5	8.7	9.8	9.5	11.5	12.0
3	10.0	9.4	9.8	9.8	11.3	12.0
4	9.5	9.5	9.8	10.0	10.5	12.0
5	9.3	9.7	10.4	10.5	10.69	12.0
6	9.0	10.0	11.0	11.0	11.0	12.0
24	11.0	10.5	11.4	11.5	12.0	12.0

Introduction of metakaolin admixture to the OPC system provides decreasing of total alkalinity of the system at initial stage to pH=8.5. Further pH is rising slowly up to 10.5 at 6 hours age. Such peculiarities of hydration and structure formation processes provide low strength gain of OPC systems with active mineral admixtures using active aggregates, limiting application areas for such materials.

Introduction of metakaolin into the alkali activated cement composition using soluble glass as an alkaline component also decreases a while total alkalinity of the system at initial stage (pH reduces to 11.8 comparing to 12). Further alkalinity reduces for 4 hours, reaching pH=10.5. After that alkalinity rises to pH=11at the age of 6 hours and reaches pH=12 at 24 hours age. Such high pH value in alkali activated cement using soluble glass at different stages provides possibility to use active aggregate without loses in strength properties.

Alkali activated OPC has low pH value at initial stage – 10.7. Further alkalinity of the system is rising and reaches pH=11 at 6 hours age and pH=11.4 at 24 ours age. Such behavior and differences from processes in OPC could explain by shifting of alkalinity source from calcium hydroxide to sodium compounds because of decreasing of total basicity of new formations (hybrid compounds). This makes it possible to predict slow strength gain at initial stages and further rapid increasing of strength after 1 days of hardening.

Introduction of metakaolin provides decreasing of initial pH to 9.5 with stability during 2 hours and rising rapidly to 11 at 6 hours age and 11.5 at 24 hours age. Such behavior could be explained by presence of high alkaline ions source in the system and bonding of active silica from the basalt rock composition at initial stages. This makes it possible to predict a little bit slow hardening at initial stages and reaching of normative properties at 28 days age.

Thus a way, from the point of view of high alkalinity of media at initial stages the best systems are alkali activated OPC with and without metakaolin admixture. They have high alkalinity rates as at initial stages (pH=12 and 11.8 respectively), so as at the age of 1 day (pH=12 for both systems).

Alkalinity of OPC systems is a little bit lower (pH=11) at initial stage, decreasing at initial stages of hardening and than stabilizing at the level pH=11 at the age of 1 day providing source for normal hardening and structure formation. Introduction of metakaolin decreases total alkalinity at initial stage to 8.5 with slow rising to 10 at the age of 6 hours and 10.5 at 28 days age. Such process of structure formation is potentially problematic for strength properties.

The worse system from the high pH value at initial stage is alkaline OPC. Low pH of the system without metakaolin (10.7) with following stabilization at pH=11 (at 1 day age) provides slow strength gain, and introduction of metakaolin decreases pH to 9.5, storing for 2 hours and rising to 11 at 6 hours age.

Also it should be mentioned that for alkali activated cement system with soluble glass the pH value is 12 at all stages regardless of metakaolin introduction.

On the other hand, the modern world needs single-component premixed cements. Alkaline component of such alkali activated cement was represented by sodium carbonate (soda ash).

To determine optimal content of alkaline component alkali activated cement (AAC) type I according to DSTU B V.2.7-181 was used with additionally alkalis (sodium carbonate) in the quantity 2, 4, 6, 8 i 10% by mass. Initial content of alkaline component in the cement was 4.5% (2.5% calculated on Na_2O). Thus, maximal alkalis content in the cement system was 7.54% by mass calculating on Na_2O. Such significant increasing of alkalis content in the system was directed for compensation of negative influence of active aggregate on structure and service characteristics of material. Test results are given in Table 4 and shown on Figure 2.

Table 4. Influence of alkaline component content on total alkalinity of cement paste media.

Time, hrs	pH					
	AAC	AAC +2% soda ash	AAC +4% soda ash	AAC +6% soda ash	AAC +8% soda ash	AAC +10% soda ash
–	10.0	10.0	11.0	11.5	11.7	11.7
1	9.0	10.0	11.0	11.5	11.5	11.5
2	9.0	9.5	10.5	11.0	11.5	11.5
3	9.0	9.2	10.5	11.0	11.2	11.2
4	8.7	9.0	10.2	11.0	11.2	11.2
5	8.7	9.0	10.2	11.0	11.0	11.2
6	8.5	8.7	10.2	11.0	11.0	11.0
24	7.5	7.8	7.8	11.0	11.0	11.0

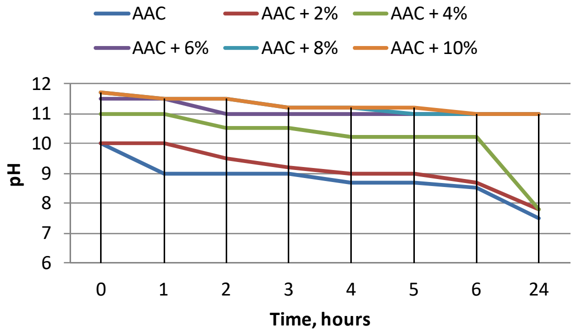

Fig. 2. Variation of pH value depending from content of the alkaline component, represented by dry salt.

Analysis of obtained results shows that using active aggregates alkalinity of the system if decreasing even at initial stage. Without additional alkaline component at initial stage pH is 10 and rapidly dropping. From the point of view of total; alkalinity of the system optimal content of additional alkaline component is 6% of soda ash that provides totally 5.4% of alkalis in the system calculation on Na_2O.

Obtained results confirms predictions that using active aggregates with dry alkali activated cement mix the traditional alkalis content is not enough. This could be explained by reaction between silica acid, leaching from the basalt rock, and alkaline component, resulting in sodium hydro silicates formation. Such process is not destructive. However, decreasing of total content of free alkalis in the media and pH value leads to slowing of structure formation processes in alkali activated cement of stop it in general. That is why for storing total alkalinity of the system the additional alkaline component content 6-6% by mass of the cement is required.

Obtained results make it possible to propose method of compensation of negative influence of active aggregates on concrete basing on single component alkali activated cements. This will provide necessary density of alkaline component in the cement media and create conditions for hardening.

Compressive strength of the concretes under study is shown in Table 5 and on Figure 3.

Table 5. Strength properties of fine grain concretes using basalt rock as an aggregate

№	Composition	Compressive strength of fine-grain concrete, MPa, at the age, days			
		2	7	28	90
1	OPC+ Soluble glass	18.8	28.4	46.8	58.4
2	OPC+ Soluble glass + 10% MK	13.8	28.4	70.8	81.5
3	AAC type I	10.8	29.4	418	48.4
4	AAC type I +10% MK	5.8	28.4	42.3	48.8
5	OPC Grade 42.5	8.8	23.4	41.2	47.3
6	OPC Grade 42.5	5.2	20.1	40.2	43.1

Analysis of obtained results shows that systems with metakaolin are a little bit weaker than systems without admixture. The best strength properties have systems using alkaline OPC (with soluble glass) regardless using metakaolin. This could be explained by presence of high sodium silicate ions in the system because of soluble glass use.

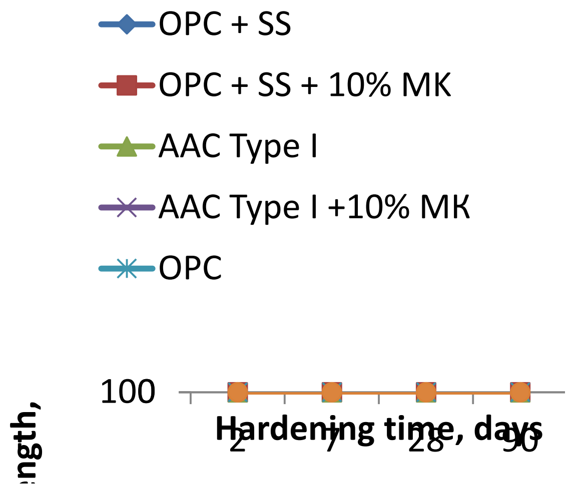

Fig. 3. Variation of compressive strength of fine grained concretes using basalt rock as an aggregate.

The systems mixed with water are characterized by almost equal strength at 28 days age and showing strength gain at further ages. This could witness about constructive development of structure formation processes and absence of huge destructive processes in the material at the stages under study.

Fine grained concretes on AAC type I basis are showing equal strength properties at 2 days age comparing to those on OPC basis. At the age of 7 days characteristics of alkaline concrete is higher than characteristics of OPC based concretes, becoming equal at 28 days age and a little bit higher at 90 days age. That is witnessing about enough potentials of properties development for the systems on AAC basis.

At the same time, strength properties are not expressing well development of destructive processes caused by ASR in concretes. The more informative are study of shrinkage (expansion) deformations of the systems under study. The basis characteristics were taken immediately after remolding, and then characteristics were fixed at 2, 7, 28, 90 and 180 days of hardening. Tests of deformation were performed by measuring tool with indicator IP-04 with accuracy 0.01 mm. Results of the study are shown in Table 6 and on Figure 4.

Table 6. Shrinkage deformation of fine grained concretes using basalt rock as an aggregate

№	Composition	Shrinkage deformations, mm/m, at the age, days				
		2	7	28	90	180
1	OPC+ Soluble glass	–0.23	–0.45	–0.63	–0.55	–0.51
2	OPC+ Soluble glass + 10% MK	–0.30	–0.49	–0.61	–0.49	–0.36
3	AAC type I	–0.21	–0.33	–0.44	–0.43	–0.40
4	AAC type I +10% MK	–0.15	–0.26	–0.31	–0.33	–0.32
5	OPC Grade 42.5	–0.25	–0.41	–0.50	–0.44	–0.40
6	OPC Grade 42.5	–0.19	–0.27	–0.41	–0.30	–0.23

Analysis of the results shows that all materials under study are characterized by shrinkage deformations in all test area. It should be mentioned that highest shrinkage for sure have compositions using soluble glass, and the lowest – alkali activated cement AAC type I. That could be explained by higher gel phases in the systems with soluble glass, which are much lower represented in the systems with dry alkaline components.

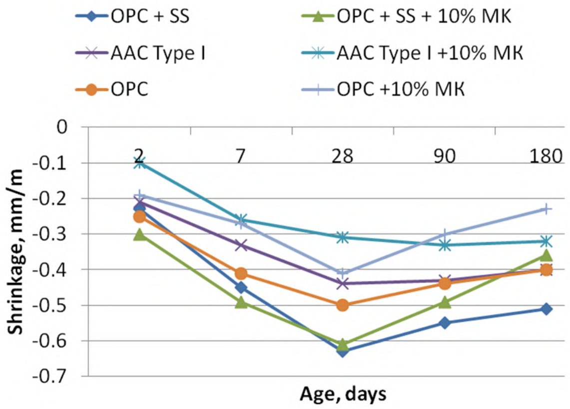

Fig. 4. Shrinkage deformation of fine grain concrete using basalt rock as an aggregate.

It has to mention that for all systems under study shrinkage is reducing with time, witnessing about development of expansion processes via ASR.

The best systems were alkali activated cement with and without metakaolin admixture, which are characterized by spline shrinkage deformation development and insignificant function changes by aggregates corrosion processes gain and expansion.

The present results are expressing specimens hardening in normal conditions. The further studies will be focused on the use of express methods of shrinkage investigation.

Conclusion

1. It is shown that the best cement composition from the high pH value at the initial stages of hardening are alkaline OPC using soluble glass as an alkaline component as in initial state, so as using metakaolin admixture (pH=12 and 11.8 respectively), keeping the rate at the age of 1 day (pH=12 for both systems). Alkalinity of OPC systems is lower (pH=11) at the initial stage, reducing at the initial terms and stabilizing at pH=11 at the age of 1 day, providing normal condition for hardening. Introducing a metakaolin decreases pH to 8.5 with rising to 10 at the age of 6 hours and 10.5 at the age of 1 day. The worth system is alkaline OPC. Low initial alkalinity (pH=10.7) with following reducing to the 10 at the age of 1 day provides low strength gain, and introduction of metakaolin admixture reduces pH to 9.5, storing it for 2 hours and further rising to 11 at the age of 6 hours.
2. Use of active aggregates could complicate of stop structure formation processes in alkali activated cements with dry alkaline component. It is shown that traditional alkalis content in the cement is not enough for normal structure formation processes, and total alkalinity of the system drops at the initial stages and keep reducing in time. Optimal content of alkalis in the system is 6-8%, providing pH 11.5-11.7, and also pH storage in time (up to 11 within 4-24 hours). From the strength point of view the best systems are alkaline OPC as it is, so as with metakaolin admixture (46.8 and 70.8 MPa at the age of 28 days respectively).
3. From the shrinkage point of view the best systems are alkali activated cements with and without metakaolin admixture (-0.44 and -0.31 mm/m respectively at the age 28 days), showing also lower shrinkage at further ages. That could witness about slowing of alkaline corrosion of aggregate processes in the material.

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Suitability of modified low carbon Roman cements for architectural restoration

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Abstract. Article is devoted to the investigation of suitability of low carbon Roman cement for restoration and finishing works. The history of the development of Roman cement as a natural hydraulic binder, which was commonly used to decorate building facades in the 19th and early 20th centuries, is presented. The properties of mortars based on Roman cement make it an excellent product for architectural restoration and conservation, as they are characterized by fast setting, high porosity typical for lime mortars, high resistance to weather conditions, high initial strength. At the same time, due to the high surface activity and increased water demand for cement, with the age of hardening, shrinkage deformations can develop, which leads to the formation of main cracks on the surface of the products. It is shown that the addition of gypsum is an effective regulator of the setting time of Roman cement and contributes to an increase in the strength of the cement paste. Analogs of Roman cement based on multicomponent cement binders modified with plasticizing and air-entraining additives are presented.

1 Introduction

In accordance with the requirements of the Paris Agreement under the UN Framework Convention on Climate Change (UNFCCC) to regulate measures to reduce carbon dioxide emissions in construction, low-carbon eco-cements will become increasingly important [1,2]. As a result of the ecological action of the cement industry in the direction of sustainable development, such low-carbon cements due to the choice of appropriate combinations of components become an alternative to conventional Portland cements [3-5].

In this regard, a significant practical interest is Roman cement, which is one of the stages of development of the technology of binders and has been widely used since the early nineteenth century. In 1796, James Parker [6] for the first time obtained a new brown cement, reminiscent of ancient Roman lime and pozzolana powders, and called it Roman cement when firing marl limestone with a significant content of clay impurities (30-35%) taken from the slopes of Mount Kent (England). French chemist Louis Vicat noted that the calcined material (clinker) with a high content of Al_2O_3 and SiO_2 has hydraulic properties. According to H. Kühl's [7] classification, the term "Roman lime" (Roman cement) covers a group of binders that are not considered burnt clinker, but also do not belong to lime due to the low content of free CaO.

At the end of the 19th century (1890), the Journal of the Technical Society of Cracow published a definition of Roman cement, which stated that this material was obtained by not roast-sintering clay-limestone marls with subsequent grinding to a powdery state. The most famous English Roman cements were made of marl limestone with inclusions of clay or raw materials from Cretaceous or Jurassic formations. In France, marl deposits from the Jurassic regions of Burgundy and chalk near Grenoble were used. The main centers of Roman cement production were also Switzerland, Germany, the Czech Republic and Galicia. In the Western region of Ukraine (XIX-XX centuries) building mixes on the basis of Roman cement were widely used, namely not far from Lviv workshops were created for the production of various standard architectural details for finishing buildings on the basis of Roman cement. This material was called "Lviv Stone", which is very similar in texture and composition to natural stone, which was proved during a survey of existing architectural monuments in Lviv by specialists-restorers in recent years. However, after the end of World War I, Roman cement was rarely used, and later the technology of its production and finishing techniques were forgotten [8].

Today Roman cement is of considerable practical interest as a natural hydraulic binder for repair and restoration works. As part of the European project EU-project ROCARE "Roman cement for the restoration of architecture to new high standards" based on research by

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foreign scientists (J. Weber, C. Gosselin, R. Kozlowski, H. Szeląg, A. Garbacik) in Austria and Poland it is established research-industrial production of Roman cement, restored the technology of its manufacture, expanded the range of products based on it and created the possibility of using the material in the restoration market [9-13].

When mixed with water, Roman cement quickly setting and hardening compared to Portland cement. This is due to the formation of calcium hydrosilicates C-S-H (B), as well as tricalcium hydroaluminate C_3AH_6 and hydroferrites C_3FH_6. To regulate the properties of the composition of Roman cement during grinding, could be added up to 5% gypsum of various modifications and up to 15% of active mineral additives. Roman cement-based mortars are characterized by rapid hardening, high porosity, which is also characteristic of lime mortars. Plasters based on such binders do not retain moisture in the walls of the building, which prevents the formation of cracks [14-16].

Roman cement is also used for the manufacture of paints for renovation of the surface of plasters and other decorative elements. Such paints are suitable for decoration, restoration and aesthetic integration of the facade and architectural elements, especially when applied to decorative elements with a wide range of details in the form of carvings or in cases where it is impossible to perform a thin layer (2-3 mm) of plaster. However, the lack of proper raw materials significantly complicates the production of Roman cement, and low production capacity leads to a significant increase in its cost [17].

At present, the production of Roman cement is established at the research and production plant of the Institute of Ceramics and Building Materials (Department of Glass and Building Materials in Krakow, Poland). Burning of Roman cement clinker takes place in rotary kilns measuring 1.25x16 m at a temperature of 800-900°C. During the burning of raw materials (natural marls) there is a dissociation of calcium and magnesium carbonate, which promotes the active passage of reactions in the solid state with the formation of the main phases of Roman cement - calcium silicates β-C_2S (belite), calcium aluminates CA and $C_{12}A_7$, ferrite C_2F. High burning temperature (above 1000°C) leads to overheating of raw materials with the formation of hydraulically inert mineral gehlenite C_2AS. However, the low burning temperature does not provide a full degree of material synthesis [18, 19].

In the production of Roman cement, the raw material mixture is burning in the form of granules. The firing temperature in the inner part of the clinker and on its surface is not the same, which prevents the achievement of an equilibrium reaction. The reaction between silica and alumina occurs only in areas of maximum burning temperatures. Highly reactive phases such as CA, $C_{12}A_7$, formed on the surface of clinker granules without the presence of glass phase, determine the rapid hardening and strength in the early stages, and with age of hardening, the increase in strength occurs due to hydration of the belite phase. Fine binder also provides pozzolanic reaction in addition to hydraulic that allows improving construction and technical properties of Roman cement (Fig. 1). The hydration of the cements studied was shown to comprise two distinct stages. The immediate setting and early strength is due to the formation of calcium aluminum oxide carbonate (or sulfate) hydroxide hydrates. The development of long-term strength is brought about by the formation of calcium silicate hydrates [20].

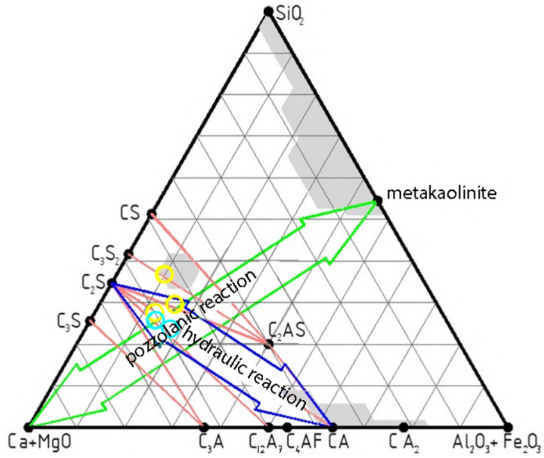

Fig. 1. Hydraulic and pozzolanic reactivity of Roman cement (according to Wolter [20]).

Roman cement is characterized by increased water consumption and rapid hardening as well as shrinkage [21, 22]. There are rapid and slow hardening types of Roman cement. For Roman cement with the initial hardening time not more than 15 minutes, the compressive strength should be not less than 6.0 MPa.

The addition of lime does not retard Roman cement hydration, therefore retardation of Roman cement is essential in hybrid mortars. Lime permits fine control of mortar (workability, workable life, strength). This results indicate a wider potential for render applications in general. If the Roman cement is retarded by means of a pre-hydration process, hybrid mortars can be produced with improved workability and workable life as well as permitting the fine control of strength and moisture transport [23].

Roman cement's compositions modified by chemical and mineral additives have been proposed [24]. Plasticizers and hardening accelerators were chosen and used that allowed rising the durability up to 35 MPa relatively. Superplasticizers and air-repellent additives help to reduce the amount of water, increase water resistance and durability. Mineral additives like slag, zeolite tuff and clay dust were chosen and used that rise the strenght from 22 to 28 MPa. In this case, Roman cement with zeolite-containing mineral additive in a dosage of 15-16%, shows maximum strength.

On the other hand, of considerable practical interest is the development of substitutes for Roman cement with appropriate physical and mechanical properties and plasters based on them. With the introduction of mineral additives of different types, it is possible to obtain a low-CO_2 multicomponent cements [25-27]. To accelerate the processes of early structure formation, it is advisable to use alkaline activation [28, 29]. Of particular note are decorative multi-component alkali activated cements for restoration and finishing works, which are chemically analogous to Roman cement [30]. Such multicomponent cements, modified with complex admixtures plasticizing and air-absorbing action, have comparable or even better performance compared to Roman cement and allow allow to use them successfully in making plasters, mortars. for restoration, finishing works and decoration of facades. Promising direction for improving the properties of multicomponent binders is nanomodification in combination with nanosilica [31, 32].

At the same time, Roman cement plays an important role in the technology of restoration work. Therefore, the task is to study the features of the processes of structure formation and the formation of the properties of Roman cement for its suitability and increasing the operational properties.

2 Materials and methods of research

2.1 Materials

Roman cement was used in experimental research (IMMB, Poland). The chemical composition of Roman cement is respectively 51.1 wt.% CaO; 33.0 wt.% SiO_2; 8.54 wt.% Al_2O_3; 2.34 wt.% Fe_2O_3; 2.01 wt.% MgO; 1.33 wt.% K_2O; 0.4 wt.% Na_2O; 0.87 wt.% SO_3; 12.33 wt. % LOI.

As can be seen from Fig. 2, on the X-ray powder diffraction patterns of non-hydrated Roman cement, in addition to the lines of basic clinker minerals β-Ca_2SiO_4 (β-C_2S) and $CaAl_2O_4$ (CA), lines of calcite $CaCO_3$ (d/n=0.303; 0.277; 0.208; 1.912 nm), quartz β-SiO_2 (d/n=0.424; 0.334; 0.249; 0.228 nm) and gehlenite $Ca_2Al(Al,Si)O_7$ (d/n=0.285; 0.176 nm) are additionally displayed. The content of SiO_2 and $CaCO_3$ is 10 and 25 wt.%, which indicates the incomplete nature of the reactions of solid-phase synthesis of clinker minerals of Roman cement.

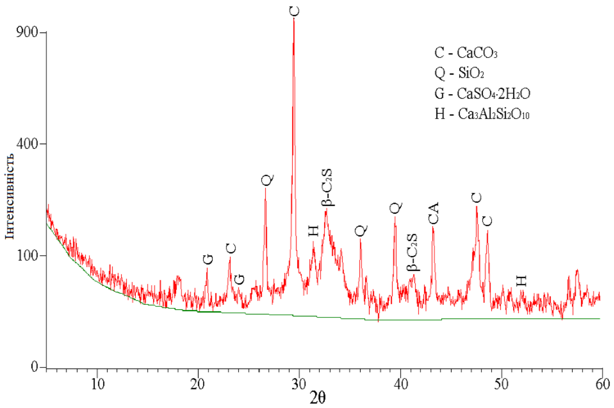

Fig. 2. X-ray powder diffraction patterns of non-hydrate Roman cement.

Roman cement is a decorative binder (the reflection coefficient of the degree of whiteness is 60%).

2.2 Methods

Determination of physical (average density, porosity, water absorption), physical and mechanical properties of Roman cement was carried out according to standard methods. The study of the phase composition of cement hydration products was performed using a set of modern physical and chemical methods of analysis: X-ray diffractometry (DRON-2.0, Siemens D5000), differential thermography (OD-1500Q), and mercury porometry (Autopore II 9220). The chemical compositions of cements and mineral additives were determined by an ARL OPTIM'X X-ray spectrometer. Calorimetric studies of hydrated cement samples were performed using a Zwick Roel calorimeter. Philips XL30 ESEM-FEG and REM-106I scanning electron microscopes were used to study the morphology of the paste surface on the basis of decorative cements and plasters. Fineness of cementitious materials was characterized by the spesific surface area using the Blaine air permeability test. Particle-size distribution was studied with the help of laser high-resolution particle size analyzer Mastersizer 3000.

3 Research results

It was established by the method of laser granulometry (Fig. 3), that for Roman cement (SSA=800 m^2/kg; A_{008}=4.0%) the content of fractions Ø1; Ø10; Ø20 and Ø60 μm is 14.5; 48.7; 59.4 and 88.3% respectively. The grain size of D10; D50 and D90 correspond to 0.79; 11.8 and 69.61 μm.

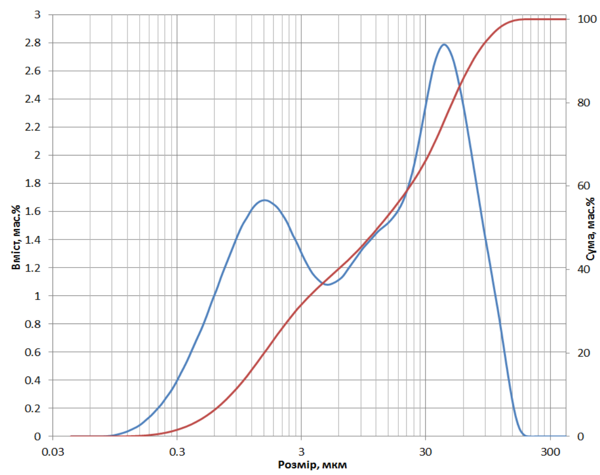

Fig. 3. Particle size distribution of Roman cement.

Based on the granulometric analysis data, the differential surface activity coefficient (K_{isa}) was calculated. This coefficient is defined as the A/V multiplication for a given particle size (ratio of particle surface area to volume, μm^{-1}) by the volume content of each material fraction, based on laser-determined graining data [33]. The K_{isa} value determines the surface activity of a given particle size in the set of cement grains. Thus, the development of the specific surface is determined by the contribution of small fractions and the maximum value of K_{isamax}=10.0 μm^{-1}·vol.% is achieved for the fraction of 0.6 μm, while for the fraction of 42.0 μm with a maximum content of particles (2.8 wt.%) K_{isa} is only 0.43 μm^{-1}·vol.%.

As can be seen from Fig. 4, the contribution of small fractions to the development of the specific surface is decisive. The high dispersion of such particles largely determines their surface energy and leads to a significant water demand of the binder.

Calorimetric analysis (Fig. 5) showed that the Roman cement is characterized by a short induction period (τ=12 min) and low heat of hydration (29.8 J/g), while the exoeffect is 31.6 cal/(gh).

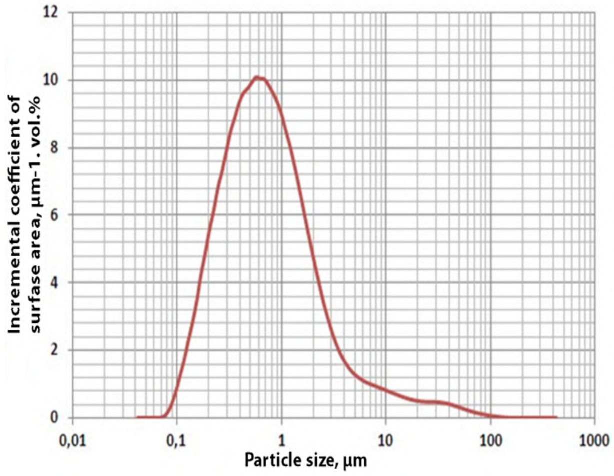

Fig. 4. Differential coefficient of surface activity of Roman cement.

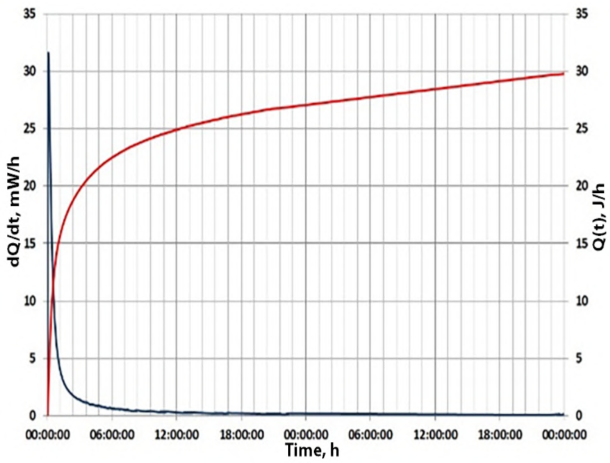

Fig. 5. Kinetics of Roman cement heat release.

Highly reactive phases such as CA, $C_{12}A_7$ determine the rapid hardening and strength in the early stages, and with age of hardening, the increase in strength occurs due to hydration of the belite phase. Initial and final setting time of the cement (water demand - 0.40) is 3 and 8 minutes, respectively, and the strength of the paste after 1; 3; 7 and 28 days of hardening is 4.9; 6.1; 7.6 and 20.8 MPa respectively. For fresh cement-sand mortar (C:S=1:3) based on Roman cement the workability (consistence by flow table) – 115 mm (W/C=1.0); in this case standard compressive strength of 10 MPa is reached.

Roman cement mortars are characterized by exceptionally accelerated hardening time, which causes difficulties in plastering. Addition of 1.0 mass.% citric acid to Roman cement (W/C=0.47; workability – 113 mm) allows to delay initial setting time for 40 min, while the compressive strength after 7 and 28 days is 4.93 and 21.8 MPa, respectively.

In order to establish the physicochemical laws of the formation of the structure and synthesis of the strength of Roman cements, the influence of gypsum was studied. For Roman cement paste, water consistency is achieved at W/C=0.40, initial and final setting time are respectively 3 and 8 min, the compressive strength after 3; 7 and 28 days is 6.1; 7.6 and 20.8 MPa (Table 1). Addition of 5 mass.% gypsum dihydrate can reduce the water consumption by 17.5%, while the initial and final setting time is delayed, and the compressive strength of the paste after 3; 7 and 28 days of hardening increases by 4.5; 4.8 and 2.7 times.

Table 1. Influence of gypsum dihydrate on the strength of Roman cement paste.

Gypsum additive, mass.%	W/C	Setting time, h-m		Compressive strength, MPa, in the age, days				
		initial	final	1	3	7	21	28
-	0,40	0-03	0-08	4,9	6,1	7,6	14,0	20,8
5,0	0,40*	0-20	0-24	4,5	19,4	32,5	38,2	44,5
5,0	0,33	0-16	0-19	10,8	27,5	37,0	49,8	55,6

As can be seen from Fig. 6, the hydration of the Roman cement takes place in two stages: the first is the hydration of the aluminate phase, due to which the Roman cement sets quickly and gains strength in the initial curing period, in the second stage the belite phase provides strength gain at a later curing time. Due to the significant water-reducing effect (ΔW/C=45%) of the Roman cement with the addition of gypsum dihydrate, the strength of the binder after 28 and 90 days of hardening is increased by 2.2 and 2.4 times, respectively, compared to the Roman cement without additives.

This indicates that the use of gypsum dihydrate and retarding additives allows to change the course of the processes of structure formation, which determines further studies of their effect on the phase composition and microstructure of the Roman cement. Peculiarities of Roman cement hydration processes were studied by methods of physical and chemical analysis.

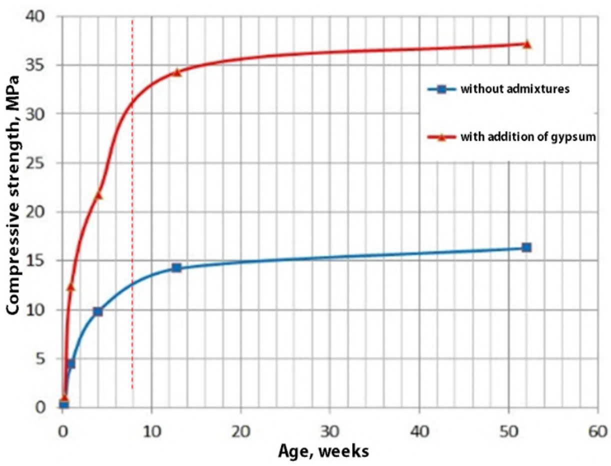

Fig. 6. Strength of Roman cement paste with age of hardening.

After 28 days of hydration, the calcium hydrocarboaluminate lines $C_3A{\cdot}CaCO_3{\cdot}12H_2O$ (d/n=0.761; 0.380 nm) are additionally observed on the diffractograms and the lines of portlandite are practically absent (Fig. 7). For Roman cement paste with the addition of gypsum, the newly formed hydrated phases of etringite (d/n=0.973; 0.561; 0.469 nm) and hydrocalumite (d/n=0.82 nm) are

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observed. To calculate the degree of hydration, β-C_2S (d/n=0.218 nm) was used as the analytical line. It was found that for Roman cement after 28 days of curing, the degree of hydration is 71.0%.

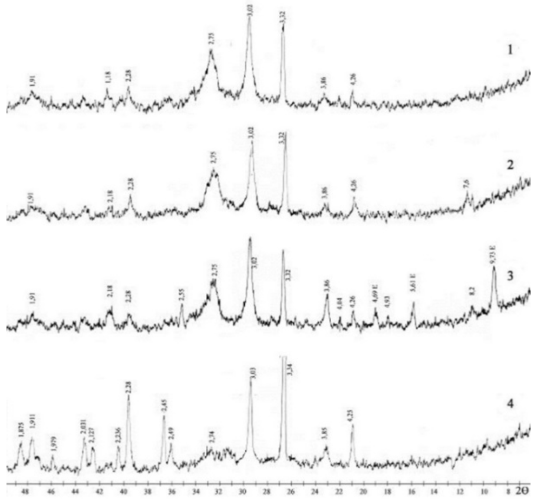


Fig. 7. Diffractograms of hydrated Roman cement paste at 28 days: 1 - non-hydrated; 2 - hydrated without additives; 3 - hydrated with the addition of gypsum; 4 - from a decor element.

According to the thermal analysis (Fig. 8), it was found that for Roman cement with the addition of gypsum, the DTA curve recorded the endothermic effect at 125°C, which corresponds to the release of water from calcium hydrosulfoaluminates. The DTA curve also shows an endoeffect in the temperature range of 600-850°C due to the decomposition of hydroaluminates and calcium carbonate. According to thermogravimetry (TG), the total weight loss during calcination for Roman cement with the addition of gypsum is 34.8%.

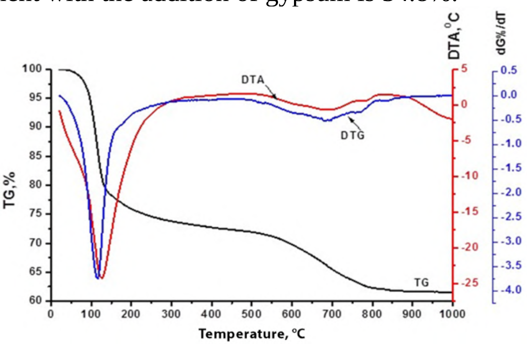


Fig. 8. Derivatograms of Roman cement, hydrated 90 days.

The method of scanning electron microscopy shows (Fig. 9) that the Roman cement, hydrated at 28 days, is characterized by a porous structure with a large number of open capillary pores. The formation of small crystals of calcium hydroaluminates (C-A-H) is observed on the pore surface. The addition of gypsum allows to compact the structure of the Roman cement paste by colmatation the open pores with AFt-phases. According to the data of microprobe X-ray spectral analysis, the relative elemental composition of the pore surface shell corresponds to the main components of Roman cement clinker, mass.%: Ca - 40.59; Al - 16.8; Si - 16.6; Fe - 0.6; O - 36.8. The surface of the pores is formed from the nuclei of crystals, as a result of which the capillary pulling of water and water absorption of the Roman cement paste are reduced.

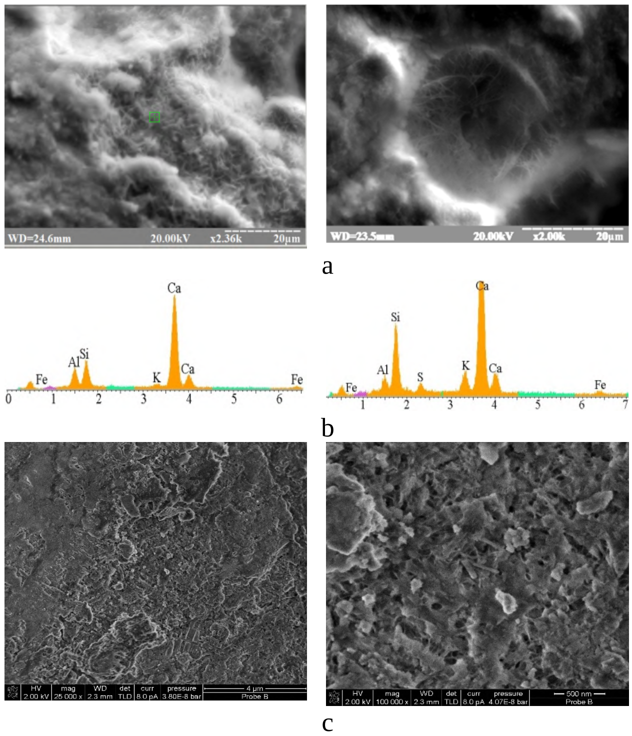


Fig. 9. Microstructure of Roman cement paste: a, c - at 28 and 360 days; b - X-ray spectra from the surface of pore at 28 days.

Roman cement is characterized by significant porosity. Thus, for a paste based on Roman cement without additives, the total porosity is 41.0% (open - 19.0%, closed - 22.0%). Addition of gypsum into the Roman cement allows to reduce the total porosity to 37.78%, while the open porosity is reduced to 11.78% (Fig. 10). [89, 133].

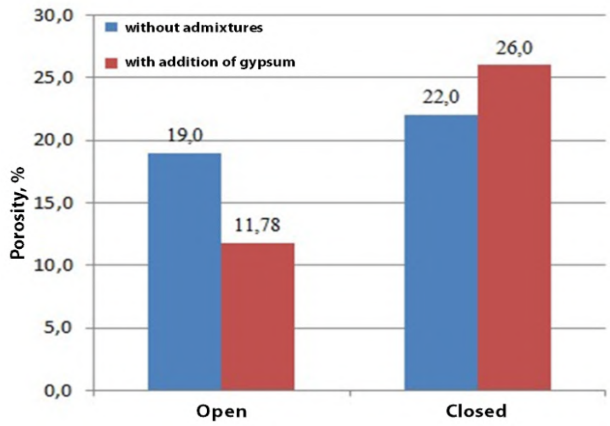
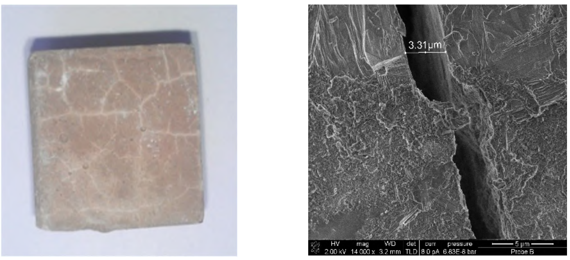


Fig. 10. Open and closed porosity of Roman cement paste.

Among the factors that determine the strength of the paste, of particular interest are the processes of destruction of its structure. Visual observations for a sample based on Roman cement (Fig. 11, a) after 1 year of curing show hair cracks covering the entire volume of the sample. The photomicrograph shows (Fig. 11, b) that the destruction of the material can cause main cracks, one of which is characterized by a width of 3.31μm, the formation of which is due to the union of closed scaly submicroscopic micro cracks in the crystalline aggregates and between them, which is the reason of deformations of shrinkage of a Roman cement.



a b

Fig. 11. The nature of the destruction of Roman cement, hydrated for 1 year: a - hair cracks in the sample; b - micrograph of shrinkage crack (x14000).

The peculiarities of chemical and mineralogical composition and high dispersion of Roman cement determine a significant increase in its water consumption, which leads to increased porosity of artificial stone, the formation of various cracks and possible peeling of plaster.

At the same time, despite many of its advantages, Roman cement is currently not widely used, and its production is low-tonnage, which determines its high cost. This is due to the relatively rare deposits of the raw material, which must have fine intergrowths of calcium carbonate and hydraulic components in the correct proportion. In addition, there are currently not enough low heat shaft kilns that are suitable kilns for the production of Roman cement.

4 Conclusions

1. The peculiarities of the chemical and mineralogical composition of Roman cement are revealed and its influence on the processes of hydration and hardening are established. High dispersion (SSA=800 m^2/kg) and surface activity of Roman cement lead to an increase in its water demand.

2. The increased content of the highly reactive aluminate phase (CA, $C_{12}A_7$) in the Roman cement determines the fast setting (initial and final setting time - 3 and 8 min, respectively) and strength in the early stages of hardening; the increase in strength with age of hardening (strength at 28 days is 10…20MPa) is achieved by hydration of the belite phase. After 1 year of hardening, main cracks may develop in the Roman cement paste due to deformation of the shrinkage.

3. The addition of gypsum is an effective regulator of the setting time, and also reduces water consumption, which leads to an increase in the strength of the Roman cement paste.

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Effect of mineral additives to a gypsum wet deformation

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Abstract. The influence of mineral additive, i.e. ground granulated blast-furnace slag on artificial gypsum stone humidity strains has been studied. The slag content was varied in the range from 0 to 0.33 by weight based on the total amount of the mixture. The measurements were carried out on prism samples with dimensions of 160x40x40 mm. The samples were placed vertically in containers with water, the deformations were measured using dial indicators. It was established that the humidity strain value depends on the content of the granulated milled blast-furnace slag. A maximum strain of over 0.001 m/m is observed for the gypsum stone without mineral additive. A relative strain is decreased with an increase in the slag content. Minimum humidity strain of 0.0003-0.0004 m/m was observed for the artificial gypsum stone with the relative slag content of 0.05-0.1 and more than 0.27. This fact confirms our assumption that the water concentrated in the contacts between the individual crystals and particles of the structure of gypsum stone has a wedging effect that contributes to a low water resistance of gypsum. The values of the humidity strains of the artificial gypsum stone are suggested for the use as additional indicators of its water resistance.

1 Introduction

Gypsum binder-based materials are characterized by the ecological safety, sufficient strength and durability and also by a low weight and relatively low heat and sound conductivity. Due to these advantages, gypsum materials are widely used for construction purposes. However, their insufficient water resistance that results in an essential loss of strength in the case of their water saturation and/or wetting restricts the fields of their broad application. A low water resistance of gypsum materials is mainly explained by the calcium dihydrate solubility and the wedging forces that are created by the water that penetrates into the pores.

As of today, many methods are available that can increase the gypsum water resistance, in particular a decrease in the water-to-gypsum ratio, an addition of polymer additives, impregnation and hydrophobization of the surfaces of gypsum stone, combination with hydraulic binders, addition of active mineral additives and additives-microfillers that contribute to the formation of the dense structure of gypsum stone. During the studies carried out to improve the compositions of gypsum binder the water resistance was evaluated by the softening factor, i.e. the compression strength ratio in the water saturated state and initial dry state.

Nevertheless, the contribution made to the water resistance of gypsum stone by abovementioned wedging forces that are created by the water that penetrates into the pores requires additional studies. However, it is known to us that these forces simultaneously result in the humidity strains of the artificial stone. Hence, the studies of the volumetric strains of the artificial gypsum stone with mineral additives and their relations with the water resistance are an important task.

2 Analytical review of literature sources

A low water resistance of gypsum items is explained by a rather high solubility of gypsum dihydrate equal to 2.04 g/l [1]. In addition, the water that penetrates into inter-crystalline cavities is adsorbed by hard surfaces and the wedging pressure is created between them that disrupts local contacts between the crystals. An assumption can be made that these reasons are interrelating and enhance each other.

Gypsum modifications are described in many research papers [2-6], etc. The water resistance of gypsum binders can be increased by a decrease in the water-to-gypsum ratio, by combination with hydraulic binders [4-6] and by addition of mineral additives-fillers [7-12], hydrophobization additives [12], polymers and the fiber [13]. The authors give different explanations to the reasons that contribute to the improvement of the properties. The complex mineral additive that includes the granulated milled blast-furnace slag, fly ash and pazzolana (zeolite) provides the densification of the structure of the cement stone and an increase in its strength, according to [15]. In [16], the internal strain of the artificial stone can be controlled through the addition of the slag-lime binder to the Portland-cement clinker. To improve physical and mechanical characteristics, the authors [17] modify binding substances by clay fillers. The electrolytes, especially in the form of the complex additive, provide an increase in the water impermeability

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[18] and strength [19] of cement composites. In [19], such an influence of potassium and sodium sulfates and carbonates is explained by the modification of the microstructure and porous structure.

The structure and the properties of gypsum materials can also be controlled through the addition of mineral fillers and other binders of a different composition and dispersion degree [4-13; 20-22]. The most stable compositions of gypsum binders are gypsum-cement-pazzolana binders [1]. Among their hydration products are not only calcium dihydrate sulfate crystals but also low-basic calcium hydrosilicates and other slightly soluble hydrates. According to [14], these can form electroheterogeneous contacts with calcium dihydrate sulfate crystals that provide the formation of the water-resistant structure.

In [4], the water resistance of gypsum made of waste is attained by mixing it with the fly ash and Portland cement. The authors [21] add mineral and organic modifiers to gypsum and explain their action by the enhancement at the atomic and molecular level. In [20], the industrial waste that contains calcium dihydrate sulfate is used as a substituent of natural gypsum. In order to form a denser structure of gypsum stone, the authors [22] use the methods of the computer simulation of the composition of the raw mixture and in [2] they substantiate an optimal proportion that provides a maximum strength for the mixed binder made of slag, gypsum and clinker. In [5, 7, 10, 13], consideration is given to the microreinforcing action of mineral additives on gypsum stone and its effect on the strength. An addition of 14% of the ultra-dispersed zeolite to gypsum resulted in an increase of its water resistance from 0.31 to 0.84 [7]. An analogous effect [10] caused by the addition of zeolite and carboxylate is also explained by an essential change in the structure. In [13], an increase in the gypsum strength is explained by the effect of the dispersed reinforcement.

The effect of mineral and chemical additives on the gypsum water resistance was studied in [4; 7; 8; 11; 12]. The authors [8] modify gypsum by the metallurgy dust and multi-walled carbon nanotubes. They explain an observed increase in the water resistance by the formation of amorphous hydrosilicate structures on the gypsum crystal surface that bind gypsum crystals and prevent an access of water to them. In [9], gypsum is modified by the ultradispersed metallurgy dust and anhydride. The authors note a change in the morphology that results in the densification and an increased strength and water resistance. In [11], the authors state an intensification of the hydration and the formation of a denser structure due to the addition of the complex chemical additive. Micro- and nanoadditives of silicon carbide *SiC* that act as crystallization centers and result in the formation of larger crystals also intensify hydration and structure formation processes [12].

It is known [18] that the properties of the materials that are based on inorganic binders are conditioned by the availability of the electrostatic interaction of the double electric layers of structural elements. The strength and the water resistance of hydraulic binders are defined by strong electroheterogeneous contacts between the particles with opposite surface charges. Air-setting binders consist of the elements that have similar charges, therefore their strength and water resistance are defined by electrohomogeneous contacts with the intermolecular interaction. In [3], a hypothesis was put forward and it was proved that maximum possible physical and mechanical parameters of the cured_mineral binders can be attained due to the equality between themselves of the total areas of particle surfaces of a dispersed phase in the volume unit that have opposite surface charges. We believe that such equality can be attained through the composition control of the hydration products of the binder and the embedment of highly-dispersed inert particles into their structure. The gypsum stone strength is mainly defined by electrohomogeneous contacts between the gypsum crystallohydrates with a weak intermolecular interaction. These contacts are destroyed even by insignificant strains [3; 14]. To provide an appropriate water resistance and to increase the strength of gypsum binders the research papers [2; 14] suggest to add mineral additives to their composition that act as the fillers and microfillers with defined surface charges and it will result in the formation of an ample amount of electroheterogeneous contacts with the edges of gypsum crystallohydrates.

It was shown in [18] that the water resistance of gypsum with mineral additives, in particular ground granulated blast-furnace slag depends on the thickness of the interlayers of gypsum dihydrade between the particles of mineral fillers. The thickness of these interlayers is related to the structural characteristic of the filled gypsum stone, i.e. the separation factor of the particles of mineral filler by gypsum dehydrate η. The dependence of the strength of artificial stone and especially its water resistance [3] has a wavelike or extreme character with the peaks that correspond to the optimal values of separation coefficient η_{opt}. A maximum strength and water resistance are provided in the case of the formation of a denser packing of the gypsum dihydrate crystals in the interlayers between the particles of the mineral filler and in the case of the correspondence of an actual value of the separation coefficient η to its optimal value η_{opt}. For this purpose, it was suggested in [3] to provide an optimal value of the separation coefficient η_{opt} that is analogous to the optimal separation coefficients of the grains of coarse filler η_{opt} and the fine filler η_{opt} in the concretes. The density of gypsum stone can also be increased through the use of nanodispersed fillers that fill intercrystalline cavities by embedding into the structure and contribute thus to the structure densification [3; 14]. In this case, the number and the dispersion degree of the fillers are selected to provide the formation of the dense packing of matrix particles in the interlayers between the structure forming parts, in particular gypsum crystallohydrates are supposed to be formed between the slag particles and nanodispersed particles should be formed between gypsum crystallohydrates [3; 14]. In addition, the nanodispersed particles of the filler can act as crystallization centers increasing thus the dispersion of crystallohydrates and making the structure denser.

Based on the conceptions of the contribution made to a low water resistance by the wedging effect of the water concentrated in the contacts between the individual crystals and particles in its structure it was suggested to use a relative linear humidity strain caused by the water saturation (swelling) ε_w in m/m as an additional indicator of water resistance.

3 Research methods and materials

To carry out experimental investigations we used the gypsum building plaster G-10, ground granulated blast-furnace slag "Zaporizhstal" and the plasticizing additive, i.e. sodium lingosulphonate in the amount of 2% of the gypsum mass.

The ground granulated blast-furnace slag "Zaporizhstal" had the following parameters: chemical composition, %: SiO_2 – 36.5; Fe_2O_3 – 5.1; Al_2O_3 – 6.7; CaO – 46.5; MgO – 5.9; SO_3 – 4.2; the basicity module – 1.19; the true density – 2810 kg/m^3; the specific surface – 3000 cm^2/g; the granulometric composition was defined using the MBI-6 microscope ruler, %: up to 10 μm -2.5; for the range of 10 to 23 μm – 11; 2 to 36 μm – 8.6; 36 to 49 μm – 12.9; 49 to 62 μm – 8.8; 62 to 75 μm – 6.8; 75 to 88 μm – 9.2; 88 to 101 μm – 6.7; 101 to114 μm – 10.6; 114 to 127 μm – 10.3; above 127 μm – 12.7. Hence, about 80 % fall to the range of 10 to130 μm, and the average particle size is 60 μm.

The humidity strain was defined using prism-like specimens with the size of 160×40×40 mm that were cured for at least 7 days and nights and dried in the temperature range of 18 to 22°C and the relative humidity of 40 to 60% to get the constant weight. At least three specimens were used to test each composition. The specimen length L was measured in advance. Each specimen was inserted vertically into the container and the steel or glass plate was laid over it. The indicator of a clock type that was clamped in the laboratory holder (Fig.1) was connected to it and initial indicator readings were recorded.

The container was filled with water to the level of the upper edge of the specimen and the indicator readings were taken every 0.25 to 0.5 hours during first 6 hours. A sight was taken on it for at least 24 hours.

The values of absolute linear humidity strain were measured for each time point i according to the indicator readings X_i:

$$\Delta L_i = X_i - X_0, \text{ mm}, \tag{1}$$

where X_0 is the initial indicator reading prior to pouring a required amount of water.

A relative humidity strain was measured for each time point:

$$\varepsilon_w = \Delta L_i / L \tag{2}$$

Based on ε_w values, the kinetic curve of the dependence of ε_w on time was constructed and using this curve a maximum value of ε_w was defined and the time required to attain it was recorded.

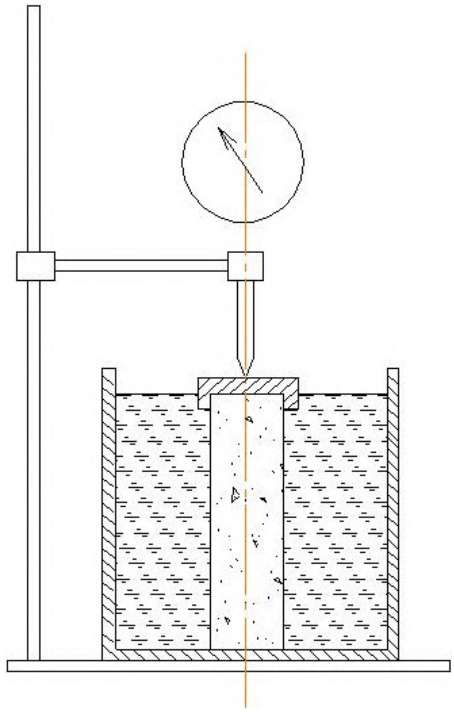

Fig. 1. Measurements of the humidity strains of artificial gypsum stone with mineral additives.

4 Research data and their discussion

The research data are given in Fig. 2 and 3 and in Table 1.

Table 1. Maximum humidity strains ε of the artificial gypsum stone with a different relative content of the mineral additive in the form of ground granulated blast-furnace slag S (G+S)

No	S/ (G+S)	W/ (G+S)	A relative humidity strain of the specimens ε_w, m/m.						ε_{wmid}, m/m
K	0	0.35	0.64020	0.78047	1.60285	1.05040	0.91300	1.12973	1.01937
1	0.09	0.32	0.59156	0.43218	0.27623				0.43332
2	0.17	0.29	0.54071	0.39653	0.54162	0.96342	0.91690	0.78600	0.69081
3	0.23	0.27	1.12251	0.72981	0.67662				0.84298
4	0.29	0.25	0.75382	0.38879	0.29888				0.48050
5	0.33	0.23	0.35869	0.32983	0.76449				0.34426

Fig.2 and 3 and Table 1 show that as soon as the specimens are immersed into the water their length starts to elongate immediately due to the humidity strain, i.e. the swelling. The strain was developed during 3 to 5

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hours and after that it attained a maximum value and actually immediately it began to come down.

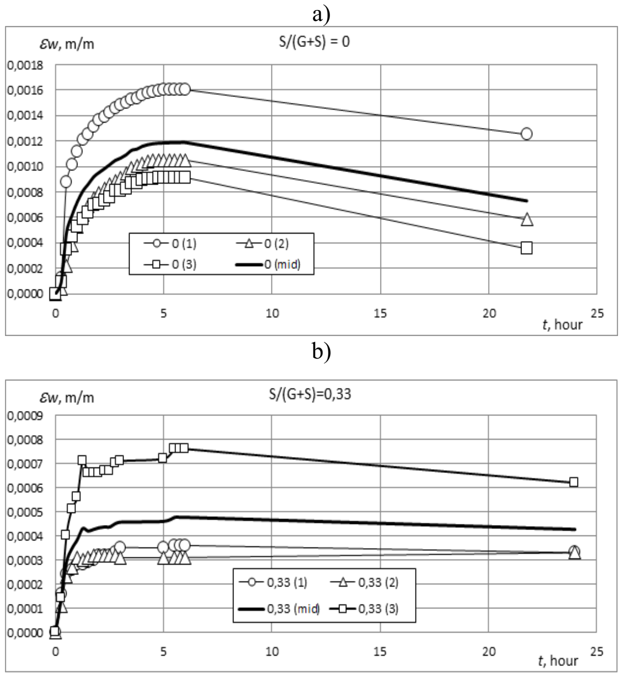

Fig.2. The dependence of the humidity strain ε_w on time t for the artificial gypsum stone with a relative content of the mineral additive, in particular ground granulated blast-furnace slag S/(G+S): a – 0 (gypsum stone without additives); b – 0.33.

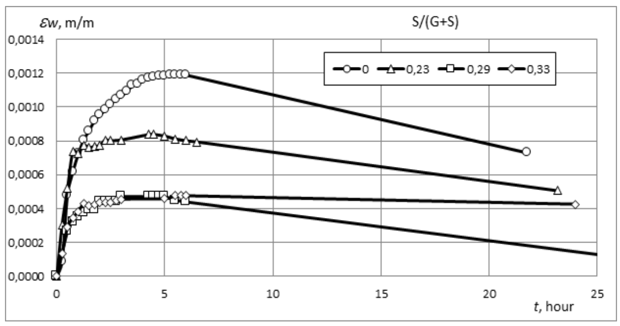

Fig.3. The dependence of the humidity strain ε_w on time *t* for the artificial gypsum stone with a different relative content of the mineral additive, in particular ground granulated blast-furnace slag S/(G+S).

It can be seen from Fig. 3 and 4 and Table 1 that the value of humidity strain depends on the content of the mineral additive, i.e. granulated milled blast-furnace slag. A maximum strain is observed for the gypsum stone without mineral additive. A relative strain is decreased with an increase in the slag content. However, this decrease has no linear character; it is wavelike by analogy to the dependences of the strength and water resistance on the slag content.

It can be seen from Fig.3 and 4 and Table 1 that minimum humidity strains are observed for artificial gypsum stone with a relative slag content of S/(G+S) 0.05–0.1 and above 0.27. It agrees with the character of the dependences constructed for the water resistance of the artificial gypsum stone as a function of relative slag content (Fig. 5) and it confirms our assumption that the wedging effect of water concentrated in the contacts between the individual crystals and particles in its structure contributes to a low water resistance of gypsum. Hence, it is reasonable to use the values of humidity strains of artificial gypsum stone as additional indicators of its water resistance.

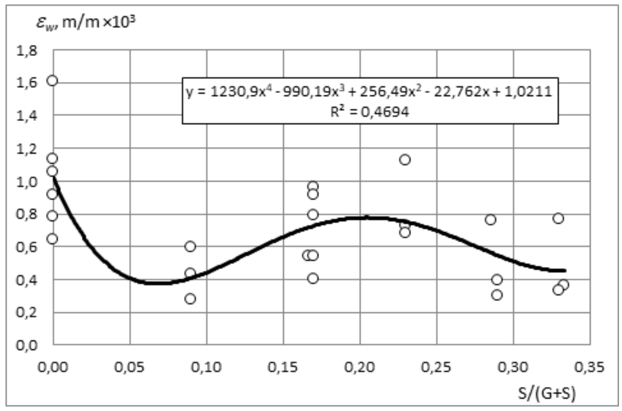

Fig.4. Dependence of a maximum humidity strain ε of the artificial gypsum stone on a relative content of the mineral additive, in particular ground granulated blast-furnace slag S/(G+S).

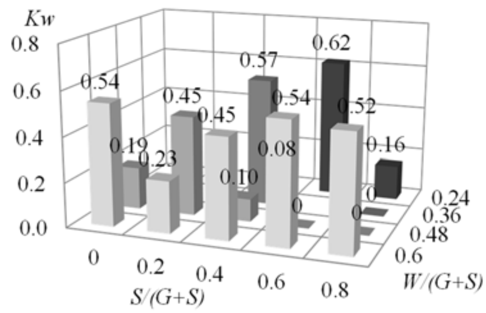

Fig. 5. The dependence of the strength and water resistance ratio K_w of gypsum-slag stone at the age of 7 days on the content of the filler –slag S/(G+S) and water-solid ratio W/(G+S) [14].

Therefore, the supplemental addition of the ground granulated blast-furnace slag to gypsum with the mineral additive results in no increase in the strength of artificial gypsum stone and it can even condition a certain reduction of it. However, its strength is increased in the water saturated state and it results in an essential increase in the water resistance, the softening factor in increased in the range of 0.6 to 0.8 and it can attain 1.

The information given above confirms the theoretical conception that the addition of mineral additives to gypsum results in an increased amount of electroheterogeneous contacts in the artificial stone structure due to the fact that the pores are filled by additive particles.

5 Conclusions and recommendations

The experimental investigations show that as soon as the specimens are immersed into the water their length starts to elongate due to the humidity strain, in particular, the swelling. The strain was developed during 3 to 5 hours and after that it attained a maximum value and actually immediately it began to come down.

It was established that the value of humidity strain depends on the content of the mineral additive, i.e. granulated milled blast-furnace slag. A maximum strain is observed for the gypsum stone without mineral additive. A relative strain is decreased with an increase in the slag content. However, this decrease has no linear character; it is wavelike by analogy to the dependences of the strength and water resistance on the slag content. Minimum humidity strains are observed for the artificial gypsum stone with a relative slag content of S/(G+S) 0.05–0.1 and above 0.27.

It confirms our assumption that the wedging effect of water concentrated in the contacts between the individual crystals and the particles in its structure promotes a low water resistance of gypsum. Hence, it is reasonable to use the values of humidity strains of artificial gypsum stone as additional indicators of its water resistance.

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Prevention of steel reinforcement corrosion in alkali-activated slag cement concrete mixed with seawater

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Abstract. Concretes mixed with seawater are characterised by enhanced performances, but action of chlorides and sulfates ensures the risk of reinforcement corrosion. Application of high consistency fresh concretes ensures changes in hardened concrete structure that causes the problem of steel reinforcement passive state ensuring. Thus mixing of plasticized concretes by seawater actualizes the search for means of steel corrosion prevention. Alkali-activated slag cements (further, AASC's) reduce effect of ions Cl^- and SO_4^{2-} on steel reinforcement in concrete due to their exchange for ions OH^- in the structure of zeolite-like alkaline hydroaluminosilicates. Complex additive «portland cement - calcium aluminate cement - clinoptilolite» was proposed to enhance the protective properties of AASC concretes to steel reinforcement. The results of DTA, X-ray diffraction, electron microscopy, microprobe analysis show that complex additive ensures to prevent steel reinforcement corrosion in AASC concrete mixed with seawater due to binding Cl^- and SO_4^{2-} ions in Kuzel's salt in AASC hydration products and exchange of these aggressive ions with OH^- ions in the structure of clinoptilolite. This effect of complex additive confirmed by surface state and the absence of mass loss of steel rebars embedded in plasticized AASC fine concrete mixed with seawater after 90 d of hardening.

1 Introduction

The actuality of green materials implementation is due to their conformity with modern tendencies in construction engineering concerning efficient consumption of raw materials and energy resources [1], as well as responsible attitude to ecology of the environment [2]. Cements, which contain inorganic additives, fully comply modern tendencies for sustainable development of mankind [3]. The ecological benefits of such cements are caused by reduction of CO_2 emission due to substitution of portland cement clinker by inorganic additives [4]. At that, materials based on the mentioned cements are characterized by high quality, functionality and durability. Efficiency of high early strength multicomponent cements based on ground blast furnace slags (further, GBFS), zeolite and fly-ash in mortars was shown [5]. Additives of polydisperse zeolite tuff and perlite provide positive effect on concrete strength in different conditions [6]. Addition of zeolite or highly dispersed chalk enhances strength of cements [7], as well as crack resistance [8] and freeze-thaw resistance of concretes [9]. Portland cements containing GBFS are characterized by increased corrosion resistance and can be used in protective materials [10].

Alkali-activated slag cement (further, AASC) can be consider as the most perspective environmentally friendly ones. Alkali activation of aluminosilicate raw materials is widely used [11, 12]. The ecological benefits of AASC's are caused by reduction of CO_2 emission while consumption of by-products as well as waste products [13]. AASC mortars and concretes are characterized by increased strength [14], heat resistance [15, 16], corrosion resistance [17], freeze-thaw resistance [18], waterproof [19] and fire resistance [20, 21] in comparison with analogues based on traditional clinker cements. Beside of high performances, AASC's can be used in decorative materials [22]. Radioactive wastes [23] and manufacturing waters [24] are effectively used in safety building materials based on AASC.

As perspective direction being taken to improve the environmental friendliness of modern concretes, has been using of seawater. It's known, that the consumption of water in concrete is 9 % of the total consumption of industrial water [25]. Thus, the most recent substantial interest has been placed on seawater as an alternative solution for impeding the exploitation of freshwater.

Seawater can be used as an activator of GBFS's hydraulic properties [26, 27, 28]. This phenomena is caused by salts of strong acids (further, SSA's), like chlorides and sulfates, dissolved in seawater [29, 30]. At that, seawater ensures increasing of AASC concrete consistency [31] and concrete strength [32] that is explained by effect of SSA's [33, 34].

However, corrosion of steel reinforcement under action of chlorides and sulfates is the main problem for concretes mixed with seawater. There are two main processes during corrosion action on steel reinforcement: carbonation and pitting corrosion, caused by chlorine-ions [35]. Sulfate-ions don't cause immediate depassivation of steel reinforcement, but determine formation of hydrogen

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sulfide (H_2S), which catalyze oxidation (carbonation) of hydrate phases.

The stability of passive film on the surface of steel reinforcement in AASC concrete, mixed with seawater, depends on concentration of free chlorine-ions and OH^- ions in pore solution, primarily in contact zone between reinforcement and concrete [36]. The passive state of steel reinforcement is provided at molar ratio of $Cl^-/OH^- \leq 0.6$ in pore solution [37].

The modern requirements to high consistency fresh concretes are governed by practice. This way the disturbance of reinforcement passive state can be caused by changes in hardened concrete structure [38]. Problem with ensuring of steel reinforcement passive state in AASC concretes, mixed with seawater, is intensified. Thus, the means for protection of steel reinforcement in plasticized AASC concretes must be developed.

It was shown, that the modification by complex additive (further, CAD) based on SSA's ensures decreasing of AASC concrete drying shrinkage as well as enhancement of crack resistance [39]. This type of modification provides mitigation of steel reinforcement corrosion. Effect of CAD is caused by less water, acceleration of crystallization, alteration of porous structure as well as by changes in morphology of hydrated phases [33, 34].

One of the ways to prevent the steel reinforcement corrosion in AASC concrete mixed with seawater is decreasing of chlorine ions in pore solution due to their binding in low soluble compounds. It's well-known that hydration products of AASC are able to bind chlorine-ions. Alkaline hydroaluminosilicates, as analogues of natural zeolites, can be refered as such phases [29]. Apart from alkaline hydroaluminosilicates, free chlorine can be binded in Cl-bearing phases like hydrotalcite $[Mg_3Al(OH)_8]Cl\cdot3H_2O$ and hydrocalumite $3CaO\cdot Al_2O_3\cdot CaCl_2\cdot10H_2O$ [40]. These phases are suitable for chlorine binding both due to exchange processes and physical adsorption [41, 42, 43]. It was shown the binding of chlorine-ions by hydrosilicate C–S–H and hydroaluminosilicate C–A–S–H gel phases [44, 45].

Formation of phases, which provide binding of Cl^- and SO_4^{2-} ions, was proposed to prevent steel reinforcement corrosion in AASC concrete. It's well-known that chlorine can be binded by tricalcium aluminate ($3CaO\cdot Al_2O_3$) in AFm phases (Al_2O_3-Fe_2O_3-mono), which are characterized by greater stability comparing to AFt phases (ettringite) while increasing alkalinity of hydration medium [46, 47, 48]. The AFm phases can include different anions (Cl^-, SO_4^{2-}, CO_3^{2-}, OH^- etc.). Thus, AFm phases can be presented by monocarboaluminate, hemicarboaluminate, stratlingite, hydroxyl-AFm and monosulfoaluminate [49]. It was shown formation of nitrate containing AFm phase along with chloride and sulfate containing ones [50].

The above results cause reasonable application of calcium aluminate cement and portland cement as additives in AASC to ensure formation of highly-calcium hydroaluminates $3CaO\cdot Al_2O_3\cdot10H_2O$ for prevention of steel reinforcement corrosion due to binding of Cl^- and SO_4^{2-} ions. Highly-calcium hydroaluminates $3CaO\cdot Al_2O_3\cdot10H_2O$ can be formed due to interaction of portlandite $Ca(OH)_2$ (hydration product of portland cement) with low-calcium hydrosilicates (hydration product of calcium aluminate cement) [51]:

$$CaO\cdot Al_2O_3\cdot(6\ldots8)H_2O + 2Ca(OH)_2 \rightarrow$$
$$\rightarrow 3CaO\cdot Al_2O_3\cdot10H_2O \quad (1)$$

$3CaO\cdot Al_2O_3\cdot10H_2O$ ensures binding Cl^- and SO_4^{2-} ions in low soluble AFm phases [52]:

$$3CaO\cdot Al_2O_3\cdot10H_2O + Cl^-, SO_4^{2-} + H_2O \rightarrow$$
$$\rightarrow 3CaO\cdot Al_2O_3\cdot CaCl_2(SO_4)\cdot10H_2O \quad (2)$$

Application of aluminosilicate ionites such as clinoptilolite (natural zeolite) in AASC concrete composition, mixed with seawater, can be mean for prevention of steel reinforcement corrosion. Zeolites are known, first of all, as cationites which exchange Na^+ ions with Ca^{2+} ions, but can also act like anionites to exchange OH^- ions with Cl^- and SO_4^{2-} ions [53]. Clinoptilolite supplements anionite function of alkaline hydroaluminosilicates (analogues of natural zeolites) during AASC hydration.

The above results allow predicting prevention of steel reinforcement corrosion in plasticized AASC concrete mixed with seawater due to application of CAD «portland cement - calcium aluminate cement - clinoptilolite».

The aim of this research was to investigate the effect of seawater on the performances of plasticized AASC concrete and to ensure prevention of steel reinforcement corrosion due to application of CAD «portland cement - calcium aluminate cement - clinoptilolite».

2 Raw materials and methods

GBFS (CaO – 47.30 %; SiO2 – 39.00 %; Al_2O_3 – 5.90 %; Fe_2O_3 – 0.30 %; MgO – 5.82 %; SO_3 – 1.50 %; TiO_2 – 0.31 %), basicity modulus= 1.11, content of glass phase= 84.0 %, specific surface= 450 m^2/kg (by Blaine), was used as an aluminosilicate component of AASC.

Alkaline components of AASC were presented by:

- soda ash (Na_2CO_3), dry state;
- five-water sodium metasilicate ($Na_2SiO_3\cdot5H_2O$), dry state;

Two reference compositions of AASC were used:

- based on soda ash (GBFS – 93.50 %, soda ash – 6.50 % (3.80 % by Na_2O));
- based on sodium metasilicate (GBFS – 88.50 %, sodium metasilicate – 11.50 % (3.36 % by Na_2O));

The AASC's were also modified by CAD, which components were presented by:

- portland cement CEM I 42,5 R (PJSC Ivano-Frankivskcement, Ukraine);
- calcium aluminate cement ISTRA 40 (HeidelbergCement, Germany);
- natural zeolite (clinoptilolite) powder (by mass, %: SiO_2 – 72.5, Al_2O_3 – 13.1, Fe_2O_3 – 0.9, TiO_2 – 0.2, CaO – 2.1, MgO – 1.07, P_2O_5 – 0.003, K_2O+Na_2O – 5.03), fr. 0 - 0.1 mm, content of clinoptilolite ≤ 93.0 %, porosity 54.0 % (JSC Zeolite-Bio, Ukraine).

Content of CAD was 10.00 % by mass of AASC. Contents of CAD components, %: (portland cement + calcium aluminate cement) – 5, clinoptilolite – 5.

The ratio between portland cement and calcium aluminate cement was 2.17:1.00 taking into account formation of $3CaO{\cdot}Al_2O_3{\cdot}10H_2O$ according to reaction (1).

Surfactants were presented by:

- sodium lignosulphonate (further, LST) according to CAS 8061-51-6 (pH ≥ 8.5);

- sodium gluconate according to CAS 527-07-1.

AASC's were mixed with fresh water or with seawater, which was presented by aqueous solution of salts, % by mass of mixture: NaCl – 78.70, $MgCl_2$ – 9.80, $MgSO_4$ – 5.76, $CaSO_4$ – 3.75, KCl – 1.73, $CaCO_3$ – 0.29. Total concentration of seawater salts was 35 g/l.

The standard quartz sand according to EN 196-1 was used in AASC fine aggregate concretes (ratio AASC to sand = 1:3).

Reinforcement was presented by steel rebars, length 120 mm and diameter 4.1 - 4.3 mm.

Fresh concretes were prepared in mixer «Raimondi Iperbet» (Italy).

Consistency (workability) was determined by cone slump according to the national standard of Ukraine DSTU B V.2.7-114:2002.

Consistency class of fresh concrete was S4 (slump 160 - 210 mm).

The performances plasticized of AASC concretes (AASC:sand = 1:3) were determined on specimens 40x40x160 mm.

The state of embedded steel rebars in plasticized AASC concrete, mixed with seawater, was estimated according to following method. The basic rebars, length (120±2) mm and diameter from 3 to 6 mm, were embedded in specimens 40x40x160 mm of AASC concrete. These rebars were degreased by acetone and weighted with accuracy of ±0,001 g before embedding. After hardening of specimens in normal conditions (t=20±2 °C, *R.H.*=95±5 %) the basic rebars were reached from AASC concrete and etched during (25±5) min in 10 % solution of hydrochloric acid with adding of urotropine (1 % by acid mass) to remove rests of cement stone and products of corrosion. The reference rebars, which weren't embedded in concrete, were weighted and etched simultaneously with basic rebars. After etching the basic and reference rebars were cleaned by distilled water and were immersed in fat solution of sodium nitrate for 5 min. Then the rebars were wiped by filter paper, dried up and weighted. The mass loss of rebars were calculated as a ratio of mean differences between masses before and after etching to surface area.

Monitoring the structure formation was carried out by X-ray diffraction (XRD), differential-thermal analysis (DTA) and electronic microscope with microanalyzer

3 Results and discussion

Effect of CAD «portland cement - calcium aluminate cement - clinoptilolite» on structure formation of AASC, mixed with seawater, was investigated.

3.1 Structure formation of alkali-activated slag cement based on soda ash and mixed with seawater

XRD indicates the slightly crystallized low-calcium hydrosilicates such as CSH(B) (d= 0.307; 0.280; 0.183 nm) and gyrolite $2CaO{\cdot}3SiO_2{\cdot}2H_2O$ (d= 0.33; 0.268; 0.180 nm) after 90 d of hydration (Fig.1, curve 1). Besides, calcite (d= 0.307; 0.191; 0.160; 0.152 nm) is formed. Specified phases are typical for AASC [54].

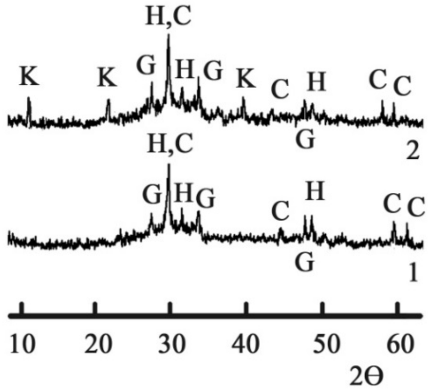

Fig. 1. XRD of alkali-activated slag cement mixed with seawater and hydrated during 90 d: 1 – the reference; 2 - modified by complex additive. Legend: H – calcium hydrosilicates CSH(B), G – gyrolite, C – calcite, K – Kuzel`s salt.

Clorine- and sulfate-binding zeolite-like minerals, which are similar to nosean $Na_8(Al_6Si_6O_{24})(SO_4){\cdot}H_2O$, sodalite $Na_4(Si_3Al_3)O_{12}Cl$, cancrinite $(Na,Ca)_8(Al_6Si_6O_{24})(CO_3,SO_4)_2{\cdot}2H_2O$ etc., can be predicted [29, 55]. However these hydrates were not identified because of their submicrocristalline state.

DTA confirms formation of slightly crystallized calcium hydrosilicates CSH(B) by endothermic effect at t= 175 (dehydration) and exothermic effect at t= 865 °C (recrystallization into wollastonite). The endothermic effects at t= 175 and 700 °C (stepped dehydration) and exothermic effect at t= 865 °C (recrystallization into wollastonite) are typical for gyrolite $2CaO{\cdot}3SiO_2{\cdot}2H_2O$ (Fig. 2, curve 1). The endothermic effect at t= 890 °C confirms presence of $CaCO_3$ (Fig. 2, curve 1).

According to electron microscopy (Fig.3 a), gel-like low-calcium hydrosilicates CSH(B) (content in probe, %: CaO – 30.19, SiO_2 - 35.42) (Fig.3 b) and prismatic formations of calcite $CaCO_3$ (content in probe, %: CaO - 53.78, CO_2 - 41.29) (Fig.3 c) were identified in the reference AASC.

Chlorine and sulfate containing AFm phases, known as Kuzel's salt $3CaO{\cdot}Al_2O_3{\cdot}0,5CaCl_2{\cdot}0,5SO_4{\cdot}10H_2O$ (d= 0.83; 0.42; 0.23 nm) [56], were also identified in hydration products of AASC, modified by CAD and mixed with seawater (Fig.1, curve 2). Specified phases were formed due to binding Cl^- and SO_4^{2-} ions by calcium hydroaluminate $3CaO{\cdot}Al_2O_3{\cdot}10H_2O$ according to reaction (2).

The presence of Kuzel's salt in hydration products of AASC, modified by CAD and mixed with seawater, was confirmed by endothermic effects at t= 330 °C (dehydration) and 480 °C (departure of chloride) as well

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as by exothermic effect at t= 1000 °C (decomposition of sulfate) (Fig. 2, curve 2). Relocation of effects to higher temperatures ensures formation of CSH(B) and gyrolite with advanced crystallization.

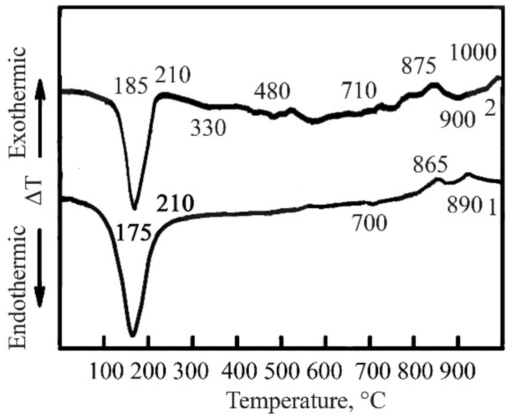
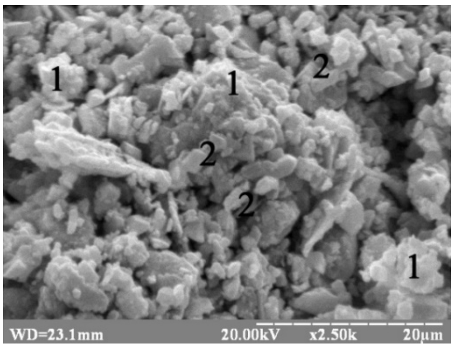
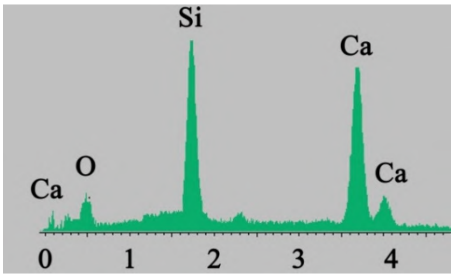


Fig. 2. DTA of alkali-activated slag cement mixed with seawater and hydrated during 90 d: 1 – the reference; 2 - modified by complex additive.

a)



b)



c)

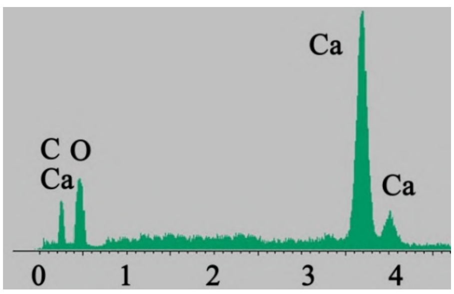
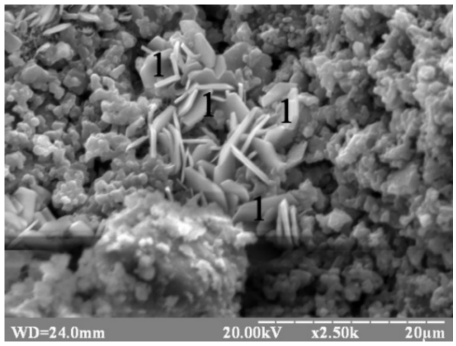


Fig. 3. Microstructure of the reference alkali-activated slag cement mixed with seawater and hydrated during 90 d: a – SEM images; b, c – microprobe analysis in points 1, 2 agreeably.

a)



b)

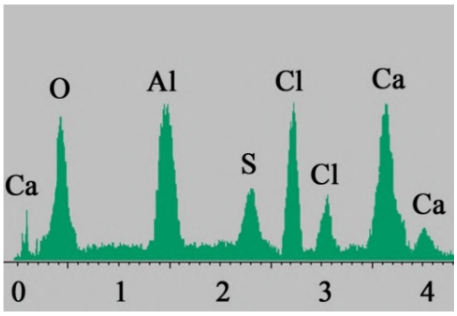


Fig. 4. Microstructure of the reference alkali-activated slag cement mixed with seawater and hydrated during 90 d: a – SEM images; b – microprobe analysis in points 1.

The modification of AASC by CAD causes formation of low-calcium hydrosilicates with a higher level of crystallization as well as hexagonal thin plates of Kuzel's salt (Fig. 4 a). The content of oxides confirms formation of Kuzel's salt, %: CaO – 32,72, Al_2O_3 – 21,51, Cl – 10,27, SO_3 – 9,56) (Fig.4 b).

3.2 Structure formation of alkali-activated slag cement based on sodium metasilicate and mixed with seawater

XRD ensures formation of slightly crystallized low-calcium hydrosilicates such as CSH(B) and gyrolite (Fig.5, curve 1). The presence of zeolite-like minerals (similar to nosean, sodalite, concrinite etc. by composition), which can bind Cl^- and SO_4^{2-} ions, can be assumed.

The presence of mentioned hydrosilicates was confirmed (Fig. 6, curve 1). Gel-like low-calcium hydrosilicates CSH(B) (Fig.7 a) (content in probe, %: CaO – 32.35 SiO_2 – 34.71) can be identified in the reference AASC after 90 d of hydration (Fig.7 b).

According to XRD, low-calcium hydrosilicates and Kuzel's salt were fixed as hydration products of AASC modified by CAD (Fig.5, curve 2).

These hydrates can be confirmed by DTA (Fig. 6, curve 2). Displacement of mentioned effects to higher temperatures ensures formation of CSH(B) and gyrolite with advanced crystallization.

The phase composition of modified AASC (Fig.8 a) is represented by low-calcium hydrosilicates as well as by hexagonal thin plates of Kuzel's salt (content in probe, %:

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CaO – 31.22, Al_2O_3 – 24.87, Cl – 12.43, SO_3 – 10.94) (Fig.8 b).

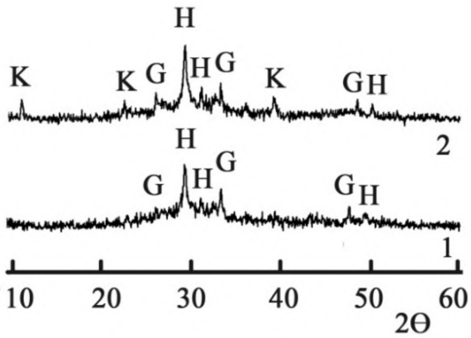


Fig. 5. XRD of 90 d hydrated alkali-activated slag cement mixed with seawater: 1 – the reference; 2 - modified by complex additive. Legend: H – calcium hydrosilicates CSH(B), G – gyrolite, К – Kuzel`s salt.

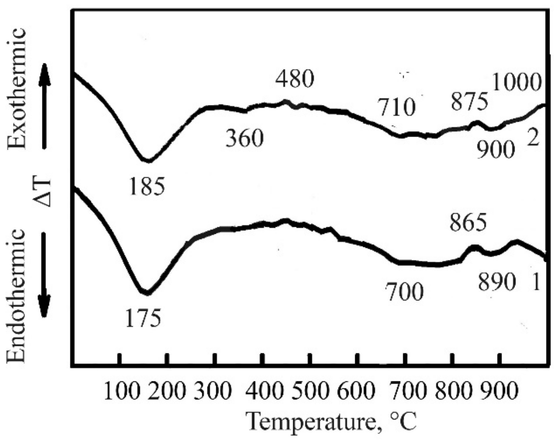


Fig. 6. DTA results of 90 d hydrated alkali-activated slag cement mixed with seawater: 1 - the reference; 2 - modified by complex additive.

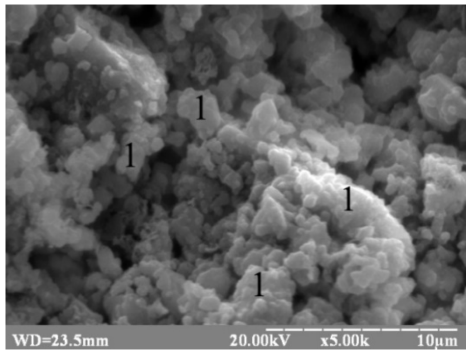
Hence, CAD «portland cement - calcium aluminate cement - clinoptilolite» ensures binding of Cl- and SO_4^{2-} ions in structure of hydrated AASC based on soda ash or sodium metasilicate while mixing by seawater. Interaction between hydration products of portland cement and calcium aluminate cement provides formation of high-calcium hydroaluminates like $3CaO{\cdot}Al_2O_3{\cdot}10H_2O$, which bind the mentioned ions in Kuzel's salt. Clinoptilolite, as component of CAD, supplements action of alkaline hydroaluminosilicates (typical hydration products of AASC) with replacement of OH- ions to Cl- and SO_4^{2-} ions.

Specified structure formation of AASC, mixed with seawater, ensures prevention of steel reinforcement corrosion due to minimization of free Cl^- and SO_4^{2-} ions in pore solution of artificial stone.

3.3 Effectiveness of complex additive in alkali-activated slag cement plasticized fine concrete

The effect of CAD «portland cement - calcium aluminate cement - clinoptilolite» on protective properties of plasticized AASC fine concrete, mixed with seawater, to steel reinforcement was investigated. Mass loss of steel rebars, which were reached from plasticized AASC concrete after 90 d of hardening was fixed.

a)



b)

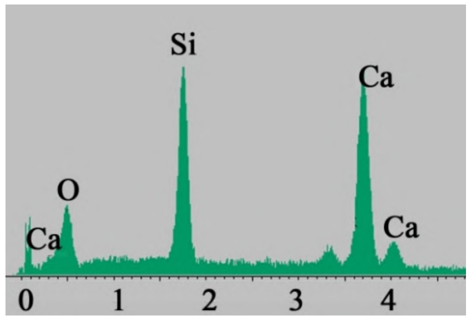
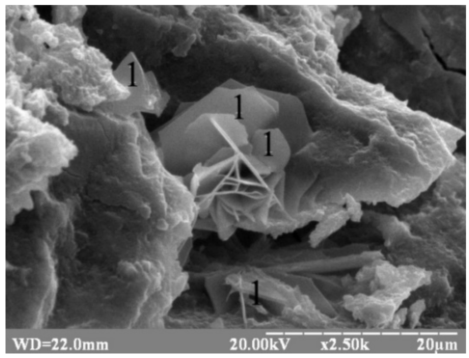


Fig. 7. Microstructure of the reference alkali-activated slag cement mixed with seawater and hydrated during 90 d: a – SEM images; b – microprobe analysis in points 1.

a)



b)

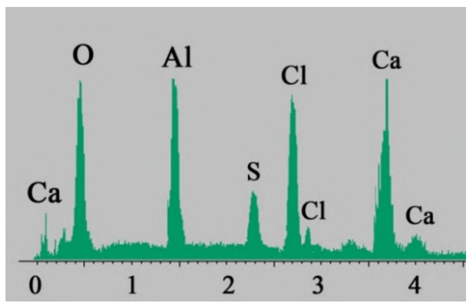


Fig. 8. Microstructure of 90 d hydrated alkali-activated slag cement, modified by CAD and mixed with seawater: a – SEM images; b – microprobe analysis in points 1.

AASC's, based on soda ash as well as on sodium metasilicate, were used as bases of fine concrete. AASC fine concrete was modificated by CAD «portland cement - calcium aluminate cement - clinoptilolite». The CAD composition, %: portland cement – 34.2, calcium aluminate cement – 15.8, clinoptilolite – 50.0. AASC fine concrete was plasticized by LST and sodium gluconate.

W/C ratios in AASC concrete based on soda ash and sodium metasilicate were 0.46 and 0.43 agreeably. W/C ratios in AASC concrete while mixing with seawater were 0.44 and 0.41 agreeably. This is evidence of AASC fresh concrete workability increasing while mixing with seawater [54]. At that, increasing of AASC concrete strength while mixing with seawater was fixed. Thus, compressive strength of AASC concrete based on soda ash while mixing with seawater corresponds to values of 35.7 MPa that is on 21.8 % greater comparing with one mixed with water (29.3 MPa). Compressive strength of AASC concrete, based on sodium metasilicate and mixed with seawater, is on 10.9 % greater comparing with one mixed with water (45.8 and 41.3 MPa agreeably). Enhancement of AASC fine concrete strength while mixing with seawater comparing with one mixed with water is caused by effect of SSA's [30, 33, 34].

The effect of CAD on protective properties of plasticized AASC concrete, mixed with seawater, to steel reinforcement was investigated.

Mass loss of steel rebars weren't fixed. This is evidence of no effect of Cl^- and SO_4^{2-} ions on steel reinforcement in plasticized AASC fine concretes, modifided by CAD and mixed with seawater.

The state of steel rebars before embedding (Fig. 9, 10) and embedded in specimens after 90 d of hardening (Fig. 11, 12) were compared.

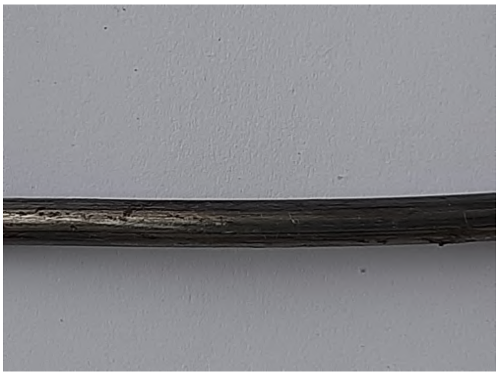


Fig. 9. Steel rebars before embedding in plasticized alkali-activated slag cement fine concrete (zoom x4) based on soda ash.

The absence of corrosion processes on surface of steel reinforcement in plasticized AASC concrete, mixed with seawater, was also confirmed by visual control.

Thus, effectiveness of CAD in plasticized AASC fine concrete for enhanced protective properties to steel reinforcement was confirmed.

Conclusion

1. Increasing of fresh concrete consistency as well as advanced strength of concrete based on alkali-activated slag cement while mixing with seawater was shown.

2. Prevention of steel reinforcement corrosion under the action of chlorides and sulfates in plasticized alkali-activated slag cement concrete mixed with seawater was ensured due to application of complex additive «portland cement - calcium aluminate cement - clinoptilolite».

3. Enhancement of protective properties of plasticized alkali-activated slag cement concrete, mixed with seawater, to steel reinforcement is explained by binding of ions Cl^- and SO_4^{2-} in Kuzel's salt (AFm phase) as well as by exchange of OH^- ions with these aggressive ions in structure of clinoptilolite.

Fig. 10. Steel rebars before embedding in plasticized alkali-activated slag cement fine concrete (zoom x4) based on sodium metasilicate.

Fig. 11. Steel rebars embedded in plasticized AASC fine concrete mixed with seawater after 90 d of hardening (zoom x4) and based on soda ash.

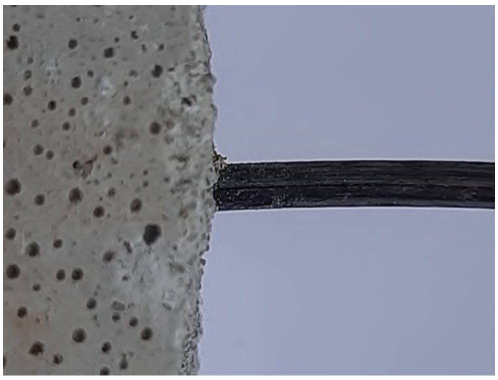


Fig. 12. Steel rebars embedded in plasticized AASC fine concrete mixed with seawater after 90 d of hardening (zoom x4) and based on sodium metasilicate.

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Study of the influence of magnetized ferromagnetic additives on the processes of cement hydration

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Abstract. One of the essential tasks for a sustainable future is to reduce harmful emissions into the atmosphere significantly. Cement production is the world's largest industrial carbon pollutant, accounting for 8 % of global emissions. More than 2.2 gigatons of carbon dioxide are emitted into the atmosphere every year. Therefore, reducing the energy intensity of products and reducing the number of harmful emissions in cement production is becoming critical. One strategy to reduce cement production emissions is to reduce the most energy-consuming component in cement – clinker. In this case, various activation methods are used for maintaining the same level of cement activity. One of these methods is the impact on the hardening binder with magnetic fields. The paper presented a study of hydration processes of blast-furnace cement activated by a magnetized ferromagnetic additive. The work established that the introduction of pre-magnetized ferromagnetic dust into blast-furnace cement composition has an activating effect on binder hydration. It shows that activation occurs both in the initial and long periods of hardening. The nature of the mutual influence of the components of the hydration system alite-lime-slag in a modified binder was revealed. The investigation determined that the ferromagnetic additive, intensifying the process of slag hardening, increases the proportion of hydrated slag by 1.5-2 times. It was revealed that the formation of the ettringite framework in the modified binder's gel is completed within one day. It is shown that in the subsequent periods, hydration of aluminates occurs mainly due to the formation of tricalcium aluminate hexahydrate (C_3AH_6), which excludes destructive processes in the late periods of binder hardening. It has been established that under the action of a ferromagnetic additive, the degree of crystallization of hydro silicates in the modified binder increases.

1 The problem and its relationship with scientific and practical tasks

Cement is one of the essential building materials. More than 4 100 000 tons of cement are produced annually globally [1], and CO_2 emissions during its production are 6.5 % of the global emissions or more than 2.2 gigatons of carbon dioxide per year [2, 3]. In the foreseeable future, there are no prerequisites for reducing the need for cement. Therefore, reducing its products' energy intensity and reducing the number of harmful emissions is becoming increasingly important. One way to reduce cement production emissions is to introduce production waste into their composition, including granulated blast-furnace slags.

The introduction of slags makes it possible to combine a decrease in the proportion of clinker in cement with production waste disposal. However, the introduction of mineral additives, as a rule, leads to a decrease in cement activity [4]. Therefore, the proportion of active mineral additives in cement is limited. A further increase in active mineral additives' share-production waste is achieved through various cement activation methods. One of these methods is the impact on the hardening binder with magnetic fields.

2 Analysis of research and publications

In [5], it is noted that magnetic fields significantly affect the spin dynamics and control the spin multiplicity of radical pairs. The electron paramagnetic resonance method made it possible to determine that cement is a paramagnetic substance and that cement hardening occurs due to paramagnetic centers' recombination [5-10]. Thus, the possibility of the influence of magnetic fields on binders' hydration processes has been proved.

Traditional methods of exposure to magnetic fields on hardening cement are short-term and therefore do not lead to significant and stable results. It was proposed in works [11] to use finely dispersed magnetized ferromagnetic additives to activate blast-furnace cement. As such an additive in the research, we used fine dust – waste from the metallurgical industry. In [12], the influence of the

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additive's magnetic and dispersed properties on the activation effect was studied. Obtained in [12], dependences of cement strength on magnetization and particle dispersity and the additive small proportion (up to 2%) led to the conclusion that the activation effect is not due to the filler or pozzolanic effect but due to the effect of magnetic fields. Still, the impact of long-term magnetic fields on the processes of cement hydration was not considered yet. Therefore, this work set the task to study the changes in cement hydration and structure formation processes that appear under long-term magnetic impacts.

3 Formulation of the problem

Studies of the hydration products of ordinary and modified by additive EN 197-1–CEM III/A 32.5 N cement were carried out to study the processes of hydration and structure formation of cement with pre-magnetized ferromagnetic dust. The research was carried out by analyzing the binder's hydration products by infrared spectrometry, thermogravimetry, X-ray phase analysis, and electron microscopy.

We have studied the original astringent and hydrated samples at 1, 3, 7, 28, and 90 days. As a magnetized ferromagnetic additive, the dust of the electrostatic precipitators of the sinter production was used. The additive was introduced in an amount of 2% of the weight of the cement.

The studies EN 197-1–CEM III/A 32.5 N cement components chemical composition are shown in Tables 1-3.

Table 1. The chemical composition of the cement clinker.

Components	Content, %
SiO_2	21.80
Al_2O_3	6.04
Fe_2O_3	2.54
CaO	62,72
others	6.90

The quantitative and phase composition of the cement clinker is shown in Table 2.

Table 2. The quantitative and phase composition of the cement clinker.

Components	Content, %
Alit	57.27
Belit	19.29
Aluminate	8.72
Alumoferrite	7.81
Other	6.90

The chemical composition of the granulated blastfurnace slag used in the CEM III/A cement used in the studies shown in Table 3.

Table 3. The chemical composition of the granulated blast furnace slag

Components	Content, %
SiO_2	38.24
Al_2O_3	7.76
Fe_2O_3	0.27
MnO	0.87
CaO	47.02
MgO	4.93
SO_3	0.12
TiO_2	0.24
Σ	99.36

The chemical composition of the dust of the sinter machine is shown in Table 4.

Table 4. The chemical composition of the dust of the sinter machine.

Components	Content, %
FeO	9-19
Fe_2O_3	45-60
SiO_2	6.5-10
Al_2O_3	0.5-1.5
CaO	6.3-9
MgO	0.5-1.5
MnO	0.2-0.3
P_2O_5	0.03-0.05
S	0.2-0.5

The data obtained from the research made it possible to carry out a quantitative analysis of the kinetics of hydration of the main components of binders and identify the factors affecting structure formation processes.

4 Statement of material and results

The imposition of weak magnetic fields on a binder during grinding and subsequent storage can affect the cement structure's defectiveness [13-16], significantly affecting its activity [17-19]. Weak magnetic fields decreasing the probability of recombination of dissociated water molecules and increase the concentration of H_3O+ and OH- ions, thereby increasing the chemical activity of water concerning the binder [17]. Having a double effect on the mixing water and the binder itself – the magnetic fields induced by the ferromagnetic additive should change the cement's structure-forming components' strength and affect the cement's strength characteristics stone.

In the early stages, the dynamics of the formation of calcium aluminates significantly affect structure formation. Analysis of the IR spectrum (Fig. 1) in the range of 515-490 cm^{-1} made it possible to obtain a quantitative characteristic of calcium aluminates'

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hydration processes in control and modified binders (Fig. 2). The content of non-hydrated calcium aluminates in the modified cement stone-aged 1-28 days is 1.5-2 times less than in the control sample, and at the age of 90 days, it is four times less than in the control sample.

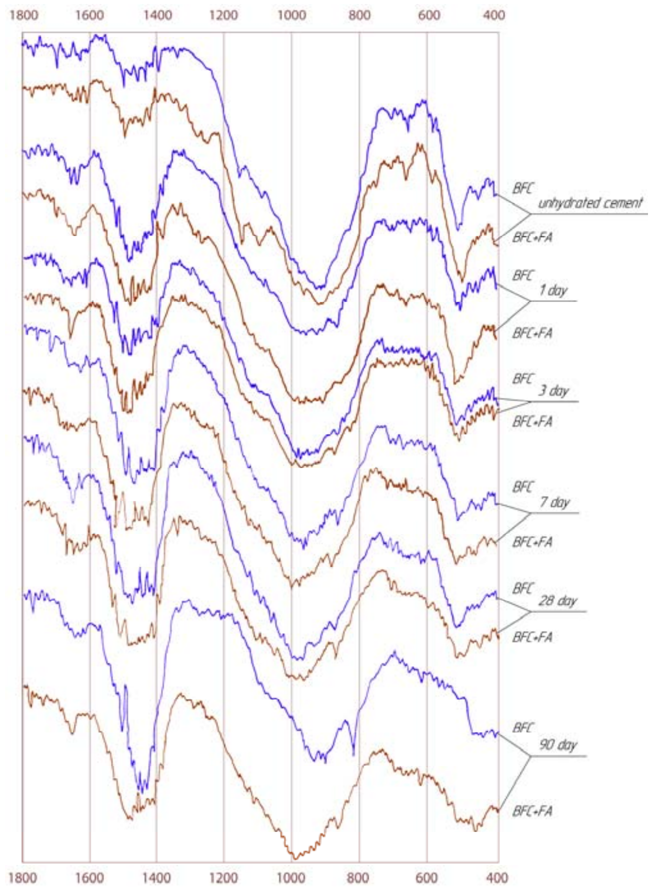

Fig. 1. Infrared absorption spectra of samples from the blast-furnace cement (BFC) and blast-furnace cement with a ferromagnetic additive (BFC+FA) in the initial state and age 1, 3, 7, 28, and 90 days.

When calcium aluminates are hydrated, CAH_6 is formed, identified on DTA (Fig. 3) by endothermic effects at 330-350 °C and 530-570 °C.

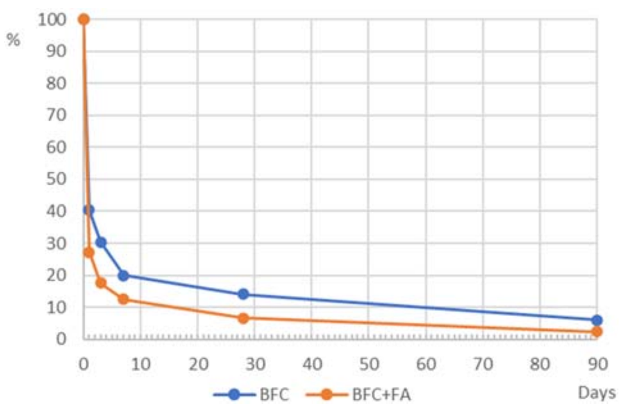

Fig. 2. Kinetics of hydration of calcium aluminates.

The significantly immense value of the cement stone's effects from the modified binder indicates the activating effect of magnetic fields on the process of formation of tricalcium aluminate hexahydrate.

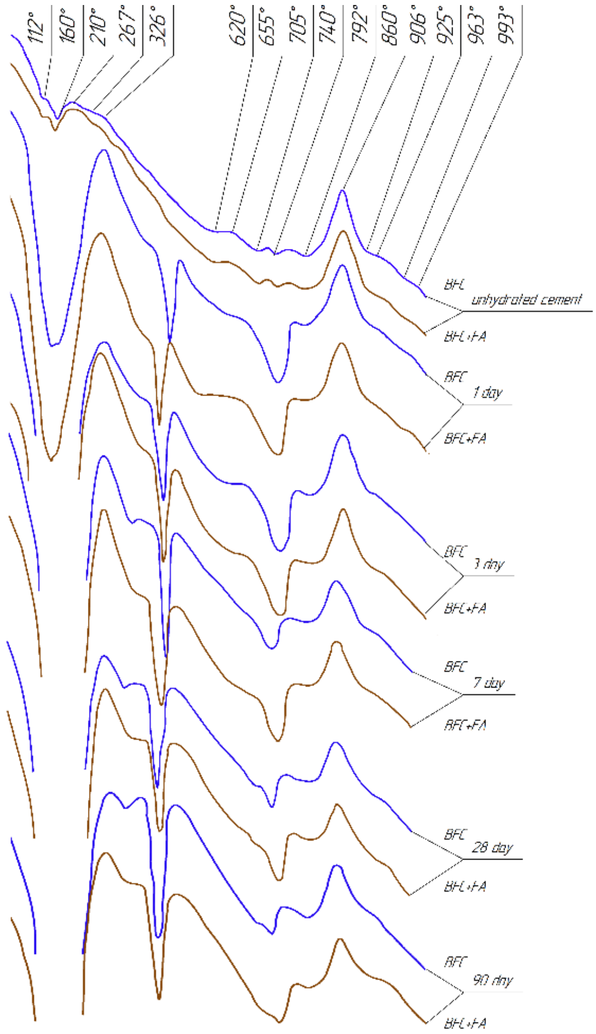

Fig. 3. Curves of differential thermal analysis of samples from the blast-furnace cement (BFC) and blast-furnace cement with a ferromagnetic additive (BFC+FA) in the initial state and age 1, 3, 7, 28, and 90 days.

At the age of 1 day on DTG (Fig. 4) of the modified cement stone, the effect is more pronounced at 140-200 ºC. In subsequent periods, the intensity of the effects of both types of binders leveled. An increase in the IR spectrum with C=1630 cm^{-1} at IR occurs synchronously.

The data indicate the intensive formation of ettringite under the influence of a ferromagnetic additive in up to 1 day and the termination of this process subsequent periods. In a standard binder, ettringite formation observes up to the age of 3 days.

The observed dynamics of the formation of calcium hydro-aluminates and calcium hydro-sulfa-aluminates allow us to conclude that, under the influence of the additive's magnetic fields, constructing the gel's ettringite framework occurs faster and completed within one day. In the subsequent periods, stable six-water tricalcium aluminate mainly formed. This mechanism excludes destructive processes in the late stages of hydration.

The kinetics of hydration of blast-furnace cement is determined by the lime-releasing clinker component –

alite. Acceleration of alite hydration increases calcium hydroxide concentration and intensifies hydration of granulated blast-furnace slag. On the X-ray diffraction patterns (Fig. 5), the process of alite hydration is indicated by a decrease in the height of the peaks with d=0.295; 0.321; 0.327; 0.519 nm.

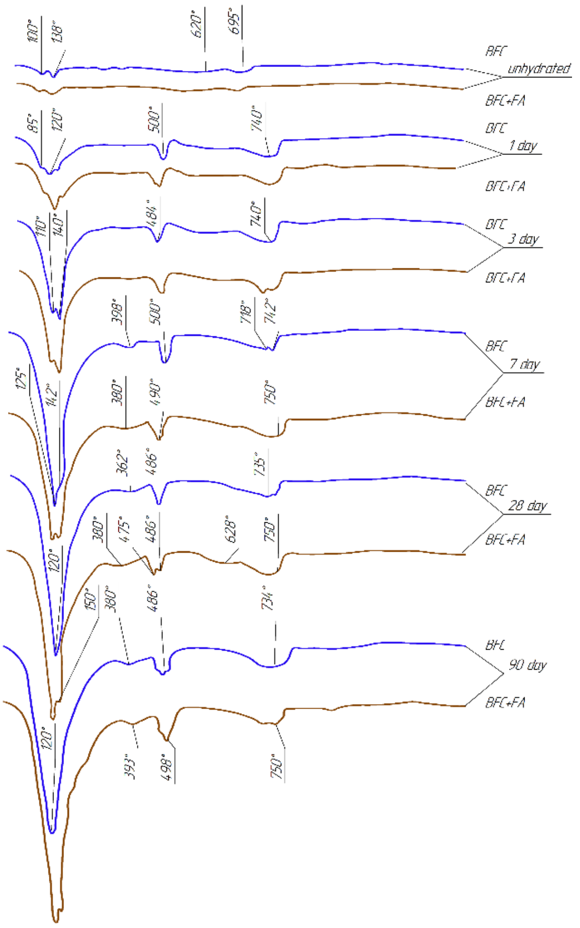

Fig. 4. Curves of differential thermogravimetric analysis of blast-furnace cement (BFC) and blast-furnace cement with a ferromagnetic additive (BFC+FA) in the initial state and age 1, 3, 7, 28, and 90 days.

A decrease in the bands' absorption intensity with C=992 cm^{-1} was observed simultaneously at 875 cm^{-1} in IR spectrograms. The results showed that the kinetics of alite hydration in the modified binder significantly differs from the usual one. At the age of 1-3 days, 13-8 % less is hydrated, and at the period of 7-90 days, 4-5 times the amount of alite is hydrated (Fig. 6).

The slowdown in the hydration of alite at the age of 1-3 days can be explained only by the reaction space's supersaturation with calcium hydroxide and the chemical reaction shift $2Ca_3SiO_5+6H_2O=Ca_3SiO_7{\cdot}3H_2O+3Ca(OH)_2$ towards initial components. The intensive hydration of alite causes an increase in $Ca(OH)_2$ in the period up to the first day. The magnetic fields induced by the ferromagnetic additive cannot influence the diffusion rate of the reaction products. Therefore, in the modified binder, the limiting factor of alite hydration is much faster than in the usual one, diffusion from the Ca^{2+} reaction zone becomes.

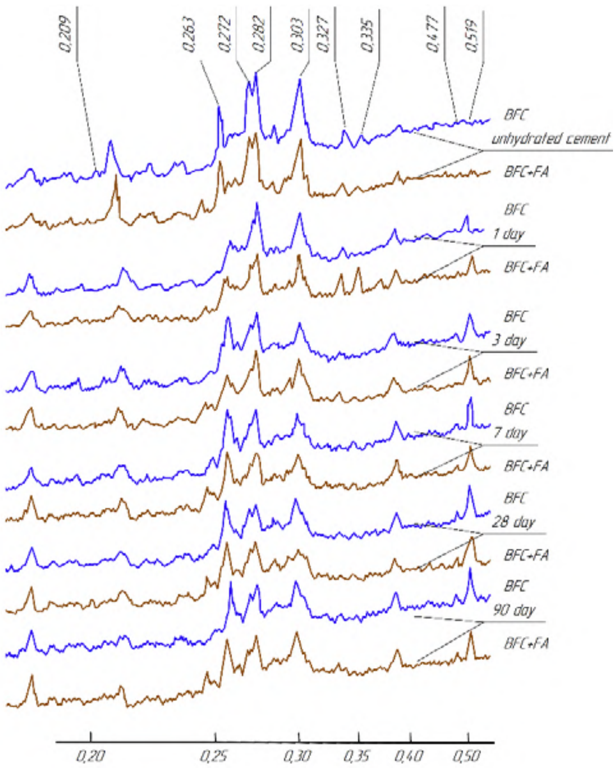

Fig. 5. X-ray patterns of samples from the blast-furnace cement (BFC) and blast-furnace cement with a ferromagnetic additive (BFC+FA) in the initial state and age of 1, 3, 7, 28, and 90 days.

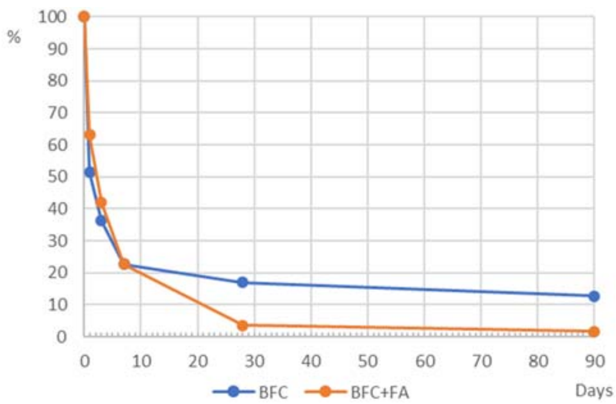

Fig. 6. Kinetics hydration of alit.

An increase in the amount of lime in the gel corresponds to the rise in the peaks with d=0.263; 0.179; 0.168 nm on X-ray diffraction patterns. The strong endothermic effect arising from the dehydration of $Ca(OH)_2$ makes it possible to control its concentration on DTA at t=485º. Analysis of the results confirmed the accelerated formation of lime in a period of up to 1 day. (Fig. 7).

In the gel made of modified cement, calcium hydroxide content is 20 % higher than in the control samples during this period. Although in the subsequent period, the alite degree of hydration under the influence of magnetic fields increases, the content of $Ca(OH)_2$ in the gel becomes 23 % lower than in the original cement at the age of 3 days, by 12 % at the period of 7 days and by 9 % in the age of 28 days. Such dynamics can be explained only by intensifying lime interaction with granulated blast-furnace slag. In this case, a decrease in the IR spectrum's absorption intensity in the region of C=721 cm^{-1} and a reduction in the exothermic effect of the slag's devitrification t=830-870 °C on DTA due observe. Simultaneously, an increase in the height of the peaks with C=648 cm^{-1} should observe, which characterize the content of the slag hydration product, boehmite, in the gel.

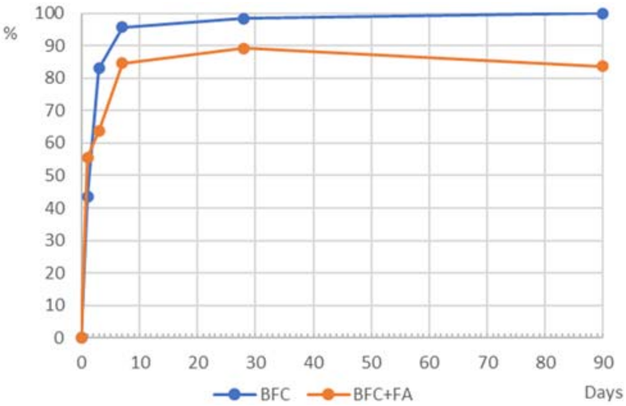

Fig. 7. Kinetics of lime formation.

Analysis of the results confirms that the hydration of granulated blast furnace slag intensified under the action of magnetic fields induced by a ferromagnetic additive (Fig. 8). There is an increase in slag hydration degree by 20 % at three days, 23 % at 28 days, and 59 % at 90 days.

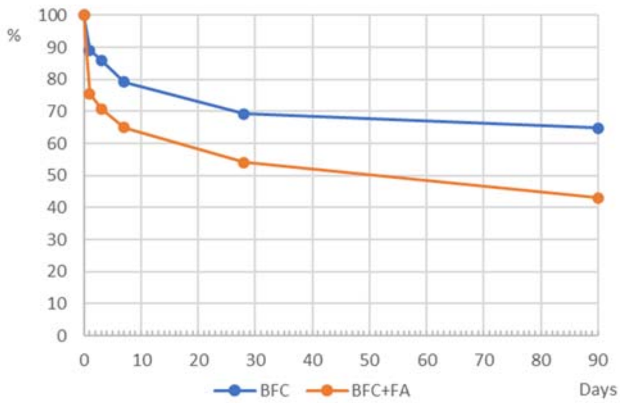

Fig. 8. Slag hydration kinetics.

In ordinary cement, after 28 days of hydration, the slag content practically does not change. In the same period, the content of slag in the modified binder decreases by 30 %. A decrease in the non-hydrated slag content corresponds to an increase in the amount of boehmite in the cement gel (Fig. 9).

In the control cement, boehmite was identified only after three days of hydration, while in the modified binder, characteristic peaks were clearly defined after hydration for one day. Like slag hydration, the process of boehmite formation in the control binder practically stops after 28 days of hardening. On the contrary, long-term continuous exposure to magnetic fields on the modified binder maintains high slag hydration rates later.

In the period 28-90 days, the content of alite in the modified binder is insignificant and amounts to 4-2 % of the original. Such content of C_3S does not provide the slag's hydration with a sufficient amount of calcium hydroxide. The slag's intensive hardening proceeds due to the binding of $Ca(OH)_2$ previously formed reserves. This process reduces the lime content in the modified cement stone of 90 days of age by 65 % (Fig. 7).

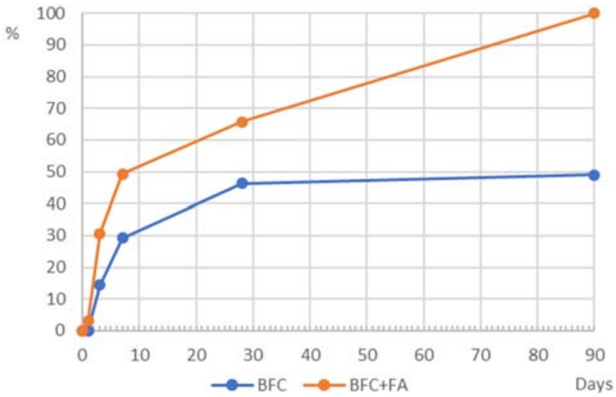

Fig. 9. Kinetics of boehmite formation.

The kinetics of cement stone's carbonization has confirmed a ferromagnetic additive's peculiarities on alite and slag's hydration processes. $CaCO_3$ has pronounced peaks with d=0.303; 0.249; 0.228; 0.209 nm on X-ray diffraction patterns and an absorption band of IR radiation with C=1500-1400 cm^{-1}. Calcite gives a noticeable endothermic effect at t=740 °C on DTA. However, due to the intensive carbonization of lime with carbon dioxide in the furnace atmosphere during heating of the sample, the concentration of $CaCO_3$ overestimated compared to other methods was obtained on DTA.

Analysis of the data obtained shows a correlation between calcium carbonate content and $Ca(OH)_2$. At the age of 1 day in the gel of modified binder calcite by 50 % more than in control one (Fig. 10).

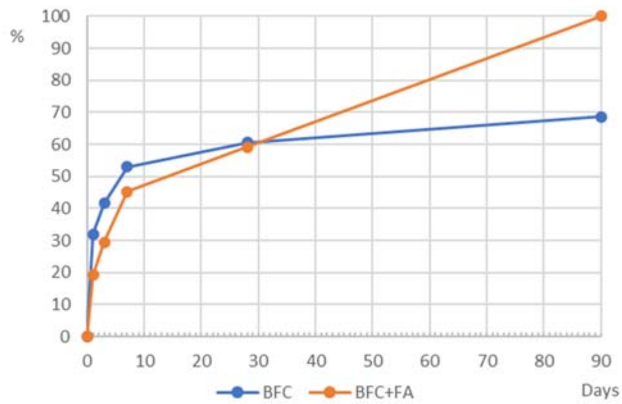

Fig. 10. Kinetics of calcite formation.

During the first ten days, the rate of lime binding with 100 grams of slag is 0.3 grams per day, from 10 to 40 days – 0.1 g/day, and in the period from 40 to 90 days, 0.05 g/day [20]. A continuous decrease in lime absorption by slag with continuous hydration of alite in conventional cement types leads to the accumulation of $Ca(OH)_2$ and, due to carbonization, to increase the $CaCO_3$ content. The accelerated release of lime in the modified binder increases the calcium carbonate content at the initial time. A higher, under the influence of magnetic fields, the rate of lime absorption by slag decreases after 28 days of hydration $Ca(OH)_2$ and "freezes" the concentration of $CaCO_3$.

At the age of 28 days in the modified gel of calcium carbonate, only 5 % more than in the control one. In the control binder, a low rate of lime binding with slag in 28-90 days leads to an increase in the content of calcium carbonate by 58 %. Over the same period, the modified binder's lime content decreases by 6 %, with an increase in the $CaCO_3$ content only by 10 %.

The considered features of the ferromagnetic additive effect on the alite-lime-slag system's hydration allow us to assume the ambiguity of the impact of the modified binder's heat and moisture treatment. In the initial periods of hardening, magnetic fields increase the difference in the lime release rate by alite and its absorption by slag. Heat treatment, increasing the rate of chemical reactions, can further enhance this phenomenon. The excessive rate of hydration products' release increases the unevenness of their distribution in the cement stone, causing destructive processes. Based on this, the combined effect of magnetic and thermal fields can lead to a drop in the cement stone's strength. It is possible to increase the modified binder's tolerance to heat and moisture treatment by expanding its slag. The increased absorption of lime thus promotes the formation of a more stable calcium silicate hydrate.

The revealed patterns make it possible to explain the greater efficiency of magnetic activation for belite types of cement. A smaller amount of lime released during the hardening of belite makes this process less dependent on diffusion. Therefore, the formation process in belite cement under the influence of magnetic fields should be more stable.

Belite hydration is characterized by a decrease in the intensity of peaks with d=0.282; 0.272; 0.269; 0.266 nm on X-ray diffraction patterns and a decrease in the intensity of absorption of IR radiation with C=900; 963 cm^{-1}. The analysis results show that the ferromagnetic additive has an intensifying effect on the process of belite hydration (Fig. 11). The content of non-hydrated belite in the modified binder is less than in control one at the age of 1 day by 12 %, 28 days by 10 %, and at a period of 90 days by 19 %. According to [20], in ordinary cement, the hydration of belite, even after four years of hardening, is only 85 %. According to the analysis data, in the modified binder, already at the age of 90 days, almost all of the belite is hydrated.

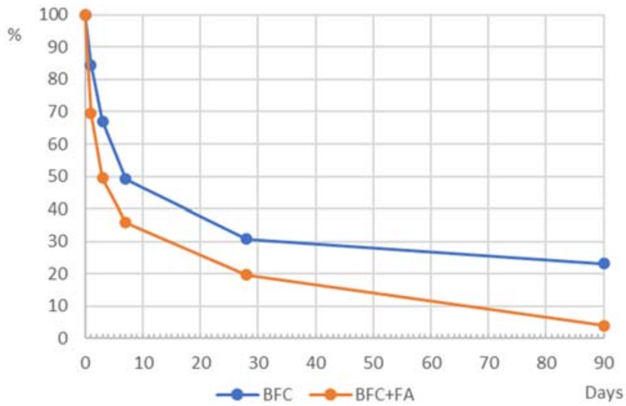

Fig. 11. Kinetics of belite hydration.

Simultaneously with the hydration of belite, there is an increase in peaks d=0.477, 0.335, 0.292 nm, which on the X-ray diffraction patterns correspond to the crystal lattice of hillebrandite. The performed quantitative analysis shows that introducing a ferromagnetic additive into the binder's composition increases hillebrandite content in cement stone of any age approximately twofold (Fig. 12).

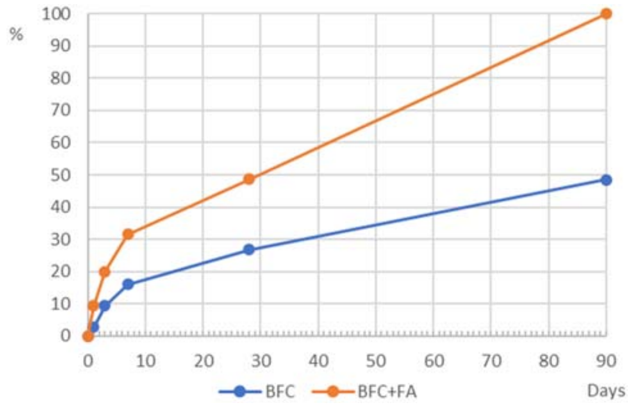

Fig. 12. Kinetics of hillebrandite formation.

The absence of intersections of the lines of the conventional and modified binder on the graph of belite hydration and the chart of hillebrandite formation indicates the monotonicity of the process of belite hydration in the presence of magnetic fields and suggests the absence of malicious processes during their heat and moisture treatment in modified belite binders.

Infrared spectrometry data confirm the results obtained. Silicates have a characteristic infrared absorption band in the 1100-500 cm^{-1} regions. When the binder is hydrated, the region of the most significant absorption of IR radiation is shifted towards higher frequencies, which corresponds to more potent and more rigid bonds in the hydro silicate. The displacement to the high-frequency regions occurs earlier and manifests more intensively on the modified binder's spectrograms. Analysis of the absorption intensity of IR spectra in the range of 1050-800 cm^{-1} made it possible to complete the picture of the structure formation of the silicate phase. Clinker and slag minerals with a chain structure characterized by intense absorption of IR radiation range from 1030-800 cm^{-1}. Research results show a higher degree of silicates' hydration at all hardening stages (Fig. 13). At the age of 3 days, the original silicates in the modified binder are 1.5 times less; at 28 days by 2.5 times, at a period of 90 days by four times. The gel's oversaturation with calcium hydroxide and the slowdown in the hydration of alite explain the change's non-monotonicity in silicates hydration rate in up to 7 days.

The range of 1020-990 cm^{-1} is typical for silicates with a network structure. The spectrograms under consideration allow one to determine the content of crystallized tobermorite in the cement stone (Fig. 14). Analysis of the results shows that the ferromagnetic additive, changing the kinetics of hydration reactions, contributes to increasing the crystallized tobermorite content in cement stone by 1.3-1.4 times.

The transition of hydro silicates from a weakly crystallized to a crystallized state changes the amount of

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adsorbed water. On thermograms, this process accompanying a decrease in the endothermic effect at 60-200 °C. Analysis of the areas of endothermic effects on DTA and mass losses on DTG in this temperature range shows a change in the interlayer liquid forming dynamics (Fig. 15).

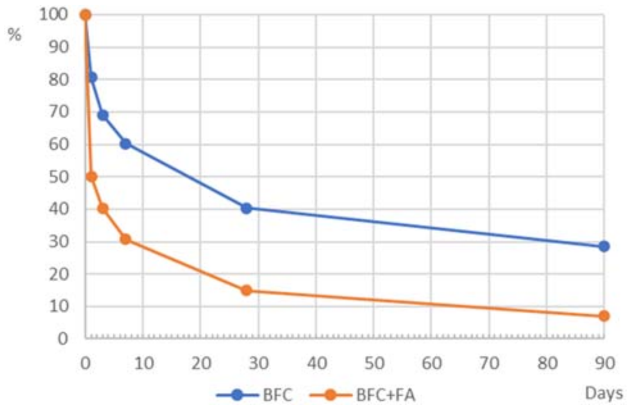

Fig. 13. Hydration kinetics of chain calcium silicates.

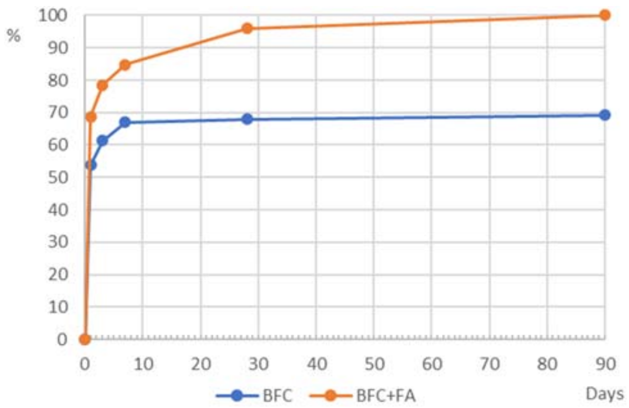

Fig. 14. Kinetics of crystallized tobermorite formation.

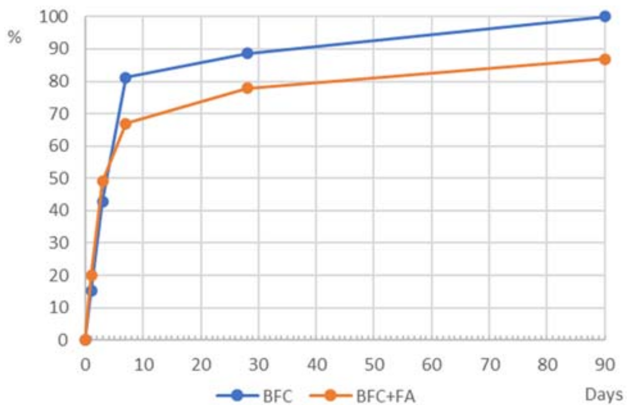

Fig. 15. Kinetics of formation of interlayer water.

The modified binder at the age of 0-3 days has a 5-10 % more, and in subsequent periods, 15-20 % less adsorbed water. Such a change in the binding dynamics of water confirms an increase in CSH formation in the initial period and a higher rate of construction of hydro silicates' crystallization structure in the subsequent period. Caused by the slag's active hydration, the cement gel's lack of calcium hydroxide contributes to forming a larger number of three-layer tobermorite [20], having a lower specific surface area than two-layer ones and adsorbing a smaller amount of water.

Accelerating the crystallization of tobermorite changes the structure of the cement stone. In Fig. 16 and Fig. 17, the cement stone structures spall from the control and modified binder. Lamellar blocks of crystallized tobermorite dominate the modified cement stone. The structure of the modified cement stone is more homogeneous and finer crystalline.

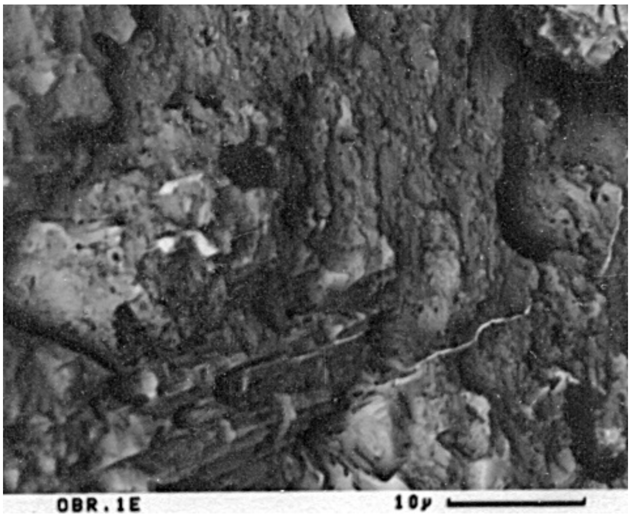

Fig. 16. The structure of blast furnace cement (BFC).

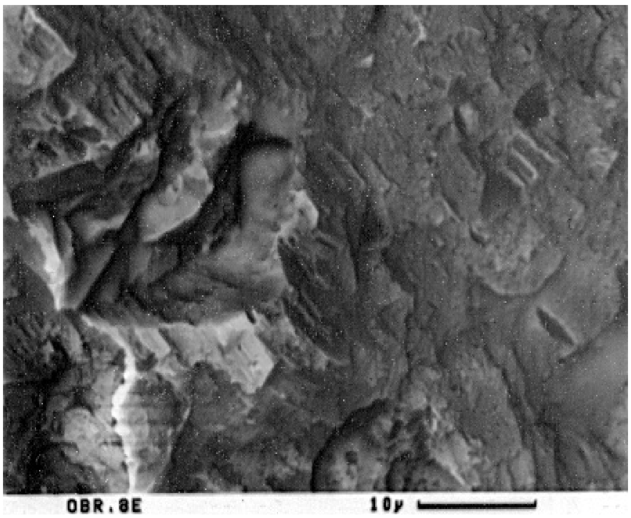

Fig. 17. Structure of cement stone from blast furnace cement with ferromagnetic additive (BFC+FA).

In [21], the orienting effect of magnetic fields on colloidal particles is noting. This phenomenon promotes crystallization and the formation of uniformly oriented crystal structures. The uniform spatial orientation of tobermorite plates observed in the modified cement stone confirms the hydrogel's magnetic fields' orienting effect. The images obtained at 8000× magnification (Fig. 18, 19, and 20) confirm a crystalline structure in the modified cement stone and a weakly crystallized, disordered structure in the control cement stone.

A photograph was taken in the phase contrasts mode (Fig. 19), making it possible to isolate a magnetized dust particle with a darker shade. The "ingrowth" of dust particles into the binder structure is noticeable.

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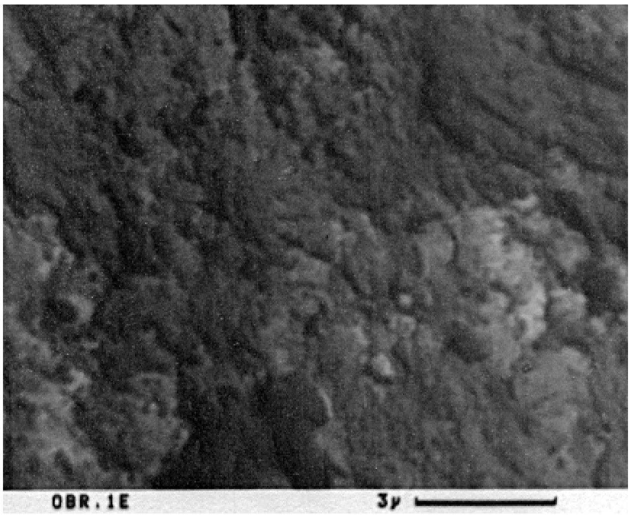

Fig. 18. Structure of blast-furnace cement (BFC).

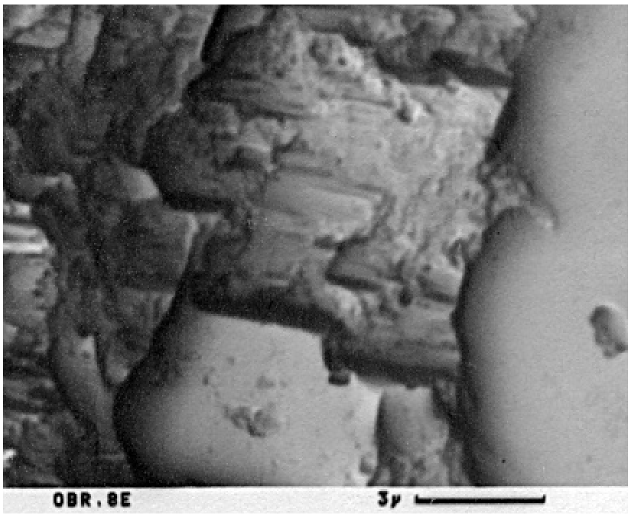

Fig. 19. Structure of cement stone from blast-furnace cement with ferromagnetic additive (BFC+FA).

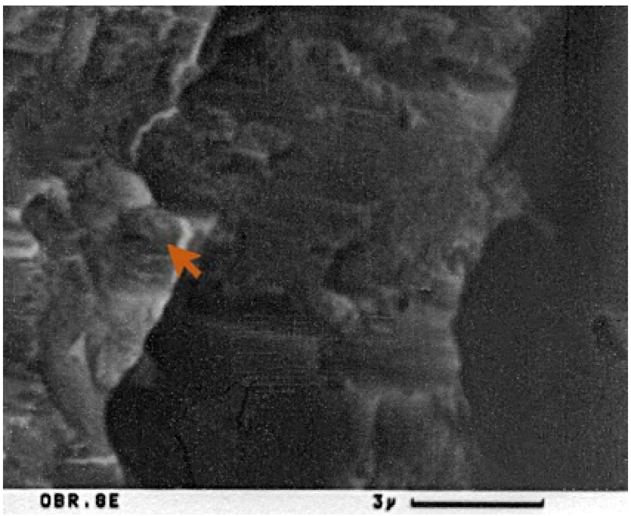

Fig. 20. Structure of a cement stone made of blast-furnace cement with a ferromagnetic additive (BFC+FA). Phase-contrast mode. The arrow marks an ingrown dust particle.

A high degree of hydration of the modified binder reduces the proportion of evaporated mixing water, reducing the cement stone's overall porosity. Fig. 21 shows the surface of a cement stone spall from a non-activated BFC. Numerous microcracks with a length of 50-200 μ and a thickness of 0.5-1 μ are distinguishable on the surface. Microcracks are oriented in different directions and, as a rule, begin at micropores. Numerous micropores are 2-30 μ in size.

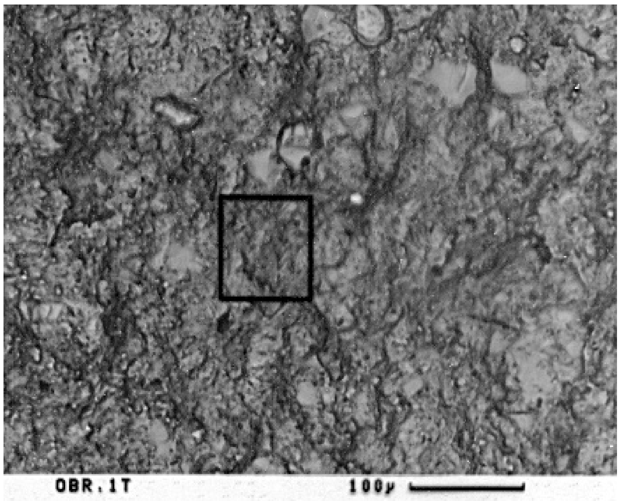

Fig. 21. Structure of blast-furnace cement (BFC).

A smaller number of structural defects distinguishes a cement stone made from a modified binder (Fig. 22, 23). A small number of pores with a size of 0.5-2 μ and the absence of broader.

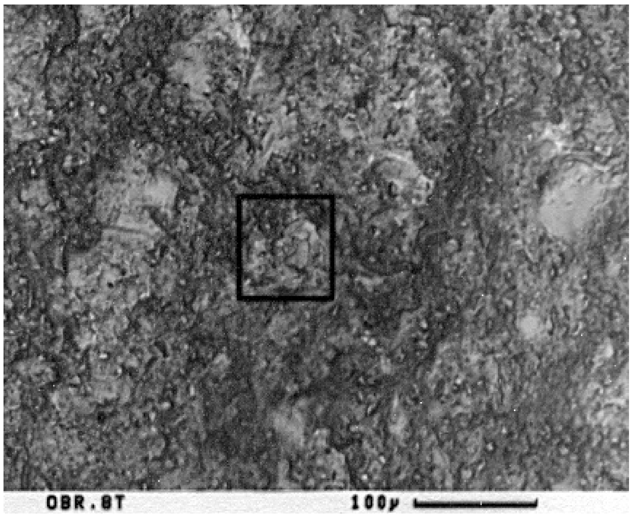

Fig. 22. Structure of cement stone from blast-furnace cement with ferromagnetic additive (BFC+FA).

A decrease in the porosity of a cement stone can be caused by factors other than magnetic fields. A cement stone structure from a binder with a reduced (0.75 %) ferromagnetic additive content was investigated to test this factor's significance. With the microprobe's help, a dust particle was found, and the microstructure in the area adjacent to it was investigated. In the images obtained in the relief mode (Fig. 24) and phase contrasts (Fig. 25), a decrease in the cement stone porosity is observed as the dust particle approaches and the magnetic field strength increases. This confirms the magnetic field strength's

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influence on the degree of hydration of the binder and the cement stone's porosity.

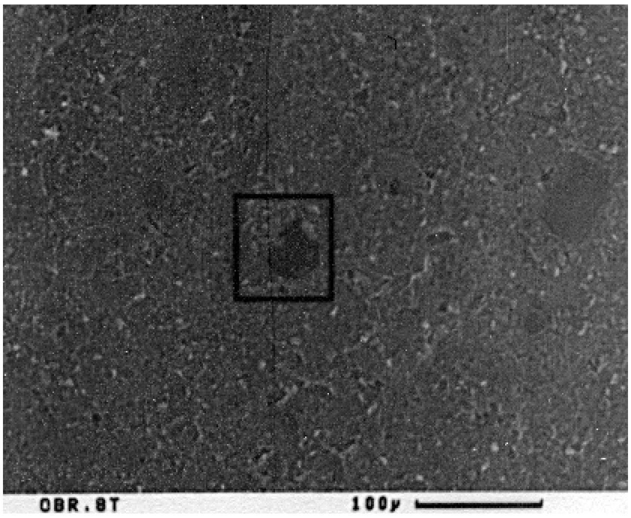

Fig. 23. Structure of cement stone from blast-furnace cement with ferromagnetic additive (BFC+FA) Phase-contrast mode.

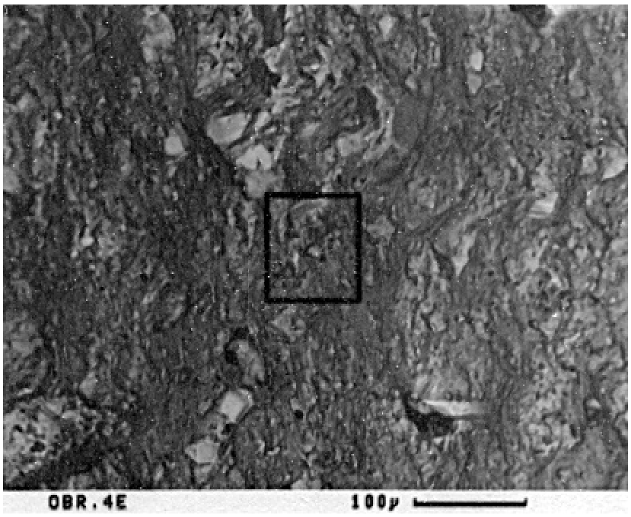

Fig. 24. Structure of cement stone from blast-furnace cement with ferromagnetic additive (BFC+FA).

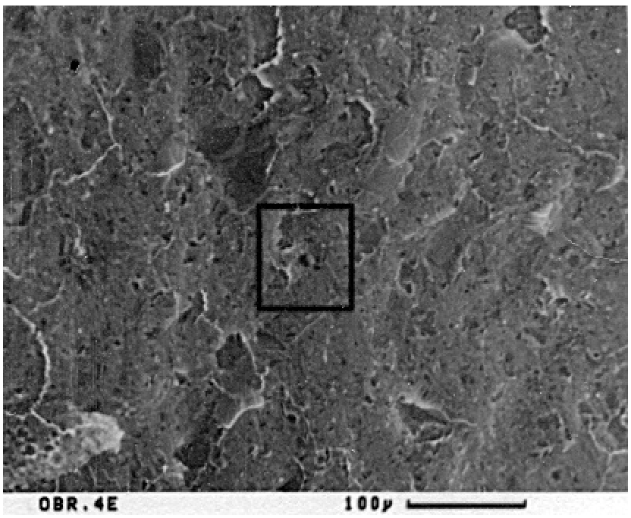

Fig. 25. Structure of cement stone from blast-furnace cement with ferromagnetic additive (BFC+FA) Phase-contrast mode.

5 Conclusions

The studies show that the introduction of pre-magnetized ferromagnetic dust into blast furnace cement composition has an activating effect on binder hydration. Activation occurs both in the initial and long periods of hardening. The additive influence on the process of structure formation at a specific point of the cement gel depends on the distance between this point and the dust particle and the magnetic fields' intensity at this point.

It proved that under the influence of magnetic fields, intensive hydration of alite in up to 1 day causes supersaturation of the gel with calcium hydroxide, which slows down the hydration of alite for a period of up to 7 days. We found that the second increase in the hydration rate of alite after seven days of age is caused by the intensive, under the additive, absorption of lime by slag. It determined that the ferromagnetic additive, intensifying the process of slag hardening, increases the proportion of hydrated slag by 1.5-2 times.

The investigation established that the reduced release of lime during hardening determines the monotony of the increase in the rate of hydration of belite in the modified binder. It determined that the most significant activating effect on C_2S hydration be achieved after 28 days of hardening.

Studies proved that the ettringite framework's formation in the modified binder's gel is completed within one day. In subsequent periods, the hydration of aluminates occurs mainly due to the formation of tricalcium aluminate hexahydrate, which excludes destructive processes in the late periods of binder hardening.

It founded that under the impact of a ferromagnetic additive, the crystallization of hydro silicates in the modified binder increases. It determined that magnetic fields have an orienting effect on the direction of hydro silicate crystals' growth, which leads to a decrease in the porosity and defectiveness of the cement stone structure.

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Development of sustainable compositions and study of the properties of porous aggregates from the waste of a mining and processing plants

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Abstract. In connection with the growing need for saving natural resources used in aggregates for concrete, the importance of lightweight structural aggregates obtained from production waste is continuously increasing. Lightweight structural concretes on porous aggregates can significantly reduce own weight of structures, make it possible to manufacture larger structures, reduce transport costs, and improve the thermal insulation and acoustic properties of enclosing structures. The use of waste from the mining and metallurgical industry to produce construction materials significantly reduces environmental pollution. The article is devoted to studying the possibility of using wastes from the mining and processing industry of enterprises of the Kryvyi Rih iron ore basin to produce lightweight porous aggregate. The paper presents the results of studies of the effect of the charge's granulometric composition, the quantitative content of the raw mix components, and the temperature of heat treatment on aggregate quality. The most suitable raw material mixture for artificial aggregate has been determined. The results of X-ray diffraction thermographic analysis of raw granules are presented. The influence of technological factors on the aggregate density and strength has been studied using mathematical modeling. The obtained equations made it possible to reveal the regularities of the raw mixture's components and temperature for the optimal aggregate density and strength. The results of studying the structure and porosity of the developed aggregate are presented. The results of X-ray thermographic analysis of the aggregate explain the mechanism of pore formation in the pellets. The basic physical and mechanical properties of the obtained aggregate are investigated, particularly attention pairing to the study of the aggregate's contact zone with the cement stone.

1 The problem and its relationship with scientific and practical tasks

One of the main tasks in sustainable construction development is reducing the mass of buildings and structures. One way to solve this problem is to use lightweight and lightweight concrete on porous aggregates. Despite the constant increase in lightweight concrete structures, their share does not exceed 30% of reinforced concrete volume.

The need to expand the production of lightweight concrete products is due to the ability to reduce the mass of buildings by 30-40%, reduce the construction time by 20%, reduce transport costs by 30-40%, and significantly improve the thermal and acoustic properties of enclosing structures [1-5]. The considered advantages can significantly reduce the consumption of resources for constructing buildings and reduce the number of harmful emissions into the environment.

There are practically no areas of construction where porous aggregate concrete cannot successfully replace heavy concrete. Traditionally, lightweight concrete using as thermal insulation and structural-thermal insulation materials. However, in the total volume of building structures, enclosing structures make up only 25-30%, and load-bearing systems - 70-75%; therefore, the need to expand structural concrete production with porous aggregates are put forward in the first place. The release of load-bearing structures from lightweight and lightweight concrete is primarily constrained by the absence or shortage of suitable and durable porous aggregates. Most of the porous aggregates are used only for the production of building envelopes. Therefore, artificial porous aggregates from local raw materials significantly waste from the mining and metallurgical industries are of exact importance.

Mining and processing plants of Ukraine annually

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store more than 130 million m^3 of sludge. Only in the Kryvyi Rih iron ore basin, more than 2 thousand hectares of agricultural land are occupied by dumps. Part of the enrichment waste, with a particle size of more than 0.14 mm, is used as a sand and crushed stone. However, a significant amount of waste has a particle size of less than 0.14 mm, not currently used. Therefore, developing a technology for obtaining sustainable porous aggregates for concretes using finely dispersed waste from mining and processing plants and concretes based on them continues to be an urgent scientific, technical, and social task.

2 Development of charge compositions and heat treatment mode

The research aims to develop optimal compositions of new porous aggregates made from the waste of mining and processing plants and study these aggregates' properties.

The selection of the optimal composition of raw materials for the porous filler included an analysis of the influence of the charge and additives' design and their granulometric composition on the final product's quality.

Dry mixtures contained:

- crushed and not crushed sludge (grains with a size of 1.25...0.14 mm);
- not crushed sludge with the addition of crushed shale;
- not crushed and crushed sludge with the addition of crushed shale;
- crushed sludge and crushed shale.

Dosing of the dry components of the charge carried out by weight. The content of crushed sludge and shale is taken as a percentage of the total dry ingredients. The content the rate of consumption of alkali silicate is taken from the total weight of the charge.

The mixture was granulated in a disk granulator to form granules with a diameter of 5...20 mm. Liquid glass is fed into the pelletizer using a spray gun.

The molding of the raw granules was carried out at different density values of alkali silicate (1.30...1.45 g/cm^3), which provided the introduction of the required amount of its solid substance into the charge. This approach made it possible to reveal the pattern and nature of the influence of the consumption of alkali metal silicate on the porous filler's properties. Raw granules' burning was carried out at 950, 1050, and 1150 °C for 5, 10, 15, and 20 minutes. Further analysis of the results showed that firing longer than 10 minutes had no significant effect on the studied parameters.

The burnt granules' testing results from a raw mixture with crushed sludge in its proportion shown in Fig. 1. The obtained results show that if alkali silicate and the amount of ground sludge in the charge increases, the average density of aggregate granules decreases. However, it is impossible to obtain an aggregate with an average density of less than 1.5 g/cm^3 due to the resulting liquid phase's small amount. The amount of the liquid phase largely depends on the content of fine particles in the mixture. The amount of ground sludge did not exceed 20%, and the larger grains did not take an active part in creating the pyroplastic melt; they dissolved only partially.

Adding a part of crushed shale to the slurry made it possible to obtain an aggregate with a lower average density than in the previous case. This dependence showed in Fig. 2. A decrease in filler granules' average density with the same fraction of the crushed charge (Fig. 1) occurs due to an increase in the liquid phase amount. This is because liquid glass forms more melting eutectics with shale minerals and more intense gas evolution occurs.

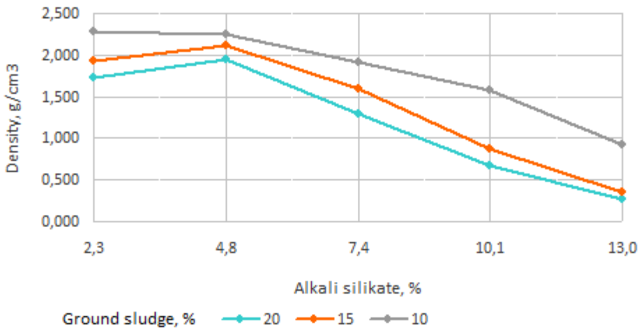

Fig. 1. Influence of the content of ground sludge and the flow rate of alkali silicate on the aggregate's front density.

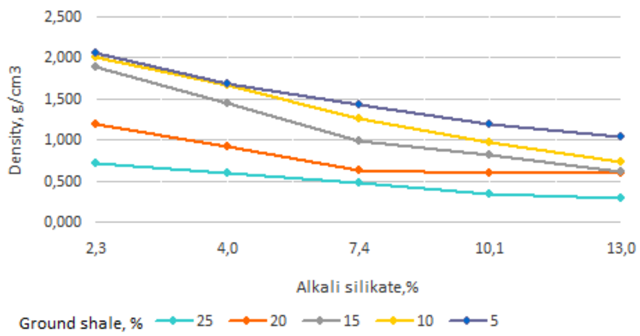

Fig. 2. Influence of ground shale and alkali metal silicate content on average aggregate density.

Studies have been carried out to study the content of crushed sludge and shale for the aggregate average density. These studies' results are shown in Fig. 3 and show that aggregate granules' average density decreases almost linearly, increasing alkali silicate consumption.

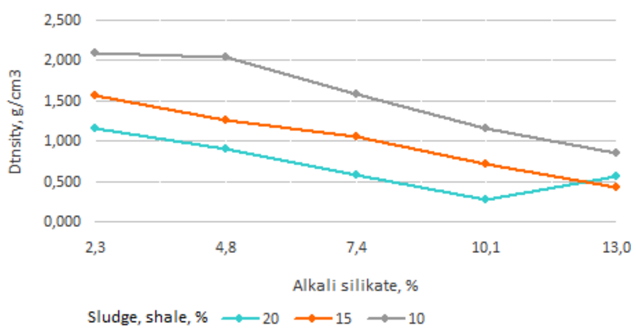

Fig. 3. Influence of the content of ground sludge, shale, and alkali silicate consumption on the average density of the aggregate.

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However, with a 15% content of crushed sludge, shale, and alkali silicate consumption of more than 10%, an increase in aggregate granules' average density is observed. A decrease explains this in the melt's viscosity and the process of compaction rather than porization. The combined effect of the milled components on the aggregate granules' average density is greater than that of each separately.

Previous studies have shown that using a mixture containing unmilled sludge and shale results in low-strength granules with low porosity and high average density. Therefore, all further studies were carried out only on mixtures with ground components. The results showed in Fig. 4 and 5.

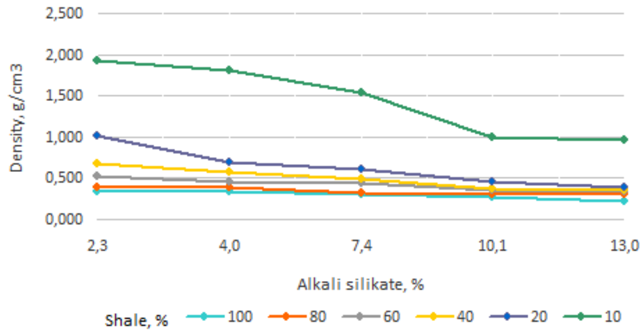

Fig. 4. The influence of alkali silicate consumption and the composition of the charge on the aggregate's average density.

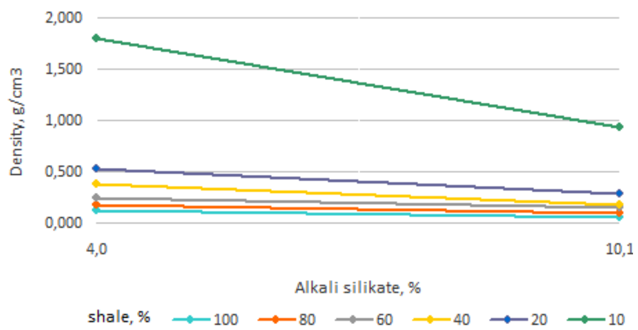

Fig. 5. Influence of the composition of the charge and the consumption of alkali silicate on the aggregate's average density.

Dependencies show that the most intensive decrease in average density occurs when there is up to 40% shale in the charge. A further increase in the shale amount reduces the average density slightly, but the granules' strength sharply decreases, and the pores increase due to increased gas release. Intense and excessive release of gaseous products does not improve the porization process but causes the formation of large interconnected pores, passing into cavities and open pores.

X-ray phase analysis of raw granule powders, dried to constant weight, showed the presence of the following minerals:

– β-SiO_2 (β-quartz);
– $FeFe_2O_4$;
– α - Fe_2O_3;
– $Al_2O_3 \cdot 2Si0_2 \cdot 2H_2O$ – kaolinite;
– hydromica;
– $K_2O \cdot Al_2O_3 \cdot 6SiO_2$ – potassium feldspar (orthoclase);
– $K(Mg, Fe)_3$ $[\cdot AlSi_3O_{10}] \cdot (OH, F)$;
– $K \cdot Al_2 \cdot [AlSi_4O_{10}] \cdot (OH)_2 \cdot nH_2O$ – illite;
– chlorites with an approximate composition of $Mg_5Al \cdot [AlSi_3O_{10}] \cdot (OH)_8$;
– $CaMg$ $(CO_3)_2$ – dolomite;

Differential thermal analysis of raw granule powders showed (Fig. 6) the presence of endothermic effects at a maximum of 140, 448, 584, and 772 °C. The total weight loss upon calcination up to 800 °C was 8.11%. The endothermic effect at a temperature of 140 °C is associated with removing adsorption water from clay minerals: kaolinite, monothermite, and illite close to kaolinite.

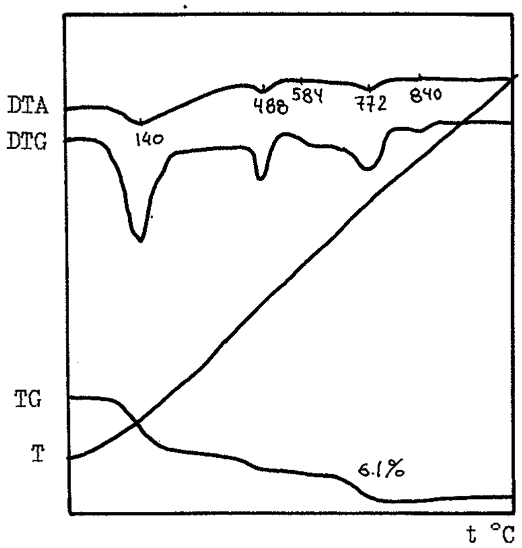

Fig. 6. Thermogram of raw granules.

The endothermic effect at a maximum temperature of 448 °C is associated with removing constitutional water from the crystal lattice of minerals: kaolinite, monothermite, followed by the crystal lattice's destruction.

A small endothermic effect at a maximum temperature of 584 °C is associated with removing constitutional water from the crystal lattice of minerals: illite, hydromica, and chlorite. The endothermic effect with a maximum of 772 °C is associated with dissociation of $CaCO_3$ and dolomite and the destruction of chloride's crystal lattice.

The blurred endothermic effect at a maximum temperature of 840 °C is associated with destroying the crystal lattice of hydromica and illite.

Since previous studies have established that the most suitable for obtaining a porous aggregate is a crude mixture consisting of crushed sludge, crushed shale, and water glass, these mixtures have been used to study the influence of technological factors on the properties of the porous aggregate. The research objective is to obtain mathematical models expressing the aggregate's average density and strength on the leading technological factors. The mathematical planning method, followed by mathematical and statistical processing of the results, was used to reduce the number of experiments.

A three-factor experiment at two levels is planned in

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the work. The variables are X_1 – the content of ground shale as a percent of the total mass of dry components; X_2 – consumption of liquid glass as a percent of the total mass of the charge; X_3 – firing temperature °C. Since firing for more than 10 minutes did not significantly affect the study's parameters, firing the granules was 10 minutes and not taken as a variable.

The levels and intervals of variation of the selected factors are shoved in the table. 1.

Table 1. Levels and intervals of variation.

Code	Code value	Value of factors		
		X_1	X_2	X_3
Main level	0	30	8.0	1050
Variation interval	X_1	10	1.4	100
Upper level	+	40	9.4	1150
Lower level	-	20	6.6	950

After statistical analysis, the equations have the following form:

$$Y_\gamma = 1.285 - 0.098X_1 - 0.570X_3; \quad (1)$$
$$Y_r = 108.13 - 24.13X_2 - 80.32X_3 \quad (2)$$

When checking the suitability of the above equations by Fisher's criterion, they all became adequate.

Analysis of equations (1) and (2) shows that within the limits of variation of the variables, the burning temperature, and shale consumption has the most significant effect on the average density of the aggregate, and the effect of the burning temperature is six times greater than the consumption of shale. As the strength of the aggregate decreases, the burning temperature and the alkali silicate consumption increase.

Fig. 7, 8 shows a graphical interpretation of the obtained dependencies.

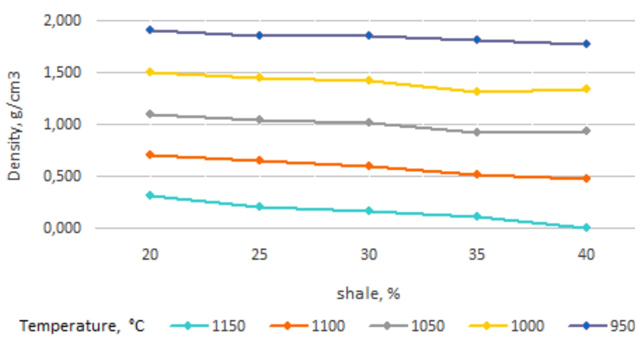

Fig. 7. Influence of technological factors on the average density of the aggregate.

3 Properties of porous waste aggregate

To obtain a complete characterization of a material and to identify its behavior in concrete, detailed studies of its properties, structure, and phase composition are required.

Such studies are essential because of the specifics of the raw materials used, allowing us to assume that we have an aggregate that differs from other aggregates similar in technology and shape in terms of structure.

The aggregates obtained both in a laboratory and in industrial conditions were subjected to research. The general view of the porous aggregate granules from the MBC wastes showed in Fig. 9.

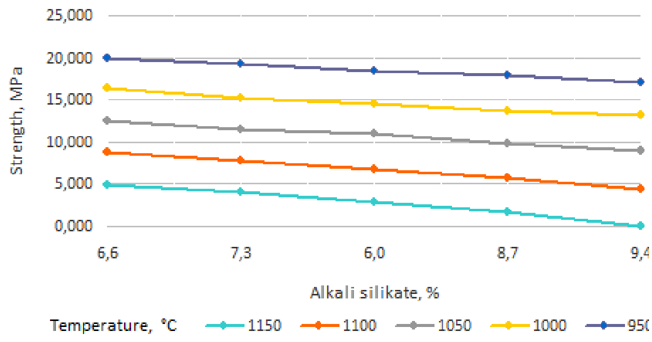

Fig. 8. Influence of technological factors on the strength of the aggregate.

Fig. 9. General view of aggregate granules, d=25 mm.

The samples of the obtained porous aggregates of dark brown color differ little from each other and have a large-porous structure with cavities. The pores are generally round, 250-1000 microns in size. The surface of the aggregate is partially melted and differs from the inner layers in its lower porosity. The absence of a dense sintered crust on the new aggregate's surface is expected to increase adhesion to the cement stone, ultimately leading to increased concrete strength.

The images were taken with a Scanning Electron Microscope (SEM) to show a porous aggregate structure from MBC wastes (Fig. 10). There is a different size of porosity of the material. The pores have a smooth surface, and the surface of the chipped partitions between the pores is glassy (homogeneous).

The nature of pore formation is the peculiarity of the new aggregate structure. The swelling of the pyroplastic melt causes this process due to the release of CO2 from the pellet volume.

X-ray analysis of granules burnt at a temperature of 1000 °C (Fig. 11 a) shows a significant decrease in β-lines of quartz, the appearance of lines of mullite, corundum, albite, nepheline and minerals of zeolite structure:

– mullite – $3Al_2O_3{\cdot}2SiO_3$ with d/n=53; 38; 35; 33.8; 28.8; 26.8; 25.4; 24.9; 23; 22; 21.2; 16.9; 15.2 mμ;
– corundum – α-Al_2O_3 with d/n=34.8; 25.5; 24; 20.8; 17.4; 16.0; 15.4; 15.08 mμ;
– albite – $Na_2O{\cdot}Al_2O_3{\cdot}6SiO_z$ – high-temperature modification with d/n =32.1; 25.1 mμ;
– nepheline – $Na_2O{\cdot}A1_2O_3{\cdot}SiO_2$ with d/n = 70.7; 40.4;

31.8; 26.8· mμ;

– zeolites with d/n = 26.1; 16.68; 15.07·mμ.

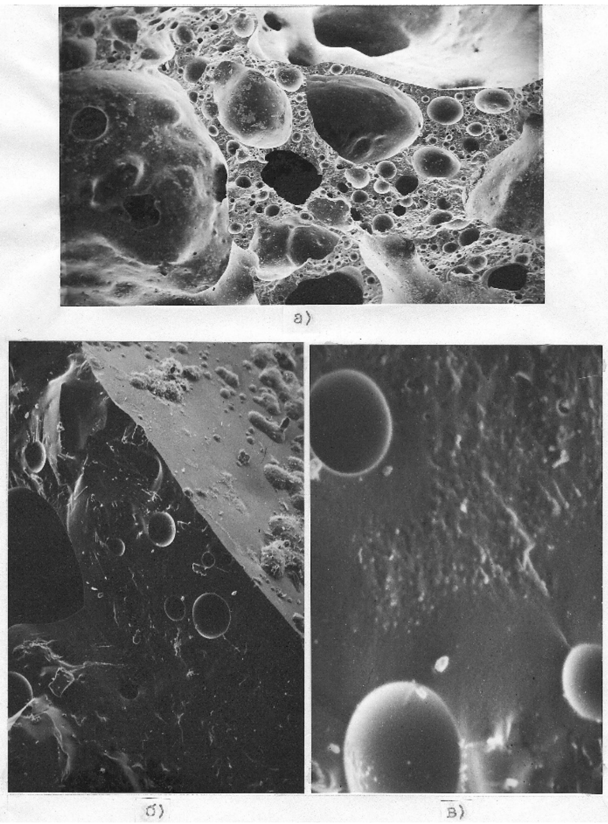

Fig. 10. Aggregate structure image with SEM: a) general view, magnification 45x; b) chipped partition, magnification 700x; c) chipped partition, magnification 3000x.

Thermographic studies of the raw granules burnt at a temperature of 1000 °C showed (Fig. 12) the presence of the weak endothermic effects with maximum temperatures of 58, 249, 590, and 800 °C.

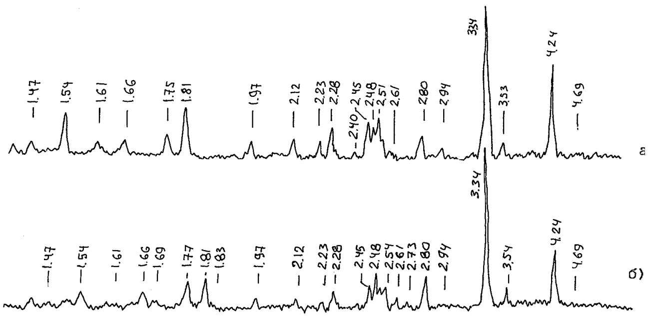

Fig. 11. Radiograph of the burnt masses: a) burnt at 1000 °C; b) burnt at 1150 °C.

All four weak endoeffects are probably associated with the polymorphic transformations in an insignificant part of silica from its total amount into phase varieties of quartz sequentially with a decrease in the temperature of endoeffects: α-tridymite → α-quartz → β-quartz → β-cristobalite → γ-tridymite. According to the X-ray phase analysis, β-quartz remains the most representative modification. When burnt, the lines of γ-tridymite with d/n=43.9 appear; 41.2; 37.3; 24.9; 16.9; 16.2; 15.9; 15.28 mμ.

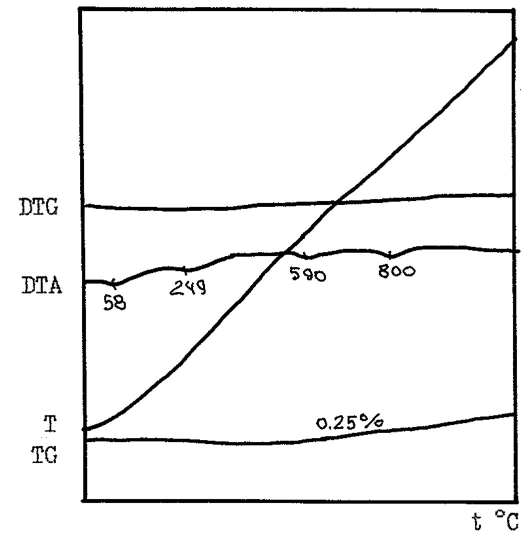

Fig. 12. Thermogram of the aggregate burnt at the temperature of 1100 °C

When calcinated up to 800 °C, the weight loss was 0.25%, which is within the experimental error. Perhaps such weight loss is due to the adsorbed water after burning. This fact may correspond to a weak endothermic effect at a maximum temperature of 58 °C.

An increase of the burning temperature to 1150 °C (Fig. 12 b) leads to an increase in mullite, corundum, γ-tridymite, and aluminosilicates of the zeolite structure and albite.

According to the methodology of State standard GOST 9758-2012 (Porous inorganic fillers for construction works, Test methods), the research was carried out. An artificial porous aggregate from MBC wastes obtained in experimental industrial conditions were tested. The test results are presented in the table. 2.

For pilot production of aggregate used a mixture of mining waste and shale in a ratio of 4:1 by weight; the consumption of liquid glass is 8% of the weight of dry components and firing temperature 1100 °C for 15 minutes.

As table 2 shows, the tested aggregate meets the requirements of GOST 9757-90 (Artificial porous gravel, crushed stone, and sand. Technical conditions) and belongs to the highest quality category.

Table 2. Physical and mechanical properties of porous aggregate from MBC wastes.

Indicators	Units of measurement:	fraction, mm		
		5-10	10-20	20-40
Density	g/cm^3	2.95	2.95	2.95
Bulk density	kg/m^3	1150	1100	1000
Average density of grains	g/cm^3	1.93	1.90	1.89
Porosity of grains	%	39.0	42.0	45.0
Moisture	%	0.70	0.68	0.74
Water absorption per hour	%	5.20	6.50	8.80
The compression strength of the aggregate in the cylinder	MPa	6.50	5.80	4.96
Softening coefficient	–	0.98	0.96	0.94
Grain shape coefficient	–	1.15	1.20	1.25
Frost resistance	cycle	>100	>100	>100

The strength of lightweight concrete is not only a function of the consumption and strength of the binder, the consumption of porous aggregates, but it is also determined by the structure and composition of the contact layer between them. Due to the difference between the obtained porous aggregate from other known ones, the processes occurring at the border with the cement stone can proceed differently and lead to hydrated compounds with different specific surface areas and porosity. Ultimately, this will lead to a change in the binder's porosity, concrete structure, and physical and technical properties.

A cement stone's contact zone with a large porous aggregate (Fig. 13) has the form of a winding line exactly repeating the granule relief, providing a tight and robust contact.

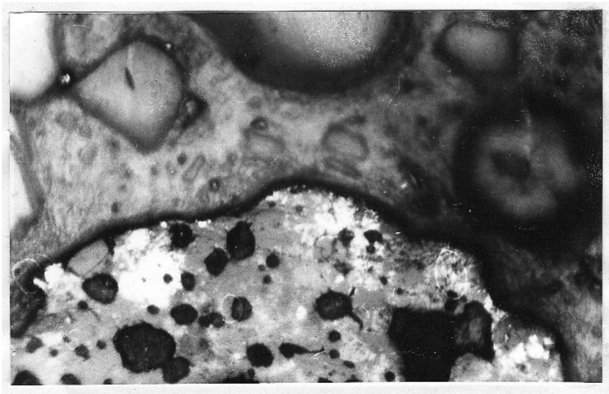

Fig. 13. Contact zone of new porous aggregate with cement stone.

The thermogram of the cement stone from the intergranular space (Fig. 14 a) showed the presence of four endoeffects with a maximum temperature of 155, 521, 663, and 818 °C.

The temperature of 155 °C corresponds to the dehydration of the high sulfate form of calcium hydrosulfoaluminate in the presence of gypsum or low-basic calcium hydrosilicates in the binder. A temperature of 521 °C corresponds to the dehydration of tobermorite-type hydrosilicates, and 818 °C corresponds to the decomposition of $CaCO_3$. When calcinated up to 400 °C, the total weight loss was 11%.

Thermographic studies of the contact zone, burnt granules (the binder) showed (Fig. 14 b) the presence of seven endoeffects with temperatures at maximum: 110, 228, 480, 584, 712, 784, 849 °C. The endothermic effect at 110 °C corresponds to the dehydration of the three-sulfate form of calcium hydrosulfoaluminate or calcium hydrosilicates of a hydrating binder; 480 °C corresponds to the dehydration of Ca $(OH)_2$; 712 °C – dehydration of tobermorite type hydrosilicates – CSH (B); 784 °C – $CaCO_3$ dissociation. At the maximum temperatures of 849, 584, and 228 °C weak endoeffects correspond to silica transformations into its polymorphic modifications described above.

In the contact zone, water was sucked into the granule body. Therefore, the weight loss upon calcination up to 800 °C was 1.5%. With a lack of water, hydration hardening occurs in the binder particles' surface layers adjacent to the granule. The conditions for forming hydrosilicates of the tobermorite type of a high crystallization degree are created (the temperature shift of the maximum endothermic effect from 633 °C for the binder 712 °C in the contact zone).

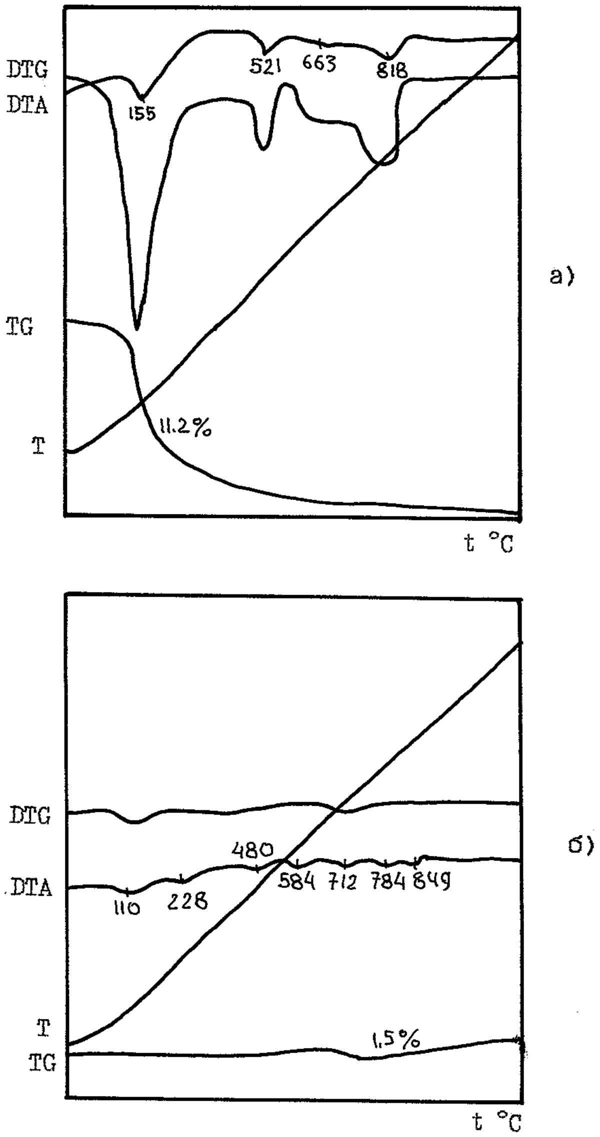

Fig. 14. Thermogram of cement stone: a) in the intergranular space; b) from the contact layer.

The microhardness measurement method was used to study the micro-strength properties of the contact zone. The results have shown that the microhardness of the aggregate (9000...11000 MPa) exceeds the microhardness of the cement stone in the contact zone (4000...6000 MPa), and the microhardness of the contact zone is higher than that one of the cement stone in the intergranular space (1500...2000 MPa).

5 Conclusions

– To obtain a porous filler, the most optimal is raw mixtures containing 20...40% shale and 6…10% liquid glass, fired at a temperature of 950...1150 °C.
– Mathematical models have been obtained that reflect the influence of technological factors on the volume, density, and strength of porous aggregates from the

waste of mining and processing plants.

- The physical and mechanical properties of the obtained porous filler, characterized by high mechanical strength, have been determined. The filler meets the requirements of the standards and belongs to the highest quality category.
- The filler has a porous structure with a predominance of pores 250-1000 μm and is composed of mullite, corundum, albite, nepheline, and minerals of zeolite structure.
- In the contact layer between the aggregate and the cement stone, a chemical interaction occurs with the formation of hydrosilicates of the tobermorite type, contributing to strengthening and intergrowth with the cement stone.

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Efficiency of application of fiber concrete as a material for manufacturing bodies of centrifugal pumps

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Abstract. The report presents the results of research on the use of composite material - fiber-reinforced concrete for the manufacture of centrifugal pump bodies. The, optimal composition of fiber-reinforced concrete with the required strength characteristics has been established. The method of casting a pump body and the results of industrial tests to determine the technological parameters of a centrifugal pump are presented. The results obtained showed that fiber-reinforced concrete bodies have an advantage over metal ones and can be recommended for use in mechanical engineering in the manufacture of centrifugal pump bodies.

Introduction

In the process of the development of the mining and metallurgical and oil and gas industries, the requirements for the quality of the products were increased, as well as the environmental and safety requirements for equipment became more stringent.

All these factors led to the emergence of new technologies for processing raw materials, the technological parameters of the equipment began to change, and new chemical liquids, more aggressive not only with respect to the material being processed, but also to the working bodies of the equipment, began to be used in technological processes.

This caused the following problems when operating the pumping equipment:

- the appearance of corrosion and erosion of pump elements in direct contact with the pumped corrosive liquid;

- the presence of solid inclusions in the pumped liquid led to abrasive wear of the pump flow path;

- as follows from the above, during the operation of the pumps, there is the appearance of hydraulic shocks during the operation of the pump and an increase in wear of the housing elements, which led to thinning of the housing walls, as well as an increase in vibration of the entire unit and a reduction in the service life of the bearings due to the growth of cavitation processes.

Based on the analysis of the main problems of the operation of pumping units, standards for the manufacture of pumping units were developed, which made it possible to unify the requirements for equipment and bring reliability indicators to a single denominator [1, 2].

Modern standards rather strictly regulate the types of materials, depending on the types of pumping equipment used. Pump elements that have direct contact with an aggressive liquid are practically not made of gray cast iron, since it is not resistant to aggressive liquids, as a result of which there is a rapid destruction of metal and frequent replacement of elements is required, which worsens the reliability of the pump and increases operating costs [3, 4]. For pumping corrosive liquids, materials with the required strength and resistance against corrosion and erosion are used, as well as special alloys that can withstand high temperatures of the pumping liquid. For example, high-alloy chromium-nickel steel is used for pumping acidic liquids. Depending on the discharge pressure, the properties of the pumped material and its aggressiveness, carbon steels and aluminum alloys are also used. Practice shows that with an increase in wall thickness, porosity forms in cast iron bodies. In this regard, the bodies are cast from carbon alloys. Considering the dimensions and weight of the pumping equipment of the mining and processing enterprise, then considerable funds are spent on casting the pump body [5,6].

One of the ways out of this situation is the use of construction materials with a low cost, but meeting the requirements of the conditions for the safe operation of equipment. This material includes fiber concrete.

Fiber concrete is a fine-grained material, one of which is a reinforcing filler. These composites are very promising for use in mechanical engineering, in particular, in the manufacture of body parts for pumping equipment [7].

Modernization of centrifugal pump casings by replacing materials with composite materials is very important.

Currently, fiber-reinforced concretes are widely used in the production of building materials and have been

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thoroughly investigated. However, there are practically no works related to the study of the use of these materials in mechanical engineering, especially for the manufacture of parts of technological equipment [8-10].

Research work on the use of fiber-reinforced concrete as a material for the manufacture of centrifugal pump casings was carried out at the Kazakh National Research Technical University named after K.I. Satpayev. These studies were carried out in a wide range from the selection of a rational composition of fiber-reinforced concrete to testing a cast body sample in an industrial environment. This article presents the main results of these researches.

Methods

To create a composite material, theoretical and experimental studies were carried out. Theoretical studies included a patent-literature review on composite materials, including fiber-reinforced concrete, as well as on existing methods of mixture preparation and casting technology for body parts. In experimental studies, the optimal composition of the mixture was determined, the mechanical properties of fiber-reinforced concrete were tested [5], the casting technology of the body was worked out and the industrial test of the finished body made of fiber-reinforced concrete was carried out. To conduct an experimental study, a method was developed for determining the mechanical properties of fiber-reinforced concrete and a method for conducting tests on an industrial bench in the conditions of JSC "Almaty Heavy Engineering Plant". The results of experimental studies were processed according to the standard method of mathematical statistics. Based on the research results, a comparative assessment of pump casings made of fiber-reinforced concrete and metal is given.

This composition of polymer concrete is selected based on a number of requirements.

1. The need to obtain a mixture with a mobility of 8 ... 9 cm, which should provide a good filling of the die for casting the product-the gearbox housing or the centrifugal pump snail.

2. The need to ensure the strength of polymer concrete in order to withstand the statistical and dynamic loads of the tested products.

The sequence of the researches carried out made it possible to obtain a composite material with the required strength characteristics by simple technology and low cost.

Results and discussion

The conducted research has established the optimal composition of fiber-reinforced concrete, consisting of granite gravel, quartz sand, quartz flour with the addition of steel fiber. Epoxy resin was used as a binder (table 1).

From the investigated composition of fiber-reinforced concrete, the 1st composition with steel fiber was selected, which made it possible to obtain a composite material that fully meets the requirements for the material for the manufacture of centrifugal pump bodies.

For the casting of the centrifugal pump body that meets the necessary requirements, special researches were carried out, which made it possible to work out the technology of manufacturing casting matrices and fiber-reinforced concrete mixtures with the development of casting technology.

Table 1. The investigated compositions of fiber-reinforced concrete.

№	Components	Composition 1		Composition 2		Composition 3	
		Con-sum-ption in %	Con-sum-ption in grams	Con-sum-ption in %	Con-sum-ption in grams	Con-sum-ption in %	Con-sum-ption in grams
1	Granite gravel	51	1000,0	52	1040,0	–	–
2	Rubble	–	–	–		51	1000,0
3	Quartz sand	25,5	502,0	–	–	25,5	502,0
4	Quartz flour	11	220,0	–	–	11	220,0
5	Andesite flour	–	–	33.6	620,0	–	–
6	Fiber:						
6.1	Steel wire	3,5*	70*	–	–	–	–
6.2	Fiberglass	–	–	3,5*	70*	–	–
6.3	Steel anchor type	–	–	–	–	3,5*	70*
7	Resin	10,6	200,0	12	240,0	10,6	200,0
8	Hardener	2,0	40,0	2,4	50.0	2,0	10,0

*Note: * - "±" to the total mass*

The technological process of forming elements of centrifugal pump casings consists of the following operations:

• matrix and mold lubrication;
• installation of reinforcing cages;
• laying the fiber-reinforced concrete mixture into a matrix (form);
• molding of body parts;
• removal of finished products;
• drying of finished products.

The carried out analysis found that the most influencing factors on the strength characteristics in the preparation of fiber-reinforced concrete should be considered strict adherence to the technology of preparation of raw materials and the mixing mode of components, as well as the content of fiber. It was found that the dosage of the components of fiber-reinforced concrete should be carried out with an accuracy of ± 2% by weight. This mode of preparation of a fiber-reinforced concrete mixture makes it possible to obtain a homogeneous mixture with an even distribution of all components in its volume. This provides an isotropic solidified mixture with the same characteristics at any point. The analysis of the research results of the factors affecting the strength of fiber-reinforced concrete showed that the optimal time for mixing the components of the mixture for its strength is 5 ... 6 minutes at a working body rotation frequency of 800 ... 1000 rpm.

According to the results of the experiments, it was found that the most rational is the following composition of fiber-reinforced concrete (by volume): granite crushed stone 50 ... 52%, quartz sand 25 ... 26%, quartz flour 11%, steel anchor-type fiber 3-4%, epoxy resin 10-11 %, hardener 2%. Such composition of fiber-reinforced

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concrete has a density of 2200 ... 2300 kg / m3, compressive strength 230 ... 240 MPa, bending strength 80 ... 100 MPa.

Figure 1 shows the finished body of a standard centrifugal pump 1K 20/30, cast from fiber-reinforced concrete.

Fig. 1. Finished body of a centrifugal pump.

The cast samples and the results of the performed experiments on mechanical tests were presented to the specialists of the quality department and the management group of JSC AZTM for external evaluation of the obtained semi-industrial sample from fiber-reinforced concrete. Experts carried out visual-optical control in order to identify surface defects that could arise during installation and operation.

Visual-optical control was carried out before instrumental and non-destructive control methods. All measurements were made after visual control or simultaneously with it.

During visual-optical control, the following were checked:

- completeness of the pump;
- quality of protective coatings and colors;
- the presence of defects that affect the performance of the pump.

At the same time, special attention was paid to the presence of defects posing a possible danger of subsequent destruction of a part or assembly unit, such as:

- local mechanical damage (tears, kinks, dents);
- stratification of the base material;
- sunsets of the main material;
- deformation of parts and assembly units;
- defects of threads;
- cracks in the base material;

After casting, the halves of the body were glued together with an epoxy compound thickened with adhesive flour, and treated with an abrasive wheel. The glued body in 2 layers is covered with a gelcoat to reduce the roughness of the body surface.

For industrial testing, a 1k20/30 pumping unit with a fiber-reinforced concrete casing is connected to a test bench in the conditions of JSC "AZTM".

The test bench is designed for testing centrifugal pumps. At the test bench, it is possible to conduct research on individual devices used in the automation of a technological process and the following can be determined:

- characteristics of the potentiometric level sensor (LS);
- characteristics of the electromagnetic relay;
- performance characteristics of the centrifugal pump;
- liquid consumption in various ways;
- study the device of the pressure switch and devices for measuring temperature and pressure, determine the thresholds for the pressure switch, measure temperature and pressure.

Evaluation of the effectiveness of the test bench is based on the registration of the parameters of a centrifugal pump in conditions close to production.

Modules of hydraulic and electrical control, which are structurally complete devices, are designed to control, measure the recorded values and monitor the work of the test bench.

Figure 2 shows the hydraulic diagram of the stand. All devices are installed in the body of the hydraulic control module, which are shown on the hydraulic diagram inside a rectangle highlighted by a dash-dot line. These are the following devices:

- CV - check valve;
- PS - pressure switch:
- V1 ... V5 - valves;
- WC - simulator of water consumers;
- T - temperature sensor;
- FM - flow meter;
- MN - manometer.

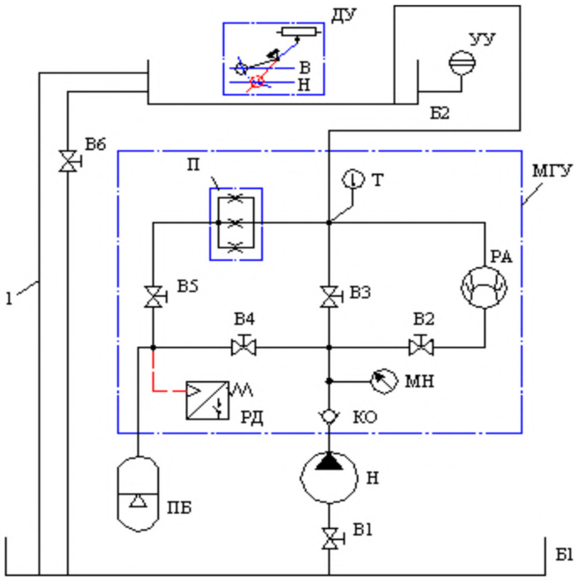

Fig. 2. Hydraulic diagram of the test bench.

In the electrical diagram of the test bench it is indicated (Figure 3):

- lS - potentiometric level sensor (installed in the upper hydraulic tank, pos. 6 in Figure 2);
- EMR - electromagnetic relay;
- PS - pressure switch (installed in the housing of the hydraulic control module);
- DEM - hydraulic pump drive electric motor;
- RH - load resistance;
- A, V, W - ammeter, voltmeter, wattmeter, respectively;
- HL2 - light indication lamp.

The supply voltage of the electrical system is 220 V, alternating current, 50 Hz. Potentiometric level sensor supply voltage - 12 V, constant current.

Comparative tests were carried out on an installation with a fiber-reinforced concrete and a metal casing under identical conditions.

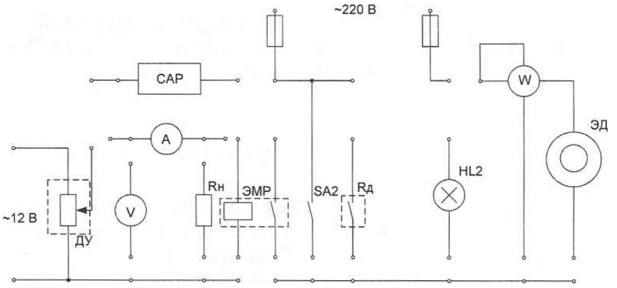

Fig. 3. Electrical diagram of the test bench.

The tests were carried out in the following order:

1. The stand was powered up. For this, the "MAINS" toggle switch on the electrical control module must be set to the upper position. Switch on the pump with toggle switch SA2.

2. Experimental studies were carried out to determine the pump performance. First, acting on the B2 valve, the maximum pressure that the pump develops (according to the MH manometer) was determined. Then, having divided the range of the pump pressure change into 5 intervals, 6 experiments were carried out. In every experiment, the pressure should be constant. The first experiment began with the minimum pump pressure (that is, with the minimum resistance of the network on which the pump was operating).

Each experiment measured:

1. Pressure at the pump outlet $p_н$ (according to the manometer);

2. The time t of passing through the flow meter the volume of water W (the volume W must be set, taking, for example, $W = 0.01$ m^3 (10 dm^3).

3. The power of the N_e supplied to the electric motor (according to the wattmeter) (when determining the power, the readings of the wattmeter were multiplied by 100, then the power was obtained in watts). The measurement results were entered in table 2.

After the completion of the test of the pump with a fiber-reinforced concrete body, the pump with a metal casing was tested in the same way. The measurement results were entered in Table 3.

When processing the research results, the following assumptions were made:

1) the pressure at the pump inlet ($p_в$) is taken equal to the atmospheric pressure (there are two reasons for this assumption: the presence of a liquid back pressure at the pump inlet, since the water level in the lower tank is higher than the pump location level; relatively low pressure losses in the suction pipeline);

2) the vertical coordinates at the pump inlet and outlet are equal, that is, $z_H = z_B$ (the vertical size of the pump is not taken into account);

3) the average fluid flow rates at the pump inlet and outlet are equal to each other, that is, $V_H = V_B$.

Thus, the pump flow is equal to:

$$Q = \frac{W}{t}\,.\ \mathrm{m^3/s} \qquad (1)$$

where, w – volume of water passing through the flow meter, m^3 , t - volume transit time W, s.

Pump power:

$$N = N_{эл} \cdot \eta_{эл}.\ \text{кВт} \qquad (2)$$

where $\eta_{эл}$ – The efficiency of the electric motor (taken constant equal to 0.7).

The pump head was determined by the formula:

$$\mathrm{H} = \frac{P_н}{\rho \cdot g}\,.\ \mathrm{m} \qquad (3)$$

where, $P_н$- pump outlet pressure, MPa, ρ – fluid density, кг/м^3, g – acceleration of gravity

Net pump power:

$$N_п = \mathrm{P}_н \cdot Q.\ \text{кВт} \qquad (4)$$

where, $P_н$- pump outlet pressure, MPa , Q – pump feed, m^3/h

The pump efficiency is:

$$\eta = \frac{N_п}{N}\ .\ \mathrm{kW} \qquad (5)$$

where , $N_П$ – net pump power, kW, N – pump power, kW.

According to the above method, the main parameters of the pump were determined and the results of calculations were entered into tables 2 and 3, and then the operating characteristics of the pump were plotted from the values: $H = f(Q)$, $N = f(Q)$, $\eta = f(Q)$ and comparative characteristics of the pump with fiber-reinforced concrete and metal casing.

Table 2. Test results of a pump with a fiber-reinforced concrete body.

# of experiment	$P_н$ – pump outlet pressure, MPa	W – volume of water passing through the flow meter, m^3	t – volume transit time W, s	$N_{ЭЛ}$ – motor input power, kW	Q – pump feed, m^3/h	N – pump power, kW	H – pump head, m	$N_П$ – net pump power, kW	η – Pump efficiency
1	0,25	0	0	3,0	0	2,1	25,3	1,12	0
2	0,20	0,116	60		6,99		20,2	1,392	62.8
3	0,15	0,158	60		12		15,2	1,422	64.2
4	0,10	0,240	60		13		10,1	1,44	65.1
5	0,05	0,332	60		16		5,1	1,45	45

The results of comparative bench tests of a 1k20 / 30 centrifugal pump with a metal casing and a fiber-reinforced concrete casing are shown in Table 4.

The test results show that the parameters of a pump with a fiber-reinforced concrete body are not inferior in characteristics to a pump with a metal body.

Conclusion

The studies carried out led to the following conclusions:

Table 3. Test results of a pump with a metal body.

# of experiment	$P_н$ – pump outlet pressure, MPa	W – volume of water passing through the flow meter, m^3	t – volume transit time W, s	$N_{ЭЛ}$ – motor input power, kW	Q – pump feed, m^3/h	N – pump power, kW	H – pump head, m	$N_П$ – net pump power, kW	η – Pump efficiency
1	0,25	0	0		0	2,1	25,3	1,09	0
2	0,20	0,110	60		5,95		19,78	1,32	62.8
3	0,15	0,150	60	3,0	9,0		15	1,35	67.5
4	0,10	0,228	60		13,15		10,1	1,368	65.1
5	0,05	0,315	60		14,5		8,65	0,945	40

Table 4. Results of bench tests of a centrifugal pump 1k20 / 30

Parameters*	Values	
	Fiber-reinforced concrete pump	Metal body pump
Mass M, kg	20,3	30,5
Volume of water passing through the flow meter, W, m^3	0,332	0,315
Time of passage of water volume *W*, s	60	60
Feed, Q, m^3/h	19,92	18,9
Head, H, m	25,3	25,3
Pressure, p $_н$, MPa	0,25	0,25
Motor input power, $N_{ЭЛ}$, kW	3,0	3,0
Pump power, *N*, kW	3,0	3,0
Net pump power, $N_П$, kW	1,44	1,368
Pump efficiency, η	0,685	0,651

* For comparison of parameters the maximum values of parameters are selected.

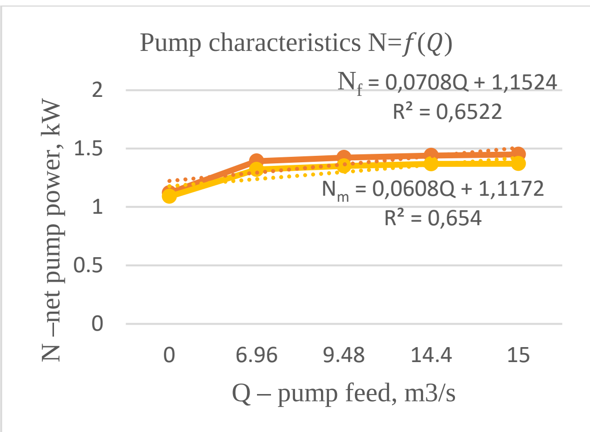

Fig. 4. Characteristics of the 1k 20/30 pump: the dependence of the useful power on the supply.N=$f(Q)$

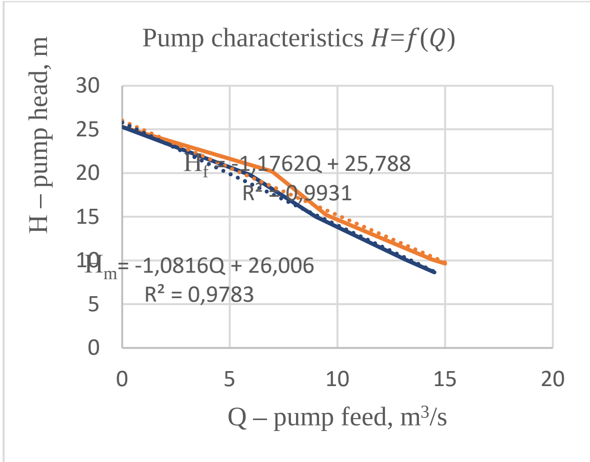

Fig. 5. - Pump characteristics 1k 20/30: the dependence of the head on the flow H=$f(Q)$.

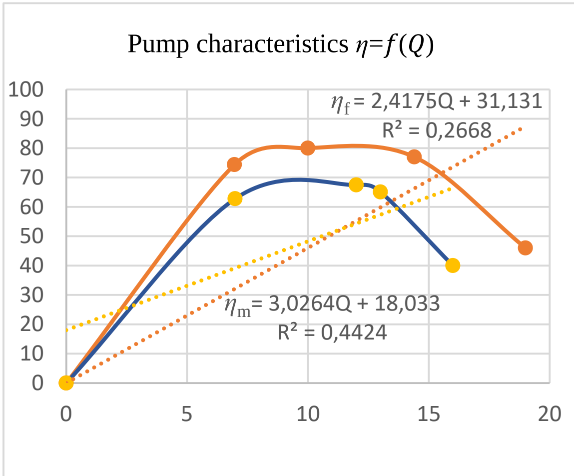

Fig 6. Pump characteristics 1k 20/30: dependence of efficiency on flow η=$f(Q)$

1. Fiber concrete in its characteristics fully meets the requirements for materials for the manufacture of centrifugal pump bodies.
2. The proposed method for the selection of the composition of fiber-concrete mixes allows you to obtain optimal mixes that guarantee the necessary physical and mechanical characteristics.
3. The bodies of centrifugal pumps cast from fiber-reinforced concrete do not require additional machining and have shown good quality during experimental tests.
4. The test results showed that samples made of fiber-reinforced concrete have a strength 30 ... 40% higher than those of metal, which makes it possible to reduce the thickness of the walls of products by 20 ... 25%, which makes it possible to reduce the mass of the pump body by 33-35%.
5. The results of the study showed that when using pump bodies made of fiber-reinforced concrete, the productivity and efficiency of the pump increase by 4-5% due to the smooth inner surface of the casing.

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Cable-stayed coverings for large-span public buildings

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Abstract. Structural schemes of coverings using lightweight roof structure from modern composite materials are investigated in this paper. A comparison of two options for cable-stayed covering of ~~a~~ circus auditorium, one with an orthogonal mesh of cables (according to a standard design) and another one, with a mesh of cables formed by two groups of stabilizing cables are considered. The possibilities of reinforcement with composite material are analyzed. Calculation and preliminary selection of cable-stayed sections are also carried out and presented. The variations of the conditional volume with the relative sag arrows, for varying values of the coefficient q_k have been investigated and shown on graphs. An optimization problem was solved and the optimal result with detailed calculations are proposed and presented in this research which enable the design of the cable-stayed coating with determination of its design characteristics. As a result, the optimum and most economical sections of the cable-stayed covering were obtained. The calculations also show the inexpediency of using a heavy roof structure for saddle cable-stayed coverings due to the exclusion of stabilizing cables from the operation with a large roof weight.

1 The problem and its relationship with engineering tasks

The interest in cable-stayed coverings, which is manifested by many researchers, designers and builders, is common and becoming an actual engineering problem to resolve. This is helped not only by the economic advantages of coatings used, but also by the development of calculation methods and design techniques. Plausible results, associated with the study of static, dynamic and kinematic properties of cable-stayed systems with the use of computer technology, have been achieved. Positive attempts have been made to solve problems of optimal design [1-3].

Currently, scientists are considering issues related to:
– a choice of constructive schemes of a cable-stayed covering;
– study of the stress-strain state of cable-stayed systems;
– methods of solving equations;
– optimal design of cable-stayed systems;
– dynamics of cable-stayed systems;
– construction of cable-stayed coverings;

The relevance of the study is determined by the use of a constructive scheme of coverage, which allows the use of a lightweight roof structure using modern composite materials. The outstanding works of local and foreign scientists in this field over the past 30-40 years are to be commended and encouraging for future research. As a result buildings and structures using cable-stayed systems are quite widespread (coverage of public and industrial long-span buildings, cable-stayed bridges and overpasses) [4, 5].

But there are also problems that hinder the spread of cable-stayed systems in construction. This is, first of all, the lack of regulatory framework for the design and calculation of cable-stayed systems. All parameters and recommendations for design and research can be found only in the works of scientists who are specialized in this field.

2 Analysis of research and publications

Hanging cable-stayed structures are mainly used to cover large-span buildings (structures) of various types [1, 6], such as stadiums, gymnasiums, entertainment and trade buildings, where they are most cost-effective and aesthetically pleasing.

Buildings and structures with cable-stayed (hanging) coating in contrast to the dome and cylindrical coatings, allow to cover the area of buildings (structures) of much larger size without economic losses, while easy to manufacture, install and operate. However, with increasing the area of the cable-stayed cover, respectively, increases the support forces in the cables (flexible threads), which are transmitted to the external support, in which case it is necessary to increase the stiffness parameters of the external support circuit.

Scientists consider issues related to the choice of structural schemes of cable-stayed cover, the study of the stress-strain state of cable systems, methods for solving equations, the optimal design of cable systems, the dynamics of cable-stayed systems, the design of cable-stayed coverings, among others.

Local and foreign experience of building structures using suspension systems are described in the works of Kirsanov, Dmitrieva, Trushcheva, Faibyshenko, Gorev [7-13].

3 Formulation of the problem

The purpose of the study is to analyze the cable-stayed coverings used in long-span public buildings, finding their optimal parameters and choosing an efficient and economical type of roof.

To achieve this, it is necessary to solve the following problems:

– to investigate the state of issues related to the design and calculation of cable systems;

– to find the expedient constructive scheme of a cable-stayed covering, to substantiate its choice;

– to study the construction of the roof of cable-stayed coverings, to develop a new type and to adapt it to the chosen structural scheme.

4 Materials, calculations and results

The problem of designing a cable-stayed cover is considered on the example of a circus building. It is designed on the basis of a typical circus project. The cable-stayed covering covers the auditorium of the circus with a diameter of 48 m.

The design of the cable-stayed cover took place in several stages:

1st Stage. Choice constructive scheme.

2nd Stage. Choice of roof design.

3rd Stage. Calculation and selection of preliminary sections of cables.

1. Choice constructive scheme.

In the typical project the device of a cable covering in the form of a cable-stayed orthogonal grid is provided. The spatial rigidity of the coating is provided by pre-stress followed by monolithic and transformation of the structure into a shell. The surface has the shape of a hyperbolic paraboloid.

Two directions of cables are the minimum necessary for creation of preliminary pressure (thus the outline of a basic contour corresponds to a grid). However, there are cable-stayed nets formed by three or more directions of cables.

A fairly economical roof solution is a light roof, but it requires a high degree of rigidity of the cable-stayed grid. Therefore, a new kinematic structural scheme is proposed, which is a cable-stayed grid with triangular cells.

Cable-stayed mesh with a triangular structure has the advantage that its elementary triangular cell is always flat. This allows the cells between the cables to be filled with fragile materials, such as glass panels or other materials.

A grid with triangular cells can be formed on any surface.

Thus, for a hyperbolic paraboloid, the supporting cables are directed along the line of the main curvature, and the stabilizing ones - at an angle of 45 ° to the main one.

Due to the fact that the existence of right triangles on the surface of a hyperbolic paraboloid is impossible [14, 15], it is assumed that the grid nodes will be arranged by forced fastening.

Fig. 1. depicts a cable-stayed grid offered in a typical design and a cable-stayed grid.

Therefore, the designed structural scheme of covering in the form of a cable grid with two groups of stabilizing cables forming triangular cells is used for implementation.

2. Choice of roof design

The maximum weight of lightweight types of roofs is normally limited to 40-60 kg / m ^{2}.

To achieve the normative indicators of heat transfer resistance, the roof is insulated with foam plates with a density of ρ = 0.5 kN / m^3 and a thermal conductivity coefficient λ = 0.043 W / m ºC.

R_0 – calculated heat transfer resistance m^2·ºC / W:

$$R_0 = \frac{1}{\alpha_в} + R_к + \frac{1}{\alpha_н}, \tag{1}$$

where: $\lambda_в$ – heat transfer coefficient of the inner surface of the fence, W / m ^{2} ºC; $R_к$ – thermal resistance of the enclosing structure, m ^{2}·ºC / W; $\lambda_н$ – heat transfer coefficient (for winter conditions) of the outer surface of the fence, W / m ^{2}·ºC.

The resistance of steel and waterproofing layer is not taken into account. When designing enclosing structures, it is necessary that their heat transfer resistance is not less than the standard value $R_0^н$. According to table 1 [16] $R_0^н$ = 2,6 m^2 ºC /W:

$$R_0 > R_0^н \tag{2}$$

From design requirements 2 plates, 60 mm thick are acceptable. The resistance to heat transfer is determined:

R_0 = 1/8,7 + 0.12/0,043 + 1/23 = 0,1149 + 2,79 + + 0,0435 = 2,917 m^2 ºC / W

R_0 = 2,917м^2· ºC /Вт > $R_0^н$ = 2,6 m^2 ºC / W, and as such, the condition is satisfied.

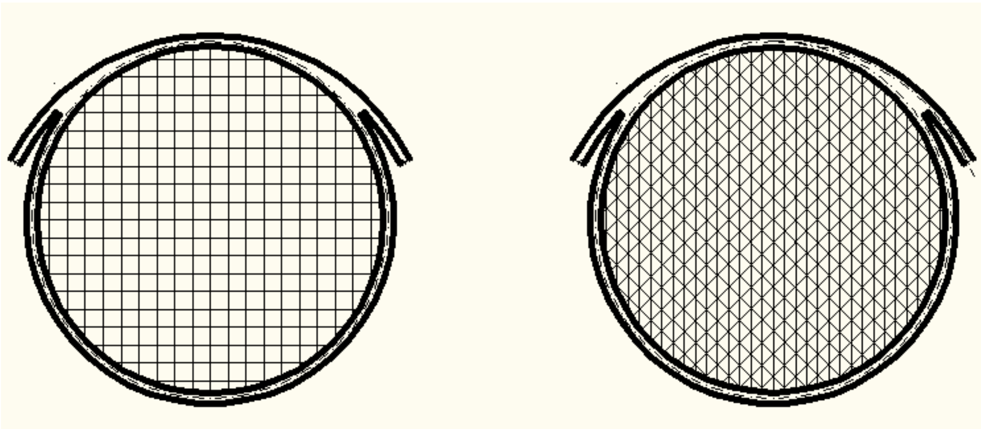
The thickness of the insulation layer is satisfactory.

To fill the triangular cell, a triangular plate of insulation is used, shown in fig. 3 [17]. It is reinforced externally with a composite material.

Let's analyze the possibilities of reinforcement with composite material. Composite materials consisting of a fibrous filler and a binder are suitable for these functions. Such materials are fiberglass and carbon fiber, which are widely used in construction.

Comparison of these materials:

1. Fiberglass – a plastic material consisting of fiberglass filler and binders (thermoactive and thermoplastic polymers). This is a material with a low specific weight and specified characteristics. They have low thermal conductivity, high strength, biological and atmospheric resistance.



a) ***b)***

Fig. 1. Cable-stayed cover of the circus auditorium: *a* – with an orthogonal cable-stayed grid (according to a typical project); *b* – with a cable-stayed grid formed by two groups of stabilizing cables.

Fig. 2. Roof construction: 1 – waterproofing layer; 2 – metal membrane; 3 – vapor barrier; 4 – insulation.

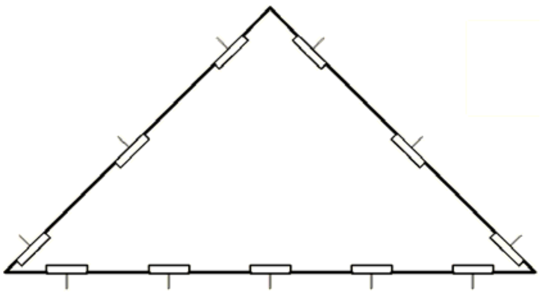


Fig. 3. The scheme of a triangular plate of a heater.

2. Carbon fiber – a material of interwoven threads of carbon fiber, located in a matrix of polymer resins. This material also has low weight and high strength (dominated by specific characteristics of steel). They are also resistant to external influences.

Comparative characteristics of these materials are considered in table. 1.

As seen from the table, fiberglass and carbon fiber have approximately the same strength characteristics with a lower modulus of elasticity of fiberglass relative to carbon fiber, but the cost of fiberglass is 9-10 times lower. Therefore, it is more appropriate to use fiberglass for external reinforcement.

Reinforcement is performed as follows: two triangular plates of polyfoam are placed on top of each other and fiberglass membrane is laid between them, which is fixed at the edges of metal plates with a thickness of 3 mm, which are fastened together with a bolted connection. This structure is externally reinforced with rolled fiberglass. Fastening of plates among themselves occurs by means of metal welded details of channel section. There are metal hooks which fastens the plate to the cables (fig. 4).

Table 1. Comparative characteristics of reinforcement materials.

Characteristic	**Fiberglass**	**CFRP** (carbon fiber)
Density, kg / m^3	1800 – 1900	1700 – 2000
Modulus of elasticity, GPa	70	140 – 145
Tensile strength (tensile), MPa	1700	800 – 1100
Poisson's ratio	0,2 – 0,25	0,25 – 0,3
Thermal conductivity, W / m ºC	0,75	0,5 – 0,1
Coefficient of linear expansion, 10^{-6}	0,45 – 8,3	0,8 – 5,2
Resistance to aggressive environments	Resistant	Resistant
Price, UAH / m^2	10 – 14	110 – 130

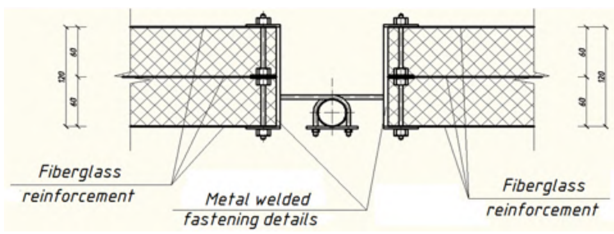


Fig. 4. Knot of fastening of plates to cables.

Fiberglass is additionally glued to metal and foam with CERESIT CT83 polymer-cement adhesive, which works effectively to allow deformation. The joints between the plates are filled with elastic mounting foam, which is resistant to extreme mechanical displacement.

3. Calculation and preliminary selection of sections

The following calculation is suitable for technical and economic comparison.

Output data:

The cover of the circus auditorium is round in plan, 48 m in diameter, covered by a cross system of cables, consisting of one group of load-bearing cables and two groups of stabilizers. According to standards [18], the snow load is 1.0 kPa, the wind load is 0.88 (taking into account all coefficients). As bearing elements of a grid we accept ropes of double twisting like LK-RO of a design 6 x 19 x (1 + 6 + 6/6 + 14) +7 x 7 x (1 + 6) as per prevailing standards [19] with the coefficient $k_p = 0.81\ldots 0.85$ and the temporary resistance of the break wires – 1,764 GPa.

The load on the coating will be entered in table. 2. Thus wind and snow loading is simply considered to be evenly distributed on a covering surface.

In saddle-shaped coverings (with a surface in the form of a hyperbolic paraboloid) the struts of all bearing ropes will be the same due to the uniform load on the cover and the pressure of the stabilizing ropes on the bearing. As such, we can distinguish one carrier thread, which does not differ in work from others, and one stabilizing thread, which characterizes the same pressures of all stabilizing cables on the carriers.

In design practice, the magnitude of the prestressing system (the magnitude of the forces of interaction of the cables) is often set, provided that the stabilizing cables are almost excluded from operation at full load on the coating. In this case, the share of interaction forces in the total load on the carrier thread is small and the determination of the forces in the grid, carried out by this method of calculation, is accurate enough to assign cross-sections of threads in advance.

Therefore, the forces in the bearing and stabilizing threads are determined by the formulas:

$$T_{\text{н}} = \frac{d_{\text{н}} \cdot l^2 \cdot a}{8 \cdot f_{\text{н}}} \cdot \left[g_1 + q + p_1 \cdot \left(\frac{l_c^2}{C \cdot l_{\text{н}}^2 + l_c^2} \right) \right] \qquad (3)$$

$$T_{\text{н}} = \frac{d_c \cdot l^2 \cdot a}{8 \cdot f_c} \cdot \left[q - g + p_w \cdot \left(\frac{C \cdot l_{\text{н}}^2}{C \cdot l_{\text{н}}^2 + l_c^2} \right) \right] \qquad (4)$$

where: d – the steps of the respective cables in the grid (since the stabilizing cables are located at an angle of 45° to the carriers, then $d = d_c = d_{\text{н}} \cdot \sqrt{2}$); $l_{\text{н}}$ and l_c – corresponding spans of the supporting and stabilizing cable; $f_{\text{н}}$ and f_c – corresponding sagging arrows; g_1 – part of the constant load (own weight of load-bearing structures and connections) applied to the pre-stress (0.13 kPa); q required value pre-stressing; p_1 – temporary (snow) load plus part of the constant load g_2 (1,4 + 0,57 = 1,97 kPa), that is applied after pre-stressing ($g_2 = g - g_1$); g – constant load (0.7 kPa); p_W – wind load (1.22 kPa); C – the coefficient of interaction of groups of cables; $a = \sqrt{1 + 16/n^2}$, where: $n = l/f$ – the ratio of the span to the sagging arrow; $q = [(p_1 \cdot C)/(C+1)] + \Delta q$, where Δq – additional part of the pre - voltage of the system (it is recommended to take $\Delta q = 0{,}1 \ldots 0{,}3 \cdot q$;

$$C = \frac{\mu_{\text{н}}^2}{\mu_c^2} \cdot \frac{A_{\text{н}} \cdot E_{\text{н}} \cdot f_c^2}{A_c \cdot E_c \cdot f_{\text{н}}^2} \qquad (5)$$

where: $\mu_{\text{н}}$ and μ_c – appropriate cable extensions $\mu = L/l$; L – design length of flexible thread; $A_{\text{н}}$ and A_c – the corresponding cross-sectional areas of the cables; $E_{\text{н}}$ and E_c – corresponding modulus of elasticity of cables; $\mu = 1 + \frac{8 \cdot f_{\text{н}}^2}{3 \cdot l^2} + \frac{tg^2\alpha}{2}$, where α – the angle of inclination to the horizontal of the line connecting the supports (fig. 5)

Table 2. Coating load.

Load	**Normative value, kPa**	**Coefficient of reliability on loading**	**Estimated value, kPa**
– own weight of a cable-stayed grid (preliminary)	0,12	1,1	0,13
– waterproofing two-layer rolled carpet of waterproofing			
– steel membrane	0,08	1,3	0,1
t = 1 mm;			
ρ = 7800 kg / m^3	0,08	1,1	0,09
– plates of a heater			
t = 120 mm,			
ρ = 0.050 kg / m^3	0,06	1,3	0,08
– false ceiling	0,25	1,2	0,3
Total:	0,59	6	0,7
Wind load	0,88	1,4	1,23
Snow load	1,0	1,4	1,4

As such, for round - in terms of cable-stayed grids from identical cables: $l_{\text{н}} = l_c$, and $E_{\text{н}} = E_c$.

Necessary cross-sections of ropes are found by the formulas:

$$A_{\text{н}} = \frac{1{,}6 \cdot T_{\text{н}}}{k_p \cdot R_{un}} \qquad A_c = \frac{1{,}6 \cdot T_c}{k_p \cdot R_{un}} \qquad (6)$$

where: R_{un} – temporary resistance of the wire to rupture.

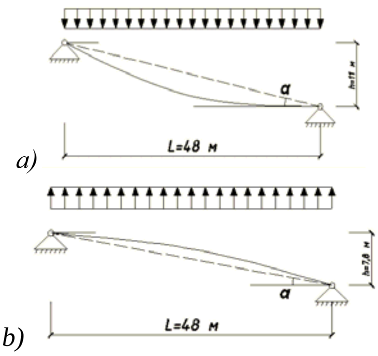


Fig. 5. Calculation schemes of cables: *a* - carrier, *b* - stabilizing.

As can be seen from the above formulas, the cross-sectional area of the ropes depends on several factors:

1. arrows sagging ropes;
2. the magnitude of the pre-stress;
3. the coefficient of interaction of groups of cables;
4. the step of the cables in the grid, which also

indirectly affects each other.

Therefore, to find the cross sections of the ropes (they should be the smallest) it is necessary to solve the optimization problem. As a target function, we use the relative volume of metal in the cables:

$$F = \sum L_н \cdot A_н + \sum L_c \cdot A_c \to \min \qquad (7)$$

where the sum of the lengths of the cables is as follows:

$$\sum L_н = \mu_н \cdot \left(2 \cdot \sum\nolimits_2^n l_{нi} + l_н\right) \qquad (8)$$

$$\sum L_c = \mu_c \cdot \left(2 \cdot \sum\nolimits_2^b l_{cj} + l_c\right) \qquad (9)$$

where: $n = R/d_н$ and $m = R/d_c$; R – coverage radius in the plan. Formulas (8) and (9) can be rewritten as:

$$\sum L_н = \mu_н \cdot \frac{S_{coating}}{d} \qquad (10)$$

$$\sum L_c = 2 \cdot \mu_c \cdot \frac{S_{coating}}{d \cdot \sqrt{2}} \qquad (11)$$

$S_{coating} = \pi \cdot 24^2 = 1809$ м^2.

Let's set the limits of variables:

1) Instead of sagging arrows, relative sagging arrows are used: $D_н = f_н/l_н$, та $D_c = f_c/l_c$. According to the recommendations [25], they vary within: $D_н = 1/15 \ldots 1/8$, $D_c = 1/25 \ldots 1/10$.

2) The magnitude of the pre-stress will be characterized by a coefficient $q_k = (q + \Delta q)/q$, which varies within 1,1…1,3.

3) The coefficient of interaction of groups of cables will depend on the coefficient $B = A_s / A_n$, which is recommended to take 0.3… 0.5 [25].

Taking into account all the formulas, certain dependencies and initial data, we finally have:

Target function:

$$F = \mu_н \cdot \frac{1809}{d} \cdot A_н + 2 \cdot \mu_c \cdot \frac{1809}{d \cdot \sqrt{2}} \cdot A_c$$

where: $A_н = T_н \cdot 11{,}8 \cdot 10^{-9}$; $A_c = T_c \cdot 11{,}8 \cdot 10^{-9}$;

$$T_н = \frac{d \cdot 6 \cdot a}{D_н} \cdot \left[0{,}13 + q + 1{,}97 \cdot \left(\frac{1}{C+1}\right)\right];$$

$$T_c = \frac{d \cdot \sqrt{2} \cdot 6 \cdot a}{D_c} \cdot \left[q - 0{,}7 + 1{,}22 \cdot \left(\frac{1}{C+1}\right)\right];$$

$$q = \frac{1{,}97 \cdot C}{C+1} \cdot k_q; \qquad C = \frac{\mu_н^2}{\mu_c^2} \cdot \frac{D_c^2}{D_н^2} \cdot B;$$

$$a_н = \sqrt{1 + 16 \cdot D_н}; \qquad a_c = \sqrt{1 + 16 \cdot D_c};$$

$$\mu_н = 1{,}053 + \frac{8 \cdot D_н}{3}; \qquad \mu_c = 1{,}026 + \frac{8 \cdot D_c}{3};$$

Limitation:

– $D_н = 1/15 \ldots 1/8$, $D_c = 1/25 \ldots 1/10$;

– $q_k = 1{,}1 \ldots 1{,}3$;

– $B = 0{,}3 \ldots 0{,}5$.

It can be seen that the target function does not depend on the pitch of the cables in the grid. Therefore, we assign it from the design requirements: the largest side of the triangular cell is taken as 3 m, hence d = 1.5 m.

There is also another requirement - the deformability of the coating which is as follows:

$$\Delta f = \frac{3}{128} \cdot \frac{\mu_н^2}{f_н^2} \cdot \frac{p \cdot l^4}{E \cdot A_н} \le \frac{l}{200} \qquad (12)$$

where: p – snow load.

The solution of the optimization problem is performed in Microsoft Excel, with the help of the "Search solution" function.

The results are presented in tables 3 and 4.

Table 3. Initial data.

Coverage radius in the plan, m	24
load:	
permanent:	0,7
– to voltage, kPa	0,13
– after stress, kPa	0,57
Temporary (snow), kPa	1,4
Wind, kPa	1,22
Temporary resistance of a wire of a rupture, GPa	1,764
Coefficient of working conditions	0,81
Modulus of elasticity of ropes, GPa	160

According to the obtained values of the cross-sectional area, we select ropes by assortment.

Thus the ropes of the bearing group – Ø33 mm with $A_н$ = 4,977 cm^2, the stabilizing group – 2 ropes Ø 12,5 mm with A_c = 1.4182 cm^2

Deformability of the coating 0,03 < 48/200 = 0.24. All conditions are met and the optimum solution is found.

To connect the cables to each other, a metal plate is used, to which the cables are fastened with a bolted connection (Fig. 6, 7). Fastening of cables in knot is compulsory.

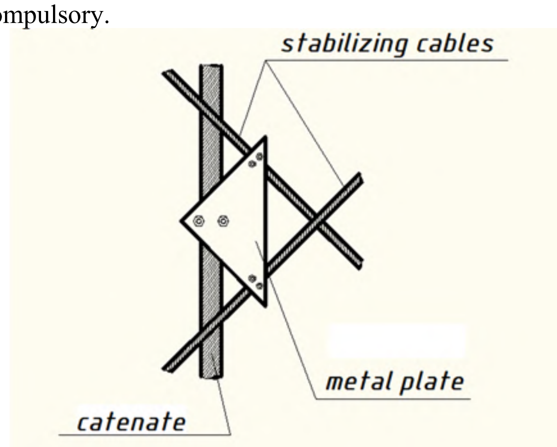


Fig. 6. Knot of fastening of cables among themselves.

Reinforced concrete support ring is designed prefabricated monolithic type. The reference circuit is partially prefabricated.

The cables are attached to the embedded parts on the side elements by means of a wedge-sleeve anchor. After adjusting the position of the cables, the contour is added to the design dimensions.

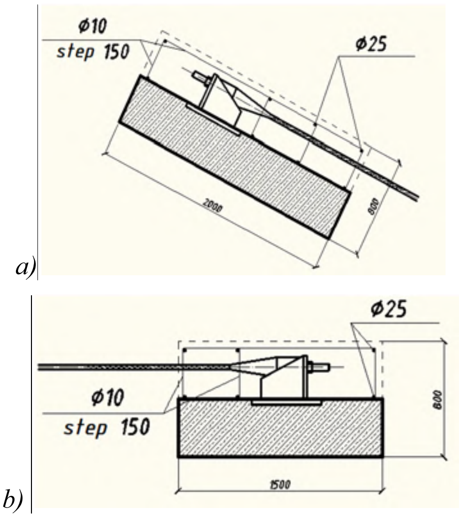


Fig. 7. Knots of adjoining of cables to a basic reinforced concrete ring: *a* – adjoining to the top onboard element, *b* – adjoining to the lower onboard element.

Table 4. The result of the optimization problem

Target function, m³ of metal		0,809	
Cross section of cables:			
– stabilizing, cm²		1,362	
– bearing, cm²		4,540	
Step of bearing cables (*d*), m		1,5	
Effort in cables:			
– bearing, kN		405,427	
– stabilizing, kN		121,663	
Variables	value		
	min	optimal	max
Relative arrows sagging guys			
– stabilizing (D_c)	0,04	0,100	0,1
– carriers ($D_н$)	0,067	0,076	0,125
Coefficient kq	1,1	1,30	1,3
Coefficient B	0,3	0,3	0,5
The value of the deformability of the coating (Δf)		0,029	0,24
Additional values			
The magnitude of the prestress, *q*		0,876	
Coefficient *C*		0,520	
Elongation of cables (μ):			
– stabilizing		1,040	
– bearing		1,042	
The coefficient α			
– bearing		1,489	
– stabilizing		1,612	

Fig. 8 shows the curves of the conditional volume of the cables for different values of the relative sagging arrows of the stabilizing and supporting cables, at different values of the coefficient q_k. The graphs show that the most economical are the options with $q_k = 1.3$ and with larger values of the sagging arrows of the supporting cables.

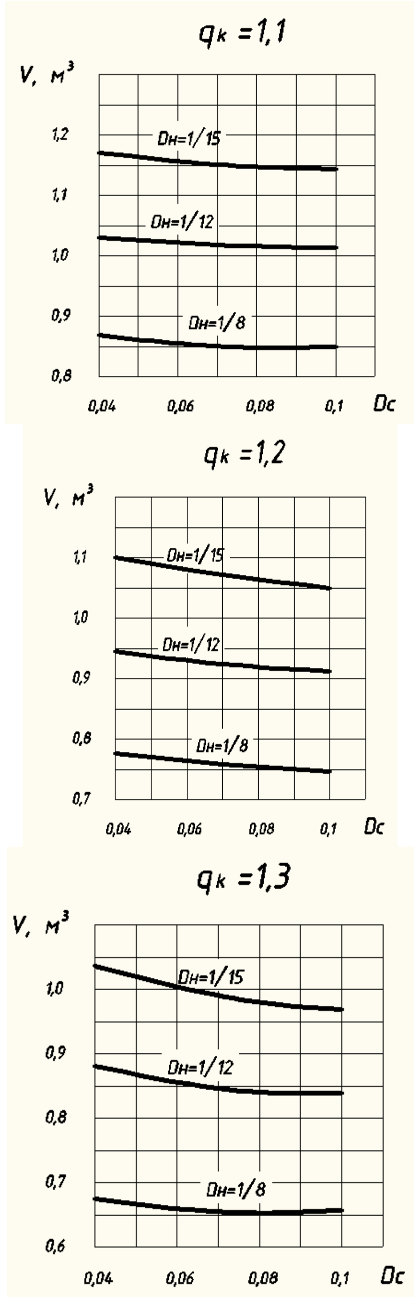


Fig. 8. Variation of the conditional volume with the relative sagging arrows, at values of the coefficient q_k.

The next step is to perform the same operation for a typical option – orthogonal mesh.

Calculations are performed according to the same formulas, but taking into account that the step in the grid is the same, that is, 2,4 m.

The load on the coating will be entered in table 5.

The solution of the optimization problem is entered in tables 6 and 7.

As can be seen from the table, this problem has no solution, as the force in the stabilizing cable is close to zero. This is due to the fact that the coating is stabilized due to its own weight, and therefore the stabilizing cables are almost not included in the functioning of the structure.

By assortment we find the necessary ropes. Ropes of the bearing group – 2Ø36 mm with $A_н$ = 11,7962 sm², stabilizing ropes are assigned the same from the design conditions.

Table 5. Load on the coating.

Load	Normative value, kPa	Coefficient of reliability on loading	Estimated value, kPa
– own weight of a cable grid (preliminary)	0,12	1,1	0,13
– waterproofing two-layer rolled carpet of waterproofing	0,08	1,3	0,1
– asphalt screed t = 15 mm; ρ = 1800 kg / m^3	0,27	1,3	0,46
– metal membrane t = 1 mm	0,08	1,1	0,09
– plates of a heater t = 60 mm, ρ = 0.050 kg / m^3	0,03	1,3	0,05
– reinforced concrete slabs t_{priv} = 53 mm ρ = 2500 kg / m^3	1,54	1,1	1,7
– filling of seams	0,2	1,1	0,7
– false ceiling	0,25	1,2	0,3
Total:	2,57	9,5	3,75
Wind load	0,88	1,4	1,23
Snow load	1,0	1,4	1,4

Table 6. Initial data.

Coverage radius in the plan, m	24
load:	
permanent:	2,96
– to voltage, kPa	0,13
– after stress, kPa	2,83
Temporary (snow), kPa	1,4
Wind, kPa	1,22
Temporary resistance of a wire of a rupture, GPa	1,764
Coefficient of working conditions	0,81
Modulus of elasticity of ropes, GPa	160

It is possible to investigate the dependence of the degree of operation of the stabilizing cables on the load on the coating. In fig. 9 and 10 show graphs illustrating this phenomenon.

The graphs show that the most effective stabilizing cable works at a load of 0.5-1.2 kPa, at a load of 2.6-3.0 kPa it becomes ineffective, and at lower values also begins to perform the functions of the supporting cable. From which it can be concluded that the most rational type of roof for saddle-shaped cable-stayed structures is a light roof.

According to the design organizations and the analysis of the indicators of the constructed buildings, the relative cost of cable coverings is:

– 56-60% of the cost of prefabricated reinforced concrete shell;

– 40-44% of the cost of coating on steel arches;

– 35-39% of the cost of the lattice steel coating.

Table 7. Solution of the optimization problem.

Target function, m^3 of metal		0,919	
Cross section of cables:			
– stabilizing, cm^2		0	
– bearing, cm^2		11,516	
Step of bearing cables (d), m		2,4	
Effort in cables:			
– bearing, kN		1028,393	
– stabilizing, kN		0	
Variables		value	
	min	optimal	min
Relative arrows sagging guys			
– stabilizing (D_c)	0,04	0,1	0,1
– carriers ($D_н$)	0,067	0,117	0,125
Coefficient k_q	1,1	1,3	1,3
Coefficient B	0,3	1,0	0,5
The value of the deformability of the coating (Δf)		0,020	0,24
Additional values			
The magnitude of the prestress, q		2,423	
Coefficient C		0,787	
Elongation of cables (μ):			
– stabilizing		1,027	
– bearing		1,062	
The coefficient α			
– bearing		1,693	
– stabilizing		1,613	

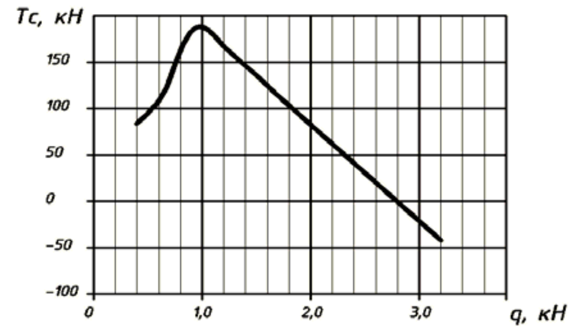


Fig. 9. The dependence of the tension of the stabilizing cable on the load on the coating

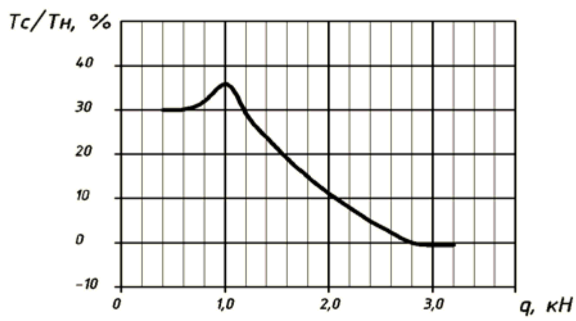


Fig. 10. Dependence of relative tension of stabilizing cables (%) on loading.

In fig. 11 shows the average relative costs of steel and concrete for different types of coatings.

Fig. 12 and 13 show the costs of steel and concrete for different roofing systems of public buildings.

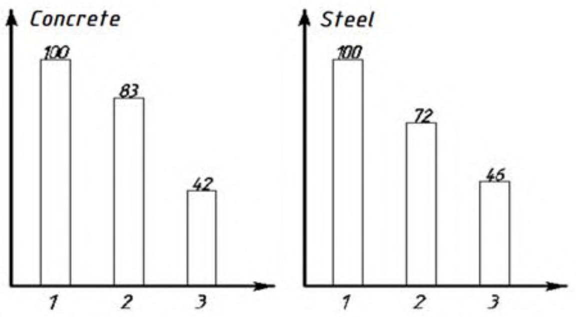


Fig. 11. Relative costs of concrete and steel for: 1 – coating of typical beam elements; 2 – covering from prefabricated reinforced concrete vaults-shells; 3 – cable-stayed cover.

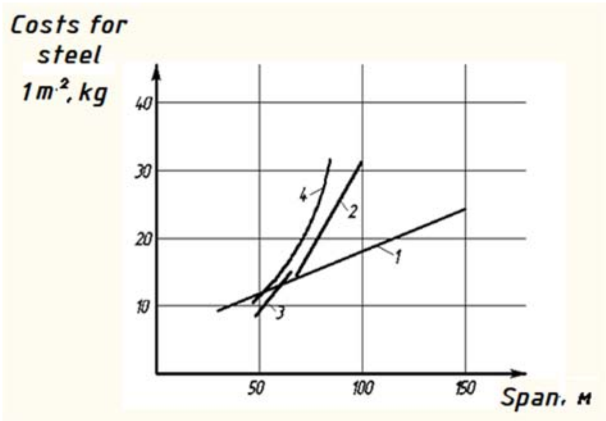


Fig. 12. Costs of steel per m^2 of coating for: 1 – cable coating; 2 – reinforced concrete shells; 3 – beam reinforced concrete structures; 4 – coating on steel trusses.

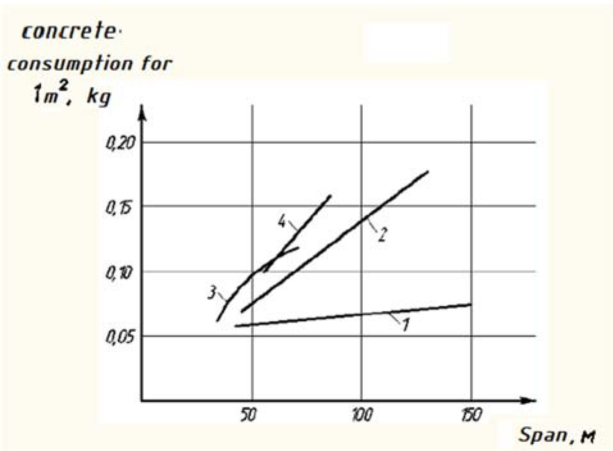


Fig. 13. The cost of concrete per m^2 of coating for: 1 – cable cover; 2 – reinforced concrete shells; 3 – beam reinforced concrete structures; 4 – coating with reinforced concrete slabs.

Finally, from the above characteristics, it can be seen that the cable cover is a more economical type of coating, especially with large spans.

5 Conclusions

Cable-stayed structures are more economical compared to other types of roofs, but their widespread use today is complicated by the lack of design and calculation standards, as well as design solutions dated 30-40 years ago.

The constructive scheme of a cable-stayed covering formed by two groups of stabilizing cables is presented and it is shown that an elementary triangular cell is formed, which allows the use of fragile roofing materials.

A new type of coating plate is proposed, consisting of triangular plates of fiberglass-reinforced insulation. This makes it possible to facilitate the design of the coating without reducing the strength characteristics.

An optimization problem was solved to design the cable-stayed cover and determine its characteristics. As a result, the optimal cross-sections of the cables were obtained. For comparison, the optimization problem for a typical coating variant was also solved.

The calculation shows the inexpediency of using a heavy roof structure for saddle-shaped cable-stayed coverings due to the exclusion from the work of stabilizing cables with a large weight of the roof.

The developed design of a cable covering is more economical in comparison with a typical design of a roof, with reduced materials and more effective performance of the elements.

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Research activation energy in thermal modification of wood

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Abstract. The analysis of the process of thermal modification of wood, which was modified by a controlled process of pyrolysis of wood heating (> 180 ° C) in the absence of oxygen, which causes some chemical changes in the chemical structures of cell wall components (lignin, cellulose and hemicellulose), durability. It is proved that in the process of thermal modification the decomposition of hemicelluloses and the amorphous part of cellulose occurs, and therefore the amount of substances that are the environment for the development of fungi in wood significantly decreases. In addition, lignin and the formed pseudolignin undergo a process of polymerization and redistribution of cell volume and give cell walls greater density, hardness, increase hydrophobicity (water repellency), thereby reducing their ability to absorb moisture and edema. Polymerized lignin fills the inner cavity of the cell, forming a closed porous structure with a low ability to bind water. It was found that the most effective parameter for reducing such substances is the temperature and exposure time. The results of thermogravimetric researches are given, the dependence of weight loss on temperature of researches on the basis of which activation energy is calculated is defined. The results of determining the activation energy show that for hardwood species this value exceeds more than 1.5 times compared to softwood.

1 Introduction

Wood, as a building material, is widely used in construction and architecture due to its mechanical and operational properties. But under the influence of atmospheric factors it is destroyed. Due to the fact that these materials are sensitive to moisture and biological damage, ie the ability to maintain functional properties under operating conditions. It is possible to increase the level of operation of facilities that use building structures made of wood. The essence of the method is to give the wood the ability to resist moisture, the spread of biodamage, which contributes to the destruction of wood and accelerate the destruction process.

Given the above, the modification of wood difficulties for the application of technological modes like time, temperature. This is primarily due to the fact that the structure and composition of wood are different and the modification process is not achieved, and the use of thermodified wood leads to its destruction [1].

Knowledge of physical and chemical properties of substances such indicators of quality, the mechanism of action of the materials allows you to make their choice on the basis of economic performance, duration and application security, environmental aspects, etc. [2, 3]. And the application allows protection to maintain their function when operating within a specified period of time [4-6].

Therefore, the development of technological modes for wood modification, research in thermophysics, the influence of structural features, this process is an unresolved component of ensuring the stability of building structures made of wood. So it is necessitate the establishment of a thermal modification mechanism for such materials.

2 Analysis of recent research and publications

In recent years towards research on thermal modification of wood known work aimed at studying the equilibrium moisture during modification, dimensional stability, durability and mechanical properties of modified wood [7]. Loss of weight, wettability, color, wood and chemical transformations subsequently been widely studied. While the necessary works that focus on quality control, modeling and study of the causes of improved properties of the modified wood.

Thermomodified wood is one of the best materials for lining [8]. In this regard measured the moisture thermally modified heat and low moisture content of thermally modified wood in comparison with the standard spruce. But it is not specified what was the degree and modes of wood modification.

Increased use of thermally modified wood [9] led to the need for reliable quality control, including control of products deviations within certain limits, allowing you to control third party in the event of certification and regulation of the complaints and demands of consumers. However, it is not specified what methods are needed to

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characterize the change in quality in terms of improved target properties of modified wood during industrial production.

A study of changes in swelling and surface roughness of wood alder and elm normal after heat treatment at two different temperatures and duration [10]. Established that the parameters of swelling and surface roughness vary considerably for the two two-temperature heat treatment durations. The value of swelling and surface roughness decreased with increasing treatment temperature and time of treatment, but these technological parameters.

The characteristics of wood due to weather conditions change over time, especially the color, which reflects chemical changes [11]. An assessment of the change in color and reflectivity of wooden surfaces due to artificial weathering, obtained using a solar box chamber that simulates external conditions and subsequent leaching of water. As the weathering time increases, the untreated surfaces of the wood samples darken. While the modified samples lighten to have a similar color or, in any case, to reduce the chromatic difference that was at the beginning of the weathering tests.

During the heat treatment is many chemical reactions that lead to changes in the components of the primary cell walls of wood and darkening material. Among other changes, thermodified wood is more resistant to fungal decay and more stable at times than untreated. This make it suitable for use indoors and outdoors as cladding, flooring, floors, garden furniture and window frames [12].

Laboratory tests have shown the positive impact of thermal modification durability, dimensional stability and thermal conductivity of wood [13]. The monitoring results showed that the elements and windows of thermally modified spruce have a significantly lower moisture content in the wood compared to the windows of unmodified, and that the wax also has a positive effect on humidity.

Natural aging is usually a relatively slow process because the artificial aging plays a role important in assessing the results by reducing the time compared to the natural weathering conditions. The approach is to protect the surface with various types of commercial products such as water-based solvents with a high solids content, powder coatings and substance-free products [14].

One approach is the modification of wood, a set of processes that provide the treated material over the ability to cope with the damage caused by the environment, by increasing the duration of treatment. The process is also performed to enhance the physical, mechanical or aesthetic properties of wood and derived products with the advantage that is not harmful to users and the environment, as well as natural wood [15].

Several authors reported an increased resistance to decay for different wood species and several types of rots. The important degradation of hemicelluloses due to thermal treatment, which are generally considered as an important nutritive source as well as a prime key in the hygroscopic wood behavior for the development of wood rotting fungi. Modification of lignin network are also be involved to explain the ineffectiveness of fungal enzymatic attacks. These heat treated wood modifications are represented by mass loss (ML). Various authors compared the weight loss (WL) caused by fungal attack to the decrease in mass of wood by heat treatment (ML).

Wood heating will lead to different processes that always depend on the heating mode used. It is recognized that hemicelluloses are degraded to a greater extent than other macromolecular components, but the relative stability of cellulose and lignin is much more difficult to determine. As is not the case above, when the wood is heated, heat-labile wood polymeric components (hemicelluloses) begin to decompose, resulting in the production of methanol, acid, and various volatile heterocyclic compounds (furans, etc.). In general, the loss of polysaccharide material becomes particularly important at temperatures above 180 °C, which largely depends on the processing conditions. However, changes in the degree of polymerization may appear at lower temperatures (above approx. 150 °C), depending on the heat treatment conditions. The total polyoses (hemicelluloses) containing a large proportion of xylan are oxidized more slowly and consume less oxygen than pure xylan. According to some studies, the decomposition of hardwood xylan begins at a temperature close to 200 °C in a normal atmosphere. Even though lignin is considered to be the thermally most stable component of wood, various changes have been observed even at temperatures below 200 °C. Assessment of lignin content in thermally treated woods indicated the increase of non-hydrolyzable residue with increasing temperature up to 200 °C [16].

There are a number of thermal modification methods that can be applied to wood, and the exact method of treatment can have a significant effect on the properties of the thermally modified wood. Major process variables are the following: time and temperature of treatment, treatment atmosphere, pressure, closed vs. open systems, wood species, wet and dry systems, sample dimensions, and use of catalysts. Also, under certain conditions, changes in wood can be observed even at 100 °C [17].

Thermally modified wood has been produced for more than 20 years, mostly in Finland and other countries of Western Europe. It is made of non-durable and less-durable wood species, such as beech, birch, pine, and spruce, etc. ThermoWood® is produced by a heat treatment process in the presence of steam and is therefore typical hygrothermal treatment. The steam acts as a blanket to reduce the oxidative degradation of wood and there are also further reactions that occur due to the presence of moisture. Because of the presence of steam, the air content in the kiln is limited from 3 to 5% during the heat treatment process [18].

Thus, from the literature it is established that thermal modification of wood is able to withstand destruction. All this gives grounds to assert that it is expedient to conduct a study to determine the parameters that provide resistance to destruction, as well as influencing the mechanism of action in the protection of wood. Therefore, thermal analysis of wood, the influence of temperature and time on this process is an unresolved component of ensuring the stability of building structures made of wood, which necessitated research in this area.

The purpose of this work is to study the activation energy of decomposition of wood and installation efficiency at thermal modification.

3 Raw materials and methods

To establish the mechanism of thermal modification of wood chips used samples of the wood as hornbeam, ash, pine. The weight of the sample was 190 mg.

Thermogravimetric study of thermal degradation processes in dynamic mode using derivatograph Q-1500 D, heating rate – 2.5 degrees per minute, a sample comparison - powder α-corundum material crucibles - alund sensitivity galvanometers, DTA – 250 mkV, DTG – 500 mkV.

4 Results and discussion

Direct data on the processes occurring in the samples of materials during their heating in the dynamic mode were obtained as a result of thermogravimetric studies. The results of the analysis of the studied materials are illustrated (Fig. 1, Table 1).

In the studied wood sample at temperatures from 75 to 100 ºC, endothermic processes take place, which are accompanied by a loss of up to 6% of their mass. Such processes are caused by the evaporation of chemically unbound water without destruction of the sample material. In addition, organic matter loses constitutional water (endoeffect with a maximum of 150 °C with additional weight loss). In the temperature range 180-250 ºC, the temperature range often used for heat treatment, wood undergoes important chemical transformation. And at temperatures above 250 ºC begins carbonization processes with the formation of CO^2 and other pyrolysis products [19, 20].

Hemicelluloses are the first structural compounds to undergo thermal action, even at low temperatures (about 140 °C). It should be noted that the basis of nutrition of biological pests of wood is hemicellulose and the amorphous part of cellulose, and the defeat of wood by different types of fungi and mold is possible only at high humidity. Because hemicelluloses are hygroscopic and intensively absorb and bind moisture, hemicelluloses create favorable conditions for the development of fungi and mold on wood. The decomposition of hemicellulose begins with deacetylation, and acetic acid is released, which acts as a catalyst for depolymerization, which further increases the decomposition of the polysaccharide. In addition, lignin and the formed pseudolignin undergo repolymerization and redistribution in cell volume. They give the cell walls greater density, hardness, increase hydrophobicity (water repellency), thereby reducing their ability to absorb moisture and swell. Repolymerized lignin fills the inner cavity of the cell - forming a closed-porous structure with a low ability to bind water. For Scots pine, which is treated at temperatures from 205 °C to 230 °C for 4-8 hours, the lignin content increases from 24.5% to 38.7%, respectively, and the hemicellulose content decreases [21].

The temperature at which the intensive destruction of wood begins, ie there is a rapid loss of mass of the samples, is 215-250 °C. In particular, exothermic oxidation processes take place in a wood sample along with endothermic pyrolysis processes (cleavage of volatile products) even at relatively low temperatures. The main increase in weight loss in the temperature range of 180-220ºC occurred due to the extractives of water and ethanol as a result of polysaccharide degradation. During heat treatment, the formation of liquid and gaseous phases in addition to solid wood. The liquid phase at temperatures of 200-250 °C is almost exclusively water and acetic acid with small amounts of formic acid, furfural and methanol [22]. Acids catalyze the decomposition of polysaccharides and reduce their content (Table 1).

Thus, the thermogravimetric parameters enable to determine the rate of thermal decomposition of the material at a given temperature and therefore show a qualitative assessment of the effects of heat, but more important task is to determine the activation energy thermooxidative degradation.

Table 1. The results of research on wood samples.

Pine wood						
Mass loss (%) for temperatures						
76°C	140°C	150°C	160°C	190°C	200°C	220ºC
1,5	2,1	3,2	4,1	5,3	6,0	6,5
Hornbeam wood						
Mass loss (%) for temperatures						
76°C	140°C	150°C	160°C	190°C	200°C	220ºC
1,2	1,3	2,6	3,7	4,4	5,8	6,2
Ash wood						
Mass loss (%) for temperatures						
76°C	140°C	150°C	160°C	190°C	200°C	220ºC
1,3	1,4	2,8	4,2	4,9	6,1	6,4

Calculation of kinetic parameters TG curve, which satisfactorily describes the kinetics of decomposition of solids based on the equation [22-23]:

$$-\frac{\mathrm{dm}}{\mathrm{dt}} = \mathrm{k} \cdot \mathrm{m}^{\mathrm{n}}, \qquad (1)$$

where is the

m – the mass of the sample that entered the decomposition reaction, mg;

n – reaction order;

k – specific reaction rate of decomposition of the material.

The dependence of the specific decomposition rate of the material on temperature is described by the Arrhenius equation:

$$\mathrm{k} = \mathrm{A} \cdot e(-\mathrm{E}/\mathrm{RT}), \qquad (2)$$

where is the

A – preexponential multiplier;

e – activation energy, kJ / mol;

R – universal gas rack, 8,314 kJ / (mol·K).

For separate stages of destruction, a possible method of calculating the activation energy is the method described in [23], which shows that the parameter E, under other equivalent conditions, is a measure of resistance to thermal oxidative destruction of the material.

The following decomposition scheme is typical for wood:

$$A_{(\text{тв})} \rightarrow B_{(\text{тв})} + C_{(\text{газ})} \qquad (3)$$

and determining the speed of decomposition reaction enables the equation:

$$-\frac{dm}{dT} = \frac{A}{V_{\text{нагр}}} \cdot e^{-E/RT} \cdot m^{n}. \qquad (4)$$

The calculation of E and n is based on the mathematical processing of the TG curve using the dependence [15]:

$$\ln\left(\ln\frac{100}{100-\Delta m}\right) = -\frac{E}{R}\cdot\frac{1}{T}. \qquad (5)$$

In this equation Δm – mass loss (%) at each temperature in the range of decomposition of the material, which is the process of the first order (n = 1) and provided depending linearization:

$$\ln\left(\ln\frac{100}{100-\Delta m}\right) = \ln\left(\ln 1\,00/(100-\Delta m)\right) \qquad (6)$$

from temperature T, K.

In Fig. 1 shows a graphical dependence of the rate of destruction of wood on the inverse temperature. The value of the activation energy (E) is calculated depending on:

$$E = \text{tg}\phi \cdot R \qquad (7)$$

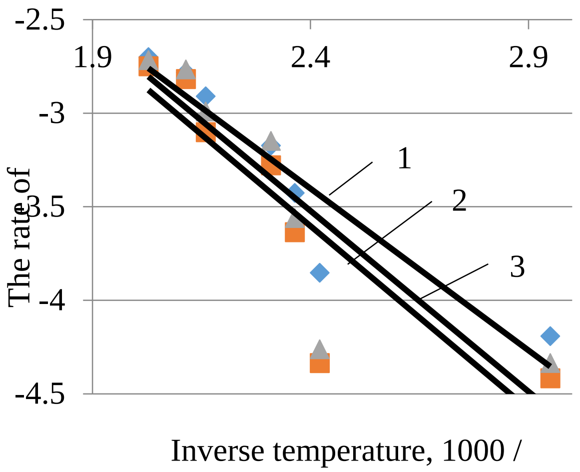

Fig. 1. Graphic dependence of the rate of thermal destruction of wood on the inverse temperature: 1 – pine; 2 – hornbeam; 3 – ash.

Table 2 shows the results of thermal analysis and calculation of the parameters required to determine the activation energy of the treated wood.

As can be seen from Table 3, pyrolysis of hardwood requires more activation energy, and therefore requires costs in its thermal modification, namely time and temperature.

One of most interesting property of heat-treated wood remains its decay resistance. Durability test with modified wood in laboratory are expensive and time-consuming. This review displays data from different analytical methods, such as spectroscopy, thermogravimetry, chemical analyses or mechanical tests that have the potential to be valuable indicators to assess the durability of heat treated wood at industrial scale. However, each method has its limits and drawbacks, such as the required investment for the equipment, reliability and accuracy of the results and ease of use at industrial scale.

Table 2. The results of thermal analysis.

t, K	Δm, %	Ln(Ln(100/100-Δm))
Pine wood		
339	1,5	0,878774
413	2,1	0,834032
423	3,2	0,475885
433	4,1	0,103154
463	5,3	-0,25292
473	6,0	-0,87824
493	6,5	-1,35181
Hornbeam wood		
339	1,2	0,744
413	1,3	-0,066
423	2,6	-0,26
433	3,7	-0,83
463	4,4	-1,04
473	5,8	-1,43
493	6,2	
Ash wood		
339	1,3	0,86
413	1,4	0,44
423	2,8	-0,02
433	4,2	-0,27
463	4,9	-0,59
473	6,1	-0,80
493	6,4	

Table 3 shows the values of activation energy during thermal decomposition of wood.

Table 3. The calculated value of the activation energy during thermal decomposition of wood.

Number in order	Wood	Activation energy, E, kJ / mol
1	Pine	13,47
2	Hornbeam	23,28
3	Ash	19,95

There is a partial increase in the values of most properties at a lower treatment temperature, eventually leading to the preservation of values at the level of untreated wood. Thus, for birch, the modulus of rupture increased by 26%, the modulus of elasticity by 24%, and the hardness in the radial plane by 34%. This is related to the fact that chemical changes are not yet significant, and they only case the restriction of the wood's ability to absorb bound water.

With higher treatment temperatures, there is a decrease in the elastic and especially the strength properties of the heat-treated wood. At higher treatment temperatures, more markedly right above 200 °C, the significant reduction of equilibrium moisture has no such effect as the consequence of more significant changes in the chemical structure of wood and the decrease in properties is significant.

Apparently, wood with a higher hemicellulose content, i.e., a lower overall resistance, exhibits a lower density, static bending strength, and toughness. Therefore, a more significant decrease was observed for the beech and birch woods than for the softwoods at higher treatment temperatures. The decrease of toughness by about 81% for beech wood with treated temperatures of 210 °C was observed in comparison to untreated wood (respectively 86% at birch). Static bending strength at heat treated birch wood decreased by 47% (respectively 59% at beech) [25-27].

The higher strength resistance (respectively mainly hardness) of birch wood compared to beech in relation to heat treatment has been demonstrated, which is probably due to the higher content of mannan fractions of hemicelluloses) [28-30].

The existing correlation between static and dynamic modules of elasticity was confirmed, but it was not statistically significant in all cases.

Our research confirmed that although untreated birch wood is not equal to beech wood from the view of wood properties, the heat treatment provides wood of similar properties. The impact of the heat treatment on the wood properties is less pronounced in the case of birch than beech, and the birch is thus more suitable for thermal modification. This simple and environmentally friendly method provides one of the ways to increase the utilization of birch wood in the industry for more valuable products than fuelwood.

Thermal modification of wood is an environment-friendly alternative method for improving several properties of wood without the use of chemicals. This paper deals with the examination of color and chemical changes in spruce (Picea abies L.) and oak wood (Quercus robur F.) that occur due to thermal treatment. The thermal modification was performed at 160 °C, 180 °C and 210 °C according to thermowood process. The color changes were measured by the spectrophotometer and described in the L*a*b* color system. Chemical changes were examined by wet chemistry methods, infrared spectroscopy and liquid chromatography. During the experiment, oak samples showed smaller color changes than spruce samples at all temperature values. During thermal modification, the content of cellulose, lignin and extractives increases, however the hemicelluloses content drops by 58.85% (oak) and by 37.40% (spruce). In addition to deacetylation, new carbonyl and carboxyl groups are formed as a result of oxidation. Bonds in lignin (mainly β-O-4) and methoxyl groups are cleaved, and lignin is condensed at higher temperatures.

Conclusion

Thus, the calculation revealed that the thermal decomposition of pine wood requires much less activation energy than the decomposition of hornbeam and ash wood.

The research results will also further signifies our strong resolve problems concerning the development of new means and methods of obtaining organic materials and operating conditions at different sites.

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Ways to increase the production efficiency of hardwood blanks

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Abstract. The article presents the main results of experimental studies on the identification of the main grade defects of oak lumber by the thermal non-destructive testing method. Regressional dependences of wood defects temperature display from the main factors for the studied grade defects are proposed. Indicators of infrared radiation (temperature range) of the main visible oak grade defects obtained as a result of experimental studies are presented. A conceptual scheme for the line control methods of identification of the main grade defects in lumber are proposed.

1 Introduction

Production of high-quality materials, determination of their properties today special attention is paid [1-6]. The full technological cycle is characteristic feature of the production of hardwood timber blanks in Ukraine – from round timber to finished intermediate products of final moisture content, since the manufacturing of such products from industrial wood is low cost-effective. In addition, in view of the very different size and quality characteristics of raw materials and the chaotic discrete location of wood defects in industrial wood, the technological process of cutting boards into blanks is characterized by considerable labor and material consumption, in which wood losses can reach 40 %.

The search of ways to increase the production efficiency of round oak timber blanks is a rather labor – demanding process and has traditionally been considered as two directions – cutting logs into industrial wood, and obtaining blanks from boards. The problem in the technology of the billets production at the stage of cutting freshly industrial wood is the significant complicacy in predicting the useful and high-quality billets without the use of effective non-destructive methods of assessment of the size and quality parameters of boards.

Modern scientific and technological achievements in the field of electronics and computer technology have led to a decisive revolution in the field of technological processes automation of sawmilling and woodworking in general. One of such scientific and technical solutions is the assessment of forest quality and sawn products by non-destructive testing methods (NDTM) before cutting them [7].

It is now possible to obtain this or that information about wood, to reveal surface or internal defects (knots, cracks, rot, various kinds of stains) using such NDTM as: optical scanning; laser scanning; ultrasound scanning; X-ray; ST scan; microwave scan; infrared scanning etc. It is known that the most effective NDTM for assessing the quality of lumber are: acoustic, radiation and thermal scanning methods [8]. Moreover, the acoustic and radiation methods are based on measuring the wood density, which allows us to assess the real shape, as well as the existing surface and internal defects of industrial wood without destroying the wood. However, they have a common drawback – high cost and, in most cases, are used to assess the quality of dry industrial wood [9-12].

Therefore, in order to reduce the cost of the process of non-destructive quality control of industrial wood, in this report we consider the hypothesis of possibility of using thermal NDTM to reveal and identify wood defects in industrial wood of oak of initial moisture content, based on statements regarding the different structure, heat capacity and humidity of defect-free wood and wood with defects [13, 14]. Profile densities of two types of imported solid wood flooring from lumber were quickly detected by their physical properties and basic chemical compositions using fast detection technology, X-ray scanning method and infrared spectrum with Fourier transform [15].

Scanning logs in industrial computed tomography provides detailed information about the quality of wood before sawing [16-18]. And near-infrared spectroscopy in combination with multidimensional statistical modeling can be a suitable forecasting model for determining the manufacturing quality [19].

An approach to computerized classification is proposed, which uses a hybrid approach using predicted profit-making capacity from slice-modeling and neural-network methods for increasing both accuracy and high processing speed [20]. Non-destructive logs scanning using georadar to detect defects in logs before sawing can

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significantly increase the productivity and output of high-quality defect-free industrial wood due to the optimal orientation of the saw blade and prevent damage of the saw blade from incised metals [21].

Numerous energy crop species and various processing methods provide thousands of biomass samples that need quick, low-cost analysis. Infrared methodology can provide high-throughput analysis of cellulosic biomass. The conventional method for biomass analysis is time-consuming, labor-intensive and unable to provide structural information. Use of infrared spectroscopy allows qualitative and quantitative analysis of biomass samples without destruction of samples, which is beneficial for in situ or in-field measurement. Chemometric analysis is able to make calibration models robust and reliable. The progress of infrared techniques and their applications in biomass study is introduced. A comparison of infrared methods and the conventional method is also summarized. We also review recent infrared applications in biomass analysis and discuss the prospects for applications of infrared techniques [22-24].

Raman spectroscopy is a technique that can detect and characterize a range of molecular compounds such as water, water ice, water-bearing minerals, and organics of particular interest to planetary science. The detection and characterization of these molecular compounds, which are indications of habitability on planetary bodies, have become an important goal for planetary exploration missions spanning the solar system. Using a compact portable remote Raman system consisting of a 532 nm neodymium-doped yttrium aluminum garnet (Nd:YAG) pulsed laser, a 3-in (7.62 cm) diameter mirror lens and a compact spectrograph with a miniature intensified charge coupled device (mini-ICCD), we were able to detect water (H_2O), water ice (H_2O-ice), CO_2-ice, hydrous minerals, organics, nitrates, and an amino acid from a remote distance of 122 m in natural lighting conditions. To the best of our knowledge, this is the longest remote Raman detection using a compact system. The development of this uniquely compact portable remote Raman system is applicable to a range of solar system exploration missions including stationary landers for ocean worlds and lunar exploration, as they provide unambiguous detection of compounds indicative of life as well as resources necessary for further human exploration [25-29].

Recently usage of timber in various industries is impossible without knowledge of its structure and physical and mechanical properties. It is therefore important to investigate the hardwood timber structural features and set the main parameters that characterize its quality and strength. The use of special non-destructive methods for assessing the lumber quality (ultrasonic, optical, laser scanning) allows measuring the real shape, presence of the surface and internal defects without timber destruction. Information obtained by dimensional and qualitative characteristics is considered when the introduction of CAD for optimal cutting. Comparing the results of the plate lumber cutting without the use of optimized systems and with cutting optimization (CAD), it can be seen that the output is useful when cutting plate materials without the use of CAD is 85 % and the plate lumber yield with the use of CAD is 90-95 %. Results of work pieces yield using lumber scanning showed that yield when cutting increases up to 10 %, confirming the rational choice of method for assessing the lumber quality [30].

Thus, the research on revealing and identification of the main wood grade defects is trending.

The purpose of this work of the study was the research on revealing and identification by the thermal NDTM of the main grade defects of wood in initial humidity of industrial oak wood.

2 Raw materials and methods

Industrial oak wood was used for research.

A control scheme has also been developed to identify the main grade defects of wood in freshly sawn industrial oak wood, shown in Fig. 1.

The control circuit provides the use of photo filters (RGB) for capturing the certain infrared radiation wavelength of the industrial wood defects after being blown with hot air.

Analysis of functional dependencies of industrial oak wood stimulation.

It is known that various types of lamps, heat guns and lasers can be the methods of thermal stimulation of the studied material. A general comparison criterion for various thermal control procedures is the signal-to-noise ratio, which can be determined by the formula [31]:

$$S = \frac{\overline{T}_d - \overline{T}_{nd}}{\sigma_{nd}}, \tag{1}$$

where is the

$\overline{T}_d$ – average temperature of the defective zone, °C;

$\overline{T}_{nd}$ – average temperature of the defect-free zone, °C;

σ_{nd} – standard deviation of the defect-free region (noise variance), which is determined by the equation:

$$\sigma_{nd} = \sqrt{\sum_{i=1}^{n} \frac{(T_{ndi} - \overline{T}_{nd})^2}{n-1}}. \tag{2}$$

It was established that internal defects can be detected provided that upon observation the signal caused by them exceeds the noise level:

$$S > 1. \tag{3}$$

It is known that internal defects of the material can be detected by the thermal method if a combination of the following conditions is fulfilled:

$$\Delta T(\tau_m) > \Delta T_{res}, \tag{4}$$

$$C(\tau_m) > C_{noise}, \tag{5}$$

$$T_{abs}(\tau = \tau_h) < T_{destr}, \tag{6}$$

Conditions (4-6) are based on the parameters: equipment (devices), ΔT_{res}; products, C_{noise}; heating, T_{abs}; defects, ΔT or C.

Thus, in order to establish the most effective method of industrial wood thermal stimulation of oak wood initial moisture, we determined the signal-to-noise ratio criterion, S, using equations (1-2) and verified the fulfillment of conditions (3-6), for which a number of experimental studies were performed. For the experiment, uncut industrial wood from oak timber was selected in an amount of 720 pieces with an average initial moisture content (40…50%), an actual thickness of 30 mm and a length of 1.7 m.

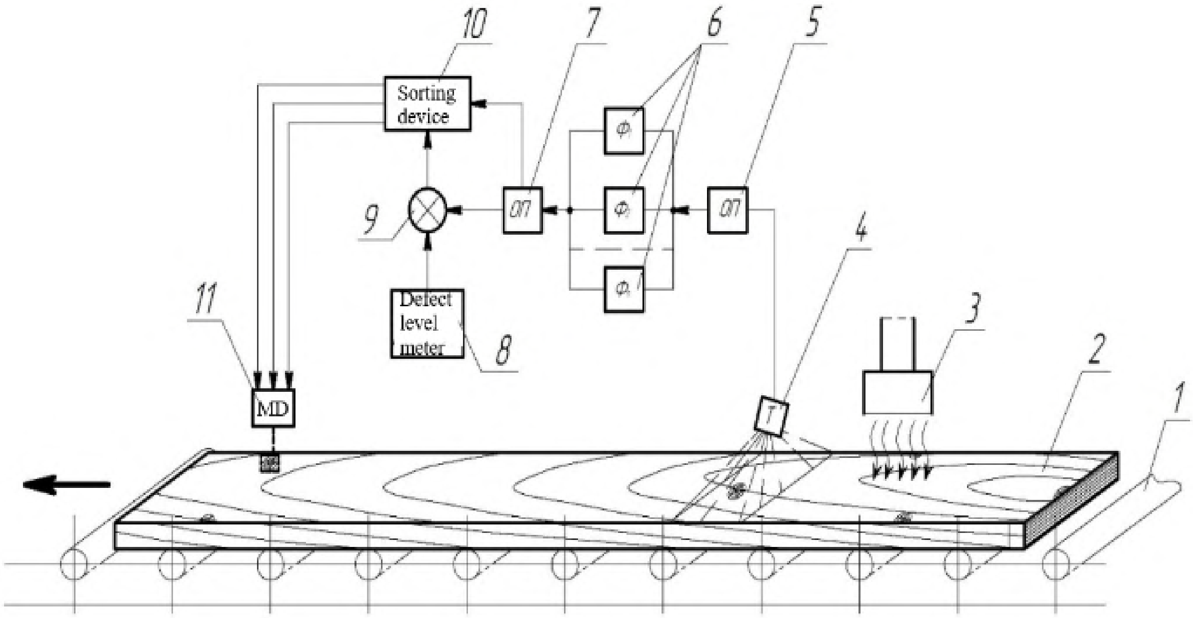


Fig. 1. Schematic diagram of the control method for identifying the main grade defects of wood in industrial wood: 1 – roller conveyor; 2 – industrial wood; 3 – installation of warm air supply; 4 – photo-video thermal imager; 5 – computing device; 6 – photo filters; 7 – computing device; 8 – defect level meter; 9 – adder; 10 – sorting device; 11 – marking device.

3 Results and discussion

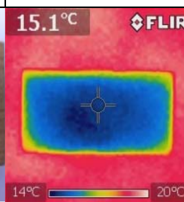
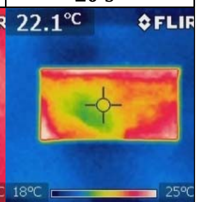
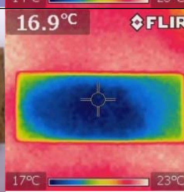
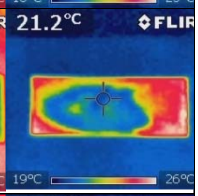
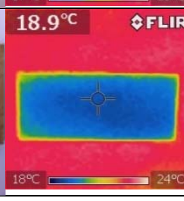
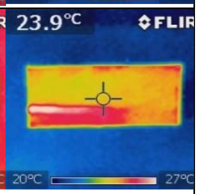
To determine the most practical and inexpensive method of thermal stimulation, an experiment was conducted in which the studied industrial wood samples were heated by two methods – incandescent lamps and a heat gun (industrial hair dryer). Laser heating was not foreseen in the experiment, due to its high cost, large dimensions and low efficiency. Thermal imaging of samples heated with a heat gun for 20 s is presented in Table 1. Image of the thermal radiation of the sample after cooling for 60-180 s is presented in Table 2.

Thus, the most effective method of thermal stimulation for performing a series of experimental studies on the identification of the main wood grade defects in industrial oak wood is the method using a heat gun (S=2.6). In the process of research work in using thermal NDTM to identify grade wood defects in oak of initial moisture content, the following indicators of infrared radiation defects were obtained: knots – t = 16…24 °C, rot – t = 22…27 °C, cracks – t = 24…31 °C.

When heating industrial wood, there is a clear difference between the thermal radiation of defect-free wood and areas with violations, which can be explained by the following reasons: different heat capacity of wood and fixed defects; different humidity of individual sections of lumber; heterogeneity of the structure of wood, affects its emissivity.

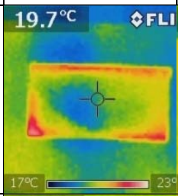
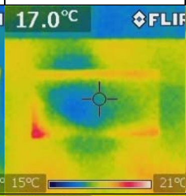
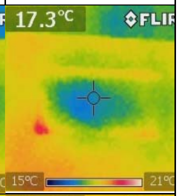
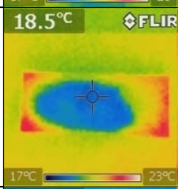
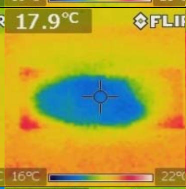
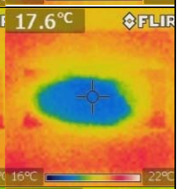
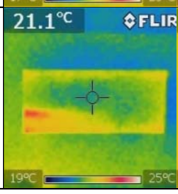
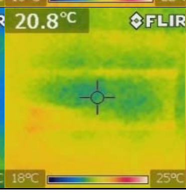
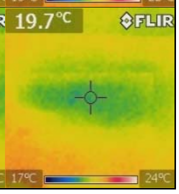
The radiation temperature range of the main variety-forming wood defects at the corresponding blowing temperature (air) and blowing time is shown in Fig. 2.

Table 1. Part of the data set of experimental studies of the parameters for assessing the quality of oak lumber after heating.

Number in order	Digital image sample	Image of the thermal radiation of the sample before the experiment	Image of the thermal radiation of the sample after heating through 20 s
1			
2			
3			

As a result of experimental studies, overlapping of the infrared reflection temperature ranges of the studied wood defects was noted (Fig. 3); therefore, to clearly capture a certain wavelength range of infrared (thermal) radiation from lumber defects, it is proposed to use RGB filters for a certain radiation wavelength spectrum.

Table 2. Part of the data set of experimental studies of the parameters for assessing the quality of oak lumber after cooling.

Number in order	Image of the thermal radiation of the sample after cooling for:		
	60 s	120 s	180 s
1			
2			
3			

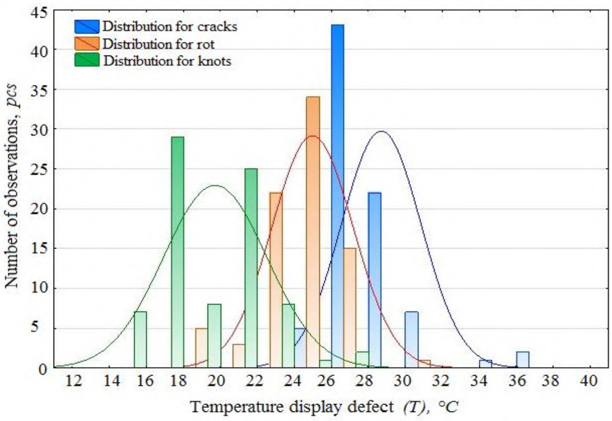


Fig. 2. Temperature range for displaying grade defects of wood when blown with air at 80 °C.

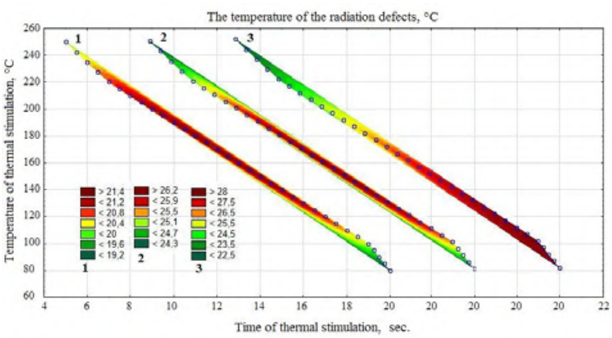


Fig. 3. The temperature distribution ranges of the display of the main variety-forming wood defects in oak lumber at a temperature of thermal stimulation: 1 – knots; 2 – rot; 3 – cracks.

Based on the research results, we obtained the regression dependences of the defects display temperatures on the main factors presented in normalized values for each of the variety-forming defects:

– knots: $y_k = 22{,}23 - 3{,}38x_1 + 2{,}98x_2 - 2{,}13x_1x_2$, $(F_{calc.} = 0{,}10; F_{tabl.} = 1{,}3)$, (7)

– rots: $y_r = 26{,}85 - 4{,}25x_1 + 4{,}40x_2 - 2{,}10x_1x_2$, $(F_{calc.} = 0{,}11; F_{tabl.} = 1{,}3)$, (8)

– cracks: $y_c = 26{,}75 - 2{,}75x_1 + 5{,}85x_2 - 1{,}25x_1x_2$, $(F_{calc.} = 0{,}16; F_{tabl.} = 1{,}3)$, (9)

where is the

x_1 – temperature of thermal stimulation of industrial wood by air, °C; x_2 – duration of thermal stimulation of lumber, s.

To select operational parameters of the identification process for each of the studied oak wood defects in freshly sawn timber, the scale is proposed to determine the time of thermal stimulation (τ, s) and the temperature of the wood defects display (t, °C) depending on the temperature of thermal stimulation (T, °C) (Fig. 4).

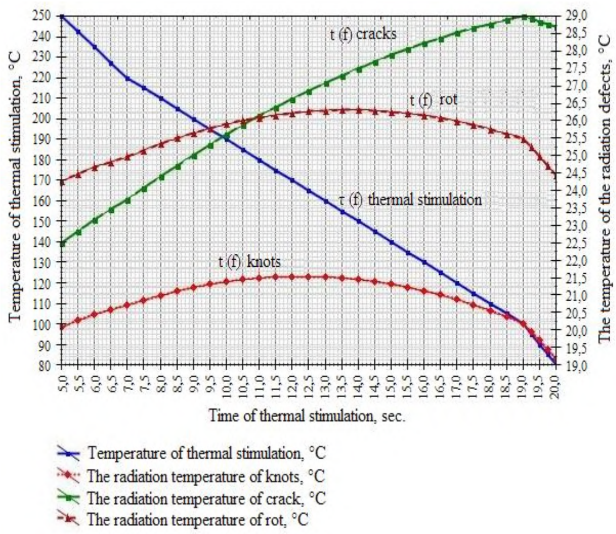


Fig. 4. The scale for determining the time of thermal stimulation (τ, s) and the radiation temperature of wood defects (t, °C) depending on the change in the temperature parameter of thermal stimulation (T, °C).

The duration of the photothermal imaging process for assessing the size and quality characteristics of industrial oak wood of initial moisture per running meter was established, which is in the range from 19 to 64 s with a fixing interval of 2 s, provided that the width of the board is not more than 350 mm and the scale factor is (K_m) – 6 (Fig. 5).

To carry out the research on the identification of oak wood defects in lumber of initial moisture content, a method and line were developed and proposed (Fig. 6) for the thermal non-destructive detection of defects, which are based on the use of photo-video thermal imaging of material surfaces and a hot air blowing lumber installation.

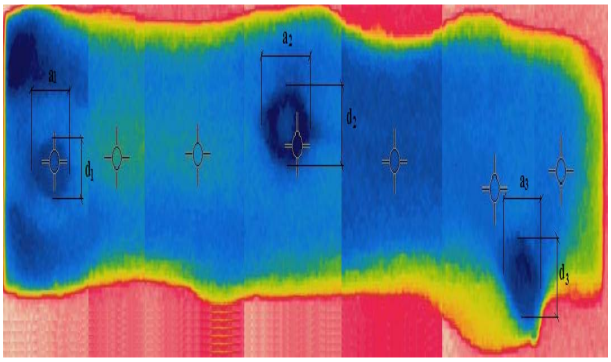
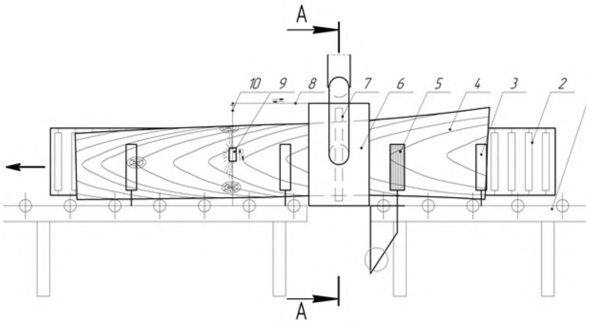
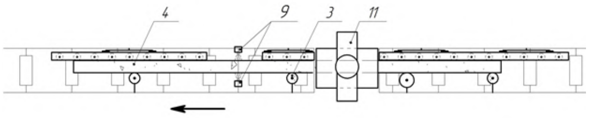


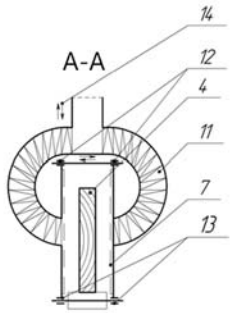
Fig. 5. An experimental study of the assessment of the quality of industrial oak wood using a thermal non-destructive testing method.



a



b



c

Fig. 6. The line of thermal non-destructive identification of variety-forming defects of lumber: a – frontal projection; b – horizontal projection; c – section AA frontal projection.

The line for thermal non-destructive detection of grade defects of industrial wood has: a roller conveyor 1, a support roller conveyor 2, pinch rollers 3, a drive pinch roller 5, an installation of blowing lumber 4 with hot air 6, a nozzle for the direction of air movement 7, horizontal guides 8 of the mechanism for regulating the photo and video heater 9 relative to the installation 6, the guides 10 of the mechanism for adjusting the distance of the video and thermal imager 9 in height and width of lumber 4, corrugated pipe d 11 blowing agent supply timber (hot air), the upper guide 12 and lower guide 13 for adjusting the mounting mechanism 6 in the thickness range of timber, the guide mechanism 14 for adjusting the distance setting adjustment timber 6.Based on the results of the studies, in order to increase the efficiency of the use of wood raw materials, recommendations were developed for manufacturers of oak billets.

4 Conclusion

The results of experimental studies have confirmed the practicability of using the thermal control method to identify the main grade wood defects in oak timber by thermal imaging using heat stimulation by guns, the effectiveness of which is established by the signal-to-noise (S) criterion.

Regression dependences of the temperature of infrared radiation of grade defects of wood on the temperature and time of thermal stimulation of the board have been obtained, on the basis of which the scale for predicting the temperature of defect radiation has been developed, which allows to control the process of grade defect`s identification.

The practical implementation of the research results is presented by the developed method and the line for the thermal non-destructive identification of grade wood defects in industrial wood, for which the control identification defects method have been developed and proposed.

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Increasing the production of gas condensate by using ammonium carbonate salts

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Abstract. The work is devoted to the problem of increasing gas condensate production in gas condensate fields. It was found that ammonium carbonate salts, in the absence of calcium chloride type waters, interact with carbonate rocks, increase the permeability of reservoirs. Solutions of ammonium carbonate salts when interacting with formation water of the calcium chloride type form chemically precipitated chalk in the pore space, while the permeability of carbonate rocks decreases. A set of experimental studies was carried out to study the displacing and washing properties of ammonium carbonate salts. It was found that ammonium carbonate salts have high displacing properties, the displacement ratio of kerosene by NH_4HCO_3 solution is 0.75-0.80, while reservoir water – 0.55-0.58. According to the results of laboratory studies of the displacing and washing characteristics of ammonium carbonate salts, conclusions were made about the effect of bicarbonate solution (ammonium carbonate salts) on the production characteristics of a well in reservoir conditions at temperatures of 80-100 °C and above. Industrial tests of ammonium carbonate salts showed an increase in gas flow by 30-50% at wells № 23 of Opishnia, № 115 of Mashivka, № 3 of Tymofiivka gas condensate fields. The effect of formation treatment with ammonium carbonate salts is achieved due to clearing of well bottom zone and increasing the formation permeability. At wells № 56, 108 of Yablunivka and № 58 of Tymofiivka gas condensate fields, an increase in the condensate ratio was observed by 22-35%. The effectiveness of this treatment is associated with the simultaneous bottomhole zone cleaning from asphalt-resinous contaminants and permeability increase, as well as with the hydrophilization of the pore space and mobility increase of condensate precipitated as a result of carbon dioxide effect, which was rejected as a result of decomposition of ammonium carbonate. Thus, experimental and industrial tests in Opishnia, Mashivka, Tymofiivka, Yablunivka gas condensate fields of Poltava region confirmed the effectiveness of using ammonium carbonate to increase hydrocarbon production. The prospect of further research is aimed at developing a technology for increasing the production of liquid hydrocarbons by using ammonium carbonate salts.

Introduction

Ukraine has significant deposits of developed mineral deposits. To date, 90 types of minerals have been explored, which are concentrated in almost 8000 deposits. For sustainable development it is necessary to increase the efficiency of natural resources [1, 2, 3].

Today, most of the gas, gas condensate and oil fields in Ukraine are at the final stage of development, the production of gas and liquid hydrocarbons is decreasing.

One of the urgent problems of the oil and gas industry is to improve the efficiency of wells operation. In modern conditions, the solution to this problem is largely determined by the timely development, justification and targeted application of new technologies to improve the efficiency of hydrocarbon extraction.

The development of gas condensate fields for depletion is accompanied by a decrease in reservoir pressure and retrograde condensation of high-boiling *C5+* hydrocarbons (condensate) with the loss of some of them into the liquid phase and their loss in the reservoirs, due to the fact that the condensate that precipitates in the reservoirs turns out to be stationary and is not involved in filtration processes.

As a result, up to 30-60% of the initial condensate reserves remain in the deposits [4-6]. In addition, there is clogging of the pores with rock particles, asphalt, resin, paraffin deposits [7-9].

Therefore, the search and substantiation of new methods of field development aimed at increasing the condensate recovery of the productive formation, at the same time, will ensure the cleaning of the bottomhole zone from pollution products and this is an urgent task.

At the first stage of development of oil and gas condensate fields, production is carried out due to the depletion of reservoir energy. This stage, called primary,

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makes it possible to extract from the underground reservoir only up to 10-25% of hydrocarbons [10]. The various methods developed later were primarily aimed at maintaining reservoir pressure – methods of secondary production, or to improve the conditions for the movement of hydrocarbons in the porous environment of the rock – methods of tertiary production. The latter include various approaches to increasing the recovery of liquid hydrocarbons from depleted and highly watered fields.

These methods and their variations, according to some estimates [11], have up to 250 names, including various schemes for the formation of excess pressure, injection of working media, thermal effects on the formation, chemical treatment of productive reservoirs, and the like.

One of the most effective ways to increase the recovery of liquid hydrocarbons from reservoirs is to inject water and CO_2 into the well [11-13]. With regard to the prospects for using the method of injecting carbon dioxide into the reservoir to increase oil and condensate recovery of depleted and highly watered fields, let us focus on the influence of the factor of carbon dioxide dissolution in water. Firstly, an aqueous solution of CO_2, entering into reactions and dissolving individual constituents of the rock, increases the permeability of the porous reservoir. Secondly, the viscosity of water increases, which leads to a decrease in its mobility, and together with an increase in the mobility of liquid hydrocarbons (through the dissolution of carbon dioxide in them), this contributes to the equalization of the mobility of water and liquid hydrocarbons, which is important for the efficiency of the process. Finally, changes in the properties of water and liquid hydrocarbons cause a decrease in the surface tension at «liquid hydrocarbons-water» interface and increase the wettability of the rock with water. All this in combination contributes to a more efficient washout of the hydrocarbon film. [14, 15].

According to 2000 estimates, there were 84 projects to enhance condensate and oil recovery by carbon dioxide injection in the world at the stage of implementation. Of these, 72 (96%) were carried out in the United States, which indicates its leadership in this important scientific and technological area. It is interesting that in work [16] the second place is given to Turkey, whose projects, according to expert estimates, allow counting on significant commercial success [16]. According to estimates, in 2014, 136 carbon dioxide injection projects are being implemented worldwide, carried out by 30 operators. Of these, 88 are considered successful, 18 are promising projects, the remaining 20 have recently started [17].

The use of carbonized water to enhance condensate and oil recovery is also known. The main advantage of the injection of carbonized water is the relatively low consumption of carbon dioxide during injection into the reservoir in comparison with other options for its use [18].

However, in both cases, pure liquefied carbon dioxide, a compressor, and special equipment for injecting liquefied gases and liquids saturated with gas at high pressures are required.

Based on the above, it can be assumed that a reagent containing 10-15% of chemically bound CO_2, which is release under formation conditions, can be highly effective.

Such a reagent is a salt of carbonate (carbonic) acid H_2CO_3, namely, bicarbonate and ammonium carbonate (NH_4HCO_3 and $(NH_4)_2CO_3$ respectively). Solutions of these salts decompose easily at temperatures of 40-90 ºC. Therefore, in some cases, it is more reasonable from an economic point of view to use reagents containing 10-15% of chemically bound carbon dioxide CO_2, which is released in reservoir conditions.

The aim of the work is to study the effect of ammonium carbonate on the filtration properties of the reservoir, displacing and washing out the properties of the solution of ammonium carbonate and the use of a new reagent to increase condensate recovery at the fields of the Dnieper-Donetsk basin.

Materials and methods

The object of the study is a 20% concentration of ammonium bicarbonate (ammonium carbonate) solution.

The influence of solutions of ammonium carbonate salts on the physical and lithological parameters of core samples, namely: permeability, porosity, size of pore channels, were studied at the UIPK-1M installation, for which the natural core was filled with ammonium carbonate salts at a concentration of 200 g/l at temperatures 30, 40, 50, 60, 70 ºC for 3 hours.

Core material from various oil and gas fields (Khukhra, Reshetniaky, Rybalske, Velyki Bubny, Novohryhorivka and Matlakhivka*)* was used as reservoir models that were studied, namely, sandstone samples of 15 pcs. with the diameter of 30 mm and length 30 mm, with a permeability of 0.051-1.320 μm^2 and open porosity, which was in the range of 9.5-22.7%. Table 1 shows the geography of the studied samples.

Permeability was determined on a stationary laboratory setup with a fixed side hydraulic compression of 3 MPa.

Ammonium carbonate salts were removed from the core samples: in one case – with distilled water, in another – with formation water. The completeness of washing was determined by the presence of ammonium and carbonate ions in the filtrate by the titrimetric method.

The displacing properties of ammonium carbonate salts were determined by the value of phase permeability in the core samples. Phase permeability was investigated on the UIPK-1M installation at temperatures of 20, 30, 40, 50, 60 °C.

The washing properties of the solution of ammonium carbonate salts were investigated as follows: during the experiments, a sample of asphaltene substances (AS) dissolved in acetone, which were taken from the Yablunivka gas condensate field, was placed in the studied formation model. Acetone was removed by heating the test layer to 45 °C.

After that, the formation model was washed with a solution of ammonium carbonate with a volume concentration of 20%. After each washing, the formation model was dried in a drying oven and the content of asphalt-resinous substances was determined by the gravimetric method. For comparison, another formation model was washed with formation water.

Table 1. Geography of the studied core samples.

Core sample №	The field where core samples taken	Well №	Selection interval *h* m
4802	Khukhra	9	2931-2988
4805	Khukhra	9	2931-2988
4809	Khukhra	9	2931-2988
4814	Khukhra	9	3046-3053
4837	Novohryhorivka	100	3693-3697
4844	Novohryhorivka	100	3693-3697
4838	Novohryhorivka	100	3693-3697
4873	Matlakhivka	36	3577-3584
5021	Reshetniaky	65	2359-2367
5023	Reshetniaky	65	2359-2367
5027	Reshetniaky	65	2359-2367
4410	Velyki Bubny	114	2921-2929
4414	Velyki Bubny	114	2929-2936
4416	Velyki Bubny	114	2929-2936
5114	Rybalske	206	4284-4294

Research results

The results of studying the effect of ammonium carbonate solutions on the physical and lithological parameters of core samples are shown in Table 2, 3.

Analysis of the data shows that the samples, from which ammonium carbonate salts were removed by distilled water, increased the permeability value by an average of 18% relative to the initial values. The theoretical size of the pore channels also increased in all studied core samples.

In addition, the effect of NH_4HCO_3 solution on the carbonate content of the samples is observed. In almost all cores, it decreased by 47-52% from the initial values (Table 2). As a result of the experiments, it can be argued that the dissolution of carbonate cements with ammonium salts occurs according to the equation.

$$2NH_4HCO_3 \rightarrow (NH_4)_2CO_3 + H_2CO_3$$

$$H_2CO_3 \rightarrow CO_2 + H_2O$$

$$CaCO_3 + CO_2 + H_2O \rightarrow Ca(HCO_3)_2$$

In this case, insoluble $CaCO_3$ converted into soluble $Ca(HCO_3)_2$.

Table 2. Change of physical and lithological parameters of core samples during their treatment with NH_4HCO_3 solution (t = 20 ºC) with subsequent removal of NH_4HCO_3 with distilled water.

№ Core sample	Initial parameters			Final parameters			Carbonation *K*, %	
	Permeability *k* 10^{-15} m²	Porosity *n* %	Pore size *l* µm	Permeability *k* 10^{-15} m²	Porosity *n* %	Pore size *l* µm	Before	After
4802	940	20.8	19.0	1030	22.9	17.3	1	0.5
4805	1050	22.1	20.9	1326	22.6	18.4	3.3	1.6
4809	620	21.1	17.3	867	17.9	15.8	2.8	1.4
4814	42	14.2	5.4	57	11.8	5.0	3.1	1.6
4837	166	20.8	24.9	172	20.6	23.1	14	11
4844	46	9.9	6.9	64	9.6	5.9	9	7
5021	1292	22.7	20.4	1341	23.0	20.6	0.9	0.4

Table 3. Change of physical and lithological parameters of core samples during their treatment with NH_4HCO_3 solution (t = 20 ºC) with subsequent removal of NH_4HCO_3 by formation water.

№ Core sample	Initial parameters			Final parameters		
	Permeability *k* 10^{-15} m²	Porosity *n* %	Pore size *l* µm	Permeability *k* 10^{-15} m²	Porosity *n* %	Pore size *l* µm
4873	172	17.9	8.4	166	14.8	8.3
5027	337	21.7	10.6	310	21.3	10.2
4410	70	16.8	5.5	56	16.5	4.9
4416	245	22.4	8.9	192	17.6	8.9
4838	1038	21.8	18.6	890	18.5	18.6
5023	366	18.8	11.7	345	18.1	10.8
5114	51	10.4	6.0	40	10.2	5.3
5119	63	9.5	6.9	45	9.0	6.0
4414	290	22.6	9.7	246	22.2	8.9

In the laboratory, a number of experiments were performed to dissolve dry chalk with 20% ammonium bicarbonate solution.

The results showed that under normal conditions, the solubility of $CaCO_3$ in NH_4HCO_3 reaches 0.85-1.12 g/l, and at a temperature of 60 ºC – 1.6-1.74 g/l. This indicates the solubility of carbonate cements, which contain a solution of ammonium bicarbonate in the core samples.

Based on the thermochemical conditions of this process, the solubility of carbonate cement will increase with increasing pressure, which is a positive characteristic of the effect of NH_4HCO_3 solution on carbonate rocks in formation conditions.

The second part of the core samples shown in Table 3, from which ammonium carbonate was removed by formation water, reduced the permeability value by 14-28%, the size of the pore channels also decreased.

The reason for this effect of ammonium bicarbonate solution on the permeability of the core samples is obviously a chemical reaction between highly mineralized water and ammonium bicarbonate with the formation and precipitation of a solid phase.

Laboratory studies carried out when mixing formation waters from gas condensate wells with a 20% ammonium bicarbonate solution showed that when the content of Ca^{2+} and Fe^{3+} in the formation waters is more than 0.5 mg-ion / l, as well as Mg^{2+} – 1.5 mg- ion/l and more, the use of ammonium carbonate is ineffective due to the formation of water-insoluble carbonates according to the scheme.

$$2NH_4HCO_3 + CaCl_2 \rightarrow CaCO_3 + 2NH_4Cl + CO_2 + H_2O$$

$$2NH_4HCO_3 + MgCl_2 \rightarrow Mg(OH)_2 + 2NH_4Cl + 2CO_2$$

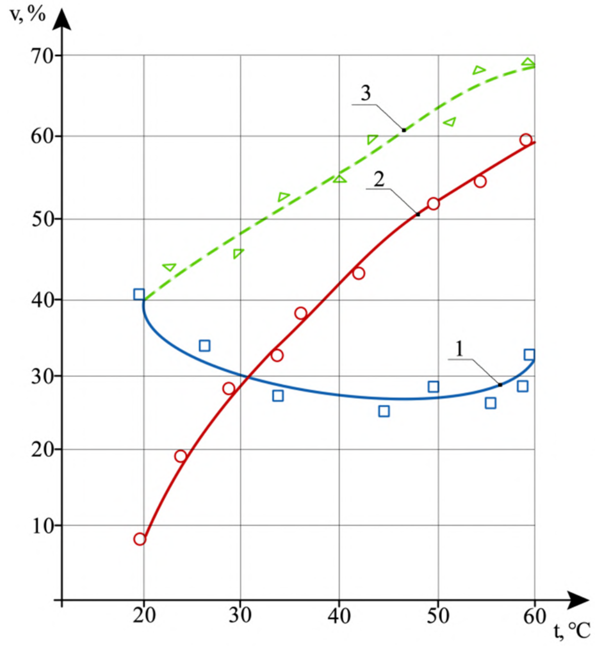

Fig. 1. Dependence of the relative permeability of core samples on temperature. Permeability: 1 – by solution of ammonium bicarbonate (in a sample of kerosene) 2 – by formation water (in a sample of kerosene), 3 – by air – (in a sample of kerosene).

Further research was aimed at studying the displacing properties of ammonium carbonate salts.

Table 4 shows the average values of the displacement coefficient, residual saturation, and relative permeability. From these data it follows that the relative permeability of the samples in descending order is as follows:

At a temperature of 20 °C:

1. by ammonium bicarbonate solution;
2. by air (in the kerosene sample);
3. by formation water (in the kerosene sample).

At a temperature of 60 °C:

1. by air (in the kerosene sample);
2. by formation water (in the kerosene sample);
3. by ammonium bicarbonate (in the kerosene sample).

Based on the results of experiments for displacing kerosene from core samples, graphical dependencies were built, which are shown in Fig. 1 and 2.

The low phase permeability of the core with respect to ammonium bicarbonate confirms the well-known phenomenon of an increase in the viscosity of aqueous solutions when they are saturated with carbon dioxide. It is known [19] that with an increase in the concentration of CO_2 in an aqueous solution up to 2.1%, the viscosity increases by 18.9%, and at a concentration of CO_2 up to 5.6% – by 27.2%.

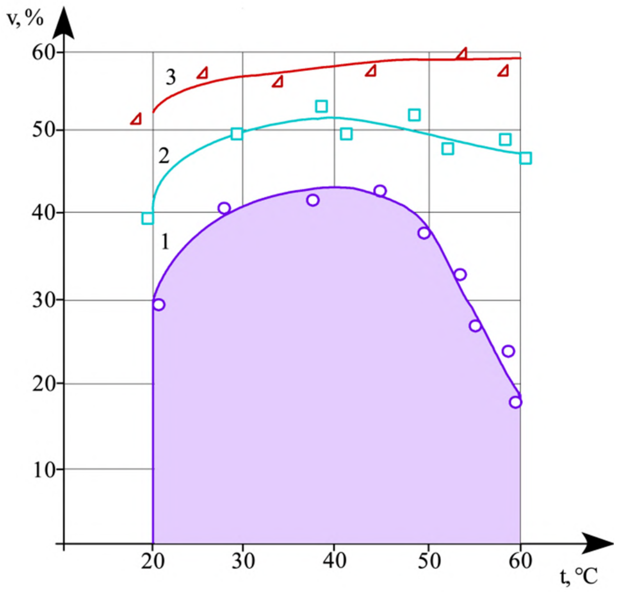

Fig. 2. Temperature dependence of the relative permeability of core samples. Displacement of kerosene from the core sample by: 1 – ammonium bicarbonate solution, 2 – formation water, 3 – air.

Analyzing the data shown in Fig. 2, it can be assumed that the increase in the temperature of the solution to 30-40 °C causes the release of some carbon dioxide, which initially pollutes the carbonate solution, increasing its viscosity, and at the same time blocks the pore space (Joumen effect). This, in turn, leads to a decrease in the phase permeability of the core to ammonium bicarbonate and low displacement of NH_4HCO_3.

However, a further increase in the temperature of the solution to 50-60 °C leads to an intensive release of carbon dioxide, which is dissolved in kerosene, changing its physicochemical properties. Studies show that as the temperature rises, the kerosene yield increases and the phase permeability of the degassed ammonia solution increases.

Further research is aimed at studying the washing properties of a solution of ammonium carbonate salts. During the experiments, a sample of asphaltene sediments (AS) dissolved in acetone, which were isolated from the Yablunivka gas condensate field, was placed in the studied formation model. Acetone was removed by heating the studied formation to 45 °C.

Table 4. The results of experiments to determine the coefficients of displacement, saturation and relative permeability.

№	**Characteristics of the experiment**	**Parameters**	**The results of the experiment**					
			Experiment temperature, ° C					
			20	**30**	**40**	**50**	**60**	**70**
1.	Displacement of kerosene by ammonium bicarbonate solution	displacement coefficient, β	0.75	0.60	0.57	0.68	0.80	–
		saturation coefficient, k_o	0.25	0.40	0.43	0.32	0.20	–
		relative permeability, k_i	0.40	0.35	0.26	0.26	0.33	–
2.	Displacement of kerosene by formation water	displacement coefficient, β	0.60	0.50	0.48	0.50	0.55	0.60
		saturation coefficient, k_o	0.40	0.50	0.52	0.50	0.45	0.38
		relative permeability, k_i	0.11	0.28	0.42	0.54	0.58	0.62
3.	Displacement of kerosene by air	displacement coefficient, β	0.47	0.43	0.41	0.40	0.37	–
		saturation coefficient, k_o	0.53	0.57	0.59	0.60	063	–
		relative permeability, k_i	0.40	0.45	0.52	0.62	0.66	–

Table 5. Influence of washing on the content of asphaltene sediments in the formation model.

Temperature, °C	**The content of asphaltene sediments, %**					
	Formation water			**20th solution of NH_4HCO_3**		
	Washing number			**Washing number**		
	1	**2**	**3**	**1**	**2**	**3**
20	86	79	53	12	4	0.1
40	72	51	23	4.5	0.1	–
60	60	29	10	1.6	–	–
80	45	11	0.2	0.3	–	–

The formation model was then washed with a solution of ammonium carbonate salts with a volume concentration of 20%. After each washing, the formation model was dried in an oven and the content of asphaltene sediments was determined by weight. For comparison, washing of another model formation was performed with formation water. The research results are shown in Table 5.

As can be seen from the table, the experiments were performed at temperatures of 20, 40, 60, 80 °C, and the formation model was washed three times. Analysis of the research results shows that the formation water only after the third wash at a temperature of 80 °C allows cleaning the formation from asphaltene sediments. At lower temperatures, the washing efficiency is low.

The use of a 20% solution of ammonium carbon dioxide as a washing liquid shows that even at a temperature of 20 °C after a single wash in the formation remains only 12% of asphaltene compounds. The efficiency of formation treatment increases with increasing temperature. From 40 °C begins the release of carbon dioxide, which, in turn, leads to increased purification of the pore space. At a temperature of 80 °C, the model formation is cleaned practically with ammonia water and carbon dioxide, which are formed during the decomposition of ammonium carbon dioxide salts.

The results of industrial tests

At the enterprises of GPD «PoltavaGasVydobuvannya» introduction of ammonium carbonate salts for treatment of the bottomhole zone of the formation was carried out. Investigations of wells after treatment were carried out on existing special research lines by the method of constant sampling in 5-6 modes of forward and 2-3 modes of reverse.

At the beginning of the test, the wells are flushed with 3-5% ammonia solution or ammonium bicarbonate, which are fed into the tubing or into the annulus. After that, the main intensification reagents are injected: ammonium carbonate salts.

The method of injection was chosen depending on the permeability of the collector. The working reagent was forced into the reservoir, kept there for 16-24 hours, then the well was developed in the barn and connected to the washing plant of complex gas treatment. After development and stabilization of the flow rate, the operating parameters of the well were removed.

The results of implementation showed that after treatment of productive reservoirs in wells № 23 of Opishnia and № 115 of Mashivka gas condensate fields (GCF) an increase in gas flow was obtained from 10 to 33.8 thous.m^3/day and from 15 to 30.4 thousand m^3/day, and at well № 3 of Tymofiivka gas condensate field increase in gas production amounted to 80 thous. m^3/day (Table 6).

Thus, the effect of bottomhole zone treatment of the formation with ammonium carbonate salts was achieved due to the cleaning of the bottomhole zone of the formation and permeability increase of reservoir.

Another effect of well intensification with NH_4HCO_3 reagent is a significant increase in the condensate factor with some reduction in gas flow. Thus, at well № 56 of the Yablunivka gas condensate field, the condensate factor increased from 54.8 to 80.9 kg/thous.m^3. The gas productivity after intensification decreased from 180 to 130-140 kg/thous.m^3. In the second month of well operation, after treatment of the reservoir, an increase in gas flow was observed, which is 55 thous. m^3/day more than the initial values. Treatment of this well shows that the proposed reagent obviously increases the mobility of the condensate. The formation was hydrophilized with the displacement of liquid hydrocarbons from the pore channels, as evidenced by a sharp increase in condensate flow. After cleaning the reservoir, gas production was increased.

Table 6. Influence of intensification on well productivity.

Period	**Gas flow rate** Q_g **thous. m^3/day**	**Condensate factor** *CF* **kg/thous. m^3**	**Condensate flow rate** Q_c**, before treatment and calculation without taking into account** *CF* **t/day**
Before treatment	14.7	69.1	1.01
After treatment	95.14	69.1	6.6
1 month	90.6	69.1	6.2
2 month	50.6	69.1	3.5
3 month	15.0	69.1	1.03

Table 7. Influence of intensification on well productivity.

Period	**Gas flow rate** Q_g **thous.m^3/day**	**Condensate factor** *CF* **kg/thous. m^3**	**Condensate flow rate** Q_c **before treatment and calculation without taking into account** *CF* **t/day**	**Condensate flow rate** Q_c **after treatment t/day**	**Condensate flow rate** Q_c **t/day**
Tymofiivka GCF, well № 58					
Before treatment	80.0	101	8.1	–	–
After treatment	122.8	117	12.4	14.4	2.0
1 month	120.0	128	12.1	15.4	3.3
2 month	110.0	120	11.1	13.2	2.1
3 month	100.0	119	10.1	11.9	1.8
4 month	100.0	108	10.1	10.8	0.7
5 month	90.0	108	9.0	9.7	0.7
Yablunivka GCF, well № 108					
Before treatment	290	55	15.8	–	–
After treatment	200	71	10.9	14.2	3.3
1 month	322	80	17.6	25.8	8.2
2 month	316	74	17.3	23.5	6.2
3 month	314	70	17.1	22.3	5.2
4-6 months	310	68	16.8	20.9	4.7
7-9 months	307	60	16.0	18.6	2.6
10 months	290	55	15.9	–	–

The most efficient is the treatment of wells № 58 of Tymofiivka and № 108 of Yablunivka gas condensate fields. The data given in Table 7, indicate that in both wells after treatment increased gas flow rate and condensate factor. The gas flow rate gradually decreased to the initial values, while the condensate factor remains high.

The effectiveness of this treatment is obviously associated with the simultaneous cleaning of the bottomhole zone from asphalt-resinous contaminants and an increase in permeability, as well as with the hydrophilization of the pore space and an increase in the mobility of condensate precipitated as a result of exposure to carbon dioxide, which was released as a result of decomposition of ammonium carbonate.

Conclusions

1. Ammonium carbonate salts, in the absence of calcium chloride type waters, interact with carbonate rocks,

increase the permeability of reservoirs due to the conversion of insoluble $CaCO_3$ to soluble $Ca\ (HCO_3)_2$.

2. Ammonium carbonate salts have high displacing properties, the coefficient of displacement of kerosene with NH_4HCO_3 solution is 0.75-0.80, while reservoir water – 0.55-0.58.

3. The NH_4HCO_3 solution has good washing properties against asphaltene contaminants. So, after washing the reservoir with ammonium carbonate salts at a temperature of 20 °C, no more than 10-12% of asphaltene substances remain in the model reservoir, and more than 60% with water.

4. Experimental and industrial tests at Opishnia, Mashivka, Tymofiivka, Yablunivka gas condensate fields of Poltava region confirmed the effectiveness of ammonium carbonate salts use for increasing hydrocarbon production. Industrial tests of ammonium carbonate salts showed an increase in gas flow by 30-50% at wells № 23 of Opishnia, № 115 of Mashivka, № 3 of Tymofiivka GCF, an increase in condensate factor by 22-35% at wells № 56 Yablunivka, № 58 of Tymofiivka GCR. The prospect of further research is aimed at developing a technology for increasing the production of liquid hydrocarbons by using ammonium carbonate salts.

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Influence of the size of hematite and magnetite ores on the parameters of the sintering process and the quality of the sinter

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Abstract. Laboratory sintering of sinter charge based on hematite and magnetite iron ores of various sizes was carried out. The purpose of the study was to determine the effect of the type and size of the ore material on the gas permeability of the sintered layer, sintering performance and the need for fuel. The granulometric composition, cold strength, strength during recovery, and reducibility of the resulting agglomerate have been studied. Differences in the course of the process of agglomeration of hematite and magnetite ores at different sizes were revealed in the research. The established patterns have practical interest from the point of view of increasing the efficiency of the sintering process, improving the quality of the sinter and reducing the harmful impact on the environment.

1 Introduction

Along with magnetite ores, hematite ores are of significant value for ferrous metallurgy. Analysis of the mineral resource base of mining and metallurgical enterprises [1-3] indicates the prospects of their use to expand industrial reserves of iron-containing raw materials. However, the technology of their agglomeration has characteristic features that distinguish them from traditional magnetite raw materials [4,5]. Thus, the ability of hematite materials to pelletize in the composition of sinter charges is, as a rule, worse in comparison with magnetite ones, which is associated both with the low wettability of hematite and with the peculiarities of the surface structure of ore grains. Sintering of hematite ores requires increased heat consumption compared to the processing of magnetite ores and concentrates. This is due to the absence in hematite ores of a powerful internal heat source from the oxidation of FeO magnetite, as well as a higher temperature of the beginning of their melting [6].

Analysis of the results of studying the process of agglomeration of iron ores [7-10] showed that, despite the vast amount of information on the patterns of formation of the structure, mineralogical and phase composition of iron ore agglomerates, there is no single point of view either on the mechanism of formation or on the influence of individual factors on qualitative characteristics of iron ore sinters. This circumstance makes it necessary to study the conditions for obtaining iron ore sinter from hematite ore, depending on its size.

2 Purpose and tasks of research

The purpose of this study is to establish and compare the regularities of changes in the indicators of the sintering process and the quality of sinter from the size of hematite and magnetite ores and sinter charges based on them. To achieve this goal, the following tasks were set:

- determination of the influence of the size of ores and sinter charges on their gas permeability;
- determination of the influence of the size of ores and sinter charges on the productivity of sintering;
- determination of the dependence of the demand for solid fuel on the size of ores and sinter charges and the type of ore;
- determination of the influence of the size of ores and sinter charges on the strength of the finished sinter in the cold state, during recovery and on the recoverability.

3 Data and methods

To determine the effect of the type of ore, the study did not use a mixture of different ores, but two separate ores - ore A, containing 100 wt.% magnegite, and ore B, containing 94 wt.% hematite. For the experiments, both ores were scattered into six fractions. By mixing the individual fractions, various grain compositions were prepared. Figure 1, a shows the size of the mixtures of fractions of the individual ores. Table 1 shows data on the chemical composition of the individual fractions of the studied ores, and table 2 - data on the chemical composition of the mixtures.

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When mixing the fractions, it was proceeded from the fact that the distribution of the mixture by size was as close to normal as possible, as is usually observed in ores and after their grinding. This normal distribution in double logarithmic coordinates is expressed by straight lines. In the area known from industrial studies of the spread of the upper limits of the size and maximum fractions of fines for sinter ores, the composition of the mixtures was expressed by straight lines. Only in one case (experiments 8 and 17) there was no normal distribution; the composition of the mixture was expressed as a curved line. Upon further graphic evaluation of the data, the location of the points for these mixtures was somewhat different from the usual one.

The proportion of the –3 mm fraction in the prepared mixtures ranged from 0–36 wt.%, the –0.1 mm fraction - within 2.7–37.0 wt.%. The maximum grain size of the ore was 10 mm.

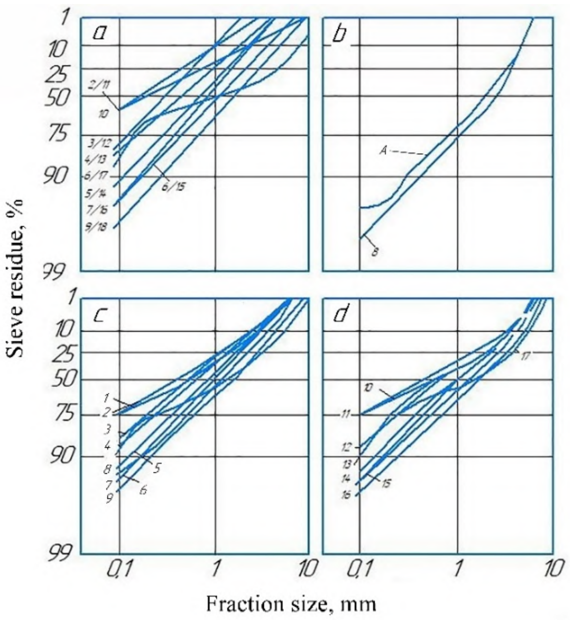

Fig. 1. Distribution of ore, return and sinter charge according to the size of fractions: a) mixtures of fractions of ores A and B; b) return for ores A and B; c) sinter charge based on ore A; d) sinter charge based on ore B. 1-9 - a mixture of fractions from ore A; 10-18 - a mixture of fractions from ore B

Table 1. Chemical composition of the fractions of the studied ores.

Fraction, mm	Substance, wt.%				
	Fe	Fe^{2+}	SiO_2	CaO	MgO
Magnetite ore A					
10-6	67.37	22.41	2.84	0.10	0.90
6-3	64.42	22.61	2.92	0,10	1.04
3-1	66.77	22.46	3,32	0.10	0.88
1-0.2	64.98	19.46	4.66	0.25	1.14
0.2-0.1	67.60	20.70	2,64	0.70	1.14
-0.1	61.19	20.37	6.63	1.44	2.32
Hematite ore B					
10-6	65.18	1.00	3.18	0.10	0.05
6-3	65.13	1.40	3.24	0.10	0.05
3-1	65.23	1.30	3.08	0.10	0.09
1-0.2	65.27	1.40	2.44	0.10	0.09
0.2-0.1	67.51	1.70	1.44	0.10	0.07
-0.1	63.82	1.25	6.10	0.10	0.28

To characterize the mixtures, the HS_{50} index was used – this is the mesh size of the strainer through which 50 wt.% of the mixture passes.

The iron content in all agglomerates was maintained at 58 wt.%. The basicity of all agglomerates (CaO / SiO_2), in turn, was maintained at 1.3, which was achieved by adding dolomite or ground limestone with a particle size of 0–3 mm. The MgO content in the finished agglomerate was to be 1 wt.%. The return addition was constant at 40 kg/100 kg ore. By varying the coke consumption, each experiment was carried out so that the return balance (the ratio of the return yield R_A to the return flow R_B) was 95-105 wt.%. The quality of additives and coke, as well as their size, were kept constant.

Table 2. Chemical composition of experimental mixtures of fractions, wt.%.

experience	Fe	SiO_2	CaO	MgO
Magnetite ore A				
1	64.28	4.86	0.74	1.54
2	65.19	4.90	0.73	1.56
3	65.14	4.41	0.48	1.28
4	65.45	4.20	0.43	1.21
5	65.93	4.20	0.43	1.21
6	65.95	3.90	0.26	1.06
7	66.06	3.82	0.24	1.06
8	66.73	3.31	0.35	1.10
9	66.46	3.56	0.19	1.02
Hematite ore B				
10	65.41	4.36	0.10	0.15
11	65.13	4.00	0.10	0.16
12	66.10	2.77	0.10	0.11
13	65.86	2.94	0.10	0.11
14	65.94	2.76	0.10	0.09
15	65.85	2.73	0.10	0.09
16	65.68	2.88	0.10	0.09
17	65.89	2.77	0.10	0.08
18	65.55	2.94	0.10	0.08

All experiments were carried out in a bowl with a suction area of 400×400 mm. The bed was a return with a size of 10–20 mm. The total height of the sintered layer was 300 mm. The vacuum during all experiments was kept constant at 800 mm of water. art. All mixtures were pelletized before being loaded into the bowl. The mixture was ignited at a temperature of 1150 °C. The duration of the experiment was considered the time from the start of ignition to reaching the maximum temperature of the exhaust gases plus 1 min. The agglomerate was then cooled by suction and dropped three times with a height of 2 m onto a steel plate. After dropping, a 6.3 mm square sieve was sieved to determine the return yield.

Sieve and chemical analyzes were performed for all finished agglomerates with equalized return balance. Then the agglomerate was subjected to drum tests, the destruction of the grains at the beginning of the reduction was investigated, and the recoverability was also determined.

4 Research results and discussion

When evaluating the research results, it turned out that the

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return size fluctuated greatly. For each ore, based on all sieve recovery analyzes, a mixed sieve analysis was calculated, which is graphically presented in fig. 1, b. It was found that the return during sintering of hematite ore B has fewer fine fractions than the return during sintering of magnetite ore A.

The oxidation state of the return in individual experiments also fluctuated. It was determined by calculation. When using ore A, it was 94%, when using ore B - 97.3%. Thus, the dependence of the oxidation state of the return on the oxidation state of the charge is visible.

Since the return flow rate of 40 kg/100 kg of ore mixture was kept constant, the return had a significant effect on the properties of the entire mixture. In this regard, in fig. 1, c, d shows the size of the entire charge A and the entire charge B. In contrast to pure ores, significant changes are visible. All sieving curves are biased towards larger fractions.

As already mentioned, when graphically evaluating the research results for the characterization of ore mixtures or mixtures with return, it seemed most appropriate to use the HS_{50} indicator. In some cases, the best indicator was the content of the fraction –0.1 mm. The graphical assessment of the measurement results in all cases was carried out, firstly, in relation to the size of the ore used, and secondly, in relation to the size of the entire charge. The need for the latter is caused by a strong change in the size of the charge due to the addition of return.

4.1 Gas permeability of the charge in the sinter bowl

Fig. 2, a, b and d show the gas permeability of the sinter charge in the bowl as a function of the size of the ore and the entire charge. The intake air flow rate was measured before ignition and at the time corresponding to 60% of the sintering time.

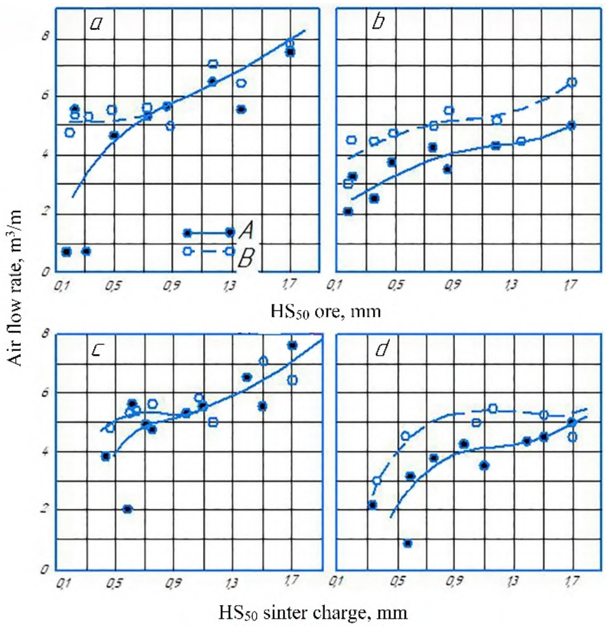

Fig. 2. Dependence of the gas permeability of the charge in the bowl on the size of the ore and sinter charge: a), c) before igniting the charge; b), d) after 60% of the sintering duration.

For both ores, a shift in HS_{50} values towards larger fractions was established during the transition from ore to to agglomeration. Before ignition, in all cases, an increase in gas permeability is observed with an increase in the grain size (Fig. 2, a).

For finer mixtures, there is a difference between the gas permeability of ores A and B: the gas permeability of ore B is higher than that of ore A. about 5 m^3/min, and for ore A - only 3 m^3/min.

The best gas permeability of hematite ore is observed when the particle size is HS_{50} = 0.7–0.8 mm or for the size of the entire charge HS_{50} = 0.9–1.0 mm. It was also found that for hematite ore these values in the area of fine fractions fluctuate strongly. The same picture is observed for the second moment of time (Fig. 2, b, d).

If in the area of coarse fractions these values lie very close to one another, then in the area of small fractions they differ significantly. The scatter area for ore A is also larger in this case. It was also found that the gas permeability of hematite ore in the area of very fine fractions by the second selected time point decreases much less than that of magnetite ore.

The higher gas permeability when using hematite ore can be explained by the greater strength of the lumps due to the adhesive components. With strong waterlogging of the sinter charge in the lower part of the bowl, less strong destruction of the formed lumps occurs here than during sintering of the charge from magnetite ore.

4.2 Sintering performance

Fig. 3 shows the dependence of the sintering performance on the size of the ore and sinter charge. Here, along with the HS_{50} index, the fraction content of –0.1 mm was also used as a parameter. As expected, sintering productivity increased with increasing ore size. At the same time, the difference between hematite and magnetite ore was not established. The achieved productivity was 40 t/m^2·day. In the same way as for gas permeability, differences between the two ores were found for the sintering performance in the area of fine fractions (Fig. 3, a and b). These differences are found when the value of the HS_{50} index for ores starting from 0.6 mm and for the entire charge starting from 1.0 mm, which coincides with the corresponding data for gas permeability.

With this method of assessment, the indicators with a fractional composition that did not correspond to the normal distribution (experiments 8 and 17) were very different from the rest of the data. Therefore, an estimate was adopted for the content of the fraction –0.1 mm. Fig. 3, b and d, it is clearly seen that with an increase in the fraction of –0.1 mm, productivity decreases. The difference is again noticeable for ores A and B in the area of fine fractions, and for ore - starting with a fraction of –0.1 mm 5 wt.%, and for the entire charge - starting with a fraction of –0.1 mm 7 wt.%. These differences can also be explained by the different lumpiness of the ore. It should be emphasized once again that all experiments were carried out with the same return content in the charge.

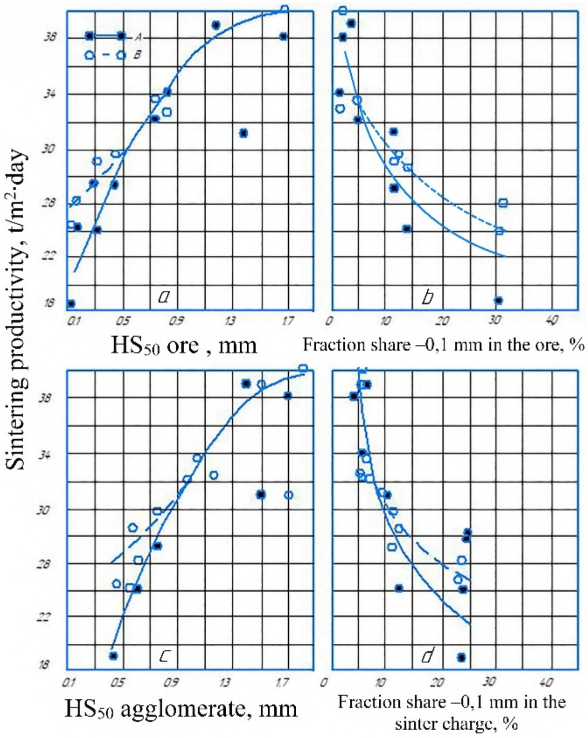

Fig. 3. Dependence of the productivity of sintering on the size of the ore and sinter charge

4.3 Moisture mixture

The moisture content of the mixture was determined by manual test. Upon subsequent determination of the moisture content, it was found that, as expected, it decreases with increasing grain size. However, the charge from hematite ore was found to have a significantly higher moisture content. It was 6.0–7.5 wt.%, and in the charge of magnetite ore – only 4.0–5.6 wt.%. From this it is seen that hematite ore in the area of fine fractions has a larger specific surface area than magnetite.

4.4 Fuel requirement

Fig. 4 shows the dependence of the demand for dry coke on the size of the ore and sinter charge. At the same time, there is a noticeable difference in the demand for coke for magnetite and hematite ores. On the other hand, the influence of the ore size is noticeable.

Starting with a certain grain size, the need for coke is constant or increases very slightly. Thus, with the value of the indicator HS_{50} for ore 1.1 and above, the need for coke for hematite ore B is 6.7 kg/100 kg of dry ore, and for magnetite ore - 4.7 kg/100 kg of dry ore (Fig. 4 , a).

The corresponding value of the HS_{50} indicator for the whole charge is 1.4 mm. With a smaller grain size, the need for coke in both cases decreases to a sharp minimum (especially for sinter charge), which is in the range of values of HS_{50} = 0.6–0.7 mm (Fig. 4, b). This minimum, related to the size of the ore, is sharply expressed for magnetite ore and is at a value of HS_{50} = 0.5 mm. In the area of even smaller fractions, a marked increase in the demand for coke was again found, both for magnetite and hematite ores.

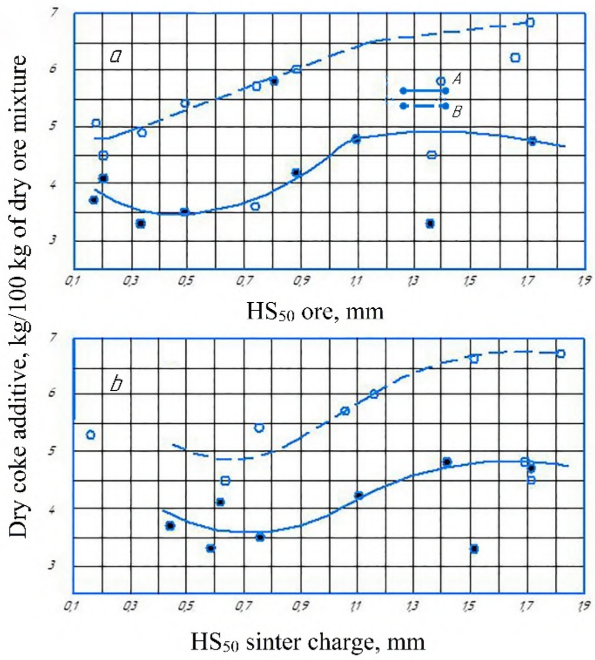

Fig. 4. Dependence of the need for coke on the size of the ore and sinter charge

4.5 Size of the finished agglomerate

The sieve analysis of the finished agglomerate clearly depends on the size of the sinter charge, but even in this case there are differences for hematite and magnetite ores. Fig. 5 shows the dependence of the content of the fraction +25 mm in the agglomerate on the index HS_{50}. In the area of smaller fractions, the points for hematite and magnetite ores are located closer to each other and in both cases in this area the data scatter is larger.

With an increase in the size of hematite ore B, a continuous decrease in the yield of the agglomerate fraction of +25 mm is observed, while for magnetite ore A, starting with an HS_{50} of 0.8 mm (for a sinter batch of 1.0 mm), this value remains constant. In general, the yield of the +25 mm fraction in the agglomerate from magnetite ore is higher than from hematite, which indicates their different sintering capacity.

4.6 Drum strength

An agglomerate sample weighing 15 kg was loaded into a drum 1000 mm in diameter and 500 mm in length and ground in 200 revolutions at a rotation speed of 25 rpm. After that, sieving was carried out into fractions +6.3 and –0.5 mm. The proportion of the +6.3 mm fraction characterizes the drum strength, the proportion of the –0.5 mm fraction characterizes abrasion.

Tests have shown that the abrasion of the agglomerate from hematite ore is 7.6–5.3 wt.% and there is a tendency to decrease it with an increase in the size of the ore. For agromerate from magnetite ore, abrasion is 8.0–6.4 wt.%, and in this case there is also a tendency to decrease it with an increase in the size of the ore. The maximum abrasion was observed at an HS_{50} value for a charge of 0.6–0.7.

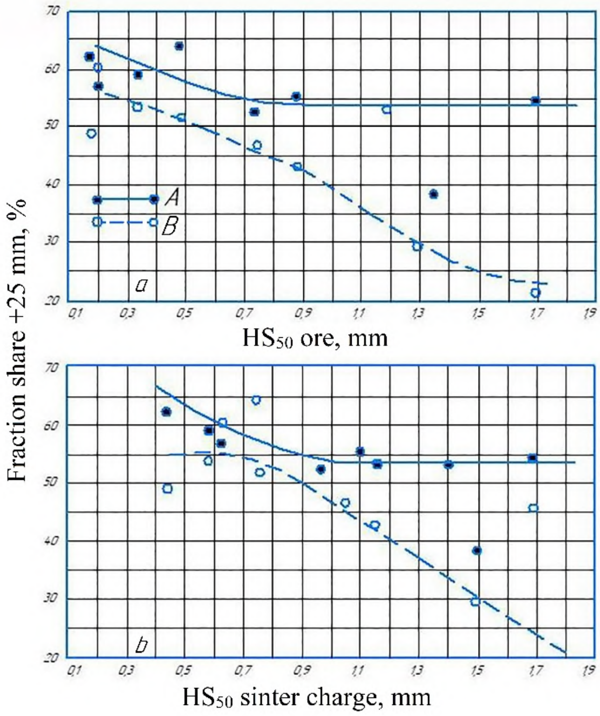

Fig. 5. Dependence of the +25 mm fraction content in the finished agglomerate on the size of the ore and sinter charge

Fig. 6 shows the dependence of the drum strength (fraction yield + 6.3 mm) on the size of the ore and charge. It should be noted that the strength of 41– 53 wt.% for agglomerate from magnetite ore and 46–58 wt.% for sinter from hematite ore cannot be considered satisfactory. These results can be explained by the basicity of the fluxed agglomerate at the level of 1.3, which often leads to a decrease in strength indicators.

However, attention is drawn to the fact that agglomerates from magnetite ore A and from hematite ore B have different strength values and the nature of its dependence on the size of the ore and sinter charge. In the agglomerate of magnetite ore A, with an increase in size, an increase in strength is first observed to reach a maximum at HS_{50} = 0.6 mm for the ore and 0.8 mm for the charge. Then, with an increase in size, a constant decrease in strength is observed, and in the area of the largest fractions, the strength indicators turn out to be lower than in the area of the smallest fractions.

In contrast to this, in hematite ore sinter B, the strength has a minimum at HS_{50} = 0.5 mm for the ore and 0.8 mm for the sinter charge. With an increase in the size to the value HS_{50} = 1.4 mm for ore and 1.5 mm for sinter strength, the strength increases to a maximum and then decreases again.

Both extremes of strength in both the smallest and the largest fractions are expressed equally sharply.

4.7 Reduction behavior and influence of the oxidation state

As known from the results of other studies [7], the agglomerate at a temperature close to 500 °C, in weakly reducing conditions, tends to especially strong destruction. To obtain data on the strength of the agglomerate during the reduction process, the following test was carried out: an agglomerate with a size of 12.5–16 mm in an amount of 500 g was loaded into a rotary kiln with an inner diameter of 150 mm and a length of 540 mm with an external electric heater. The speed of rotation of the furnace was 10 rpm. The oven has four 20 mm high plates. Inside the sample was heated for 40 min with a reducing gas consisting of 24 vol.% CO; 16 vol.% CO_2, and 60 vol.% N_2, up to 500 °C. The exposure at this temperature was 1 h. Then, in a stationary furnace, the sample was cooled with nitrogen to 400 °C, and then with air access. After the end of the experiment, the sample was dispersed according to the size class of +6.3 mm and –0.5 mm. The degree of agglomerate reduction was calculated from the weight loss.

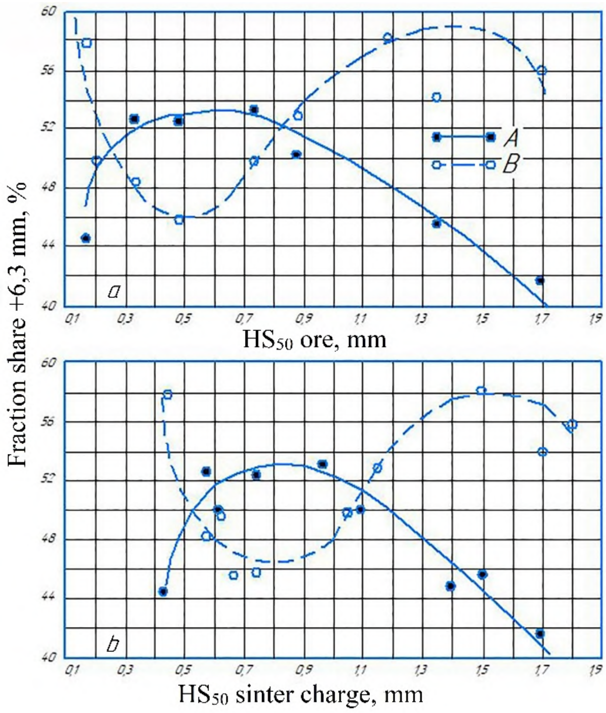

Fig. 6. Dependence of drum strength on the size of ore and sinter charge

The recovery test showed that all the resulting agglomerates under these conditions were more or less destroyed. So, for agglomerate from magnetite ore A, the residual content of +6.3 mm fractions was 0.2-5.3 wt.%, and from hematite ore B - 0.7-14.4 wt.%. These data are very unsatisfactory and are also explained by the basicity of agglomerates 1.3, at which they have a high tendency to destruction under weakly reducing conditions.

Fig. 7 shows the dependence of agglomerate abrasion on the size of the ore and sinter charge. At the same time, a decrease in abrasion is seen with an increase in the size of the ore or batch.

No differences were found between magnetite and hematite ores. The points for both ore grades are evenly spaced around the straight line. When determining the dependence of abrasion on the content of the fraction –0.1

mm, it was found that when the content of this fraction is more than 10 wt.%, the abrasion remains constant even at very unfavorable values (32 wt.%) and decreases only when the content of the fraction –0.1 mm is below 10 wt.%.

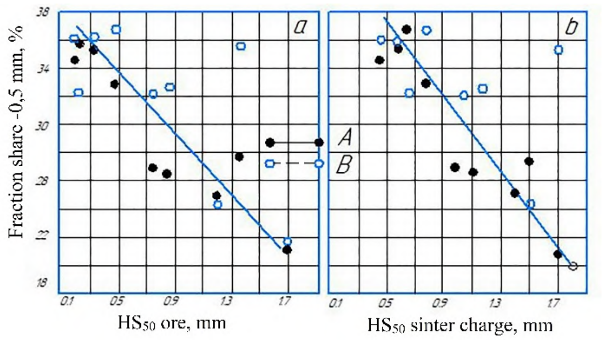

Fig. 7. Dependence of the destruction of the agglomerate at the beginning of recovery on the value of HS_{50}

As already mentioned, under these conditions, the demand for coke with an increase in size increases. However, at the same time, the FeO content in the finished agglomerate also increases. Fig. 8 it can be seen that with an increase in the FeO content, abrasion decreases. It can be assumed that this influences the improvement of abrasion with increasing particle size.

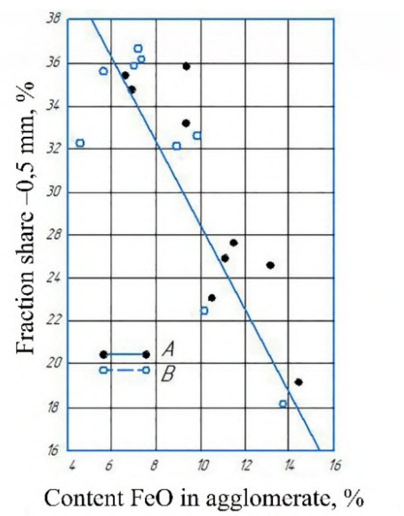

Fig. 8. Dependence of agglomerate destruction at the beginning of recovery on the FeO content

The sintering performance, as expected, clearly depends on the coke consumption. In fig. 9 clearly shows the difference in the demand for coke when using hematite and magnetite ores. To achieve the same productivity, this requirement for both ores differs by 1.5–2 kg of coke/100 kg of ore mixture.

The demand for coke also determines the FeO content or the oxidation state of the agglomerate. With the same fuel consumption, the oxidation state of sinter from hematite ore B is 2–3% higher than sinter from magnetite ore A. However, since the demand for coke for magnetite ore with the same size of sinter charge is about 1.5–2 kg lower than for hematite, the oxidation state of the finished agglomerate, as can be seen from fig. 9, with a corresponding change in the consumption of coke in both cases is the same and does not depend on the content of magnetite in the sinter batch.

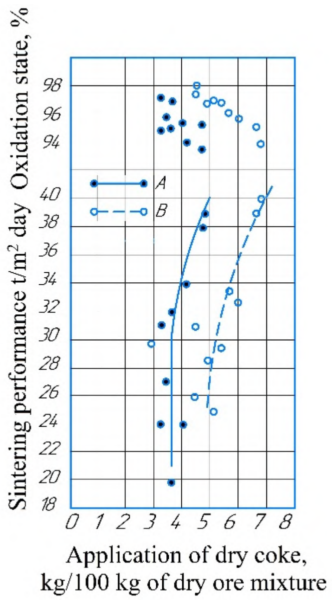

Fig. 9. Dependence of the sintering performance and the oxidation state of the agglomerate on the demand for coke

The agglomerate was tested for reducibility at a reduction temperature of 1000 °C with simultaneous loading of the sample. The amount of oxygen withdrawn was measured in wt.%/min at a reduction rate of 40%. The obtained indicators of recoverability can be considered very high. For both ores, with an increase in the grain size, a certain decrease in reducibility is noticeable. But since with an increase in particle size, the need for coke increases, and thereby the FeO content in the finished agglomerate, fig. 10 shows the dependence of the recoverability on the FeO content.

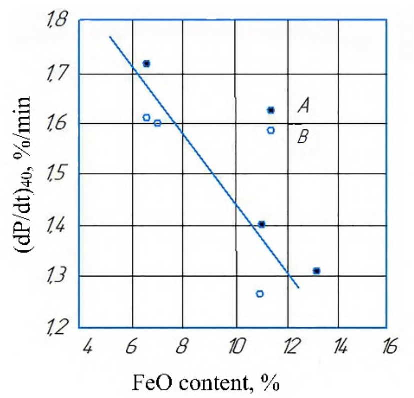

Fig. 10. Dependence of reducibility on the FeO content in the agglomerate

With an increase in the FeO content in the agglomerate, the reducibility decreases. It is also seen that the reducibility of agglomerates from magnetite and hematite ore mixtures is the same.

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5 Conclusions

Experiments on sintering artificially obtained mixtures of fractions from magnetite ore A and hematite ore B made it possible to reveal a number of features of this process depending on the grade and size of the ore. In particular, it can be concluded that:

- the gas permeability of the layer and the sintering productivity increase with increasing size for both ores. Only in the area of very fine fractions was there a difference between hematite and magnetite ore.

- better gas permeability and higher productivity of sintering in the area of fine fractions for hematite ore can be explained by better lumpiness of the charge due to the higher content of adhesive components;

- the minimum need for fuel was observed at an average particle size;

- the best values of the drum strength of the agglomerate were obtained with different sizes of hematite and magnetite ores, and the nature of the change in drum strength from the size differs significantly for these ores;

- a certain increase in strength charge an increase in the size of both ores or sinter mix was observed with an increase in the FeO content in the agglomerate;

- the oxidation state of the sinter at the same size and a certain predetermined consumption of coke is the same for both the hematite ore sinter and the magnetite ore sinter.

The established patterns will make it possible to optimize the granulometric composition of the sinter mixture, which will lead to an increase in the efficiency of the sintering process, namely, to a decrease in solid fuel consumption, which, in turn, will reduce the harmful effect on the environment by reducing CO_2 emissions. In addition, improving the strength of the agglomerate will reduce the formation of dusty fractions (<0.1 mm) during shipment and further transportation to the consumer.

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Force index computation for a magnetic separator based on permanent magnet

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Abstract. Magnetic separation devices are widely used to separate tramp of iron from a specific feed of materials. Many industries rely on those devises and the variety of technological solution depend mainly on the characteristic of the tramp to be separated. In this paper, main characteristics of low intensity magnetic separation devices based on permanent magnets for dry feed are considered to evaluate force index computation.

1. Introduction

For a suspended magnetic separator based on permanent magnet, its capacity to generate enough force index and torque of rotation are essential for assessing its efficiency [1]

The torque must rotate the particle following its axe of magnetisation and the force index should attract it to the separator. Both factors depend on magnetic induction generated by the permanent magnet as it's expressed in equation (1).

$$\overrightarrow{\boldsymbol{fm}} = \boldsymbol{\nabla}(\underrightarrow{\boldsymbol{B0^2}}) \tag{1}$$

Understanding factors impacting magnetic induction flux is very essential to move forward with understanding force index mechanism. Many studies discussed explicitly those factors, like:

shape and configuration of the magnet : flat magnets produce less B than bar magnets .If magnets are put in an assembly, the produced B depends on the configuration type: attraction or repulsion. [2].this help identifying the location of the "zero force" in the separator design.

Orientation of the field: Field flux shape depends on the orientation of the magnetisation inside the magnet. Particle should be surrounded by the magnetic induction flux, in order for the force to be applied .It was proved for rectangular magnets, that orientation through their thinnest direction help increasing the produced B and give a higher energy [3]

Also, uniformity of the magnetic field should be taking seriously into consideration. If H is not uniform, the particle has to be pushed to a smaller distance, from an initial energy state to a final energy state. [4].

This paper, by means of computing method using finite element, aims to propose a program evaluating the required force index to pull the particle to the magnet, starting by magnetic induction flux calculation.

The program can be used in the design phase of the magnetic separator by choosing the optimum dimensions and precise magnet parameters. It can also be used in the final stage by simulating the behaviour of the separator towards the particle.

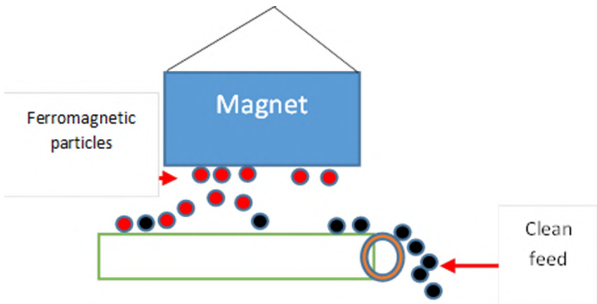

Fig. 1. Suspended magnet separator.

As vector potential method appears to be more effective method to calculate magnetic induction than scalar potential for this application [5]. This method is used in two dimensions with triangular elements. Permanent magnet is chosen as parallelepiped magnet, where its dimensions are shown in "Fig.2",:

Firstly, a mathematical formulation based on vector potential is presented, and then boundary conditions are discussed. Afterwards, finite element method is used in order to convert the obtained equation into matrixes.

Secondly, a brief presentation of the program generated by MATLAB is given in order to implement the data using the finite element method.

Thirdly, an analytical formula based on the shape of the magnet is also considered as to compare the results obtained by the finite element method and the analytical formulas.

Furthermore, three study cases are presented to evaluate and test the reliability of the program and to explore its features.

2. Theoretical background

2.1.Introduction

Magnetic field vectors can be expressed in terms of either the magnetic field strength H or the magnetic induction B[6] .the field vectors are related by:

$$\mathbf{B} = \boldsymbol{\mu}_{\mathbf{m}}.\mathbf{H} \tag{2}$$

With μ_m : the magnetic permeability constant.
In a vacuum, the permeability has the value of

$$\boldsymbol{\mu}_{\mathbf{m}} = \boldsymbol{\mu}_{\mathbf{0}} \tag{3}$$

When a magnetic field passes through a material, the material acquires an induced magnetization M given by:

$$\mathbf{H}.\boldsymbol{\chi}_{\mathbf{m}} = \mathbf{M} \tag{4}$$

Where χm the magnetic susceptibility of the material.
The magnetic induction can also be expressed as

$$\mathbf{B} = \boldsymbol{\mu}_{\mathbf{0}}.(\mathbf{H}+\mathbf{M}) \tag{5}$$

Eq (2),(4) and (5) show that

$$\boldsymbol{\mu}_{\mathbf{m}}= \boldsymbol{\mu}_{\mathbf{0}}.(1+ \boldsymbol{\chi}\mathbf{m}) \tag{6}$$

Which relates the permeability to the susceptibility.
Following Maxwell‘s equation for magnetostatic. magnetic field is expressed as follow:

$$\nabla\mathbf{x}\mathbf{H}=\mathbf{J} \tag{7}$$
$$\nabla.\mathbf{B}=\mathbf{0} \tag{8}$$

Where j is the density charge.
Via a magnetic vector potential approach. The flux density may be written in terms of the vector potential A as:

$$\mathbf{B}\mathbf{x}\nabla = \mathbf{A} \tag{9}$$

Where A is the vector potential
By using Lorentz gauge, the Alembert equation was found as follow:

$$\mu\mathbf{J} = \Delta\mathbf{A} - \mu\frac{\varepsilon\partial^2 A}{\partial t^2} \tag{10}$$

In quasistaionary terms:

$$\mu\mathbf{J} = \Delta\mathbf{A} \tag{11}$$

And finally, vector potential is expressed via Poisson's equation formulation

2.2.Boundary conditions

The permanent magnet is a suspended one in the air, its flux lines are parallel to the boundary edge. Hence the Dirichlet conditions are the best to express this problem.
A = 0 at the boundary of the space of study of the permanent magnet

3. Finite element formulation

3.1.Introduction

The boundary value problem under consideration is defined by the second order PDE:

$$\boldsymbol{\mu}\mathbf{J}=\Delta\mathbf{A} \tag{12}$$

3.2.Domaine discretization

Triangular elements are used in this case, with the following interpolation equation:

$$\emptyset^{\mathbf{e}}(x,y) = \sum_{\mathbf{j=1}}^{\mathbf{3}} \mathbf{N}_{\mathbf{j}}^{\mathbf{e}}(x,y)\emptyset_{\mathbf{j}}^{\mathbf{e}} \tag{13}$$

By using variation formulation, we get the expressions of the matrices

3.3.Final formulation

Set of matrices are represented as follow:

$$\mathbf{K}_{i,j}^{\mathbf{e}} = \int\left(\left(\frac{\boldsymbol{\alpha}\mathbf{d}N_i^e}{\mathbf{d}x}\frac{\mathbf{d}N_j^e}{\mathbf{d}x}\right) + \boldsymbol{\beta}\mathbf{N}_{\mathbf{i}}^{\mathbf{e}}\mathbf{N}_{\mathbf{j}}^{\mathbf{e}}\right)\mathbf{d}x \tag{14}$$
$$\mathbf{b}_{\mathbf{i}}^{\mathbf{e}} = \int \mathbf{N}_{\mathbf{i}}^{\mathbf{e}}\mathbf{f}\mathbf{d}\mathrm{x} \tag{15}$$
$$\mathbf{g}_{\mathbf{i}}^{\mathbf{e}} = \boldsymbol{\alpha}\mathbf{N}_{\mathbf{i}}^{\mathbf{e}}\mathbf{d}\emptyset/\mathbf{d}x \tag{16}$$
$$(\emptyset^{\mathbf{e}}) = \begin{pmatrix}\emptyset_{\mathbf{1}}^{\mathbf{e}}\\ \emptyset_{\mathbf{2}}^{\mathbf{e}}\end{pmatrix} \tag{17}$$
$$(\mathbf{K})(\emptyset) = (\mathbf{b}) + (\mathbf{g}) \tag{18}$$

4. Finite element program

4.1.Introduction

For its simplicity and reliability of results, MATLAB is used to program the finite element formulation of matrixes.
The basic structure of this program is split to many sections.
Global declaration section: where the model is presented, characteristic of the environment, magnet and particle are defined like number of elements, nodes, magnetic induction, type of elements. This section can be updated with each specific study case.

Main function: this section is considered the heart of the program. It includes all equations and formulas related to calculating all necessary parameters.

Sub-program function: this section is only optional as it can be included in the Main function section. On the other hand, it's considered essential to create a clean and a visible program. Especially if type of elements and dimensions changed (ex: quadratic instead of triangular). It includes all sub-functions required to calculate the final equation like: Stiffens matrix and source matrix.

Results view section: in this suction, graphs, tables and curves can be obtained to visualise the output of the program.

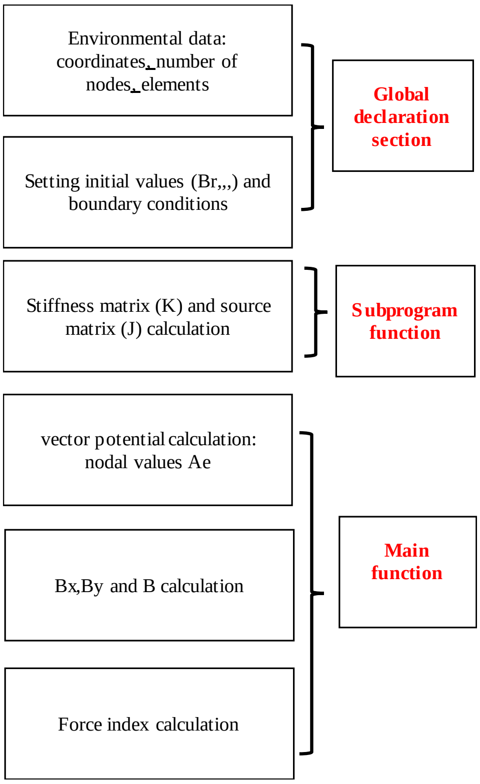

Fig. 2. Main sections of MATLAB program.

4.2.Magnetic induction Formulation

Fig below "2" describes set of steps related to the main sections of the program as discussed above.

Following steps mentioned below allow to calculate the nodal values of force index in each node. In case where global force index is desired, vector potential and magnetic induction values should be calculated for each element, to allow creating a global matrix structure for magnetic induction and it's gradient.

5. Analytical model

5.1. Introduction

Several previous publications had already discussed the behaviour of magnetic field of a rectangular permanent magnet. Elaboration of mathematical formulation depends mainly on type of model (spring model, charge model….) and number of dimensions (two or three) [6, 7, 8].

In this work, the charge model method is taken into consideration as a reference to compare the obtained results. According to this model, magnet is considered as a set of distribution of equivalent "magnetic charge" [8].

Expressions are presented in three dimensions, nevertheless they will be customized to fit two dimensions model.

Considering magnet having two surfaces, expressions of the magnetic induction will be separated based on top (Z=0) and the bottom (Z=L).

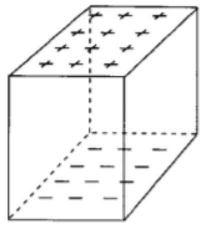

Fig. 3. Rectangular magnet: equivalent Charge model.

5.2.Formulation

For the top surface of the magnet (z=0), B(Z) is:

$$\mathbf{B_z}(z) = (\boldsymbol{\mu_0} * \mathbf{M_s}/\boldsymbol{\pi}) * [\frac{\pi}{2} - \frac{\tan^{-1} z * \sqrt[2]{a^2+b^2+z^2}}{a*b}) \quad (19)$$

For the bottom of the magnet (Z=L),B(Z) is:

$$\mathbf{B_z}(\mathbf{z}) = (\boldsymbol{\mu_0} * \mathbf{M_s}/\boldsymbol{\pi}) * [\frac{\tan^{-1}(z+l) * \sqrt[2]{a^2+b^2+z(z+l)^2}}{\mathbf{a*b}} - \frac{\tan^{-1} z * \sqrt[2]{a^2+b^2+z^2}}{a*b}) \quad (20)$$

a and b are the length and the width of the magnet
Z is the distance between the magnet and the particle.
Ms: Magnetization of the magnet

6. Simulation and computing

6.1.Case 1:comparing the magnetic potential

6.1.1. Introduction

To create a model of the permanent magnet. FEMM was used with the following data:

2a = 2 mm
2b = 2mm
L = 1 mm
Br = 1.4T according to Y.

Both Femm [9] and Marc were used to compute the magnet, yet only Marc's results were taken into consideration, as it allows more precision and variation of results based on the orientation of the magnetization.

https://doi.org/10.1051/e3sconf/202128007013

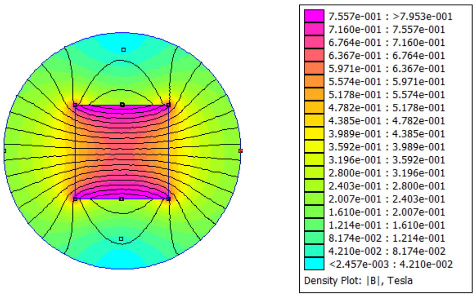

Fig. 4. Computation of magnetic induction flux -Femm.

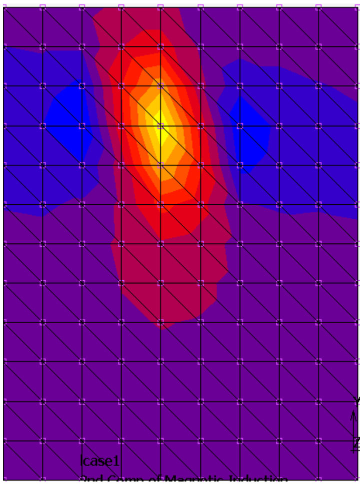

Fig. 5. Computation of magnetic induction flux -MARC.

6.1.2. Results

Fig 4 and 5 visualize flux lines of the magnet. As it can be seen, flux lines tend to reach the terminal and the pole spacing.

Fig. 6 shows the results of the variation of nodal magnetic vector potential obtained by the Marc and MATLAB methods for 36 nodes. As it can be seen, the difference between the two curves is hardly perceptible, because the estimated margin of error for Marc is less than 3%. As stated in its official publication [10] and it can therefore be considered identical to the results given by MATLAB.

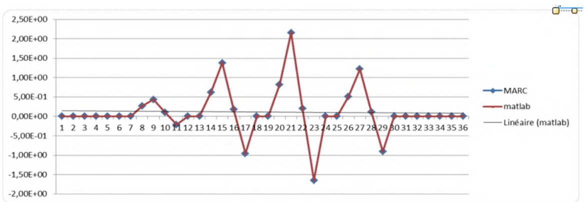

Fig. 6. Values of vector potential for 36 nodes. Node 21 present the maximum value of vector potential, afterword's the values start decreasing.

The table below N "1" helps understanding variation of values of vector potential generated by the magnet following Y direction.

Nodes are taking following Y direction. It is clear that as the distance from the magnet increases, the values of the potential vector drop decrease.

As the magnetic vector potential can be interpreted as potential energy per unit element of current, so direction of vector potential will determine the needed energy required by magnet to create an attraction force with the particle (fig 7)

Table 1. Values of potential vector.

NODE	MARC	MATLAB
19	2,05E-10	0
20	0,821356	0,8214
21	2,15875	2,1588

As it can see in "fig 6 and 7", the difference between both results is hardly perceptible. Error margin is less than 6%, this part of the program can be considered validated.

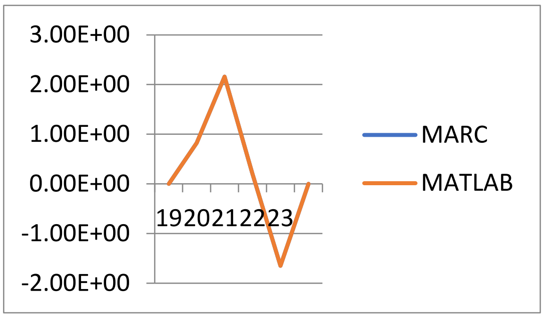

Fig. 7. Variation of vector potential.

6.2.Case 2: comparing magnetic induction

For this case, same data as the first example will be used to calculate the external magnetic induction generated by the magnet.

Table below "2" illustrate values of magnetic induction starting from the outer surface of the magnet to the location of the particle.

The analogy between values of vector potential and magnetic induction is very similar. Once Again, the more the distance from the magnet increases, the more the magnetic induction values decrease.

To validate the programme, an analytical calculation has been developed. Figure 8 shows that the values can be considered almost identical for the first two values, which is logical given the change of medium between the magnet and the air.

Table 2. Variation of magnetic induction.

No	B(Z) Analytical model (T)	B(Z) by Matlab (T)
0.0000	0.1470	0.15170
1.0000	0.0693	0.07146
2.0000	0.0298	0.03073
3.0000	0.0141	0.01451
4.0000	0.0071	0.00730
5.0000	0.0037	0.00380
6.0000	0.0019	0.00190
7.0000	0.0008	0.00080
8.0000	0.0003	0.00029

 https://doi.org/10.1051/e3sconf/202128007013

The understanding of the behaviour of magnetic induction outside the magnet is a major factor in the choice of magnet material. This means that each magnet has a unique internal energy and induction field range.

6.3.Case 3: distance choice between particle feeds and magnet based on force index.

Following this case, impact of burden on force induction will be explored. Likewise, same data will be taken into consideration .As for the particle data:

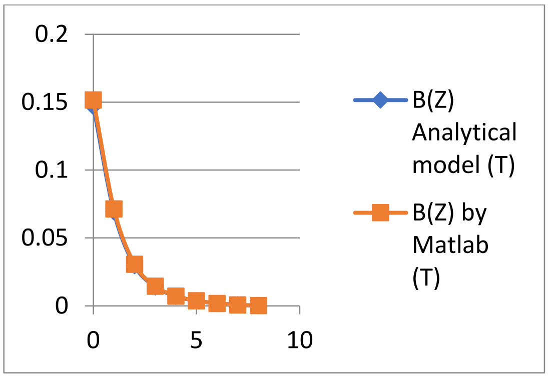

Fig. 8 Variation of magnetic induction.

- µp=1000
- ϱP= 7800 Kg/M^3
- Pb= 800 Kg/M^3
- Φ= 10 mm
- N= 0,33
- G=9,8
- µ0= 4∏ 10^(-7)

In general, “burden” is a material with a different permeability covering the ferromagnetic particle required to be separated (figure 9).

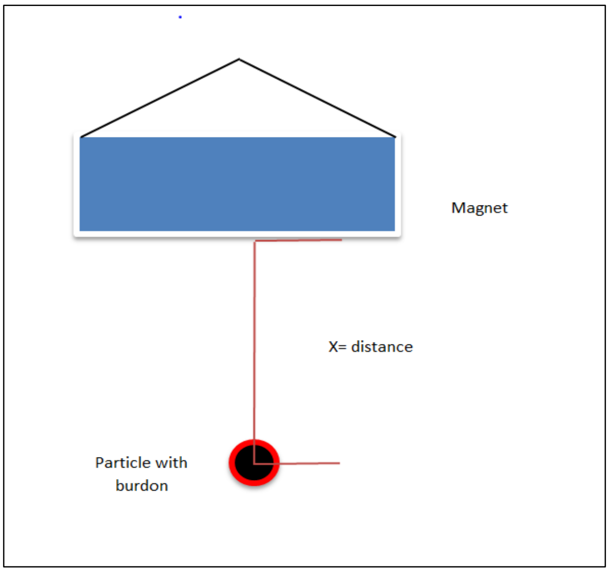

Fig. 9. Separation with burden.

Force index required to achieve the separation is:

- without burden : fm= 0,0318 T^2/m
- with burden : fm= 0,0374 T^2/m

As it can be seen, force index required to attract a particle covered by burden is more important than the value required for a particle alone.

SvoBoda in his work [1], explained explicitly the impact of the burden on the required force index depending on the dimensions of the burden. Force index increases steeply with increasing depth of the burden .

He stated also that force index depends solely on the shape of the particle size and not on its geometry, like it’s the case with the magnetic force.

Therefore, this factor must be taken seriously during the separator design process to get precise data.

By considering results of magnetic induction in case 2, the optimum distance between the magnet and the particle feed should me 1 mm to achieve a field gradient superior than 0,037^2 required to achieve the value of force index.

The further we get from the magnet, the more force index is required to achieve the separation process. Consequently, the bigger the magnet dimensions should be.

When dealing with real process, it is essential to take into consideration the distance between the suspended magnet and the conveyor band including the feed as one of the main factor for the magnetic separator choice to get the optimum design.

7. Conclusion

A finite element program for calculation of the force index is presented. Numerical simulation of the vector potential, magnetic induction and force index have been carried out in 2D Cartesian form.

This program can be used for modelling the permanent suspended magnetic separation and analyse the behaviour of different flux.As it was shown in case 1 and 2.

It can also be used to assist in the design phase of the separator to obtain optimal dimensions while simulating its force index behaviour towards the magnetised particle under different circumstances as it was shown in case 3.

Given the impact of the burden surrounding the particle on the required force index, as it was shown in case 3, most of separator designers, take into consideration this factor .As the force index required increases depending on the burden’s volume.

The logic to elaborate the force index has been presented following the different stages of the program. Starting with the vector potential and ending with the calculation of the induction field gradient.

The program allows to communicate the results of each step of the simulation and to compare them with the analytical results as presented above (cases 1-3).

The results showed that the estimated error between computed and analytical values is between 3% and 6 %

In addition to all the features of this program, it can Also interact with different platforms to allow calculus for large numbers of nodes (ex 13000 Nodes).

Furthermore, duo to its subprogram function section, the program allows a quick switch to a different type of elements and give the possibility to compare results for each simulation.

It worth mentioning also that although the used approach has been applied to a rectangular magnet, it's equally applicable to the analysis of the magnetic field and force index a calculation of a cylindrical magnet, by taking into account the correct formulas.

This allows for the program to cover more types of magnetic separators and to help better understanding the real process of separation.

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10. *Electromagnetic analysis* (Marc tutorial)

Plant secondary metabolites as bioactive substances for innovative biotechnologies

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Abstract. Plants are natural sources of bioactive compounds, and the intensive use of wild plants to obtain them, in particular secondary metabolites, depletes natural biocenoses. Instead, modern biotechnological methods, especially cell and tissue culture in vitro, make it possible to get environmentally friendly, highly productive plant raw materials that are able to synthesize and accumulate specialized substances, which are valuable for pharmacology, cosmetology, and medicine. Regenerating in vitro-plants of different plant species such as Acorus calamus L., Phalaenopsis sp. were obtained in our research. It was proved that by changing the cultivation conditions it is possible to change the content of substances of secondary metabolites in explants and in the nutrient medium under aseptic culture.

1 Introduction

Constant changes in environmental conditions necessitate changes in the biochemical and physiological processes of all living organisms in order to increase their adaptive capacity. Numerous mechanisms of adaptation to the action of abiotic, biotic and anthropogenic factors specify unique properties of plants. Plants synthesize hundreds of thousands of organic compounds, which are divided into three main groups. The first group includes primary metabolites − compounds that are directly required for plant growth. The second one − phytohormones, which perform a regulatory function in the plant body and metabolism in general. To the third group, scientists attribute organic substances with relatively low molecular and high biological activity, namely substances of specialized metabolism. The other name for this group of substances is secondary metabolites [1, 2].

As early as the XX-th century, Nobel laureate in physiology and medicine, Albrecht Kossel firstly introduced the term «secondary metabolite», and Chapek described this kind type of substances as the final products of metabolism. Further development of science − the emergence of new research methods in molecular biology, biochemistry, physiology helped to establish that secondary metabolites play several roles in the growth and development of the plant organism, and are also synthesized in response to various stressors [3].

Plant tissues and organs synthesized a huge variety of compounds of secondary origin. Primary metabolites are formed in the cells of all plant species, but specialized substances may be unique to individual species. The plant usually synthesizes a complex of such substances, the individual components of which have an additional and enhancing effect on more than one molecular target. Secondary metabolism originates from different primary pathways, which indicates changes in the activity of enzymes of main metabolism during evolution. As a result of such changes, completely new compounds were formed that increased the plant resistance to the factors of a certain environment and the gradual transformation of primary compounds into specialized metabolites [4].

Scientists classify secondary metabolites by type of their chemical structure into the following classes:

- alkaloids;
- isoprenoids;
- saponins;
- glycosides;
- phenolic compounds etc.

Each of these groups includes from units to several hundred or thousands of individual compounds. Their chemical structure determines the specificity of the functions of such substances. For example, plants can synthesize secondary metabolites to protect itself against various pathogens (viruses, bacteria, fungi, etc.) or to neutralize toxic products of primary metabolism. Interestingly, some secondary compounds largely determine the nutritional and taste qualities of various plant products. All the plants' properties for the formation of multifunctional organic compounds with various properties helps to produse body care products, immune support, a great use in medicine (for example, as analgesics, antioxidants, blood pressure normalizers, etc.), use as food supplements, bioindications, and other [5,6].

1.1 Plant phenolic compounds

Phenolic compounds are included to one of the most diverse and numerous classes of secondary metabolites of the aromatic series, characterized by the presence of a benzene ring consisting of six Carbon atoms (C_6); and one or more hydroxyl groups (OH). The classification of phenols is based on determining the number of Carbon atoms and aromatic rings in molecules (from one or two benzene rings to many – polyphenols). Depending on the chemical structure and properties are distinguished [7]:

- simple phenols;
- coumarins;
- tannins;
- flavonoids;
- xanthones;
- chromones;
- stilbenes;
- lignans.

In the plant body, the phenolic substances synthesis occurs with the involvement of enzymes of the three main ways of transformation of aminoacid phenylalanine:

- polyketide pathway (elongated side chains of phenylpropanoids, flavonoids are formed ($C_6 - C_3 - C_6$);
- shikimatic pathway (synthesis of phenyl-propanoid derivatives ($C_6 - C_3$));
- acetate-mevalonate pathway (formation of aromatic terpenoids, in particular monoterpenes).

Natural phenols are synthesized and accumulated in all plant organs, for example in members of the *Orchidaceae*, *Theaceae*, *Gentianaceae* and other families, the content of which is 2-3% of the total mass of organic matter of plants, in some cases can reach 10% or more. These compounds have a strong effect on plant growth, elongation of stems and roots, inhibiting seed germination, play an important role in wound healing, cell division [8,9].

Phenolic compounds determine the color of leaves, flowers, fruits. They are also involved in the growth and reproduction of plants involved in the mechanisms of protection against ultraviolet radiation (UV-light), infection with pathogenic microorganisms, parasites or from being eaten by animals, and so on. Phenolic substances are synthesized when the plant cell receptors recognize potential pathogens by preserved pathogenic-associated molecular features, which leads to a response to a biological stimulus. Therefore, the development of infection is limited long before the spread of the pathogen throughout the body. They are also part of plant foods and beverages, such as vegetables, fruits, cereals, legumes, chocolate, tea, coffee and others. In addition, phenolic compounds determine the healing properties of plants, making them extremely valuable for cosmetology, pharmacology and medicine. The study of the content of certain phenols gives grounds to distinguish between plant species, i.e. to use as a marker for molecular taxonomy [10].

1.2 Sources of xanthones phenolic compounds

Xanthones are heterocyclic compounds belonging to secondary metabolites, namely polyphenolic substances with the molecular formula $C_{13}H_8O_2$. Xanthones have been studied since the early 1900's and it has been established that the natural sources of these compounds are plants, as well as fungi, lichens and even bacteria.

The classification of these polyphenols is based on the number of benzene rings, as well as the type, number and position of substituents. The biosynthesis of plant xanthones occurs by converting shikimic acid with the formation of aromatic rings, and acetate – in the pirone ring. These substances are derivatives of diphenylketone and the simplest formula of the xanthone molecule has the form (Fig. 1) [11,12].

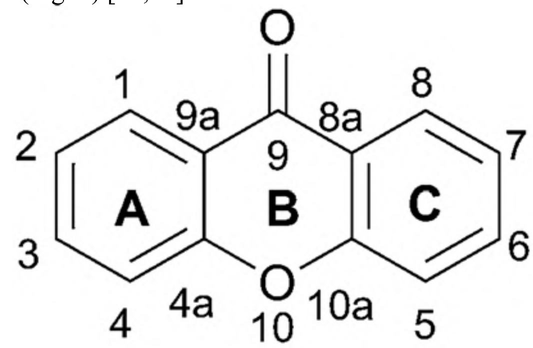

Fig. 1. Formula of xanthone with numbers of Carbon atoms

Xanthones isolated from natural sources are classified into 6 main groups:

- simple xanthones;
- xanthone glycosides;
- prenylated xanthones,
- xanthanolignoids;
- bixanthones;
- mixed xanthones.

From ancient times to the present days, people use plants in folk and conservative medicine as a source of bioactive substances for the prevention and treatment of various diseases. It has been experimentally proven that these secondary metabolites act as lipid peroxidation inhibitors, metal chelators, free radical scavengers, ie as antioxidants. Thus carry out hepatoprotective, anti-inflammatory action and prevent the development of cancerous tumors. As for the representatives of phenolic compounds, xanthones are characterized by other medicinal properties, namely: antiviral, antibacterial, antifungal, etc. [13,14].

Especially well-known plant sources of these polyphenols are representatives of the following plant families: *Moraceae*, *Polygalaceae*, *Gentianaceae*, *Hypericaceae*, *Iridaceae*, *Asparagaceae* and others. That is why these plants are very valuable for the pharmaceutical industry and there is a need for alternative methods of obtaining plant raw materials with advanced modern biotechnological measures [15-18].

1.3 Sources of flavonoids phenolic compounds

Flavonoids are another group of polyphenolic compounds that have the general formula $C_6 - C_3 - C_6$. They are also classified by the number of benzene rings and the type of substitution into the following main groups:

- halcones;
- catechins;

- flavonols;
- flavonones;
- anthocyanins;
- isoflavones;
- proanthocyanidins.

Natural flavonoid sources are algae, mosses, horsetails, ferns, as well as gymnosperms and angiosperms. Among the angiosperms representatives are the families *Lamiaceae*, *Rosaceae*, *Fabaceae* and others can be mentioned, which synthesize flavonoids different in structure and properties. Flavonoids are accumulated in leaves, roots, fruits, seeds of plants. Like other phenolic compounds, they are derivatives of phenylalanine and malonyl-CoA. One molecule of flavonoid compound consists of two phenyl residues A and B combined with a propane link, which can close in an oxygen-containing heterocycle C (Fig. 2) [19-21].

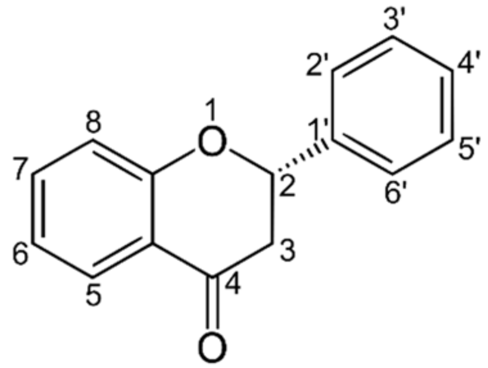

Fig. 2. Formula of flavonoid with numbers of Carbon atoms.

Flavonoids are plant pigments that also play an important role in increasing the plant resistance to stress factors. In addition, they help determine the quality of food, acting as preservatives and have strong antioxidant, anti-inflammatory, antimutagenic and anticancer properties. These polyphenols can modulate key functions of cellular enzymes. Due to these properties, plants containing flavonoids are also used in the manufacture of medicaments, as well as nutraceutical, pharmaceutical, medical and cosmetic applications [22,23].

1.4 Biotechnological importance of secondary metabolites of plants

Due to the increased need in the use of unique in structure and properties of substances of specialized synthesis, the volume of extraction of plants-sources of secondary metabolites from natural sites is increasing, resulting in reduced biodiversity of natural phytocenoses. It also leads to a decrease in the number of individual plant species, which are becoming rare and some even endangered. Instead, the development of plant biotechnology allows it to be used as a raw material for the extraction of valuable compounds not only from wild or artificially grown plants, but also from microclonal propagation and culture of plant cells, tissues and organs *in vitro*. The use of these cultivation methods opens up the possibility of regulated synthesis of bioactive secondary metabolites, genetic transformation in order to obtain more productive regenerating plants, while preserving their natural sources. Regulation of the formation of valuable substances is carried out by selecting the composition of nutrient media, lighting, temperature under which plants are cultivated [24].

Growing plants in controlled conditions on artificial nutrient media allows to obtain plant biomass in almost unlimited quantities, which is actually used as a source of valuable metabolites. Plant raw materials obtained in this way are environmentally friendly, not contaminated with chemical fertilizers, pesticides, herbicides, radioactive isotopes, heavy metals and the like. The use of cell cultures and painstaking selection work made it possible to get a wide range of bioactive substances (xanthones, terpenoids, alkaloids, glycosides, etc.) of plant origin both on a laboratory and industrial scale. Examples of applications of this technology are:

- cloning of plants;
- obtaining cell cultures of different types (meristem culture, callus production);
- cultivation of individual plant organs (lateral or apical buds, anthers, «hairy roots»);
- suspension cultures;
- bioreactors, etc.

The intensity of the process of formation of bioactive metabolites *in vitro* is influenced by: plant growth regulators; mineral composition of the nutrient medium; carbohydrate nutrition of explants; physical factors, such as light intensity and wavelength, artificial selection of producer cells. Thus obtained bioactive substances are widely used in pharmacological, medical, food, cosmetic and other industries for the production of goods to improve the quality of life and treatment [25,26].

That is why the aim of our research was to study different species of plants grown under aseptic conditions, callus production, as well as the use of nutrient media as additional environmentally friendly sources of pharmacologically valuable secondary metabolites. Growing plants in controlled conditions on artificial nutrient media allows to obtain plant biomass in almost unlimited quantities, which is actually used as a source of valuable metabolites.

2 Materials and methods

Cultivation material was obtained by different plant species microclonal propagation under aseptic culture conditions. Then cloned plants were grown *in vitro* for 3-5 months at 24 °C, 16-hour photoperiod on a modified agar nutrient medium Murassige-Skuga [27]. The chemical composition of the used nutrient medium:

- standart Murazige-Skuga nutrient medium (mix of micro- and macroelements) (Sigma, Germany);
- mesoinozit (China);
- composition of vitamins (LLC UKRCHIMEXPO, Ukraine): B_1 (thiamine), B_6 (pyridoxine), C (ascorbic acid), PP (nicotinic acid);
- Fe_2SO_4 (LLC «UKRCHIMEXPO», Ukraine);
- sucrose (LLC «UKRCHIMEXPO», Ukraine);
- agar (Spain);
- composition of plant growth regulators (Sigma, Germany): indolyl acetic acid, kinetin;

- casein hydrolyzate (Sigma, Germany) and yeast extract (LLC «UKRCHIMEXPO», Ukraine) were added to the nutrient medium prepeared fot *Phalaenopsis sp*.

The agar medium was also used as a source of bioactive substances. *In vitro* cultivation of plants was carried out in the research laboratory «Introduced and natural phytodiversity» of O. V. Fomin Botanical Garden of Taras Shevchenko National University of Kyiv.

Plant material and nutrient medium were quantitatively analyzed according to generally accepted methods: 96% ethanol solution was used for extraction and spectrophotometric analysis of phenolic compounds. Determination of the total content of phenolic compounds was performed using Folin-Chekolte reagent [28, 29], and the content of flavonoids − 0.2% solution of nitrate crystal hydrate of zirconyl chloride (IV) and rutin as a standard (with modifications) [30].

The content of xanthones determined chromatographically with UV-light identification of spots (at λ = 200-400 nm) by our own modification. According to the literature, the extraction of xanthones from plant material involves the use of solutions of toxic polar solvents of high concentration (70-96%): methanol, hexane, chloroform, butanol, ethylacetate or their different mixtures with 96% ethanol [31-33]. Hence, the presence of such solvents requires pre-purification of the extracts for further use in the analysis. Our modifications of the xanthone extraction method concerned the replacement of such a kind of solvents with environmentally friendly ethanol (DKP Pharmaceutical Factory LLC, Ukraine) only: 70% solution − for the extraction and 60% solution − for spectrophotometric analysis of xanthone content.

The approbation of methods covered in the literature, we noticed that repeated filtration (3-4 times) of extracts [34] instead of increasing the accuracy of the analysis, led to significant losses of the amount of test solution, which was absorbed by the filter components and it was difficult to drain the sediment. Accordingly, we noticed a negative effect on the accuracy of quantitative analysis. For that reason, we changed the extracton to one stage of 3 hours duration. The chromatographic analysis involved the use of 40% acetic acid (LLC «UKRCHIMEXPO», Ukraine) − as a mobile phase for separation the xanthones from other phenolic compounds.

The secondary metabolites content analisis in the nuriant medium is insufficiently mentioned in scientific papers only in liquid and suspension cultural medium but not in agar medium [35]. Therefore, we extracted secondary metabolites from agar medium by our own method using a low temperature staining a 70% ethanol solution, followed by centrifugation to remove rasidual particles of the agar medium [36]. The secondary metabolites content analisis of the medium was done by the same method as for the *in vitro*-plants. All extracts from plant material and nutrient medium were analyzed spectrophotometrically (SF SHIMADZU UV – 1800, Japan).

Biochemical analysis of plant material and samples of nutrient medium was carried out in the laboratory «Physiological basis of plant productivity» of the Department of Plant Biology at the Educational-Scientific Center «Institute of Biology and Medicine» of Taras Taras Shevchenko National University of Kyiv.

Our experiment was performed in triplicate, results − statistically processed according to conventional methods using the standard program Microsoft Office Excel. In preparing, the method analyzed the average data obtained, the differences between which considered significant by Student's criterion (at $P \leq 0.05$).

3 Results and discussion

As a sourse of bioactive compounds, we used different types of plants. The explants of plants of the families *Orchidaceae* (Fig. 3a) [37] and *Acoraceae* (source plant material belonged to different localities formed in 2 groups for the experiment) (Fig. 3b) were obtained [38].


a)


b)

Fig. 3. *In vitro*-regenerated plants of *Phalaenopsis sp.* (a) and *Acorus calamus* L. (b)

Quantitative analysis of secondary metabolites content (total phenolic content) showed a steady increase in the content of phenolic in the nutrient medium used for cultivation of *Acorus calamus* L. (by around 30 %) (Fig. 4).

It was also described the differences in phenolic compounds content in explants of the same plant during the experiment: increasing by 2 times in explants of Group 1 in leaves and roots (Fig. 5a) and of Group 2 − only in leaves (Fig. 5b).

The obtained data on the flavonoid content in explants of *A. calamus* indicate a changing of their concentration during the experiment and aslo depending on the part of the explants: decreased in explants of Group 1 (Fig. 6), increased in explants of Group 2 (Fig. 7).

We also identified variations in chemical composition xanthones depending on the type of the explant. As an example, *A. calamus* explants of both groups syntesized and accumulated only one type of xanthones – swerchirin. There were also differences in xanthone content among the explants of two different localitets of *A. calamus.*

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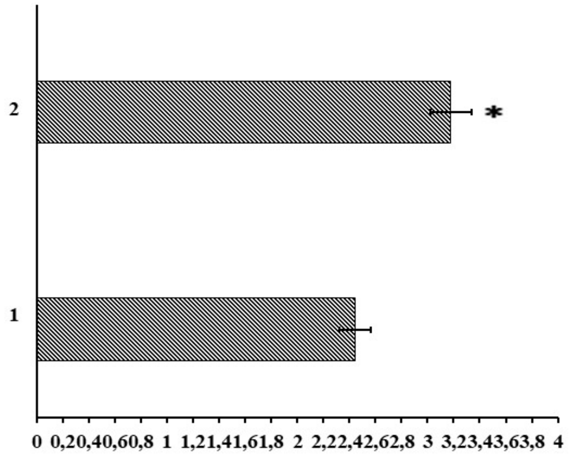
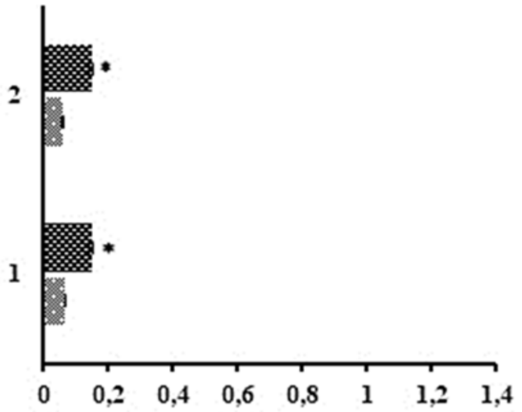
Group 1 of explants accumulated compounds in leaves and roots (Fig. 8).

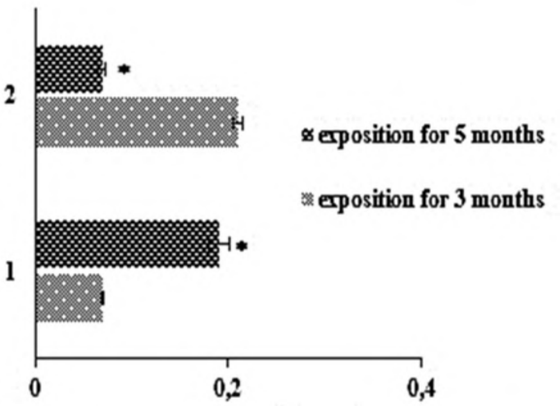


Content of phenolic compounds, mg/g

Fig. 4. Content of phenolic compounds in the nutrient medium used for cultivation of *A. calamus*, mg/g by DMW (significant at P ≤ 0,05): 1) exposition for 3 months, 2) exposition for 5 months.



a) **Content of phenolic compounds, mg/g**



b) **Content of phenolic compounds, mg/g**

Fig. 5. Content of phenolic compounds in explants of *A. calamus* L., mg/g by DMW (significant at P ≤ 0,05): a) Group 1, b) Group2, 1) in leaves, 2) in roots

However, explants of Group 2 acumulated swerchirin only in leaves and lost the starting amount of these compound in roots (almost by 50%) during the experiment (Fig. 9).

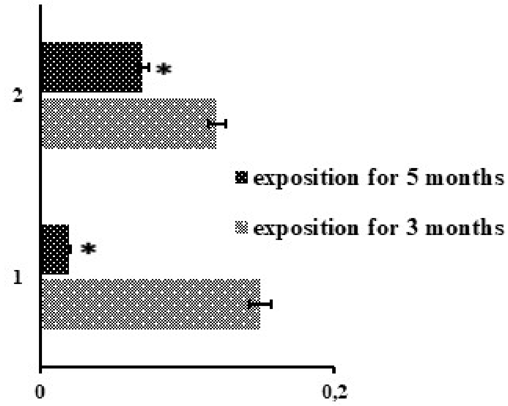


Fig. 6. Content flavonoids in explants of *A. calamus* L. (Group 1), mg/g by DMW (significant at P ≤ 0,05): 1) in leaves, 2) in roots

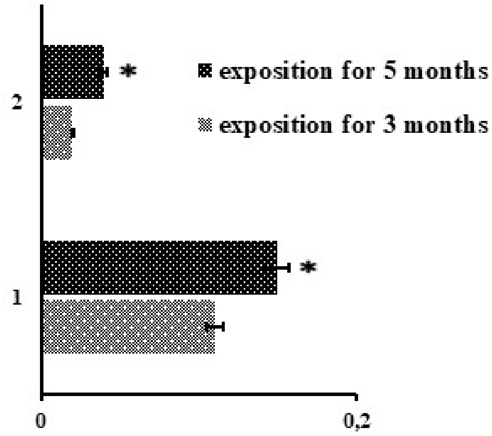
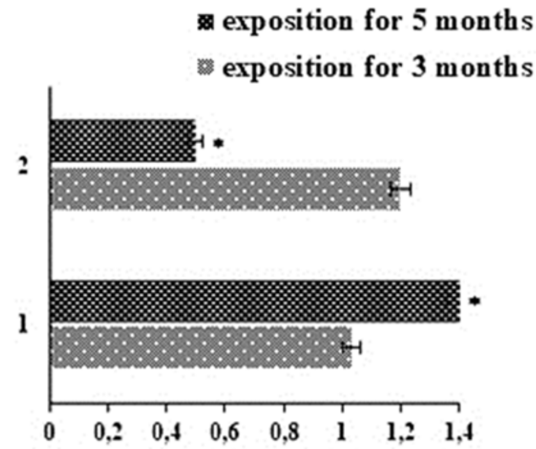


Fig. 7. Content flavonoids in explants of *A. calamus* L. (Group 2), mg/g by DMW (significant at P ≤ 0,05): 1) in leaves, 2) in roots



Content of swerchirin, %

Fig. 8. Content of swerchirin in explants of *A. calamus* (Group 1), % by RMW (significant at P ≤ 0,05): 1) in leaves, 2) in roots

The amount of xanthones in the nutrient medium decreased significantly over the same period of time, and the content of flavonoids was too low to be detected by a quantative analysis We also identified a different composition of xanthones depending on localities of explants that were cultivated on this medium (Fig. 10 and Fig. 11).

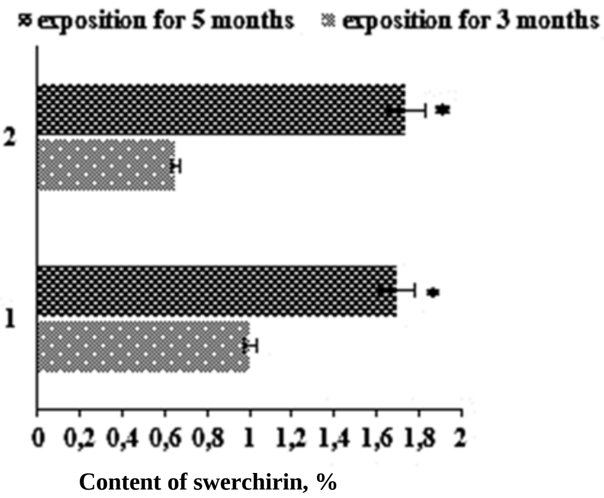


Fig. 9. Content of swerchirin in explants of *A. calamus* (Group 2), % by RMW (significant at P ≤ 0,05): 1) in leaves, 2) in roots

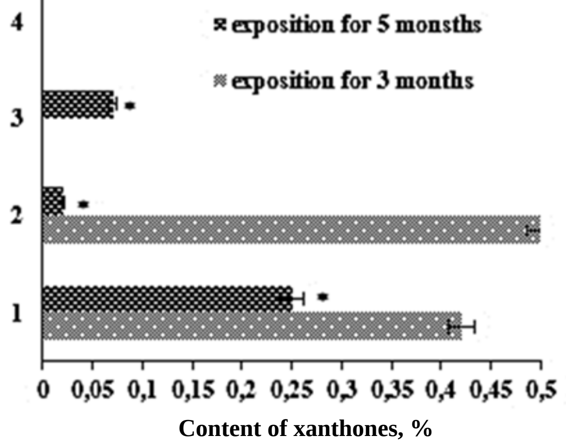


Fig. 10. Content of xanthones in the nutrient medium used for cultivation of *A. calamus* (Group 1), % by RMW (significant at P ≤ 0,05): 1) 1-hydroxy-2,3,5-trimethoxyxanthone, 2) mangostenone A, 4) swerchirin

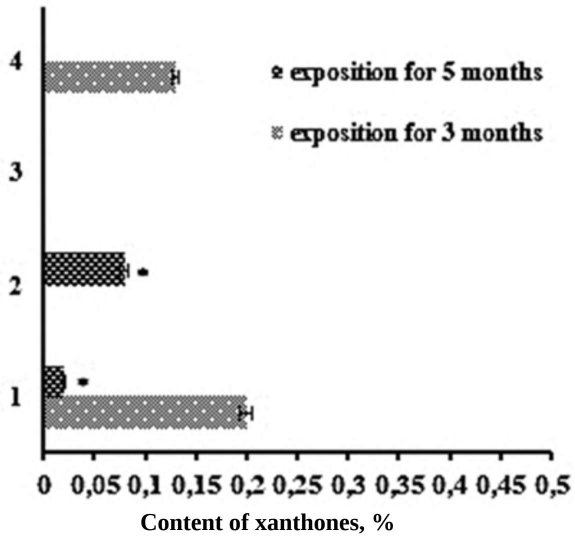


Fig. 11. Content of xanthones in the nutrient medium used for cultivation of *A. calamus* (Group 2), % by RMW (significant at P ≤ 0,05): 1) 1-hydroxy-2,3,5-trimethoxyxanthone, 2) mangostenone A, 4) swerchirin

In contrast, *Phalaenopsis sp*. explants contained different xanthones: 1-hydroxy-2,3,5-trimethoxyxanthone, decussatin, swertiaperennin, swerchirin, α-mangostin (Fig. 12).

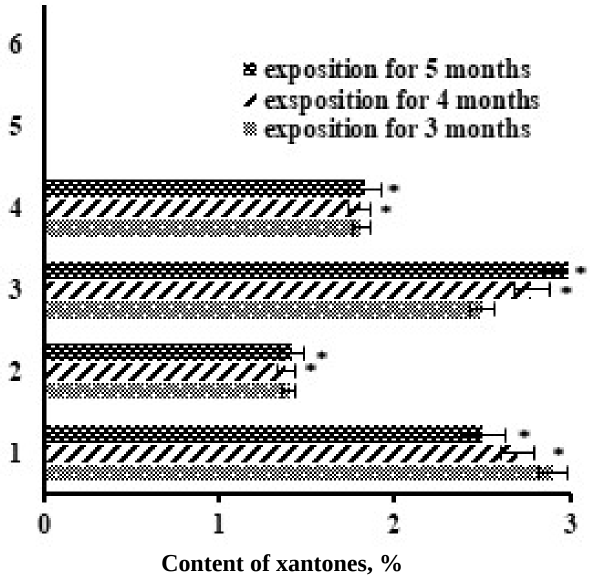


Fig. 12. Content of xanthones in explants of *Plalenopsis sp.*, % by RMW (significant at P ≤ 0,05): 1) 1-hydroxy-2,3,5-trimethoxyxanthone, 2) decussatin, 3) swertiaperennin, 4) α-mangostin 5) mangostenone A, 6) swerchirin.

The nutrient medium used for cultivation of *Plalenopsis sp.* explants contained decusatin, α-mangostin, mangostenone A and swerchirin (Fig. 13).

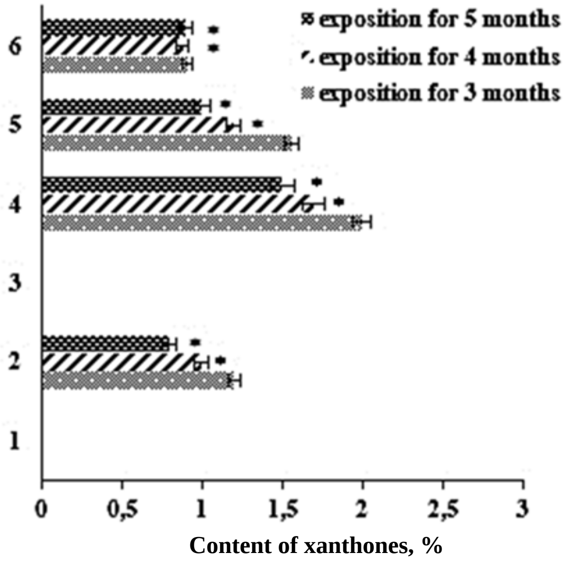


Fig. 13. Content of xanthones in the nutrient medium used for cultivation of *Plalenopsis sp.* explants, % by RMW (significant at P ≤ 0,05): 1) 1-hydroxy-2,3,5-trimethoxyxanthone, 2) decussatin, 3) swertiaperennin, 4) α-mangostin 5) mangostenone A, 6) swerchirin

All plants grew under the same conditions, so we assume that the differences in the metabolites content could be caused by genetical factors that influenced

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biochemical and physiological features of experimental plant material and the agar nutrient medium.

Given that the changing conditions of plant cultivation (duration of exposure, type of explants, chemical composition of the living environment), it is possible to regulate the content of special metabolism substances.

4 Conclusion

The unique properties of plants to synthesize a wide range of bioactive substances, in particular compounds of secondary origin, makes it possible to use these natural resources. In order to preserve the biodiversity of natural biocenoses and extract the necessary substances, biotechnological methods are used, espesially plant cell, tissue and organ aceptic culture.

The results of our study fully confirm the data on the secondary metabolites extraction from the plant material and nutrient medium grown under *in vitro* conditions. It is also indicates the dependence of the synthesis of bioactive compounds on the species of plants, their origin and, accordingly, the type of explants obtained from them, as well as the exposure time and cultivation conditions.

We consider promising research of plants, cell cultures and various modifications in the chemical composition of the nutrient medium as environmentally friendly sources of pharmacologically valuable bioactive metabolites.

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Parameter analysis of non-metallic inclusion formation in thermite alloys

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Abstract. The methodology of calculating parameters of the primary and secondary non-metallic inclusion formation in thermite alloys is offered. The regularities of the growth time of non-metallic inclusion in the form of corundum depending on its size, mass and quantity are analysed. It is shown that in the thermite alloy obtained by self-propagating high-temperature synthesis, the average size of corundum inclusions, surrounding the heterogeneous inclusions of chromium carbide, is 15.4 μm. It is shown that during the process of aluminothermic reactions of the SHS process a significant number of small inclusions of corundum is formed. It is shown that the alumina particles are dissolved in the alloy and they are the centers of crystallization and play the role of inoculating modifier.

Introduction

Today, one of the main indicators of metal quality and, correspondingly, the quality of final products is the contamination of non-metallic inclusions, and both the number of inclusions and their nature and physicochemical composition matter [1]. It should be noted that special attention is paid to the role of fine non-metallic inclusions in the process of the microstructure forming of steel in liquid and solid states. It is shown that the influence of fine non-metallic inclusions on the formation of the primary and secondary microstructure of steel is due to their interaction in the liquid metal melt with clusters, as well as the action of both crystallization nuclei and inhibitors of growth of the primary crystals [2]. Non-metallic inclusions significantly reduce the technological and mechanical properties of steels, contributing to the formation of various defects. One of the ways to solve the important task to increase the strength and plasticity of steels is to reduce contamination by non-metallic inclusions, reduce their size, and ensure their even distribution. During the different influences, the diverse kinds of phase and structural rearrangements occur in non-metallic inclusions, which contributes to the size changes of inclusions, their phase and structural state modifications and undoubtedly affects the local areas of the steel matrix near non-metallic inclusions. The nature of these modifications can significantly change the adhesion bonds at the inclusion-matrix interfacial boundaries [3]. The problem of controlling non-metallic inclusions is based primarily on the estimation not only of the inclusion's total number, but also the inclusion's critical size, and the assessment of the compositions; the size-based distribution of inclusions [4].

One of the unsolved problems of the metallurgical processes theory is the reliable calculation of the mass, size, and composition of non-metallic inclusions in steel. There is a large array of experimental data on this topic, but the available theoretical developments can only claim to solve certain aspects of the problem for a few classes of non-metallic inclusions [5]. Thus, in [6, 7] there is a systems review of non-metallic inclusions FeO-MnO-SiO_2-Al_2O_3, which are most common in the practice of steelmaking.

In [3] the processes of steel destruction near non-metallic inclusions are analyzed and the peculiarities of the structure of inclusions as phases of introduction and their influence on the occurrence of the thermal and deformation stresses are discussed. The author shows the influence of the non-metallic inclusions nature on the mechanism of microdestruction formation in steel under the different deformation conditions; and also - inactive areas.

Based on Gibbs' method of chemical potentials, the thermodynamic relations, describing the origin and growth of non-metallic inclusions in steel, were obtained [8]. The influence of non-metallic inclusions on the properties and structure of the different types of steel is described in [9-16]. The influence of the morphology of non-metallic inclusions on the destruction of high-strength corrosion-resistant steel was carried out in [17]. The conditions for reducing the content of non-metallic inclusions, such as oxide and sulfide in corrosion-resistant nitrogen-containing steel, are considered in [18]. The authors in [19] proposed measures to reduce the size and number of non-metallic inclusions in the cord steel. They used the method of estimating non-metallic inclusions, which was developed by the author [20]. The share of the area occupied by non-metallic inclusions is one of the evaluation criteria.

The estimation of large single non-metallic inclusions in steel in accordance with the statistics of extreme values is given in [21].

The method for determining the mass of corundum inclusions in steel was proposed in [22]. In order to do this, the concentration of aluminum bound in oxides was found firstly:

$$[Al]_{oxigen} = [Al]_{general} \cdot 0{,}675. \quad (1)$$

Then, using the known molar mass of the elements in the formula of alumina, and knowing the mass of the metal in the ladle, the mass was determined:

$$m_{Al_2O_3} = \frac{[Al]_{oxigen} \cdot 1{,}89 M_{Me}}{100\%}. \quad (2)$$

Analysis of the impact of corundum inclusions on the mechanical and technological properties of steel shows the contradictory nature of research. Thus, the authors of [23] argue that the inclusion of corundum impairs the technological properties of steel, especially if they form clusters. And in [24] it was noted that corundum does not have a negative effect on technological plasticity, but on the contrary, even increases it, while cracks are usually formed in silicates.

On the example of simple carbides (M_6C, $M_{23}C_6$, M_3C, M_7C_3, M_2C and MS types) with the help of their crystal-chemical and thermodynamic analysis the influence and probability of phase transitions, in both liquid and solid steel under the thermal and thermoplastic influence, were evaluated in the work [25]. The study of the specifics of the influence of alloying elements on the composition of carbides of the MS and M23C6 types in the multicomponent Ni – 13.5Cr – 5Co – 3.4Al – 4.8Ti – 7.3W – 0.8Mo – 0.015B – 0.12C system was carried out in work [26].

In the work [27] the attention was paid to the study of the structure and properties of a wear-resistant alloy, based on cobalt with niobium carbide. The work [28] is devoted to the study of the regularities of combustion of powder and granular mixtures of Ti-C-Ni with the different mass fraction of Ni in the mixture and the analysis of synthesis products by the different methods. It is shown that the average grain size of carbide is 2-4 μm, which is an order of magnitude smaller than the original size of titanium particles (50 μm), i.e. during combustion is the so-called «self-dispersion» of titanium particles, and the nickel bond prevents the growth of titanium carbide synthesis.

The issue of predicting the release of carbidonitrides and carbides in microalloyed steel using thermodynamic calculations is disclosed in the work [29]. The calculation of the chemical composition and total mass of non-metallic inclusions in the course of out-of-furnace processing and casting of steel is given in the work [30]. The authors of the following work [30] found that the composition of inclusions in both deoxidized and non-deoxidized aluminum steel is well amenable to thermodynamic modeling taking into account the influence of slag and other factors, for example, the receipt of aluminum as an impurity in ferroalloys).

The above confirms the need to expand research in the field of studying the effect of non-metallic inclusions on the physicochemical properties and structure of steel.

The issue of calculating the parameters of formation of non-metallic inclusions is insufficiently studied, so it seems appropriate to propose a method of calculating the parameters of formation of non-metallic inclusions, as the primary as secondary in thermite alloys.

Results and discussion

It is known that in order to obtain a dense SHS-material with high physical and mechanical characteristics, it is necessary to take into account the patterns of combustion of the reaction mixture, the formation of chemical and phase compositions of the final product, the crystallization behavior of the alloy [31]. As it is noted in [32] during the formation of a thermite alloy layer of the Fe-Cr-C system on a metal-based SHS process, the layer formation zone is characterized by macrostructure stability and positive effect of oxidative nonmetallic inclusion in the form of corundum (as α-modifications of Al_2O_3). Corundum, creating the effect of inoculating modification of the thermite alloy, in turn, promotes the formation of chromium carbides in the resulting thermite alloy.

The total reaction, which determines the overall material balance of the process of forming a layer of thermite alloy in the SHS process, has the form [33]:

$$6(Fe_2O_3)_{sl}+6(Al)_{sl}+13(C)_{sl}+(Fe)_{sl}\rightarrow 9(CO)\uparrow+(C)\uparrow+$$
$$+(Fe)\uparrow+Fe_{Me}+3(Fe_3C)_{Me}+(Al_2O_3)_{Me}+2(Al_2O_3)_{sl}. \quad (3)$$

The reaction of formation of chromium carbides has the following form:

$$2(Cr)_{Me}+(C)_{Me} \rightarrow (Cr_2C)_{Me}. \quad (4)$$

In the formed layer of thermite alloy complex carbide phase contains 78.7% of the mass. Fe + 14.6% of the mass. Cr + 6.7% wt. C and/ is formed according to the reaction:

$$Fe_{Me}+3(Fe_3C)_{Me}+(Cr_2C)_{Me}\rightarrow Fe_{10}Cr_2C_2\rightarrow 2(Fe_5CrC). \quad (5)$$

The distribution of chemical elements of charge materials in the formation of a layer of thermite alloy based on iron, the SHS process is determined according to the method [33] from the material balance of the reaction (3):

$$\Sigma(3+4):\ 6(Fe_2O_3)_{sl}+6(Al)_{sl}+2(Cr)_{sl}+14(C)_{sl}\rightarrow 9(CO)\uparrow+$$
$$+(C)\uparrow+(Cr)\uparrow+(Fe)\uparrow+Fe_{Me}+3(Fe_3C)_{Me}+(Cr_2C)_{Me}+$$
$$+(Al_2O_3)_{Me}+2(Al_2O_3)_{sl}. \quad (6)$$

Due to the fact that the liquid phase of the thermite melt is stored on the metal surface of the casting for a short time (15-25 seconds), mixed in the formed functional layer corundum does not have time to affect the slag in full and affects the formation of metal structure.

According to [34], the formation of a new phase inside the melt begins with embryos. Embryos, as a new phase, can be formed when the melt is supersaturated with the components of the new phase.

If we imagine that the nuclei of the new phase are formed on the seed, we should take into account their higher solubility and higher melting point compared to the formed metal phase solid + liquid with larger crystals. Therefore, for further growth, the embryos of the new phase must exceed some critical size.

During aluminothermic reactions of the SHS process, a melt consisting of iron and aluminum oxides is formed firstly. If in the first approximation we accept the inclusion of critical size in the form of a spherical embryo, then to calculate the formation of the embryo from the melt, we can use the formula [34]:

$$r_k = \frac{2\sigma_{SL} \cdot M_r}{\rho RT \ln C_r / C}, \tag{7}$$

where r_k – critical radius of the embryo, cm; σ_{SL} – interfacial tension, erg/cm^2; $C_r/C=\alpha$ – melt supersaturation; M_r – molecular weight of non-metallic inclusion, g/mol; ρ – density of the chemical compound, kg/m^3; R – gas constant, which is equal to $8{,}3143 \cdot 10^7$ erg/mol; T – melting point of the compound, K.

The supersaturation of the melt for alumina is equal to:

$$\alpha_{Al_2O_3} = \frac{K_f}{K_{Al}} = \frac{[\%Al]_f^{\,n} \cdot [\%O]_f^{\,m}}{K_{Al}}, \tag{8}$$

where K_{Al} – equilibrium constant of aluminum; f– index indicating the actual concentrations of aluminum and oxygen dissolved in liquid iron.

According to the formula of alumina Al_2O_3, the values n = 2 and m = 3 are taken.

The maximum solubility of oxygen in liquid iron is 0.17%.

Determine the equilibrium constant for aluminum at a temperature of 1873 K according to the formula:

$$\lg K_{Al} = \frac{-64000}{1873} + 20{,}48.$$

Accordingly:

$$K_{Al} = 2{,}046 \cdot 10^{-14}.$$

$$\alpha_{Al_2O_3} = \frac{[30]_f^{\,2} \cdot [0{,}17]_f^{\,3}}{2{,}046 \cdot 10^{-14}} = 1{,}71 \cdot 10^{16}.$$

Let's accept for oxidative non-metallic inclusion in the form of Al_2O_3:

$$\sigma_{SL\ Al_2O_3} = 23373\ \ erg/cm, \ln \alpha_{Al_2O_3} = 37{,}377.$$

Substituting the obtained data, the critical radius of the embryo Al_2O_3 is equal to:

$$r_{k_{Al_2O_3}} = \frac{2 \cdot 2337 \cdot 102}{4 \cdot 8{,}3143 \cdot 10^7 \cdot 1873 \cdot 37{,}77} = 2{,}095 \cdot 10^{-8}\,cm.$$

Substituting the obtained data, the critical radius of the embryo Al_2O_3 is equal to:

Calculate the critical radius of chromium carbide inclusions (Cr_3C_2), taking the chromium content of 28% and the carbon content of iron in 4%.

Determine the equilibrium constant for chromium at a temperature of 1873 K according to the formula:

$$\lg K_{Cr} = \frac{-20260}{1873} + 7{,}357.$$

Therefore K_c=0.0316

The supersaturation of the melt for chromium carbide is equal to:

$$\alpha_{Cr_3C_2} = \frac{K_\phi}{K_{Cr}} = \frac{[\%Cr]_f^{\,n} \cdot [\%C]_f^{\,m}}{K_{Cr}}, \tag{9}$$

According to the formula of chromium carbide Cr_3C_2 values are n = 3 and m = 2.

Then we get:

$$\alpha_{Cr_3C_2} = \frac{[28]_f^{\,3} \cdot [4]_f^{\,2}}{0{,}0316} = 11114937,\ \ \ln \alpha_{Cr_3C_2} = 16{,}22.$$

To determine the interfacial tension of non-metallic inclusions should take into account their melting point. According to [34], we assume the melting temperatures of Al_2O_3 and Cr_3C_2 are equal to 2044 ^{0}C and 1895 ^{0}C, respectively. Calculate the interfacial tension for chromium carbide:

$$\sigma_{SL\ Cr_3C_2} = 3{,}328 T_m - 4416,$$

$$\sigma_{SL\ \ Cr_3C_2} = 3{,}328 \cdot 1895 - 4416 = 1890 \quad эрг/cm^2.$$

Substituting the obtained data, the critical radius of the embryo Cr_3C_2 is equal to:

$$r_{k_{Cr_3C_2}} = \frac{2 \cdot 1890 \cdot 180}{6{,}68 \cdot 8{,}3143 \cdot 10^7 \cdot 1873 \cdot 16{,}22} = 24{,}032 \cdot 10^{-8}\ \ cm.$$

The critical size of the non-metallic inclusion of Al_2O_3 is $3.85 \cdot 10^{-23}$ cm^3, and Cr_3C_2 - $2{,}746 \cdot 10^{-22}$ cm^3.

It should be noted that the probability of formation of the critical size of the embryo of non-metallic inclusion increases with decreasing its size and increasing the supersaturation of the melt [35]. Therefore, the probability of homogeneous nucleation of alumina inclusions is much higher than the inclusions of chromium carbide.

Chromium carbide inclusions are formed heterogeneously on oxidative inclusions of Al_2O_3 as on seeds. This statement is reflected in the macrostructure of the iron-based thermite alloy sample, where a significant number of carbide inclusions surround small crystalline inclusions, which were identified by the metallographic analysis as corundum inclusions (Fig. 1).

The metallographic analysis shows that the average size of corundum inclusions surrounding the heterogeneous chromium carbide inclusions is 15.4 μm ($1.54 \cdot 10^{-3}$ cm).

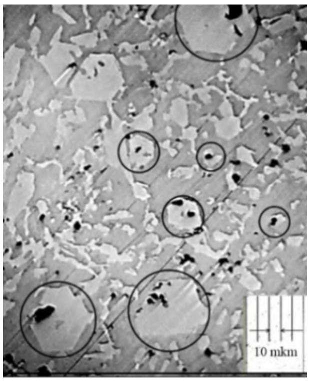

Fig. 1. Inclusion of corundum in the macrostructure of iron-based thermite alloy.

The nature of nonmetallic inclusions concentrated in a thermite alloy obtained by the SHS process on pure iron powder as a metal filler was investigated on undigested metallographic sections on an MIT-8 optical horizontal microscope (light field mode). Used iron powder by PZHRV brand 2.300.28 (GOST 9849-86) fraction <300 μm.

Analysis of the macrostructure of sample №1 showed that nonmetallic inclusions, probably of exogenous origin, are rare in the metal base (Fig. 2, a). Mostly disoriented oxides up to 5 μm in size were observed. The formed layer of thermite alloy presents globular and acute inclusions of Al_2O_3 (Fig. 2, b), which were identified as the primary inclusions that were not removed from the metal.

In sample №2 in the formed layer of the thermite alloy there are globular inclusions of pink color, which can be identified as iron oxides (Fig. 2, c). In the area close to the surface, there are elongated clusters of corundum inclusions, and exogenous slag inclusions of the products of the reaction of iron oxide with aluminum (Fig. 2, d). In sample №3 in the formed layer of thermite alloy there are accumulations of small inclusions of corundum (Fig. 2, e, f), inclusions of chromites (Fig. 2, g) (it should be assumed that chromium got into the thermite charge from rolled scale) and exogenous slag inclusions (Fig. 2, h).

To obtain a wear-resistant alloy was added to the thermite charge carburetor for carburization in the form of a modifier by MK91Abrand fraction up to 5 mm and chromium powder by PHA brand (GOST 14-00186482-051-2005) fraction 300 μm. Analyzing the macrostructure of the formed thermite alloy layer, it was determined that the carbide component predominates in the samples (Fig. 3).

In the process of alumothermic reactions of the SHS process, a significant number of small inclusions of corundum are formed, which serve as centers of crystallization in the formation of carbide inclusions and play an important role in the nucleation of chromium carbides.

It should be noted that taking into account the presence of metallic chromium in the initial charge during the formation of a layer of thermite alloy based on iron, which significantly reduces the final melt temperature, we assume it equal to 2000 ^{0}C, which is much lower than boiling temperature at atmospheric pressure of iron and aluminum.

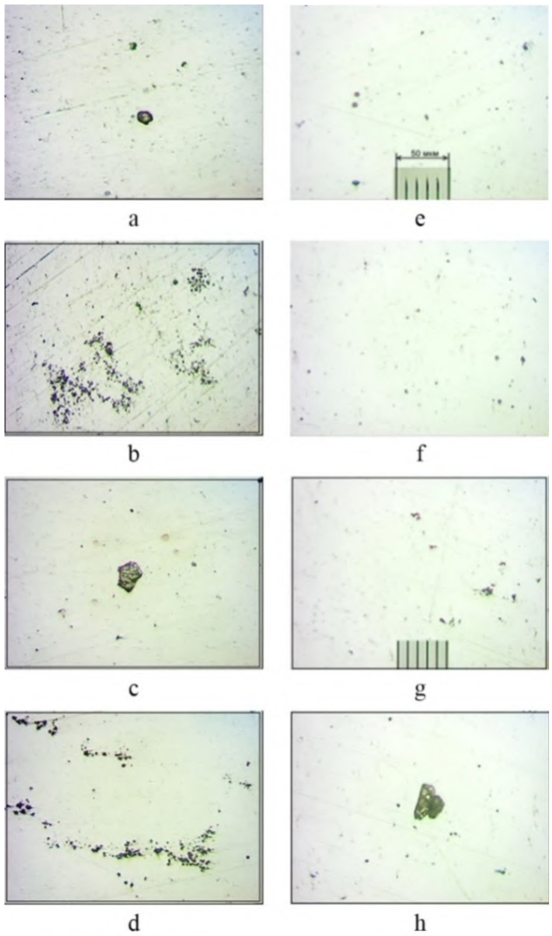

Fig. 2. Macrostructure of thermite alloy obtained by the SHS process on the pure iron powder of PZHRV brand 2.300.28.

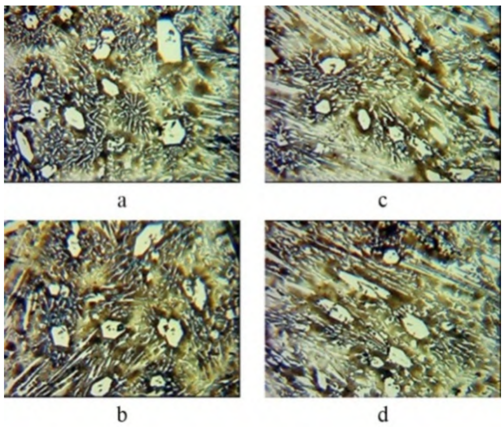

Fig. 3. Macrostructure of the thermite alloy obtained by the SHS process with the addition of PHA chromium powder: (a) –(d) - samples №1-№4 (with etching).

It is known that most of the aluminum is consumed in the process of aluminothermic reaction of the SHS process. According to the diagram of the state of the iron - aluminum part (Fig. 4), about 5% of aluminum dissolves in liquid iron at a temperature of 1536 ^{0}C.

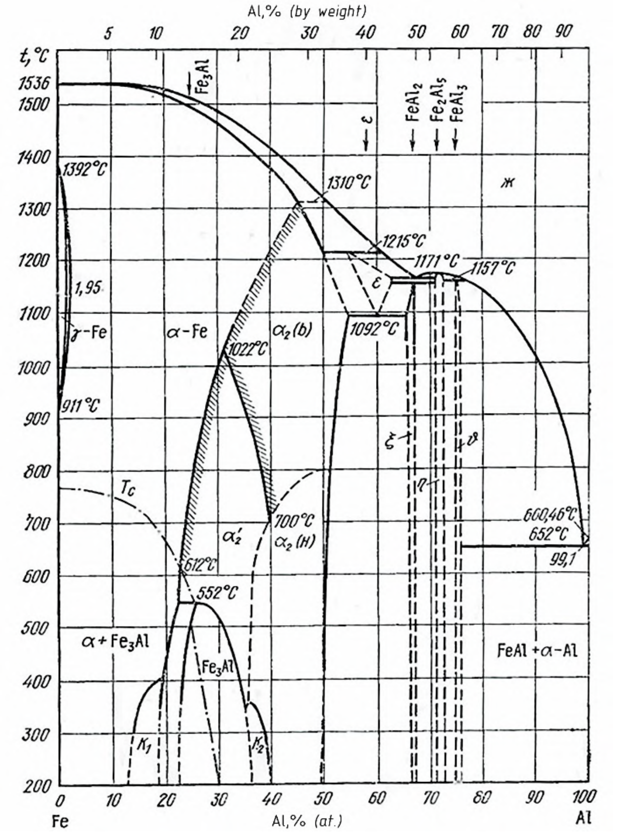

Fig. 4. State diagram of iron-aluminum [36].

Therefore, it seems appropriate to determine the supersaturation of the components that form non-metallic inclusions of corundum in the molten iron.

For the primary inclusions, the equilibrium constant according to the formula of Hoxen and Chipman [34] is:

$$\lg K_{\mathrm{Al}}^{\mathrm{pi}} = \lg(a_{Al}^2 a_O^3) = -\frac{64000}{T} + 20{,}48.$$

At the temperature of 1973 K it is equal to:

$$\lg K_{Al}^{pi} = -\frac{64000}{1973} + 20{,}48 = -11{,}96.$$

Therefore:

$$K_{Al}^{pi} = 10^{-12}.$$

According to the dependence of the solubility of oxygen in iron on temperature (Fig. 5), we assume the solubility of oxygen equal to 0.339% at a temperature of 1973 ^{0}C.

At a temperature of 1973 ^{0}C we take the solubility of oxygen equal to 0.339%.

According to formula (8), the supersaturation of the melt is equal to:

$$\alpha_{Al_2O_3}^{pi} = \frac{5^2 \cdot 0{,}339^3}{10^{-12}} = 9{,}74e^{11}.$$

According to formula (7), the critical radius of the embryo Al_2O_3 is equal to:

$$r_{\mathrm{k}\ Al_2O_3}^{\mathrm{pi}} = \frac{2 \cdot 2337 \cdot 102}{4 \cdot 8{,}3143 \cdot 10^7 \cdot 1973 \cdot \ln 9{,}74e^{11}} = 5{,}152e^{-6}\ cm.$$

When determining the number of the primary inclusions, we calculate for the mass of the formed layer of thermite alloy based on iron 100 kg.

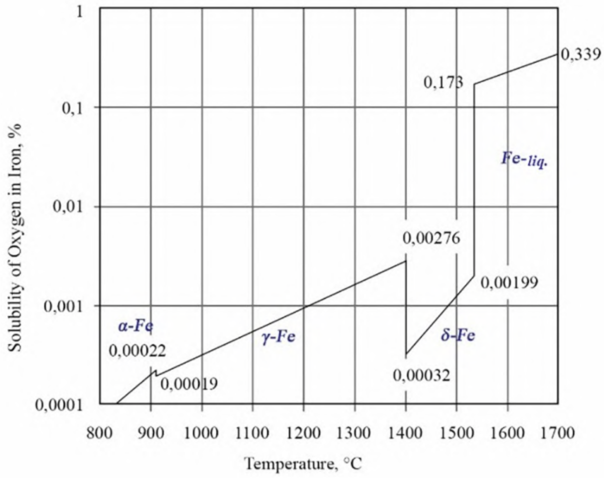

Fig. 5. Diagram of the solubility of oxygen in iron [37].

The density of the thermite alloy is 7.2 g/cm^3 and its volume is 13889 cm^3. The density of corundum inclusions is 4 g/cm^3.

The volume of non-metallic inclusion of the critical size is equal to:

$$V_{\mathrm{k}}^{\mathrm{pi}} = 4/3\pi r^3,\ V_k^{pi} = 4/3 \cdot 3{,}14 \cdot (5{,}152e^{-6})^3 = 5{,}73e^{-16}\ cm^3.$$

The mass of the non-metallic inclusion of the critical size is equal to:

$$M_k^{pi} = V_k^{pi} \cdot \rho_k,\ M_k^{pi} = 5{,}73e^{-16} \cdot 4 = 2{,}29e^{-15}\ g.$$

Both aluminum and oxygen are used to form corundum inclusions, and the limiting element is oxygen that is dissolved in the melt.

100000 g of melt contains 0.339 · 100000/100 = 359 g of oxygen (O_2).

The mass of aluminum is: 359 · 54/48 = 404 g.

The total mass of corundum is: 404 + 359 = 763 g.

Determine the number of inclusions of critical size:

$$\frac{M_{Al_2O_3}}{M_k^n} = \frac{763}{2{,}29e^{-15}} = 3{,}33e^{15}.$$

According to the work of Bogdandi L. [38], the existence of a free symmetric circular diffusion field around the embryo is assumed. Based on Fick's second diffusion law [39], the following embryo growth equation was proposed:

$$r = r_0 + 2VD(C_\infty - Cr)t, \qquad (10)$$

where r – inclusion radius to time t, cm; r_0 – the radius of inclusion at time t = 0 s, cm; V – molecular volume of oxide, m^3; D – diffusion coefficient of oxide components; C_∞ – diffusion coefficient of oxide components in the melt; C_r – concentration of oxides in the surface of the non-metallic inclusion.

For the primary inclusions, the growth of embryos is:

$$r^{pi} = 5{,}152e^{-6} + 2 \cdot 25{,}5 \cdot 1{,}5 \cdot 10^{-4}(0{,}339 - 0{,}173)t.$$

It should be noted that in the process of growth of non-metallic inclusions must follow the law of conservation of mass [40]. If two germs of non-metallic inclusions are located next to each other, then the growth of one germ of critical size is necessarily accompanied by the dissolution of the other. Therefore, as the diffusion increases, the total number of non-metallic inclusions decreases.

The change in the size of the primary inclusions of corundum depending on time is presented in table 1. It is determined that in 0.1 s the inclusions reach the dimensions sufficient for floating through the formed layer of thermite melt 10 cm thick for 6 s. Virtually all the primary inclusions are concentrated on the surface of the melt and form layer consisting of small particles of corundum.

The number of the primary non-metallic inclusions with a total mass of corundum of 763 g is calculated by the formula (Table 1):

$$N_{NMI}^{pi} = 763 / M_{NMI}, \tag{11}$$

where M_{NMI} – mass of specific non-metallic inclusions, g (Table. 1):

$$M_{NMI} = \frac{4}{3}\pi r^3 \rho_{NMI}, \tag{12}$$

Table 1. The size of the primary inclusions of corundum depending on the time of their growth.

Growth time of the primary inclusions of corundum, s	The sizes of inclusions of corundum, cm	Mass of corundum inclusions, g	Number of corundum inclusions
0,0001	0,000363	2,46e^{-15}	3,1e^{17}
0,0010	0,00147	4,44e^{-15}	1,72 e^{17}
0,0100	0,00363	9,53e^{-14}	8,01 e^{15}
0,1000	0,0115	3,87^{-11}	1,97 e^{13}

The rate of gravity sedimentation emergence of inclusions is determined by the formula:

$$V_{gs} = 2gr\ (\rho_{melt} - \rho_{NMI}) / \eta, \tag{13}$$

Where g – acceleration of free fall, which is equal to 1000 cm/s^2; r – radius of non-metallic inclusion, cm; ρ_{melt} – melt density equal to 7.2 g/cm^3; ρ_{NMI} – density of non-metallic inclusion, which for oxidative non-metallic inclusion in the form of Al_2O_3 is equal to 4 g/cm^3; η – melt viscosity equal to 0.05 MPa·s.

The rate of ascent of the primary inclusions of corundum depending on the time of their growth is presented in Table 2.

Table 2. The rate of emergence of the primary inclusions of corundum depending on the time of their growth.

Growth time the primary inclusions of corundum, p	The rate of ascent of the primary inclusions of corundum, cm/s
0,0001	0,000363
0,0010	0,00147
0,0100	0,00363
0,1000	0,0115

For secondary inclusions, the equilibrium constant according to the Hoxen and Chipman formula [31] is similar to the equilibrium constant of the primary inclusions $K_{Al}^{si} = 10^{-12}$.

The initial oxygen content of 0.173% and the final oxygen content of 0.001% are taken. According to formula (8), the supersaturation of the melt is equal to:

$$\alpha_{Al_2O_3}^{si} = \frac{1{,}5^2 \cdot 0{,}173^3}{10^{-12}} = 3{,}89e^{11}.$$

According to formula (7), the critical radius of the embryo Al_2O_3 is equal to:

$$r_{k\ Al_2O_3}^{si} = \frac{2 \cdot 2337 \cdot 102}{4 \cdot 8{,}3143 \cdot 10^7 \cdot 1973 \cdot \ln 3{,}89e^{11}} = 3{,}03e^{-8}\ cm.$$

For secondary inclusions according to formula (10), the growth of embryos is:

$$r^{si} = 3{,}03e^{-8} + 2 \cdot 25{,}5 \cdot 1{,}5 \cdot 10^{-4}(0{,}173 - 0{,}001)t.$$

We calculate the total mass of corundum, taking into account that 100000 g of melt contains 0.173· 100000/100 = 173 g of oxygen (O_2). The mass of aluminum is: 173 · 54/48 = 194 g. That is, the total mass of corundum is: 173 + 194 = 367 g

The sizes of secondary inclusions depending on time of growth are presented in Table 3.

Table 3. The size of the secondary inclusions of corundum depending on the time of their growth.

Secondary growth time inclusions corundum, s	The size of the inclusions of corundum, cm	Mass of corundum inclusions, g	Number of corundum inclusions
1e^{-8}	3,63 e^{-6}	7,8 e^{-16}	4,71 e^{17}
1e^{-7}	1,15 e^{-5}	2,53 e^{-14}	1,45 e^{16}
1e^{-6}	3,63 e^{-5}	7 e,8 e^{-13}	4,59 e^{14}
1e^{-5}	1,48 e^{-4}	2,53 e^{-11}	1,45 e^{13}
1e^{-4}	3,63 e^{-4}	7,99 e^{-10}	4,59 e^{11}
1e^{-3}	1,15 e^{-3}	2,53 e^{-8}	1,45 e^{10}
1e^{-2}	3,63 e^{-3}	7,99 e^{-7}	458915409
1e^{-1}	0,0115	2,53 e^{-5}	14512179
1e^{0}	0,036	7,99 e^{-4}	458915
1e^{2}	0,115	0,0253	14512

The number of secondary non-metallic inclusions with a total mass of corundum of 367 g is calculated by the formula (Table 3):

$$N_{NMI}^{si} = 367 / M_{NMI}. \tag{14}$$

We assume the crystallization temperature of the formed layer of thermite alloy based on iron 1500 ^{0}C, the average size of secondary oxide inclusions 1.03 e^{-3} cm, and the dynamic melt viscosity 4.26 MPa·s (Table 4).

According to formula (13) determine the rate of emergence of secondary inclusions.

Thus, in the melt with a thickness of 10 cm, the rate of ascent of secondary inclusions is 1.59e^{-3} cm/s, and the time of ascent of secondary inclusions, respectively, 6289 s. Therefore, the secondary inclusions are not removed from the thermite alloy and serve as centers for heterogeneous nucleation of chromium carbide inclusions.

Table. 4.Study of the viscosity of the steel grade ROM2SF10-MP [41].

Temperature, ^0C	Density, $\cdot 10^{-3}$ kg/m^3	Dynamic viscosity, MPa·s	Logarithm of dynamic viscosity
1400	6,60	11,70	2,460
1440	6,50	7,87	2,063
1450	6,40	7,23	1,978
1460	6,30	4,66	1,540
1500	6,12	4,26	1,451
1510	6,07	3,97	1,382
1520	6,02	2,93	1,041
1530	5,97	2,82	1,038
1550	5,88	2,77	1,020

Conclusions

The calculation method of parameters formation of the primary and secondary nonmetallic inclusions in thermite alloys is offered. The regularities of the influence of the growth time of non-metallic inclusion in the form of corundum on its size, mass and quantity are analyzed. The regularities of the formation of chromium carbides around oxidative nonmetallic inclusions in the form of corundum during the crystallization of a thermite alloy are shown. The formation of chromium carbide inclusions occurs sequentially: first the homogeneous nucleation of corundum inclusions, and then the heterogeneous formation of chromium carbide inclusions. It is determined that the volume of the critical size of the nonmetallic inclusion in the form of Al_2O_3 is $3.85 \cdot 10^{-23}$ cm^3, and in the form of Cr_3C_2 - $2{,}746 \cdot 10^{-22}$ cm^3.

It is shown that in a thermite alloy obtained by self-propagating high-temperature synthesis, the average size of corundum inclusions surrounding the heterogeneous inclusions of chromium carbide is 15.4 μm. It is shown that in the process of alumothermic reactions of the SHS process a significant number of small inclusions of corundum is formed. This indicates that the alumina particles are dissolved in the alloy and they are the centers of crystallization and play the role of inoculating modifier. It is shown that secondary inclusions are not removed from the thermite alloy and serve as centers for heterogeneous nucleation of chromium carbide inclusions.

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Spatial ultrasonic cleaning process control based on its current state evaluation

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Abstract. Ultrasonic cleaning is one of the most promising types of cleaning in terms of environmental friendliness, cost and efficiency. The condition of the cleaning body must be taken into account for optimal control of the ultrasonic cleaning process. This allows you to irradiate only those areas that really need it. The modelling of the process of ultrasonic cleaning of bodies of different configurations and the analysis of the parameters of ultrasonic responses at different stages of cleaning were performed. This allowed us to identify the parameters by which the assessment of the process should be formed. The main parameter was the change in the time of receipt of the threshold value of the signal, and the auxiliary - the change of the nonlinearity coefficient of the second order. The change in the time of receipt of the threshold value of the signal is an indicator of dirt peeling, and the change in the nonlinearity coefficient demonstrates the approach to the final result of cleaning. These parameters became clear input data for the 3-D fuzzy interval controller. The functions of affiliation were defined and the base of rules was formed. Modelling of the ultrasonic cleaning process using the established method of estimating the course of the process and the use of 3-D fuzzy interval controller showed about 35%energy savings.

1 Introduction

Effective cleaning is an important component of both production cycles and the possibility of ongoing equipment repairs. High quality in the absence of heavy manual labour and the use of aggressive chemicals makes ultrasonic cleaning one of the most promising types of cleaning. Modern technological developments and general trends in energy saving pose new challenges to increasing energy efficiency of ultrasonic cleaning. There are several approaches to overcoming these challenges. First, it is a study of the features of physical processes that provide the process of ultrasonic cleaning. The main physical phenomenon that provides ultrasonic cleaning is ultrasonic cavitation - the implosion of bubbles that occur under the action of changes in fluid pressure during sonication. This is the release of energy, which separates the dirt from the body. Cavitation in the ultrasonic bath has a zonal distribution, so the cleaning efficiency is affected not only by the parameters of the ultrasound, but also the size of the bath, the location of the emitters. Adjusting these parameters can significantly improve the quality of cleaning, as demonstrated in [1]. The distribution of cavitation is also greatly influenced by the frequency of ultrasound, and other parameters, such as fluid temperature, ultrasound intensity, oxygen content, affect the power of cavitation [2]. The large number of interrelated parameters that affect the ultrasonic cleaning process complicate the process of forming a control based on standard methods. Therefore, another approach to increase the energy efficiency of ultrasonic cleaning is to improve the methods of controlling this process. Thus, Duran Fecir proposed to use the evaluation of the process by the physical properties of the cleaning fluid, namely: conductivity and turbidity [3]. In [4], the evaluation of the process is based on the temperature of the liquid. Such approaches increase the efficiency of ultrasonic cleaning, but ignore the real state of the cleaning body, forming a control based on indirect evaluation.

More flexible is the formation of assessment based on machine learning, which was used in [5] and [6]. In these works, the condition of the treatment facility (in both cases, part of the pipe) was assessed by applying a neural network to the received ultrasound responses. The results of these experiments prove the possibility of using the analysis of ultrasonic responses to assess the degree of contamination of the body, but the algorithms used are limited by the shape of the treatment object and cannot be applied in the general case. Therefore, it is necessary to develop an evaluation methodology that will allow you to form a control based on the state of the treatment plant of any configuration.

For greater efficiency, the control of the ultrasonic cleaning process should take into account its spatial distribution and the actual state of the cleaning body. Otherwise, there will be ultrasonic treatment of already cleaned areas or insonation with insufficiently intensive ultrasound of areas that require it. For optimal redistribution of the intensity of each emitter of the ultrasonic bath, it is proposed to use a 3-D fuzzy interval controller type 2 [7], which is essentially designed for

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spatially distributed processes with complex expert evaluation of input parameters.

Modeling the application of a new method for assessing the state of the ultrasonic process and the formation of control using a 3-D fuzzy interval controller type 2 showed an increase in energy efficiency of cleaning by 40%.

2 Problem description

Let the ultrasonic cleaning take place with the help of m ultrasonic emitters located in the given positions and given by the intensity coefficients $u(z) = (u(z_1), u(z_2), \dots, u(\,z_m))$. Input parameters are measured in *P* spatial positions Z_1, Z_2,.. Z_p. *P* and *m* are independent. With the help of spectral analysis of ultrasonic responses, it is necessary to form a method for assessing the course of the ultrasonic cleaning process, followed by the formation of a spatially distributed control action. Carry out comparative modeling of control on the basis of the developed technique concerning traditional control of process of ultrasonic cleaning limited by a time indicator.

3 Methods for assessing the state of the course of cleaning by ultrasonic responses in the tank

3.1 Evaluation of mechanical properties of the body using ultrasound nonlinearity

Ultrasonic non-destructive evaluation is widely used to quantify the mechanical and structural properties of the body. It has established itself well in many industries and continues to expand its application [8-10]. Existing studies indicate the feasibility of using to determine the degree of heterogeneity of the mechanical properties of the body coefficients of nonlinearity of the second and third orders [9, 11- 12]

$$\boldsymbol{\beta_2} = \frac{\boldsymbol{A_2}}{\boldsymbol{A_1^2}}, \quad (\mathbf{1})$$

$$\beta_3 = \frac{A_3}{A_1^3}. \quad (2)$$

But in the case of ultrasonic cleaning, the situation is complicated by a significant change not only in the properties of the body, but also in the properties of the liquid, because some of the contaminated particles will be in a suspended state after exfoliation.

In the general case, the loss of signal intensity is described by an exponential dependence

$$I(x) = I_0 e^{-2\alpha x}, \quad (3)$$

where I_0 is the intensity of the sound wave at the entrance to the material, α is the value of the attenuation coefficient, which depends on the frequency of the ultrasonic wave and the properties of the material.

In addition, the loss of intensity will depend on the ratio of the densities of the boundary media and the speed of ultrasound in them. With this in mind, the intensity loss can be written as

$$I(x) = I_0 e^{-2\alpha x} \left(\frac{\rho_2 c_2 - \rho_1 c_1}{\rho_2 c_2 + \rho_1 c_1}\right)^2, \quad (4)$$

where ρ_1, c_1, ρ_2, c_2 are body density and ultrasound rate for 1 and 2 media, respectively.

If we take into account the absorption and scattering of suspended particles of contaminants in the substance [13], we obtain the following general view for the reflected intensity, which will be returned to the sensor when the reflected ultrasonic wave from the body

$$\begin{aligned} I(x) &= I_0 e^{-\sqrt{n}(1-\eta)} e^{-2\alpha x} \left(\frac{\rho_2 c_2 - \rho_1 c_1}{\rho_2 c_2 + \rho_1 c_1}\right) e^{-\sqrt{n}(1-\eta)} = \\ &= I_0 e^{-2\alpha x} \left(\frac{\rho_2 c_2 - \rho_1 c_1}{\rho_2 c_2 + \rho_1 c_1}\right) e^{-2\sqrt{n}(1-\eta)} = \\ &= I_0 e^{-2\left(\alpha x + \sqrt{n}(1-\eta)\right)} \left(\frac{\rho_2 c_2 - \rho_1 c_1}{\rho_2 c_2 + \rho_1 c_1}\right) \end{aligned} \quad (5)$$

where $\eta = \int_0^\infty \exp\left\{-\frac{1}{V}\sigma(\lambda, r) Z\right\} \varphi(r) dr$ is concentration by size; $\varphi(r)$ is particle size distribution function, $V = \frac{\pi d^2}{4} Z$ - where *d* is the diameter of the emitter, *z* is the distance to the body, $\overline{n}$ is the average concentration of solid particles in the liquid.

According to formula (5) we obtain the largest change in the value coming to the sensor when changing the ratio at the boundary of the media, ie with complete purification. The change in intensity also significantly depends on the thickness of the contamination, the concentration of contamination in the liquid and the particle size distribution.

Also during cleaning there is a change in the configuration of the body, which also affects the parameters of the ultrasonic signal received by the sensor. To determine the influence of the features of the body configuration on the time of receipt of the threshold value and the nonlinearity coefficients of the second and third orders, modelling was performed for different shapes of the body and the corresponding values were calculated..

3.2 Modelling of ultrasonic cleaning bodies of different configurations

K-wave was chosen as the simulation software. The advantage of this product is the simulation of large-scale propagation of ultrasonic waves in a reasonable time [14-15]. The sensor and the emitter were located in the lower right corner of the simulated area. The section of the cleaning body was set with a density ρ = 7800 kg / m^3 and the speed of propagation of the ultrasonic wave c = 5100 m/s, which corresponds to the metal product. The contamination was determined by the density ρ = 3100 kg / m^3 and the speed of propagation of the ultrasonic wave

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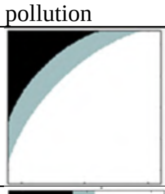
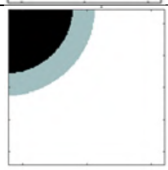
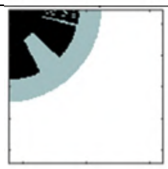
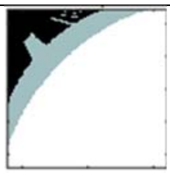
c = 2500 m / s, which corresponds to corrosion. The following were chosen as different shapes of areas: the sector of a circle, the sector of asteroids and the sectors of a circle and asteroids with holes. Ultrasonic responses were recorded for the body of each configuration and with different thickness of contamination. These responses were processed using a fast Fourier transform and obtained the values of the largest 3 amplitudes (Table 1).

Table 1. Parameters of ultrasonic responses when cleaning bodies of different configurations

Body number	The initial appearance of the body with pollution	The thickness of the contamination,mm	Signal time, µs	The value of the amplitudes of the first three harmonics, Pa			β_2	β_3
1		60	2669	0.2379	0.0758	0.0411	1.339	3.053
		40	2818	0.2922	0.1046	0.0612	1.225	2.453
		20	2956	0.3173	0.1004	0.0569	0.997	1.781
		0	3105	0.36	0.084	0.0833	0.648	1.785
2		60	2467	0.1026	0.0229	0.0090	2.175	8.333
		40	2728	0.154	0.0633	0.0199	2.669	5.449
		20	2884	0.1498	0.0619	0.0038	2.758	1.13
		0	2914	0.1104	0.03	0.0059	2.461	4.385
3		60	2466	0.1016	0.0238	0.0099	2.306	9.44
		40	2728	0.1601	0.0571	0.0206	2.228	5.02
		20	2882	0.1414	0.0599	0.0076	2.996	2.688
		0	2924	0.0927	0.025	0.01	2.909	12.553
		the cleaned opening	3033	0.0846	0.0314	0.0158	4.387	26.094
4		60	2669	0.2377	0.0759	0.0409	1.343	3.045
		40	2818	0.2942	0.1041	0.0625	1.203	2.454
		20	2956	0.3238	0.101	0.06	0.963	1.767
		0	3106	0.3419	0.0718	0.0831	0.614	2.079
		the cleaned opening	3105	0.3629	0.0869	0.0824	0.66	1.724

For clarity, we construct graphs of dependences (Fig. 2), which show that the presence of a cleaned hole causes an increase in the nonlinear component (second-order coefficient) regardless of the geometric shape of the body.

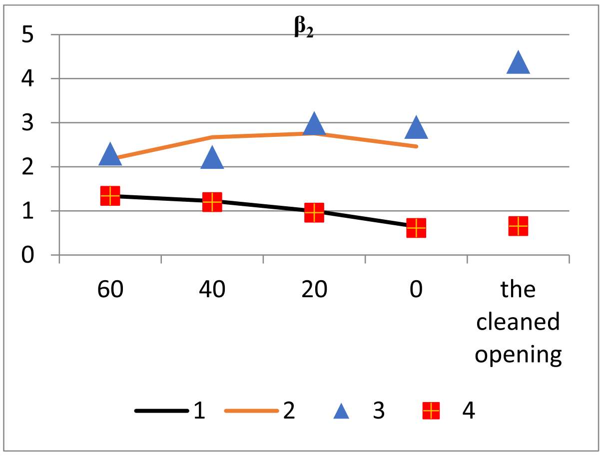


Fig. 1. Nonlinearity coefficient of second order with different thickness pollution.

For the sector range - significantly (from 2.909 to 4.387) for astroyidalnoho sector small (0.614 to 0.66). The general nature of the change is uneven - reduction coefficient β_2 occurs when a layer of pollution below a certain level, and the increase can be observed for certain geometric shape when the layer of pollution reduced, but overall remains high. In Fig. 2 shows that for any body β_2 factor value at the last stage of cleaning is reduced.

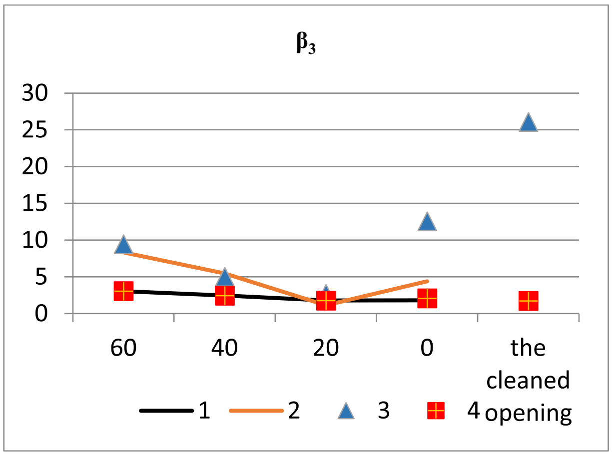


Fig. 2. Nonlinearity coefficient of third order with different thickness pollution.

Cleaning the holes, on the contrary, causes it to increase. Therefore, we can draw the following conclusion: an increase in the coefficient β_2 indicates either the cleaning of the holes, or a decrease in contamination, the layer of which remains quite significant.

The nonlinearity coefficient of the third order is even more dependent on the geometry of the body and does not show patterns in the process of ultrasonic cleaning. Therefore, the decision was limited to the analysis of only the second-order coefficient.

An important factor that has a stable behavior and allows you to assess the course of the process of ultrasonic cleaning is the time after which the threshold value of the signal. In fig. 8 shows that the change in time occurs almost linearly with a constant increase. Nonlinearity is observed only at the stage of hole cleaning, when the change in the time of receipt of the threshold signal may decrease.

With the increase of suspended particles of contamination in the liquid, the state of the liquid, not the body, has a greater influence on the response signal. There was a decrease in the time of receipt of the threshold signal and an increase in the main amplitude.

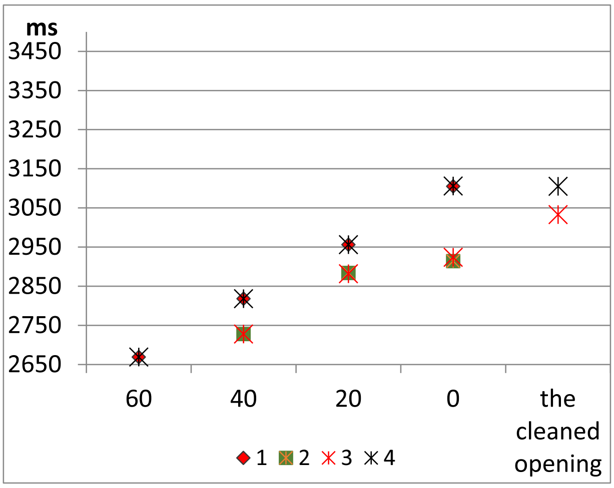


Fig. 3. The time of receipt of the threshold value of the signal depending on the thickness of the contamination for table 1 bodies.

Thus, the value of the change in the time of the signal, the coefficient of nonlinearity of the second order and the value of the change of the main amplitude, you can estimate the state of the ultrasonic cleaning, namely:

1. The change in the thickness of the contamination almost directly proportionally affects the change in the time of receipt of the ultrasonic response.

2. The coefficient of nonlinearity of the second order can determine the thickness of the contamination: a significant increase in the coefficient (more than 50%: $\frac{|4.387-2.909|}{2.909}$=0.51 for body 3 in table 2) with increasing time of receipt indicates the cleaning of various holes, ie the final stage of purification. The main amplitude decreases.

3. A less significant increase in the nonlinearity coefficient of the second order with increasing time of receipt ($\frac{|2.996-2.228|}{2.228}=0.5$ for the body 3) is evidence that the contamination is still quite significant and the area requires intensive cleaning. The behavior of the main amplitude is arbitrary.

4. The increase of the main amplitude with the decrease of the nonlinearity coefficient of the second order is a clear indicator of a stable purification process.

4 Control of ultrasonic cleaning based on 3-D interval fuzzy controller

4.1 Controller inputs

Therefore, the input parameters that will allow to assess the state of the ultrasonic cleaning process are the last two measured values of the time of receipt of the threshold signal and the nonlinearity coefficient of the second order.

The value of the "change" of the signal is obtained as the relative difference of the last two measurements of the threshold time. If this value is equal to 0, then the product of the ratios of the nonlinearity coefficients of the 2nd and 3rd orders is chosen as this parameter

$$x_1 = \frac{t_2 - t_1}{t_2}, \tag{6}$$

where t_2, t_1 are the times of receipt of the threshold value of the signal for the current and past measurements.

To determine the "purity" of the signal, we use the ratio of nonlinearity coefficients of the 2nd order

$$\mathrm{x}_2 = \frac{\beta_2^{(2)} - \beta_2^{(1)}}{\beta_2^{(2)}}, \tag{7}$$

where $\beta_2^{(2)}, \beta_2^{(1)}$ are values of the current and past nonlinearity coefficients of the 2nd order.

4.2 Membership function for inputs

The values of x_1, x_2 are normalized in the interval [-1,1]. Since the sign of the input parameter is fundamental, the normalization was not carried out evenly, but as the ratio of the found value to the maximum modulo with the same sign. For both input variables, we set five linguistic labels: significant positive (LP), mean positive (MP), zero (Z), mean negative (MN), and significant negative (LN). Given that the current value of the signal received by this sensor is most affected by the state of the immediate environment, the following type was chosen for the membership functions

$$\begin{aligned} \underline{\mu}(x_i, z) &= \exp\left(-\frac{\left((x_i-a)^2 + 2\left(\left|2\left|z-z_0\right|-1\right|-1\right)^2\right)}{\sigma_1}\right) \\ \overline{\mu}(x_i, z) &= \exp\left(-\frac{\left((x_i-a)^2 + 2\left(\left|2\left|z-z_0\right|-1\right|-1\right)^2\right)}{\sigma_2}\right) \end{aligned} \tag{8}$$

where $\underline{\mu}(x_i, z)$ та $\overline{\mu}(x_i, z)$ are the upper and lower values of the membership function, x_i is the crisp input, $z =$

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$(z_1, z_2, \dots, z_P)$ is the radial input coordinate (the sensor location),a is the value of the linguistic mark with which the membership function acquires the maximum value: for (LP) – a = 1, for (MP) - a = 0.5, for (Z) – a = 0, for (MN) – a = -0.5 and for (LN) – a= -1, z_0 is the value of the spacious radial output coordinate (radiator location), σ_1 та σ_2 – are parameters conditioned by physical properties of the cleaning tank and the number of sensors and outputs and belong to the interval [0,1], $i = 1,2$ is the number of variables. Fig. 4 shows a diagram for the linguistic mark (MN) and the output z_0 = 0.2 with σ_1 = 0.1 and σ_2 = 0.2.

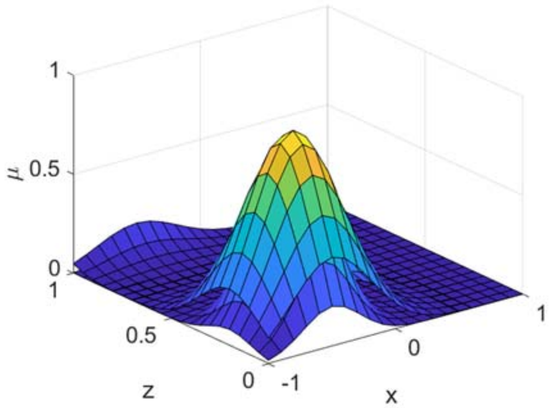

Fig. 4. Diagrams of the upper and lower membership functions for the mean positive mark (MN) for the output z_0 = 0.2;

This type of function will provide a spatial effect of the sensor signal on all emitters. At the minimum distance we get the maximum value of the function, and at the distance of the output from the input the value of the function decreases.

4.3 The rule base

Taking into account the above-described method of evaluating the course of the ultrasonic cleaning process, a base of rules for a fuzzy controller was formed (Table 2). This database is two-dimensional and does not depend on the number of sensors. Spatial distribution is taken into account through the membership functions of the input parameters. When forming the database of rules, the main role is taken into account the time of receipt of the threshold value of the signal $(\boldsymbol{x_1})$.

Table 2. The rule base

$x_2/\,x_1$	$\widetilde{LN}$	$\widetilde{MN}$	$\widetilde{Z}$	$\widetilde{MP}$	$\widetilde{LP}$
$\widetilde{LN}$	$\tilde{S}$	$\tilde{M}$	$\tilde{M}$	$\tilde{L}$	$\tilde{L}$
$\widetilde{MN}$	$\tilde{S}$	$\tilde{M}$	S	$\tilde{M}$	$\tilde{L}$
$\widetilde{Z}$	$\tilde{S}$	$\tilde{S}$	$\tilde{S}$	$\tilde{M}$	$\tilde{L}$
$\widetilde{MP}$	$\tilde{S}$	$\tilde{S}$	$\tilde{S}$	$\tilde{M}$	$\tilde{L}$
$\widetilde{LP}$	$\tilde{S}$	$\tilde{S}$	$\tilde{M}$	$\tilde{L}$	$\tilde{L}$

A negative value of this factor indicates contamination of the liquid, and a positive value indicates the peeling of the contamination.

For the second parameter, which is a relative change in the nonlinearity coefficient of the second order $(\boldsymbol{x_2})$, the following dependences: a negative value indicates that the purification is occurring and is approaching the final stage, and a positive value indicates the presence of a significant amount of contamination.

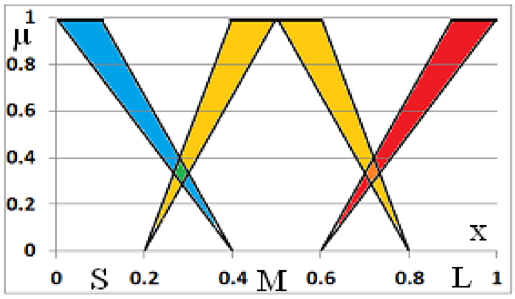

Fig. 5. Membership function for output.

The original membership function is two-dimensional and determines the value for each emitter separately. The output function is normalized in the interval [0,1], because the clear value of the output - the intensity of the emitter - is always non-negative. The second view is shown in Fig. 5.

4.4 Algorithm of the controller based on 3-D fuzzy interval set type 2

According to work [7], the operation of the controller based on the 3-D fuzzy interval set of type 2 will occur in the following steps:

1. Obtaining a clear input according to the method described in this article and its phasing.
2. Formation of the conclusion on the basis of base of rules.
3. Combining spatial information and reducing it with a maximum operation.
3. Data accumulation and type reduction through the search for a centroid by the Karnik-Mendel algorithm [16].
4. Formation of a clear conclusion.

5 Results and discussion

To confirm the effectiveness of the newly developed method for evaluating the course of the ultrasonic cleaning process, a complete modelling of the process was performed using a 3-D fuzzy interval controller. The location of the contaminated body, 4 emitters and 4 sensors were specified (Fig. 6). The figure shows working emitters in the form of concentrated circles - purification cycle 1 (colour saturation is directly proportional to the radiation intensity). Ellipses at the boundaries of the area indicate the location of the sensors. The contamination was exfoliated at a radiation intensity at the point of contamination of more than 50% compared to the maximum.

The cleaning was carried out in 4 cycles, which is how long the complete cleaning lasted with all the emitters on. At each step, a power factor was determined for each emitter, which was normalized to [0,1]. Table 3 shows the parameters obtained for each cleaning cycle, and the power determined by them. To take into account the presence of contamination in the liquid with each cycle, increase the number of suspended particles. For a better illustration, the input parameters x_1 and x_2 in the table are not normalized, and u is given the most normalized, because it is with such power factors that the processing takes place in the next cleaning cycle.

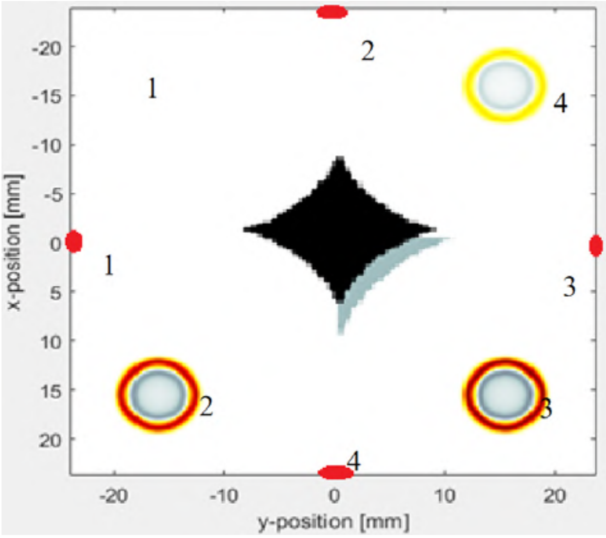

Fig. 6. Modelling of ultrasonic cleaning.

Table 3. Input and output parameters in ultrasonic cleaning.

Step #	x_1	x_2	u	Power saving, %
0	-	-	[1 1 1 1]	0
1	[0.0010 0 0.0597 0.0970]	[0.2240 0.0055 0.0015 -3.4094]	[0 0.9175 1.0000 0.3638]	42.97
2	[-0.0005 0 0.0010 0.0016]	[-0.1886 -0.3178 -0.0137 0.0778]	[0 0.4930 1.0000 0.6643]	46.07
3	[0 0 0.00051 0.00051]	[-0.0153 0.2671 0.0510 0.0100]	[0 0.7260 1.0000 0.1956]	51.96
Total			Σ[1 3.1365 4 2.2237]=10.3602	**35.25**

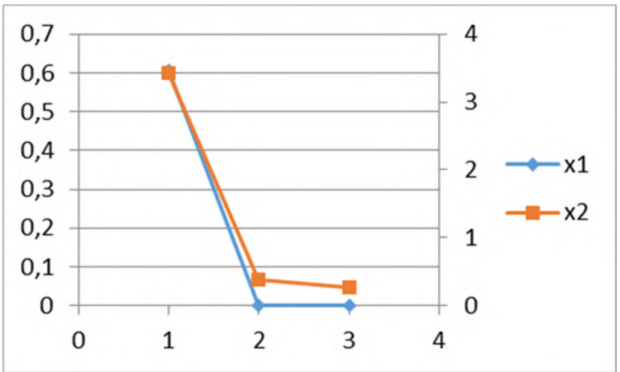

Fig. 7. Reduction of the deviation modules x_1 and x_2 by cleaning cycles.

These tables show that in each cycle, the maximum power factor of the emitter, which is closest to the contamination. At the same time, there is a constant decrease in the modulus of the vectors x1 and x2. A graphical representation of the reduction of input parameters is presented in Fig. 7.

One of the indicators of the need to stop the cleaning process is the acquisition of the limit value of the module for x_1 and x_2.

Due to the fact that the emitters did not work at full power, energy savings amounted to 35. 25% (100%-10.3602/(4·4)%).

Conclusions

In this work, a method of evaluating the course of the process of ultrasonic cleaning by ultrasonic responses was formed. To determine it, the purification of bodies of different configurations was modelled and the analysis of the received signals was performed. Parameters of responses that were considered during the analysis: the time of receipt of the threshold value of the signal and the first three harmonics. It was decided to limit the time of receipt of the signal threshold value and the nonlinearity coefficient of the second order to determine the assessment of the course of the ultrasonic cleaning process. It is the relative changes of these values and became the input parameters for the 3-D fuzzy interval controller, which performs spatially distributed control of the ultrasonic cleaning process. Energy savings using the established estimation technique and 3-D fuzzy interval controller amounted to about 35% compared to traditional control, which is limited to time only.

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Developing of X65 steel coils making at Steckel mill using thermo-mechanical control process

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Abstract. The process of thermo-mechanically controlled rolling in the conditions of Steckel mill of Ferriera Valsider plant was developed for the first time for hot-rolled coils in the sizes of 12 mm × 1510 mm from steel of X65 grade for further production of electric welded pipes according to the API-5L standard. The developed process provides carrying out of the roughing-rolling in two stages to facilitating the forming of a smaller austenite grain and therefore more dispersed and homogeneous inherited ferrite structure in the finished rolled product. At the implementation of the process, the holddown of the temperature at the desired level at 1780 Steckel rolling mill has been carried out by adjusting the number of burners in furnace coilers. The process of controlled air cooling of rolled coils to a temperature of 400 °C after winding in the developed technology for Steckel's mill condition of Ferriera Valsider plant is applied for the first time that allowed to reduce the thickness of the air scale layer and to improve the surface quality. The performed research has been allowed to evaluate the feasibility of the operating equipment and to determine the possibility of coils fabrication related to the nowadays world requirements and satisfied to the demand of European electric-welded pipes manufacturers.

1 Introduction

Ferrous metallurgy, and hot rolling in particular, is one of the most energy-consuming industries. The improvement of metallurgical technologies is referred to a modern urgently needed global trends aimed to the reducing of carbon dioxide emissions, decreasing the impact on climate change, creating the new environmentally friendly metal materials that reduce a material consumption and increase the safety of vehicles, engineering structures, pipelines and other specific infrastructure.

The most common method of making flat rolled products for large diameter pipes is rolling on plate reversible mills [1, 2], as well as on continuous rolling mills [3, 4]. A special place is occupied by the production of plate steel for pipe assortment at Steckel rolling mills. This method is less common, but is successfully used by global manufacturers. There is no analogue of the production implementation of large-diameter pipe assortment at the Steckel rolling mills in the territory of post-Soviet space. At the same time in Canada, the USA, South Korea, China, this method of production is common [5, 6].

Obtaining the required properties of the rolled steel in all cases is achieved mainly by the thermo-mechanical processing with or without of the accelerated cooling. The progressiveness of Steckel mills use lies in the significant manufacture greening through the use of heat-preserving and insulating furnace coilers, which help to reduce of the energy costs, make less the scale formation and CO_2 emissions. There are three general approaches to rolling product making that are used as inputs to the pipemaking process [7–12]: normalizing, thermomechanical controlled processing (TMCP), and quenching and tempering (Q&T). The combination of rolling processes in Steckel mills with TMCP has significant prospects at the point of view of obtaining steels of high and ultra-high strength grades, raising the standards of human safety.

The use for the manufacture of large-diameter pipes of plate or coiled steel, and hence their manufacture as longitudinal or spiral seam ones, depends largely on the political and historically formed technical and technological aspects of a particular region. While in large-scale projects in Eastern European and Asian countries are predominate longitudinal seam pipelines, in a number of European countries, as well as in Canada and the USA, spiral seam pipes are widely used [13, 14]. There are steels from X42 to X120 according to API standard using [15]. Undoubtedly, the advantages and disadvantages are available for both manufacturing options, from sheet metal products and pipes, and ending with the direct operation of pipelines.

In recent years, the process of manufacturing of hot rolled products on Steckel rolling mills has developed. The hot-rolled strength steel was the basic assortment made on such mills, producing at which is necessary to maintain temperature of metal in austenitic area. Modern Steckel mills and processes allow to produce

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rolled products with controlling the temperature level to obtain the desired set of mechanical properties of the finished rolled product [16–19]. Functioning mills by their design are divided into several types: single-stand, double-stand, roughing rolling stand, with additional finishing stands [16, 19].

The processes of Steckel mill rolling high-strength steels, intended mainly for the production of large pipe, were investigated in papers [20–23]. The processes proposed by the authors of works [20, 21, 24], related to the production of rolled products for large diameter pipes of steel grade X80, are of practical importance. It should be noted that these technologies are implemented on the equipment created in the 1990's, which allows to conduct a particular analysis of technical capabilities and differences of equipment built earlier. In paper [22], the authors present a study of the influence of temperature on the formation of structural components along the strip in the production of austenitic steels, the results of which can be partially applied in the development of the technology or its adjustment.

In works [25–30] the researches of separate processes which also using on design of a rolling at Steckel mill are presented. At indicated, temperature and strain rate conditions play a significant role in obtaining a high-quality steel structure, mechanical properties and other quality indices [25–30]. So in paper [31], the temperature drop in closed coilers is taken into account, and the theoretical consideration of the indentation of a roller tool into a slab allows one to evaluate deformation and power modes [29, 32–35]. The most important factor is the friction conditions, the forecast of which during hot rolling is carried out according to complex equations that have restrictions on the parameters of the chemical composition of rolled steels [36]. Also, the results of a study on laboratory modeling of Steckel mill rolling, which are presented in work [37] are of a particular interest. The above approaches are associated with a number of assumptions that reduce the accuracy of preventive technological solutions. Therefore, conducting research in an industrial environment at Steckel mill is a more accurate, albeit more expensive, method.

It should be noted that a limited number of studies leave open the question of assessing the technical capabilities of the existing equipment of Steckel rolling mills relate to developing a new assortment of high grade categories. From year to year, the level of customer requirements for pipe steel increases significantly and sometimes exceeds the level of requirements of standards that are regularly reviewed. A significant toughening of requirements also has applied to API 5L X65 steel [38–41], compared to the years of commissioning of the Steckel mill (in case of Ferriera Valsider plant). Hence, designing the production technology of rolled steel for pipes on the Steckel mills of Ferriera Valsider plant of steel grade X65 is an urgent task that will assess the technical capabilities of the existing equipment and establish the possibility of producing coils that meet nowadays world requirements and meet the needs of European manufacturers of electric-welded pipes.

Purpose of the research. The purpose of the work is to develop the production technology of the assortment of hot-rolled coils of steel grade X65 at the Steckel rolling mill of the Ferriera Valsider plant (Italy), taking into account the technical features of the existing heating and rolling equipment.

2 Materials and strategy of research

The main equipment of the Steckel rolling mill line of the Ferriera Valsider SpA plant is a methodical pusher furnace with six zones for heating slabs, manufactured by Bendotti company, which is heated by natural gas with a capacity of 120 t/h, mill 3170 for rolling slabs and strip plates for the Steckel rolling mill, which includes reverse duo stand with a rolling force of up to 25 MN, and a stand with vertical rolls, a seven-zone roller furnace for intermediate heating of the strip plate, which is heated by natural gas. The Steckel rolling mill includes a reversible quarto stand 1780 with a rolling force of up to 24 MN and a chamber furnace with natural gas-heated drum coilers located on both sides of the rolling mill 1780. Unit for laminar cooling of the strip after rolling with a length of 41 m, which allows to cool the metal at a speed of up to 40 °C/s. Winders for coiling the strip up to 20 mm thick.

The main assortment of the rolling mill is heavy plate and coiled rolled products for construction purposes, including resistant to atmospheric corrosion, rolled products for shipbuilding and production of parts for mechanical engineering. The assortment produced is determined by the existing technological regulations of the operation of all main equipment, i.e. high heating temperatures of slabs for rolling, about 1230 °C, high temperature of the furnace with intermediate heating of the rolling from 1100 °C to 1250 °C, high temperatures of furnace coilers about 1070 °C. It should be noted that at these temperatures there is a significant reserve of energy-power parameters. The actual rolling force in roughing and finishing stands is in the range of 12-14 MN, with a relative reduction per a pass from 15% to 50% according to the assortment, which makes possible further development of technology and expansion of the assortment. The scheme of the main technological line for the production of hot-rolled coils at the Ferriera Valsider plant is shown in Fig. 1.

In Fig. 2 the finishing stand of the Steckel mill 1780/quarto with furnace coilers and in Fig. 3 is the laminar cooling system are shows. The assessment of the plant capacity to master the technology of production of coils of pipe assortment was based on the analysis of the technical characteristics of the existing equipment.

As a result of the analysis and preliminary calculations of maximum allowable technological loads on the main equipment of the stands, with the help of mathematical modeling complex insufficient power of the main drive engines of the 3170 mill and 1780 Steckel rolling mill at quite high power characteristics of both stands, which does not allow to operate them at full

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power. Based on the calculation, the following results were obtained, Table 1.

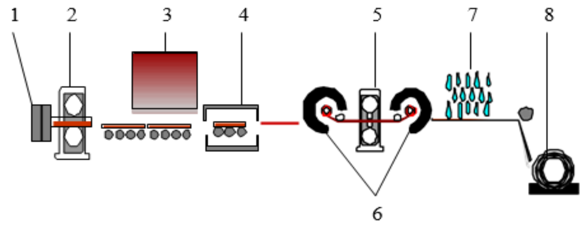

Fig. 1. The scheme of the technological line for the production of hot-rolled coils at the Ferriera Valsider plant: 1 – stand with vertical rolls; 2 – roughing stand 3170; 3 – continuous pusher furnace; 4 – continuous roller furnace; 5 – Steckel stand 1780; 6 – furnace coiler; 7 – laminar cooling; 8 – coiler.

Fig. 2. Finishing stand of the Steckel mill 1780/quarto with furnace coilers.

Fig. 3. Laminar cooling system.

Table 1. Comparison of actual and calculated engine power.

Stand/type	Number of main drive engines	Maximum rolling force, MN	Actual engine power, kW	Calculated, required engine power, kW
3170/duo	2	25	2x2240	2x4430
1780/quarto	2	24	2x4480	2x5770

Thus, improving the efficiency of the mills at the Ferriera Valsider plant by increasing productivity, reducing specific energy consumption, improving the quality of products is possible by installing new, more powerful main drive engines. Insufficient engine power makes difficulties in the development and implementation of thermo-mechanical rolling technology on the existing equipment.

Development of the production technology of the pipe assortment coils is possible in two following options. Implementation on the rolling mill of TMCP technology without accelerated cooling with the need to complete the deformation in the ferritic range, which will lead to a significant (up to 30%) loss of productivity due to the forced increase in the number of passes. In addition, when performing finishing rolling it will be quite difficult to plan and implement the operation of the furnace coilers as part of the power characteristics during coiling, and directly maintain the required temperature of rolling, which will vary widely. The use of TMCP technology with accelerated cooling is a more acceptable option. The undoubted advantage of this technology is the higher consumer properties of the products, which has been repeatedly emphasized by many studies, lower production costs, including by reducing the level of microalloying elements added to the steel, reducing energy consumption for heating and rolling. In addition, and what is especially important for this Steckel rolling mill, is the reduction of loads on the engines of the main drive and furnace coilers due to the deformation in a higher temperature range.

3 Results and Process Developing

As a billet for the production of coils with dimensions 12 mm x 1510 mm, steel grade X65 was considered the use of slabs of "AZOVSTAL IRON AND STEEL WORKS" current production, cross section 220 mm x 1510 mm. The chemical composition of the experimental slabs are given in Table 2. Slabs are heated in a six-zone methodical furnace. The heating temperature of slabs for rolling should be 1170°C ± 10 °C. Determination of the required austenitization temperature was carried out on the basis of data on the solubility temperatures of NbC and Nb particles (C, N) in the structure of a uninterruptedly-casted slab. The heated slabs enter the roughing stand of the duo mill 3170, preliminary passing the water wash box to remove furnace scale from the surface. The temperature of the slabs after the water wash should be 1130 °C ± 10 °C.

Rolling in a rough stand should be carried out according to the longitudinal scheme in two stages. The first stage of the rolling is carried out in the upper part of the austenitic area in the temperature range from 1130 °C to 1020 °C, where intensive recrystallization of the deformed austenite takes place, with a reduction of more than 10% per a pass, except for the first two or three passes, in which the reduction is limited by the maximum angle of capture, power and engine torque. After performing the first stage, the roll is cooled by translational movement on the roller conveyor to a temperature of 920 °C. The absence of deformation in this temperature range allows to keep part of the niobium in dissolved form for further dispersion hardening of the metal, as at this stage incoherent particles Nb (C, N), as well as Ti (C, N) separated, do not make significant changes in steel hardening. The last 2-4 passes are performed in the area of recrystallization inhibition in the temperature range of 920-880°C, with a reduction ≥10%.

Implementation of rough rolling in two stages promotes the formation of smaller austenitic grains, and more dispersed and homogeneous inherited ferrite structure in the finished rolled products. The thickness of the rolling should be not less than three times the final thickness. The recommended temperature-deformation modes of rolling through the passes in the stand 3170 are given in Table 3.

After rolling in a roughing stand, a 40 mm thick rolling is cooled on a roller conveyor to a temperature of 830-820 °C. Then the rolling goes to the continuous rolling furnace, where the temperature is equalized in cross section and length, as well as the side edges are heated. The temperature of the metal after equating in the rolling furnace should be 835 °C ± 5 °C.

The final rolling is carried out in the stand of the quarto Steckel rolling mill. Rolling in the Steckel stand should begin at a temperature of 825-835 °C, i.e. below the temperature of complete inhibition of austenite recrystallization, and end at a temperature of not less than 810 °C. The reduction on all passes must be at least 10%. During the implementation of the described temperature-strain parameters during finishing rolling, austenitic grains are extracted, the boundaries of which are fixed by Nb (C, N) phases released during rolling and will significantly grind the inherited ferrite grain. The recommended temperature-deformation mode of rolling on passes in a stand 1780 is given in Table 4.

Table 2. The chemical composition of the experimental steel grade X65.

Melt number	Section of slabs, mm	Chemical composition, %														
		C	Mn	Si	S	P	Al	Nb	V	Cu	Ni	Cr	Mo	Ti	N	B
1002129	220 x 1510	0.09	1.40	0.23	0.002	0.011	0.036	0.030	0.066	0.02	0.02	0.03	0.01	0.015	0.0070	0.0005

Table 3. Recommended temperature-deformation schedule of rolling in the roughing stand 3170.

Number of the pass	Thickness before the pass, mm	Thickness after the pass, mm	Reduction, %	Temperature before the pass, °C	Rolling force, MN
1	222	202	9.0	1130	14.07
2	202	183	9.4	1122	14.22
3	183	165	9.8	1117	14.25
4	165	148	10.3	1113	14.24
5	148	132	10.8	1107	14.28
6	132	117	11.4	1102	14.28
7	117	103	12.0	1094	14.38
8	103	90	12.6	1087	14.43
9	90	78	13.3	1076	14.61
10	78	67.5	13.5	1066	14.26
11	67.5	58	14.1	1051	14.46
12	58	49.5	14.7	1037	14.54
Cooling on a roller conveyor					
13	49.5	44.5	10.1	917	14.42
14	44.5	40	10.1	902	14.40

Table 4. Recommended rolling schedule in the stand 1780 of the Steckel rolling mill.

Number of the pass	Thickness before the pass, mm	Thickness after the pass, mm	Reduction, %	Temperature before the pass, °C	Rolling force, MN
1	40	35.5	11.25	830	14.60
2	35.5	31.5	11.27	829	13.97
3	31.5	28	11.11	828	13.22
4	28	24.5	12.50	827	13.75
5	24.5	21.5	12.24	826	12.89
6	21.5	18.5	13.95	825	13.50
7	18.5	16	13.51	824	12.49
8	16	14	12.50	822	11.23
9	14	12	14.29	819	11.87

The schedule of reductions is calculated so that the last pass is performed during the rolling process.

Changes in temperature and rolling force in the passes in the Steckel stand are shown in Fig. 4. In order to meet the conditions of the thermomechanical rolling process, it is necessary to maintain the temperature of the metal in the passes in the Steckel stand. When modeling the technology of maintaining the temperature at the desired level, which is low with relation to the current technology, is carried out by adjusting the number of burners in the furnace coilers.

After rolling, the strip is transferred without delay to the laminar cooling unit. The sequence of going through the technological units before laminar cooling should be as follows: (i) Furnace coiler before the mill → (ii) Steckel rolling mill → (iii) Laminar cooling. Due to the short distance of the rolling fields, the work of all technological equipment must be synchronized. Cooling of the coils on the accelerated cooling unit should be performed at a speed of 12-14 °C/s to a temperature of 560-580 °C.

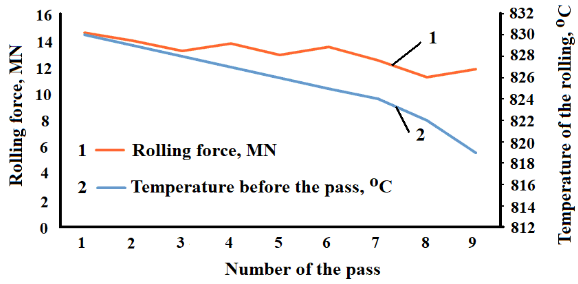

Fig. 4. Dynamics of changes in rolling force (1) and temperature (2) in the passes in the Steckel stand.

The accelerated cooling from the lower range of the austenitic area will form the final dispersed ferrito-bainite structure in the finished product. At this stage the separation of Nb (C, N) particles from the solid solution will significantly increase the strength of the metal. After the accelerated cooling, the strip is rolled into a coil on the finishing coiler. In order to reduce the thickness of the air scale, the rolled coils must be subjected to additional controlled air cooling to a temperature of 400 °C, using industrial aerators. The final slow cooling of the rolls is performed in the warehouse during 48 hours.

4 Conclusions

For the conditions of the Steckel rolling mill of the Ferriera Valsider SpA plant, the assessment of technical capacity and the development of a complex technology were conducted for the first time for the production of coils of steel grade X65 for further production of large diameter electric-welded pipes for oil and gas. The calculations were conducted and the required capacity of the main engines of rolling mills 3170 and 1780 were installed for the first time at the Ferriera Valsider SpA plant, which will increase the productivity, reduce specific energy consumption and improve the quality of produced products. In order to improve the quality of the surface of the coils, the use of controlled air cooling of the coils after coiling was proposed for the first time for Steckel rolling mill.

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Optimization of the combined explosion hardening processes

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Abstract. The proposed method for calculating the loading parameters makes it possible to determine the wear parameters after explosion hardening. The calculation method is simple and less time consuming compared with calculation methods that involve the use of nonlinear programming methods. The main methods of increasing the wear resistance of mining equipment parts using explosion methods are generalized. The reserve for increasing the wear resistance consists in the optimization of deformation parameters during the power and thermal intensification of processes and the development of new methods and technologies of hardening. The factors (parameters) of the studied processes: explosive cladding, alloying, hardening, are formulated. Optimization of the processes under consideration is possible by decomposing the process into simpler ones with subsequent optimization of the parameters of these processes and the synthesis of the obtained solutions. For the first time, a solution to the multicriteria problem of two-stage explosion hardening is presented. It is proposed to split the process into simpler ones. Optimization criteria are proposed for each of the simplified processes. The problem is reduced to a conditional extremum problem, which is solved by composing the Lagrange function. By transforming the wear equation, the optimal ratio of strength and ductility for parts operating under abrasive wear conditions is determined.

Introduction

This research examines the processes of increasing the wear resistance of mining equipment parts using pulsed energy sources. These processes include explosive cladding with wear-resistant materials, explosion hardening, explosion-thermal hardening and frictional hardening.

The research is devoted to solving the topical scientific and technical problem of increasing the resource and operational reliability of parts and assemblies of mining equipment. This is due to the fact that at present the physical wear and tear of production assets of the mining and metallurgical complex (MMC) of Ukraine is 70-75%. The costs of repair, installation and dismantling of parts of equipment operating under intensive wear conditions are comparable with its high cost. Nevertheless, MMC occupies a major place in the national economy of Ukraine, providing a third of industrial production and more than 40% of export profits. The most effective and cheap methods for increasing the wear resistance and durability of mining equipment parts for buckets and bucket teeth for excavators, hammer crusher bits, ball and rod mill armor linings are methods of impulse hardening, alloying and cladding.

The reserve for increasing the wear resistance of mining equipment parts is optimization of parameters, power and thermal intensification of these processes, development of fundamentally new methods and technologies of hardening [1, 2]. In addition, the search for technologies for restoring the wear resistance of parts without dismantling them is also promising. Therefore, the purpose of this research consists in developing a universal analytical method for calculating the optimal parameters of the processes of increasing the wear resistance and durability of parts using pulsed energy sources.

Optimization of the problems of impulse metalworking is quite fully covered in the literature [3-8]. Most of the optimization problems of deformation and shape changing are reduced to determining the extreme values of the response parameters and the values of the corresponding determining parameters [9, 10]. The method of choosing the geometry of the deforming tool according to the criterion of the minimum surface load in the areas of contact with the workpiece is of interest [3].

In this case, the system of regularities of elastic-plastic deformation underlying the theory of rolling are replaced by variational principles. In this case, the problem is reduced to the calculus of variations and optimal control and can be studied in two ways. Either the extreme trajectories (Euler-Lagrange theory), or by experimental trajectories (Hamilton-Jacobi theory) could be determined. The task is reduced to finding «geodesic lines» which the shortest arcs connecting two are given points on a certain surface. This minimal problem is a typical example of a questions vast class for the calculus of variations.

In general, in most research, it is believed that obtaining an extreme value of a parameter is possible only for certain values of all factors, which significantly complicates the calculations and obtaining the final results. A number of researchers [11, 12] take into account the factors that are most significant, using the method of

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frozen parameters or successive approximations. To determine the significance of the factors, the values of several of them are fixed while others change. Then the values of the latter, minimizing the full power of forming, are determined [13, 14].

A number of practical problems of the metal processing theory have an alternative nature. For example, reducing material consumption increases the likelihood of stamping scrap. The solution of such problems requires the use of the mathematical apparatus of probability theory.

The design of technological processes is usually reduced to solving a multivariate problem with full or partial formalization of the compared options optimality criterion. The cost of a product could be a fully formalized, complex criterion. However, the widespread use of the cost criterion in the design of sheet-stamping production processes is difficult both due to the lack of the necessary information support for the dependence of the cost of products on the technology of its production, and on performance indicators.

It is more expedient to evaluate the efficiency of a technological process as a physical system using the state function, i.e. entropy. It is characterized by the tendency of systems to an equilibrium state, equilibrium and to equiprobable microscopic chaotic molecular processes. At the same time, plastic deformation occurs under conditions of inhomogeneity not only of the stress-strain state, but also of the structure, chemical potential, and temperature. I.e., shaping and hardening processing are characterized by a complex thermomechanical and physicochemical environment. As a result, irreversible energy flows arise, causing local entropy production.

The process of plastic deformation and the subsequent depletion of the parts resource obtained by pressure treatment methods is ultimately determined by the ratio of competing flows. This is an energy flow that seeks to destroy the metal during processing and operation, or prevents it. The predominant flow determines the reliability of the structure at this operation stage. However for problem solving, it is necessary to have a system of equations for the kinetic state of a physical object and dynamic return. At the same time, the solution and composition of these equations are considered only for some special cases without obtaining quantitative indicators.

In addition, the development of the mathematical apparatus, mathematical modeling methods and computer technology significantly increases the reliability and calculations quality. Therefore, according to a number of researches [15] experimental and static methods for studying the processes of manufacturing and operation of machines structural elements are giving way to a less costly method of mathematical modeling. Regarding the modeling of technological processes of forming parts, this really takes place [16]. The calculation technique [16] for assessing the parameters of the state of parts during manufacturing, repair and subsequent operation is the methodological basis for the development of the theory and practice of creating highly reliable structures, assemblies and parts. A set of mathematical models of the service parameters of parts evolution during operation: the accumulation of damage and a decrease in fatigue life, etc. do not solve the issues of the need for preventive maintenance and measurements of parts and structures as a whole; nevertheless, the methods of «operations research» taking into account static data allow solving a complex of problems of economics, operation and repair. However, the general strategic task of uniformity of machine parts service life is solved by the joint efforts of constructors, technologists, operators, mathematicians and economists.

However, the determination of the significance of all factors is compatible in terms of labor intensity with the procedure for enumerating all the parameters.

The foregoing allows us to state that to date, in the theory of sheet stamping production, considerable scientific knowledge has been accumulated in the use of methods of the optimal control theory and mathematical modeling to increase the efficiency of metal forming processes. The widespread use of optimal control methods for solving specific technological problems is relevant.

In conclusion of the paragraph, it should be noted that a variety of problems of the optimal control theory is inherent in the process of sheet-stamping production, and the fact that the application of the methods of this theory to shaping technologies is in it’s development stage.

Material and methods

For a functional description of the processes under consideration, it is necessary to formulate the factors (parameters) of the researched processes. The main parameters of explosion welding (kinematic and physical) include: speed of movement of the point of contact v_c, dynamic impact angle β, plate driving speed v_0, pressure, impact duration, temperature in the impact zone. In addition, the process efficiency is largely determined by the technological parameters:

– detonation velocity D, which characterizes the type of explosive charge;

– dimensionless welding parameter r – the ratio of the mass of the explosive to the mass of the driver (plate, pipe);

– distance between the welded workpieces – welding gap h.

The factors affecting the degree of explosive hardening include the applied pressure, the duration of the impact pulse, the nature of the loading, and the velocity of the linear pulse.

For explosive friction hardening the factors are the same as for explosion hardening, only instead of the linear impulse velocity the velocity of the friction material is used.

In addition, the physical and mechanical characteristics of the processed material affect the efficiency of the explosion welding process and the degree of hardening.

Optimization of the analyzed processes by theoretical analysis of numerical modeling is possible using the calculation method described in [17, 18]. The latter includes a set of models that characterize the properties of the original blanks and the evolution of these properties

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during processing and operation. Taking into account the fact that the researched processes depend on a smaller number of factors, we adapt the method used in structural mechanics by V.Z. Vlasov and in the processing of metals by pressure by V.I. Ershov, applying them to the processes of explosion welding and hardening by a laid-on charge of an explosive, converging shock waves, explosive-thermal, explosive-frictional, multiple combined explosion, multiple compression by reflected shock waves.

Calculation

The processes of explosion welding, hardening by converging shock waves, a laid-on charge of explosives, proceed under the action of one type of external load, the rest of the processes occur under the action of several independent or dependent loads.

In the former case the process is described by function $p_1(y_1...y_k)$:

$$F_i = F_i\begin{bmatrix} p_1(y_1, y_2, ..., y_k); \varepsilon_1, \varepsilon_2, ..., \varepsilon_l; \\ z_1, z_2, ..., z_m; S_1, S_2, ..., S_n; ... \end{bmatrix}. \quad (1)$$

In the latter case:

$$F_i = F_i\begin{bmatrix} p_1(p_1, p_2, ..., p_k),\ p_2(p_1, p_3, ..., p_n), ..., \\ p_n(p_1, p_2, ..., p_{n-1}); \varepsilon_1, \varepsilon_2, ..., \varepsilon_l; \\ z_1, z_2, ..., z_m; S_1, S_2, ..., S_n; ... \end{bmatrix}. \quad (2)$$

The processes under consideration are fast.

Therefore, practically without error, function (2) can be replaced by functions of the form:

$$F_i \approx F_i' = F_q(F_1, F_2, ..., F_n), \quad (3)$$

where F_i – parameter characterizing the efficiency of the considered process;

$p_1, p_2, …, p_k$ – factors that characterize the influence of each type of load on the process of cladding with a wear-resistant layer, hardening by the previously listed methods of explosion hardening;

$\varepsilon_1, \varepsilon_2, …, \varepsilon_l$ – factors characterizing the conditions of deformation;

$z_1, z_2, …, z_m$ – factors characterizing the properties of the deformable workpiece (geometric and physical-mechanical);

$S_1, S_2, …, S_n$ – factors describing structural transformations in the hardened material;

F'_i – the function approximating function F_i;

F_q – determines the influence of a complex of interactions of factors, p_k on F_i.

From the specific conditions of deformation hardening, functions $F_1, F_2, …, F_n$ are determined by one of the types of load.

When the process takes place under the influence of several independent external loads $n>1$ function F_q must be determined from additional conditions. To determine function F_q for the processes under consideration, the equality of the intensity of deformations is extremely uniform [17] at the minimum total power of deformation.

It should be noted that for fast processes of explosive hardening, frictional and shock-wave loading of the hardened material acts for several microseconds. Subsequent loading by a technological equipment element occurs much later and lasts several tens of milliseconds, so these processes can be considered as processes occurring under the action of two or more independent external loads.

Results

Let us consider the practical use of the analyzed method for the process of explosion-friction hardening. The steps are as follows:

1) the process is subdivided into two simple processes: explosive loading and frictional interaction of the technological friction sliding pad with the workpiece. Explosive loading by a plane shock wave of the pad-workpiece system results in the occurrence of a stressed triaxial uneven compression and driving of the technological pad. Contact friction stresses act on the contact surface of the workpiece with the tool. They have a significant effect on the final deformable state of the workpiece;

2) determining a functional link $F_i=F_i(p_k)$;

3) in accordance with equation (2), the functions F_q are determined. In this case it is considered that p_1, p_2 are not independent, but may influence each other. Here p_1 affects the speed of movement of the technological pad and the force of normal pressure between the pad and the workpiece.

4) determining the relation between factors p_1, p_2 from the condition of the minimum deformation energy when the deformations of the hardened surface are limited to the limit uniform one.

At the final stage we obtain the explosive-friction process dependence on many factors.

A method based on the decomposition of a combined process into simple ones and subsequent synthesis makes it possible to optimize the processes under consideration. Process conditions, properties of the deformable workpiece and structural changes in the surface layer of the workpiece. In this case:

$$F_i = F_i(p_1, p_2). \quad (4)$$

We expand function F_i in Taylor's series at points $(p_1, 0)$ and $(0, p_2)$ and adding the obtained results we have:

$$F_i = 0.5\begin{bmatrix} \overline{F}_1(p_1, 0) + \overline{F}_2(0, p_2) + \dfrac{\partial \overline{F}_1}{\partial p_2}\Delta p_2 + \\ \dfrac{\partial \overline{F}_2}{\partial p_1}\Delta p_1 + \dfrac{\partial^2 \overline{F}_1}{\partial p_2^2}\Delta p_2^2 + \dfrac{\partial^2 \overline{F}_2}{\partial p_1^2}\Delta p_1^2 + ... \end{bmatrix}, \quad (5)$$

where $\overline{F}_1$ and $\overline{F}_2$ are the values of the function in the said points $(p_1, 0)$ and $(0, p_2)$.

The mutual influence of factors is assessed by the sum of the terms containing the partial derivatives of the function at the corresponding points.

Since the sum of the terms containing partial derivatives is not zero ψ_Σ. Therefore, it is reasonable to determine function F_i in the form of a sum corrected taking into account function ψ_Σ and functions F_q. Unlike the methods of V.Z. Vlasov and V.I. Ershov, which are reduced to the problem of finding the extremum of several variables using numerical iterative solution methods and the method of searching for variable parameters, for example, the steepest descent, on a grid. Functions $F_1, F_2,\ldots, F_n$ are presented in the form (1), (2). At the same time, we represent elementary processes as a set of even simpler processes.

An increase in the number of factors taken into account results in a significant complication of the calculation and final formulas. An attempt to take into account only the most significant factors does not lead to a significant simplification of calculations. The approach to regarding problems of this class means that the problem of finding the optimal loading parameters is solved by numerical methods of nonlinear programming. The use of numerical methods allows finding the points of local extrema and does not guarantee the determination of the global extremum. In addition, it is not possible to perform an analysis of calculations to determine certain factors for the final result. In our case, it is the hardening deformation of the flat surface of the part, for example, the working surface of the tooth of the excavator bucket.

To maximize wear resistance under conditions of shock-abrasive wear, it is necessary to minimize the mass wear [17, 18], which after minor transformations is reduced to the form:

$$U = f\,\frac{H_a}{H_m}\cdot\frac{L\cdot b\cdot\sigma_n}{\sigma_в}\cdot\frac{(1+\delta)}{\delta}, \tag{6}$$

where U – mass wear;
f – coefficient of friction;
H_a – abrasive hardness;
H_m – hardness of the part material;
$\sigma_в$ – temporary resistance to destruction;
L, b – length and width of the contact surface;
σ_n – standard pressure;
δ – relative elongation of the part material;
β – empirical coefficient;
γ – density of the part material.

To reduce wear, it is necessary to reduce the value of the coefficient of friction, increase the hardness of the material, the temporary resistance to fracture and the relative elongation of the material of the part. The minimum value of the coefficient of friction is reached at a certain value $\sigma_n = \sigma_n^0$. Its value is largely determined by the operating conditions and the geometry of the part. The relation has no extremum by $\sigma_в$ and δ, however, if the numerator and denominator (6) are divided by σ_n, in the denominator we come to expression $\bar{\varepsilon}\cdot\delta$, where $\bar{\varepsilon} = \frac{\sigma_в}{\sigma_n}$. Since $\sigma_в > \sigma_n$, then $\bar{\varepsilon} > 1$. At the same time $\frac{H_m}{H_a} < 1$.

Product $\bar{\varepsilon}\cdot\frac{H_m}{H_a} = \lambda$ is less than 1, and the sum determined by statistical data:

$$\lambda + \delta \approx const. \tag{7}$$

In this case product $\lambda\cdot\delta$ provided (5) will be maximal when $\lambda \approx \delta$. For hardened Hadfield steel, when rubbing against granite with an interlayer of iron oxides $\lambda \approx \delta \approx 0.4$, when rubbing against manganite– $\lambda \approx \delta \approx 0.7$.

To solve the optimization problem, we proceed as follows, the axis passing from the center of the cutting edge of the charge and perpendicular to it is denoted as x_1, and the axis perpendicular to it – e. In this case, e is an arbitrary energy parameter (specific energy, impulse or pressure). As a result of calculating the deformation process (at the first stage), dependence $e(x_1)$ was obtained. It characterizes the distribution of the energy parameter along coordinate x_1. This function is approximated by an exponential, power or other dependence with its subsequent linearization by dependence $e' = A + B\bar{x}$, where $\bar{x}$ – a new logarithmic or another coordinate used for linearization. The distribution of pressure, specific impulse, energy of the placed charge over the surface of the part is described by dependence $\mu = f(q_0, D_0)$, i.e. it depends on q_0 and D_0, where q_0 – specific mass of the charge, D_0 – detonation velocity. The task is formulated as follows: find such values of parameters q_0 and D_0 at which dependence e from dependence family e' suits dependence $\mu(q_0, D_0)$ in the best way.

A quadratic functional of the following form is taken as the criterion of the optimization:

$$y_\sigma = \int_0^{x_1} \left(\mu - e'\right)^2 dx_1, \tag{8}$$

An optimization criterion for calculating shear deformations when moving a friction deforming tool is set similarly. Energy parameter dependence is presented in the form $e_F = A_F + B_F x_1$, and the located one – $\mu_F = f(q, D)$. The optimization criterion will be of the analogous form:

$$y_\tau = \int_0^{x_1} \left(\mu_F - e'_F\right)^2 dx_1, \tag{6}$$

To determine the optimal values of the parameters of the two-stage deformation process, we compose the following system of equations:

$$\frac{\partial y_\sigma}{\partial q} + \alpha_{11}\frac{\partial y_\tau}{\partial q} = 0; \tag{7}$$

$$\frac{\partial y_{\sigma}}{\partial D}+\alpha_{12}\frac{\partial y_{\tau}}{\partial D}=0\,; \tag{8}$$

$$y(q,D)=0\,. \tag{9}$$

Here α_{11}, α_{12} – Lagrange multipliers; $y(q, D)$ – the equation of coupling q and D.

Multiplying equation (7) by $\frac{\partial y}{\partial D}$, and equation (8) by $\frac{\partial y}{\partial q}$ and subtracting equation (8) from equation (7) we obtain:

$$\frac{\partial y}{\partial D}\left(\frac{\partial y_{\sigma}}{\partial q}+\alpha_{11}\frac{\partial y_{\tau}}{\partial q}\right)=\frac{\partial y}{\partial q}\left(\frac{\partial y_{\sigma}}{\partial D}+\alpha_{12}\frac{\partial y_{\tau}}{\partial D}\right) \tag{10}$$

In this case, equations (9) and (10) are solved together.

If the linear approximation of e' is rough, we use the piecewise linear approximation of function $e(x_1)$ with any required precision. After calculating the specific mass of the explosive charge at the second stage of the calculation, we determine the contribution of reflected waves and other factors.

In the future, it is planned to experimentally and numerically verify the analytical results of the calculation and implement the method in a specific technological process.

In the case of using a flat explosive charge and dependence (4) to determine the energy parameters of the external loading and the deformed state of the hardened layer of the surface of the part, an analytical solution to the problem is possible using the methods presented in [17, 19] and the expression of integral (8) in elementary functions.

The proposed method can be included as a fundamental component of an integrated mathematical model for predicting the life cycle of a certain class of parts [20-22]. These classes of part are made by the parts obtained with the methods of sheet and die forging. The complex model includes the synthesis of mathematical models of the workpiece initial state, a mathematical model of the part manufacturing process (proposed in this study), the evolution of the service properties of the part, the accumulation of damage, etc. The considered mathematical model of the part manufacturing process assumes obtaining the results of the evolution of the properties of the processed parts with their maximum approximation to the operationally necessary ones. In the material of parts obtained using the methods of plastic deformation (shaping, hardening), there are significant changes in the physical and mechanical properties and structural state. It allows to significantly affect the resource and operational reliability of the parts obtained by using combined and multi-stage deformation processes. In addition, the question of the need to use hardening processing of parts manufactured by pressure processing is being resolved.

Conclusions

The proposed method for calculating the loading parameters of combined and multi-stage deformation processes makes it possible to simplify the calculation of the parameters of the hardening process and reduce the calculation time by methods involving the use of nonlinear programming methods.

The transformation of the wear dependence by mass enabled the determination of rational parameters of the plasticity of the part depending on the ratio of the hardness of the abrasive and the surface of the part and the ratio of the normal pressure of the abrasive and the strength of the material of the part. In conclusion, it should be noted that the considered technologies can be successfully used to strengthen the elements of railway tracks, tracked vehicles, in loading and unloading equipment.

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The assessment of the process of drawing a cylindrical workpiece without pressing with alternating strain of the workpiece flange

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Abstract. The development of a method for drawing cylindrical parts without pressing the workpiece flange, which allows reducing the cost of production due to the use of dies without a fit ring and single-acting presses. The performed research revealed that this method results in obtaining cylindrical parts with drawing ratios typical for pressing drawing. In this case, the different thickness of the finished product is several times less compared with the same type of semi-finished products obtained by drawing with a fit ring. Steel, aluminum and copper workpieces were researched. The best results were shown by more plastic materials. This method is not applicable for materials with the less than 0.25 mm thickness.

Introduction

The method of manufacturing cylindrical parts by drawing in the cold state is used at almost all mechanical engineering enterprises, which include forging and workpiece-preparation workshops and sections. In large-scale production, rather productive drawing methods are mainly used, such as drawing with pressing the flange, with pulling ribs and sills, drawing on sheet stamping machines, drawing out from a tape, drawing out with thinning the wall, etc. [1-3]. In the medium and small batch production, the above methods are used. Other methods include stamping with elastic media, liquid and gas, soft metals, explosion stamping, package drawing, pulsating drawing, stamping with a profile tool, drawing with heating and local cooling, drawing on sheet punching hammers and hydraulic presses, drawing on hydraulic presses, rotary drawing, stamping with workpiece end support, non-pressing drawing [4-6]. In single and small-scale production, the use of most of the above methods is impractical due to the high costs and the duration of the die tooling manufacture, the use of multi-operation, which makes it difficult or almost impossible to switch to the production and development of products new types. The decisive role here will be played by partially universal or universal equipment, which can be used at any stage of manufacturing a new product [7-9].

From this point of view, the application of the non-pressing method in single and small-scale production is promising and low cost, since there is no need to complicate the equipment by the fit ring and use double- and triple-action presses. Therefore, the purpose of the work consists in the experimental research of the possibilities of the drawing method with alternating strain of the flange and the development of recommendations for production.

Material and methods

Drawing without a fold holder for flangeless parts is only possible with a low drawing coefficient $m = d/D \geq 0.75 \div 0.85$ [10, 11]. To implement this process, simple equipment is used, where the stamped part is mainly pulled to dip. It is difficult to turn a flat part into a hollow one. The process is accompanied by the formation of an insignificant amount of folds and their smoothing when pulling the cup through the gap between the die and the punch. Moreover, parts made of plastic metals and alloys with a large flange can be drawn without noticeable signs of corrugation without pressing only to a shallow depth of $h \approx (3 \div 6)\,s$. High values of h correspond to workpieces with big thickness. Drawing without pressing parts with big flange is only possible before the start of decreasing the size of the initial workpiece [5, 13, 14].

To test the possibility of obtaining high-quality cylindrical parts by drawing without pressing the flange, experimental research was carried out on round workpieces of various diameters and thicknesses. The workpieces dimensions exceeded the ultimate ones, but they were corrected according to the L.I. Shofman condition of the stability loss [11, 17]. Workpieces made of 08 kp steel, aluminum A2 and copper M4 were subjected to drawing without pressing. The diameters of workpieces made of 08 kp steel were 77, 80, 83 mm, thickness – 1.2 mm, punch diameter – 46.8 mm. For aluminum the diameters of the workpieces were 83, 86, 89 mm, thickness – 1.4 mm, the punch diameter – 46.4 mm. For copper – 58, 61, 64 mm, workpiece

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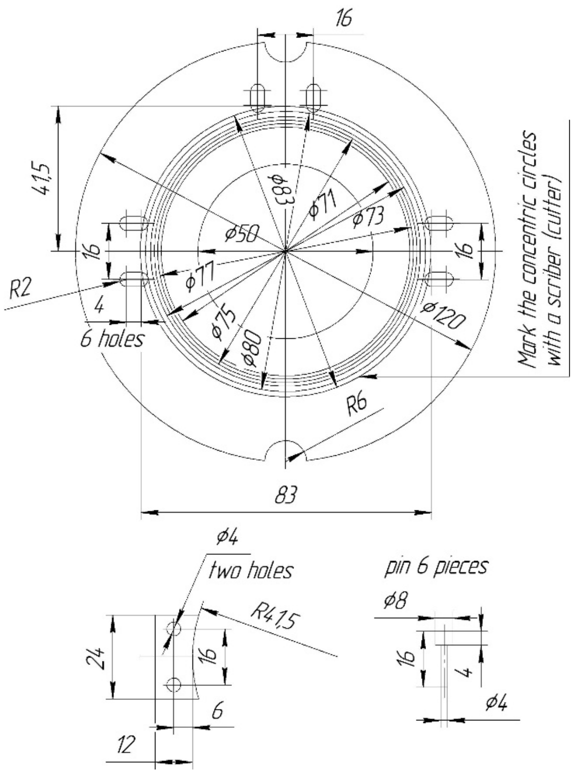
thickness – 0.25 mm, the punch diameter – 49 mm. For all sizes of workpieces, the diameter of the inlet of the die was 50 mm. The radius of curvature of the die for all experiments was chosen the same and equal to 5 mm, the radius of curvature of the punch for all experiments was 4 mm.

The process of drawing without a fold holder is accompanied by the difficulty of centering the workpiece on the die and, as a result, unilateral tightening of the semi-finished product, the appearance of premature folds and destruction at the location of strains, and these processes are aggravated when using the same die for workpieces of different diameters.

a)



b)

Fig. 1. A die with centering elements: a – a photo of the die; b – a detailed outline of the matrix.

Therefore, to conduct these experiments, a universal die with movable centering elements was designed, with the help of which the workpiece was accurately aligned with the hole of the die and punch. Here, the clamps move along the radial grooves simultaneously and synchronously with each other to the center or from the center of the die, which ensures self-centering of the workpieces (Fig. 1). The ultimate diameters for drawing is performed without fold formation are: for steel – D = 76 mm, for copper – D = 56 mm, for aluminum – D = 80 mm [15-17].

Calculation

At the first stage of drawing the punch stroke was limited according to the leap in effort at the stroke-effort diagram of the tensile machine. So the corrugations formed on the flange prevent the workpiece from being pulled into the die hole. It was noted that for different thicknesses of the workpieces, the value of the stroke of the punch, at which the leap in effort was observed, was also unequal. An empirical dependence was proposed for calculating the length of the penetration of the punch into the workpiece. It accurately described this process component

$$l = r_d + r_p + s/2, \quad (1)$$

where s – the workpiece thickness; r_d – the radius of the die rounding; r_p – the radius of the punch rounding.

After the first stage of drawing passed, the semi-finished product with corrugations was removed from the die, turned by 180° and reinstalled. It was centered with the use of moving elements. The stroke of the punch was turned on and the semi-finished product was deformed until the corrugations on the flange were smoothed out. Then the punch was stopped and it was given a precisely calculated stroke until a new formation of folds of the inverse curvature on the flange. The length of the reverse stroke of the punch was calculated by mathematical dependence

$$l_2 = l_1 + \Delta h, \quad (2)$$

where l_1 – the length of the punch stroke at the first step; Δh – the addition to the reverse stroke calculated by the G. Backhaus model taking into account the Bauschinger effect [14, 18-20, 22-25].

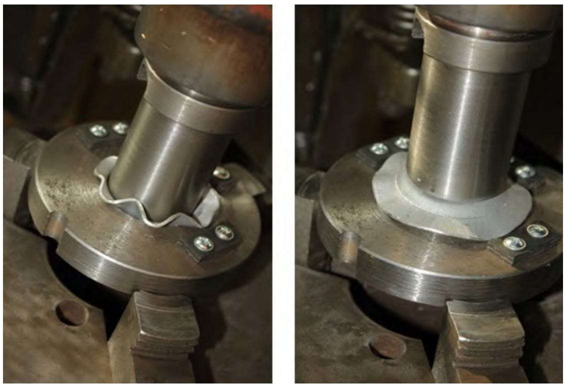
Then the semi-finished product was removed from the die, turned over by 180º and the process was repeated until the desired product height was obtained. Thus, all batches of workpieces were drawn, and their final height exceeded the standard height of the products obtained by drawing without pressing the flange and corresponded to the height of the drawn parts with the use of pressing. So, e.g. the drawing coefficient for the aluminum part with the workpiece diameter D = 80 mm was m = d/D = 0.58, the workpiece height – h = 24.5 mm (according to the tables of Romanovskyi V.P. [17, 21, 26-28]). It is recommended to perform this drawing with pressing, cutting allowance – about *3.5* mm according to the data of Skvortsov G.D. [17, 29, 31]. I.e. the final height of the finished part is 21 mm. It is impossible to obtain such a part by drawing without pressing the flange.

Results

However, the experiment result revealed that the use of drawing with step-by-step stretching of the workpiece flange makes it possible to produce parts of sufficient quality with this ratio of the dimensions. Figs 2, 3 demonstrate drawing steps with the workpiece turning and Fig. 4 – the semi-finished products and the finished part.

a) b) c)

Fig. 2. The workpiece drawing without a fold holder (material – 08 kp steel, the workpiece diameter – 77 mm): a – the punch approach to the workpiece; b –the formation of folds at the direct stroke of the punch; c – smoothing out the folds at the reverse stroke of the punch.



a) b)

Fig. 3. Drawing with turning the workpiece (material –A2 aluminum; the workpiece diameter – D = 86 mm): a – the direct stroke of the punch (the 4-th turning of the workpiece); b – the reverse stroke of the punch (the 5-th turning of the workpiece).

When conducting experiments on drawing workpieces without pressing the flange, the thicknesses of the obtained parts were also measured [30, 34, 35]. To do this, we used a micrometer thickness gauge with a measuring range of 0–25 mm and a division value of 0.01 mm to determine the strain mechanism and to formulate recommendations on the application of this process to production. The question of the legitimacy of determining the additional stroke of the punch by theoretical dependences based on the Bauschinger effect [32, 33] and recommended for use in this drawing method also remained open. Some results of the performed experimental research are presented in Table 1, which shows the dimensions of the workpieces and the drawn parts, their thickness in the characteristic zones of the profile, the material, the number of turnings to obtain the given height, the variants of the loss of stability and destruction, as well as the size of the first stroke of the punch and the addition at the reverse of the stroke load.

a)

b)

c)

Fig. 4. Semi-finished products and the completed part obtained by the method of step-by-step stretching of the flange (material – A2 aluminum, the workpiece diameter – 86 mm, m = d/D = 0.58, the thickness – 1.4 mm, the punch diameter – 46.4 mm, the height of the part after cutting the flange – 22 mm, the number of turnings – 8): a – the semi-finished product after the first step; b – the semi-finished product after the fourth load reverse; c – the completed part after cutting the flange.

However, it was noted that this process does not go smoothly and there are difficulties and shortcomings in the size of the stroke of the punch, as well as alignment of the workpiece after turning, which results in its destruction in the form of the separation of the bottom (Fig. 5).

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Table 1. The results of experiments on the drawing with a step-by-step stretching of the flange.

The material of the workpiece	**M4 copper**		
D, mm	58	61	64
m = d/D	0.86	0.82	0.78
Workpiece height / Number of turnings mm/ps	4.2/4	–	–
The first stroke of the punch / Addition at the reverse, mm	1.2/0.5	–	–
The relation of the thicknesses of the part and the workpiece in S_d / S_D	0.99; 0.96; 0.98; 0.89; 0.88	–	–
Notes	high-quality	folds at the end loss of bottom stability	
The material of the workpiece	**08 kp steel**		
D, mm	77	80	83
m = d/D	0.65	0.625	0.60
Workpiece height / Number of turnings mm/ps	16.2/6	17.5/6	19.8/8
The first stroke of the punch / Addition at the reverse, mm	5.5/2	5.5/2	5.6/2
The relation of the thicknesses of the part and the workpiece in S_d / S_D	0.94; 0.84; 0.89; 0.83; 0.81	0.92; 0.79; 0.86; 0.79; 0.79	0.92; 0.79; 0.84; 0.77; 0.76
Notes	high-quality	high-quality	high-quality
The material of the workpiece	**A2 aluminum**		
D, mm	83	86	89
m = d/D	0.60	0.58	0.56
Workpiece height / Number of turnings mm/ps	20.1/6	22.1/8	24.4/8
The first stroke of the punch / Addition at the reverse, mm	6.5/2.5	6.5/2.5	6.5/2.5
The relation of the thicknesses of the part and the workpiece in S_d / S_D	0.92; 0.8; 0.86; 0.79; 0.77	0.94; 0.77; 0.84; 0.77; 0.76	0.93; 0.77; 0.86; 0.76; 0.75
Notes	high-quality	high-quality	high-quality

Fig. 5. Pulling down of the workpiece part and it's destruction in the form of the separation of the bottom.

These phenomena's leaded to an increase in the number of rejected parts and the instability of the drawing process, which is unacceptable in the current production. Therefore, during the course of this experiment, some improvements in the die design were made and the methodology for calculating the additional stroke of the punch was improved taking into account the results of the experimental research.

Discussion

The table demonstrates that it is possible to obtain the aluminum and steel parts after at least six turnings. The number of turnings depends on the workpiece diameter and the drawing coefficient. With the larger diameter and the smaller the drawing coefficient, the greater number of the turnings is necessary to obtain a normal part. Aluminum is a more ductile metal in this case; in comparison with steel it requires a smaller number of steps with the same initial parameters and drawing coefficient. However, the thickness of the workpiece is higher for aluminum than for steel, which may explain the better stability of the workpiece flange and the possibility to obtain increased strains during one step. Drawing of thin metals by this method is difficult, because when the workpiece approaches the shape of the finished part, the corrugations are not completely smoothed out and remain on the product, which is unacceptable. Besides, the turning of thin workpieces and their strain results in a loss of bottom stability in the form of local buckling of metal. It is shown in the table for copper workpieces whose thickness is 0.25 mm.

The results of the measurements of the thicknesses of the characteristic zones of the semi-finished product allow us to conclude that the nature of the strain of the workpiece by this method is radically different from the method of the strain by drawing with a fit ring. The data in column 6 shows that the workpiece deforms along its entire perimeter. This is not characteristic of the classical drawing method, where the bottom of the part is practically not deformed, and mainly the workpiece flange is subjected to plastic strains [36, 39]. When turning, during shaping, the zone of transition of the wall to the bottom of the part and the workpiece flange are subjected to the greatest strains. Moreover, the main difference is the thinning of the flange, and not it's thickening as in the classic drawing. Plastic strain covers all zones of the workpiece and the end face of the workpiece receives compressive deformations in thickness, which indicates the large tensile stresses acting here, comparable with their value at the transition of the wall to the bottom. Based on the experimental data, the ratio of thicknesses in these zones is practically of the same order: steel – 0.83/0.81; 0.79/0.79; 0.77/0.76; aluminum – 0.79/0.77; 0.77/0.76; 0.76/0.75.

However, the experimental result revealed that the use of drawing with step-by-step stretching of the workpiece.

Conclusions

Thus, the conducted experiments confirmed the possibility of manufacturing cylindrical parts by drawing without pressing the workpiece flange with its step-by-step stretching. It will allow applying the method to a single and small batch production using simple presses and mold tools without a fold holder. However, one question remains open. It is the problem of the maximum diameter of the workpiece for this method, more precisely, the ratio of the diameter of the workpiece to the diameter of the part. Also the possibilities of stamping workpieces that are outside the range of sizes given in this research have not been analyzed.

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Modelling for degreasing the mining equipment downtime by optimizing blasting period at Erdenet surface mine

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Abstract. Erdenet copper-molybdenum deposit is the biggest one in the world and has a significant impact on Mongolian society and economy. Today LIEBHERR-994B hydraulic shovels from Germany, electric shovels including EKG-10 and EKG-15 from Russia operate for the mining works, and dump truck BelAZ - 75130 used for transportation. The causes of shovel downtime are classified as technical, technological, and organizational. During the study period, 41% of the total downtime of the excavator's park was technical, 45% was technological, and 11% was organizational downtime. For shovels, 7% of technological downtime is due to blasting, and for dump trucks 8.7%. In open-pit mining, blasting is performed on a weekly basis, so the duration of this technological downtime can be considered almost constant. If the time between blasts or period of blasting can be arranged optimally, it will be possible to reduce mining equipment's downtime due to blasting.

1 Introduction

The mining industry in Mongolia is one of the leading sectors that determine the country's economic development. The continues and efficient operation of any mining enterprise is inextricably defined with the operating costs of mining equipment, including a shovels, a dump trucks and a drilling rigs.

Operating costs are mainly dependent on the reliability of the equipment and its exploitation management. Following the growth of the world's population and the demand for mineral products, Mongolia's mining and processing sector are rapidly developing on a large scale, captivating large amounts of foreign and domestic investment. Hence, the mining sector income for approximately 30 percent of Mongolia's budget and plays the main role in the economy in terms of employment and production [1].

Due to the high capital expenditures and operation expenditure of any mining industry, continuous operation and economic efficiency depend on the proper organization of each mining process and the equipment exploitation management. Especially, it is essential to enhance profitability by increasing the utilization rate of dump trucks and shovels, which account for more than 70 percent of the total operating costs of the mining industry and reducing costs [1].

Under certain operating conditions, the profitability of a mining machinery depends on its reliability, technology, and maintenance. These parameters and factors interact with the end result of the machine's operation. In other words, maintenance costs depend on the level of reliability, on the other hand, reliability depends on the level of operation.

Therefore, in order to improve the service life of the mining machine, comprehensive research has been carried out to determine the level of reliability and technological quality during its operation, the quality of the maintenance system, and the economic viability [2].

As noted above, as Mongolia's investment and foreign relations in the mining sector expand, the use of mining machinery manufactured in Germany, the United States, the Republic of Korea, and Japan is increasing. Today, not only mining machinery manufactured in these countries but also machinery manufactured in Russia have a high level of reliability of electrical and mechanical systems based on the previous base, ergonomic problems are fully solved, equipped with diagnostic equipment, work performance information system, mechanisms, and assembly units. The operations are fully automated and manufactured at the smart machine with a high level of mechatronics [3, 4, 5].

Research and study have been performed to improve the operation and reliability level and the optimization of the process of the industry's open-pit shovelss and dump trucks, but it must be kept up to date with current technological advances.

"Erdenet Industry" state-owned corporation is one of the largest mining and processing plant in Mongolia. Nowadays, the depths of the Erdenet open-pit mine have been changed from 1,500m to 1,265m, and the experience of similar mines around the world shows that when the

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average transportation distance of mining rock and ore is more than 10 km and the depth of the mine is more than 100m, operating costs increase and production efficiency decreases. Due to the increasing depth and transportation distance of mining rock mass of the Erdenet open-pit mine and the declining ore grade of the deposit, the cost of mining and concentrate processing is increasing every year.

The following equipment is used for the mechanization of Erdenet open pit mining and the approach is expected to use this type of equipment until 2036 years:

- Shovels:
  - EKG15 from Russia
  - Liebherr-994B from Germany
- Dump trucks:
  - BelAZ 75130
- Drilling rigs:
  - SBSh-250MNA.

As a result of the analysis of the exploitation level of shovelss using at the Erdenet open-pit mine, the numerical values of the main parameters of their reliable operation were determined and the average level for the park is shown in Table 1.

Table 1. Shovels park reliability indicators.

Reliability indicators	Average value
Mean time between failure, hours	432
Availability ratio	0,768
Technical utilization rate	0,642
Failure flow parameters, 1/hours	0,002315
Average recovery time, hours	43,4
Specific duration of unplanned repair, hours/hours	0,0993

In order to assess the general level of the electrical shovel and dump truck utilization, the volume of the excavated and transported rock mass is shown for each type of shovels using at the Erdenet open-pit mine (Figure 1).

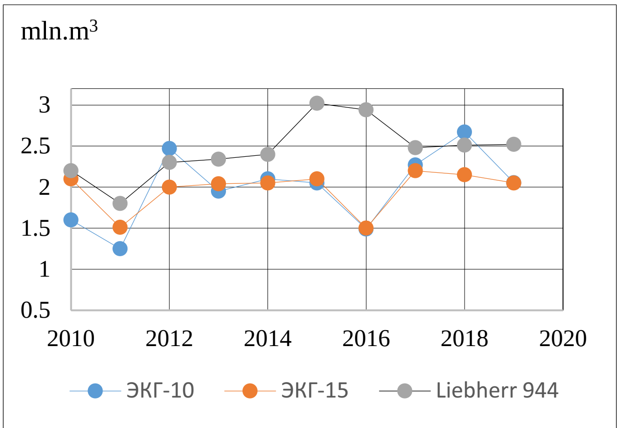

Fig. 1. Shovels' productivity by per year.

The increase in the shovels' productivity may be due to enhanced concentrator capacity. But, makes it impossible to conclude that equipment utilization has increased or downtime has decreased.

The average calendar time utilization factor for shovelss used in open pit mining is 0.75. The study defined that in the case of an shovels park, planned downtime accounts for the majority of total downtime, but it is necessary to analyze the causes of unplanned downtime to determine for opportunities to improve utilization and further study mining equipment reliability.

In general, the operation and productivity of shovels, which are the main machines in the mining industry, on the one hand, depends on the weather condition, technical state, and technological activities, the other hand, it directly affects the operation and downtime of other technological machines, such as dump trucks.

Therefore, based on the dispatcher's data, the causes for the downtime of the shovels are shown in Figure 2. It is clear from Figure 2 that 41% of the total downtime of the shovels park during the study period was technical, 45% was technological, 11% was organizational downtime and 3% was other causes [1].

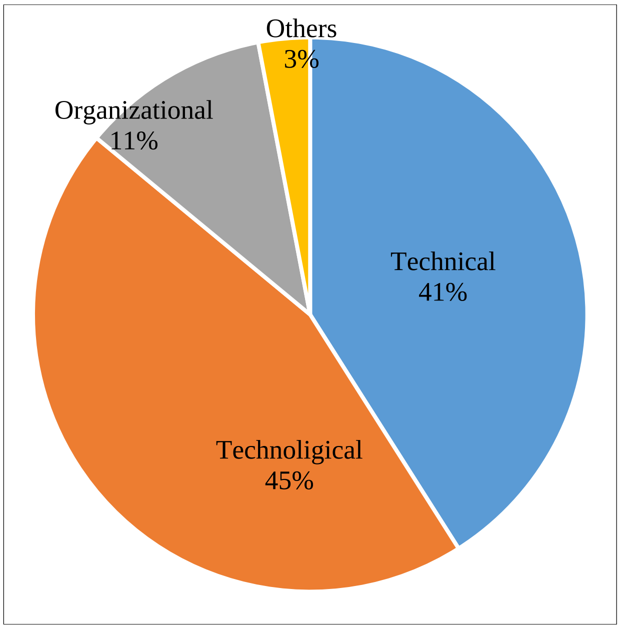

Fig. 2. The causes and types of shovel park downtime.

The causes of downtime related to the technical and technological operation and organization of shovels are classified as follows.

- The causes of downtime related to the technical:
  - Repair
  - Maintenance of one year
  - Planned maintenance
  - Unplanned maintenance due to mechanical failure
  - Unplanned maintenance due to electrical failure
  - Technical service due to mechanical part
  - Technical service due to electrical part
  - Others
- The causes of downtime related to the technological operation:

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- The processing plant cannot accept ore
- without operator
- without dump trucks
- The causes related to the organization:
  - due to change shovels working position
  - due to blasting
  - due to averaging and blending ore

During the study period, 55% of the total downtime due to the organization of the shovel was caused by the processing plant and 44% was due to without dump trucks (Figure 3).

Due to the close relationship between concentrator operations and open-pit mining, as of 2005, 36% of technology-related downtime was due to blasting operations, 39% due to averaging and blending ore, and 25% due to change the working position of shovels. As of 2020, 7% of technology downtime is due to blasting, 89% to averaging and blending ore, and 4% due to change shovel's working position (Figure 4).

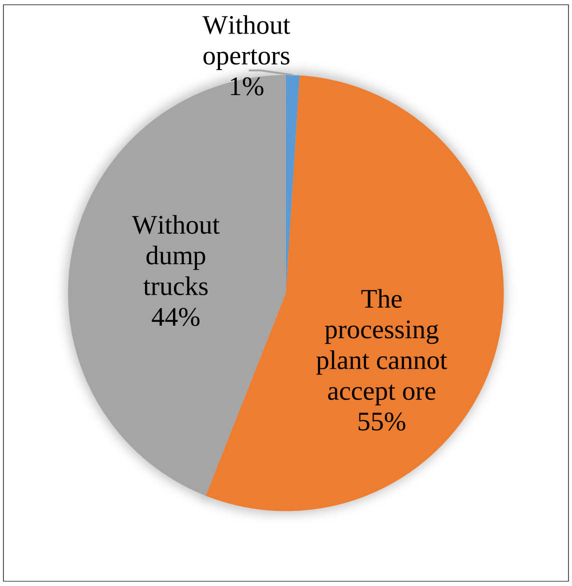


Fig. 3. The causes and types of total downtime due to the organization of the shovel.

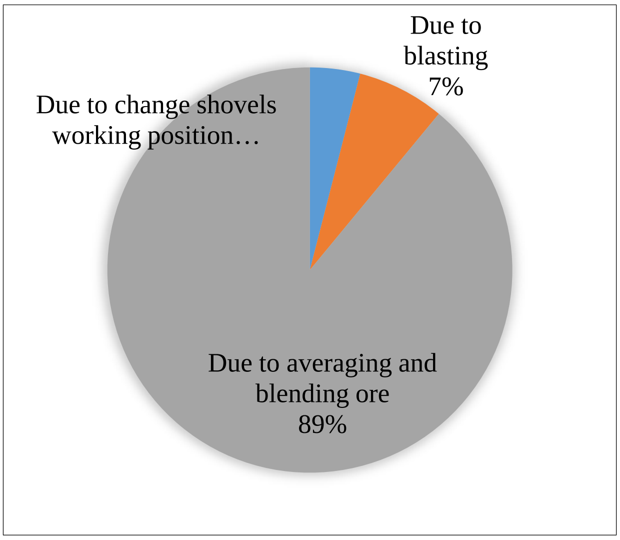


Fig. 4. The causes and types of technological downtime of the shovel.

These technological downtimes can be considered almost constant, as blasting is carried out on a weekly in the Erdenet open-pit mine, and changing the shovels working position are performed based on mining plaining and progresses. As blasting is a high-risk process, all machinery and equipment are immediately shut down to blast at the mine. The duration of blast-induced downtime is usually 1 ... 2 hours, but is very high in terms of cumulative downtime value for all mining equipment throughout the year.

Blasting is one of the most important operations in mining extraction, the purpose of drilling and blasting is to break and prepare the fragmented rocks for digging and transportation process. In the mining industry, the volume of the rock mass to be blasted per year is determined by the productivity of mining, which is one of the main parameters for selecting drilling rigs according to the rock hardness of the deposit and the bucket of shovels [6, 7, 8]. In addition to determining the number of blasts to be carried out per year and the cost of preparing 1m^3 of the rock mass for excavation and transportation work, one of the downtime's causes of mining equipment is blasting operation.

The blasting at the Erdenet surface mine is carried out every Friday at 3 pm, with a signal at 2pm to ensure the safety of workers at the open-pit and to stop all mining operations for approximately 1.2 to 1.9 hours. According to a study of the mining equipment included shovels and dump trucks, the average duration of downtime due to blasting is on average 13-28.9% just for the shovels's park. Therefore, let's consider the level of downtime due to blasting operations for the mining equipment [6].

2 Research methods

When the number of shovels in the shovels's park is 8 working at the Erdenet mine, the duration of downtime varies depending on the blasting operation, with a maximum of 865 hours and a minimum of 664 hours per year, and just for a shovel with a maximum of 93.1hours and a minimum of 83hours (Table 1).

It is also clear from Table 1 that this phenomenon is observed in the dump truck's park [6].

Table 1. The duration of downtime for the shovels and the dump trucks, due to the blasting work.

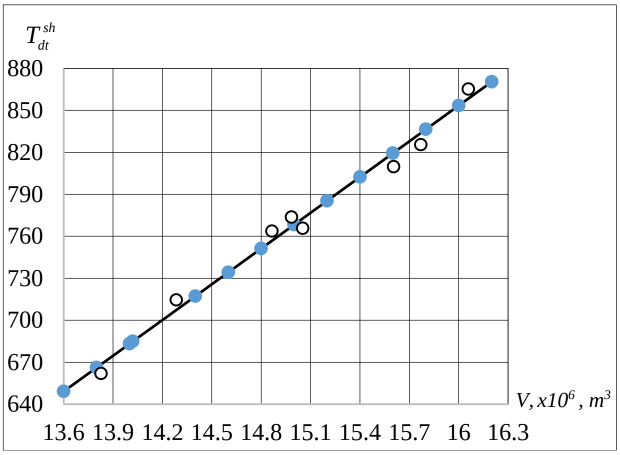
The blasted rock mass, 10^6 m^3	The average duration of downtime for the			
	the sho-vels's park	a sho-vel	the dump truck's park	for a dump truck
13.85	664	83	1560	48.1
14.36	722	92.5	1650	66
14.91	765	95.6	1860	86.5
14.988	770	96.2	1905.7	19.8
15.003	765	109.2	2100	87.8
15.556	811	101.3	2422.8	101.3
15.7	825	91.66	2350	97.9
16.105	865	96.1	2613	115.5

The blasting work is carried out once a week on the Erdenet surface mine, so approximately 52 times per year.

The duration of downtime due to blasting operation depends on the volume of the rock to be blasted per year on the one hand, and the number of blasts per year on the other, i.e. the time between two consecutive blasting works.

The volume of the blasted rock will change with the increase and decrease of the annual open-pit work. Based on the study, the duration of downtime of the shovels and the dump trucks at the Erdenet surface mine due to the blasting will be considered depending on the volume of the rock mass that will blast per year for their park.

A regression correlation (Figure 4) between the duration of downtime for shovel's park and dump truck's park during the year and the volume of the blasted rock in a given year was established and analyzed using statistical software.



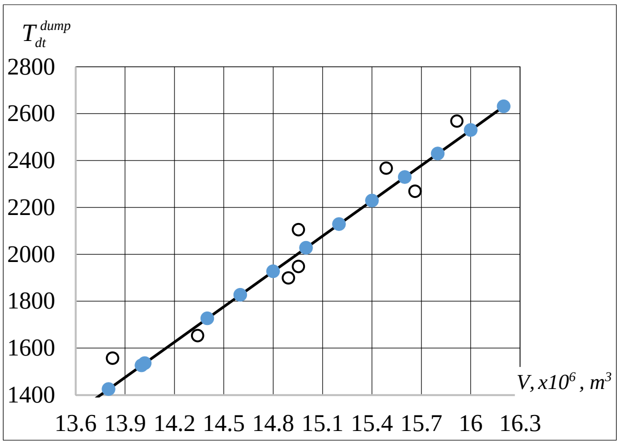


Fig. 4. Correlation between mine equipment downtime and blasting rock mass: for shovels's park; b. for dump truck's park

As a result, the relationship between the volume of the rock mass to be blasted per year and the downtime due to blasting operations:
for shovel's park:

$$T_{dt}^{sh} = -508.481 + 85.122V, \quad r = 0.923 \tag{1}$$

for dump truck's park:

$$T_{dt}^{dump} = -5503.82 + 502.1256V, \quad r = 0.817 \tag{2}$$

There is a strong correlation between the parameters under consideration since the values of the correlation coefficients r=0.923 and r=0.817 for equations (1) and (2), which show the relationship between the duration of downtime of equipment park and the volume of blasting rock mass. For equations (1) and (2), when the probability is 95%, the values of the Fisher test are F (1.6) = 42, F (1.6) = 37, and the total error are 5.62, 7.8, indicating that the relationship is correct.

The number of blasting blocks will be determined by the volume of the rock mass to be excavated during the year. By reducing the number of blasting per year and optimizing them, it is possible to decrease the downtime of shovels, dump trucks, and other machinery used at the mine. As result, this will allow them to improve their work to a certain extent.

Therefore, it is necessary to define the optimal number of blasting per year. The mining machine's production is limited by the shovel's production, which is the head mining equipment. Hence, it is essential to determine the number of blasting per year and the volume of rock to be blasted once concerning the shovel's operation.

The purpose of preparing the rock for excavation is to ensure the continuous operation of the shovel. Therefore, based on the theory of supply or resource allocation, let's determine the volume of a one-time blasting by dynamic programming.

The purpose of resource allocation theory is to determine the optimal amount of product supply (S), average resource level (Sd), inter-supply time, or supply rotation interval (t) depending on the level of consumer demand and supply. In resource management theory, the following conditions are considered in several variants [9]. These include:

- ✓ reserve intervals are different, and the amount of supply is constant;
- ✓ backup rotation interval and reserve size are variable;
- ✓ reserve turnover intervals are regular, and resource supply is unstable.

The basic condition for operating shovels and dump trucks with a regular uniform load throughout the year is to provide them with a constant supply of blasted rock at regular intervals (Figure 5).

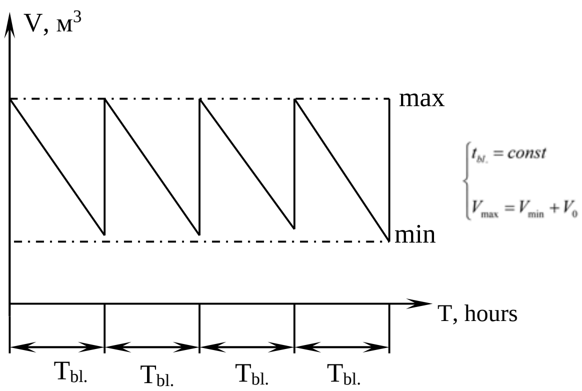


Fig. 5. Distribution of to be blasted the rock mass resources.

3. Result and discussion

In practice, the condition that the supply is regular when the supply time interval is regular is satisfied when the demand does not fluctuate over time. In our case, the number of equipment available may be uneven during the supply period due to maintenance and repair. Therefore, it is appropriate to consider the volume of the blasting rock mass or the volume of excavation and transporting resources between the minimum and maximum values required.

In this case, the volume of reserve to be prepared varies from the minimum to the maximum, depending on the demand for the supply (the blasting rock mass) in a given interval (the time between two consecutive blasts or the frequency of blast). In other words, the values of the maximum number of shovels to be available and the minimum number of resources to be prepared in the interval between the supply of the reserve are determined.

The time between the two blasts, or the reserve rotation interval, is given by the following formula, which is the average daily output of the shovels working on the bench and the ratio of the rock mass on the bench to be ready for excavation.

$$t_{bl.} = \frac{V_j}{Q^j_{sh.}} \tag{3}$$

where: j - the number of benches where shovels is in operation, V_j - the volume of the blasted rock mass on the j bench , m^3; $Q^j_{sh.}$ - average daily output of shovel, m^3/hour.

The number N_{year} of blasting per year, expressed in terms of the volume of the rock mass to be blasted during the year V_{year} and one time V_0, is expressed as follows.

$$N_{year} = \frac{V_{year}}{V_0} \tag{4}$$

where: V_{year} - the volume of the rock mass to be blasted per year, m^3; V_0 - volume of one time blasting, m^3.

The purpose of blasting is to distribute the blasting block N times a year in order to minimize equipment downtime. By reducing the number of blasting per year, it is possible to decrease downtime of equipment and to reduce the lost of productivity of equipment due to blasting work [7, 8]. However, as this increases the size of one time blasting, the cost of one-time blasting will increase, and the optimal number of blasting per year will be found at the lowest downtime of equipment and blasting costs.

To simplify the task of optimizing the number of blasting per year, or the volume of one-time blasting, we assume that the volume of blasting is regular for a given year. From this, it can be assumed that the average volume of one-time blasting is regular. Therefore, the linear model for optimizing the number of blasting per year by the cost of blasting operations can be formulated as follows, taking into account the deviation of the value of the resource allocation from the minimum to the maximum value and formula (4).

$$Z(V_0, t) = \frac{V_{\max}}{V_{\min}} = \left(N\bar{V}C_{bl.op} + \frac{V_{year}}{\bar{V}} T_{d.t} C_{l.d.t} \right) \tag{5}$$

where: N - number of blasting per year; $T_{d.t} = nt_i$ - duration of shovel's downtime due to blasting work; $C_{l.d.t}$ - loss per hour of shovel's down time, USD/hour; $C_{bl.op}$ - cost of blasting one cubic meter of rock mass, USD/m^3.

Based on the modeling equation (5) for optimizing the number of blasting per year, we can say that the actual blasting cost will increase directly by the volume of the blasting block, and the downtime of equipment will be a hyperbola type and located in the first quadrant of the coordinate plane.

Therefore, the volume of one tome blasting rock mass or solution of the equation is determined by the intersection of the straight line represented by the first addend of equation (5) and the hyperbolic represented by the second addend. Our task is one-dimensional because the blasting block for one time or resource distribution is a one-time allocation, and resource allocation is a multi-step static decision-making process. Instead, the decision and state vectors for each stage are one-dimensional. Therefore, let's optimize the linear model (5) by dynamic programming.

To do this, consider the number of blasting per year as a step in the decision-making process and let's transform the modeling equation expressed by equation (5) in the following order.

Divide the volume of the rock mass to be blasted or the annual reserve V_{year} required for shovels and dump trucks into V_0^i i=1, 2, ..., N sub-sets of one-time blasting. The cost $z(V_0^i)$ of the resource or cost of the blasting rock mass, the downtime (t) of the equipment and downtime loss $z(t^i)$ are attended for each V_0^i.

Therefore, the cost of blasting during a given year can be given by the sum function:

$$Z(V_0^1, t^1, \ldots V_0^N, t^N) = \left(\sum_{i=1}^{N} z(V_0^i) + \sum_{i=1}^{N} z(t^i) \right) \tag{6}$$

and the amount of resource to be used, or the volume of rock to be blasted per year, is expressed by the formula:

$$V_{year} = \sum_{i=1}^{N} V_0^i \tag{7}$$

and the following condition are met.

$$V_0^i > 0 \tag{8}$$

Therefore, the task of optimizing the number of blasting per year is determined by a mathematical model expressed by the following equation with the objective of minimizing blasting costs.

$$Z(V_0^1, t^1, \ldots V_0^N, t^N) = \left(\sum_{i=1}^{N} z(V_0^i) + \sum_{i=1}^{N} z(t^i) \right) \to \min \tag{9}$$

$$V_{year} = \sum_{i=1}^{N} V_0^i, \ V_0^i > 0 \tag{10}$$

The first addend of equation (9) is expressed the volume of the rock mass to be blasted at one time and the cost of the blasting rock mass for 1m^3. Loss of production due to downtime of the shovels' park is expressed as the number of not working machines and their downtime. So, equation (9) can be written in the following form.

$$Z\left(V_0^1, \mathrm{t}^1, ...V_0^N, \mathrm{t}^\mathrm{N}\right) = \left(\sum_{i=1}^{N}\left(V_0^i C_{bl.op}\right) + \sum_{i=1}^{N}\left(nt_i C_{l.d.t}\right)\right) \to \min \quad (11)$$

where: n – the number of not working shovelss during i blasting due to blasting work; t_i - duration of i blasting work or duration of downtime time for one machine due to blasting; - loss of shovel's downtime for per hour, USD/hour; V_0^i - volume of rock mass to be fragmented during i blasting work, m^3; $C_{bl.op}$ - cost of blasting for one cubic meter of rock mass, USD/m3.

At the beginning of the resource allocation, i at the beginning of the process, the amount of resources allocated is $V_0^i = 0$, and at the end of the allocation, $V_0^i = V_{yeat}^i$. Therefore, since the state space is one-dimensional, as described above, there will be only $s_0 = 0$ and $s_N = V_{year}$ at the beginning and end of the distribution, and during the distribution the state s_0 will be transformed to the s_N state under optimization conditions. We divide the interval [0, N] into sub-intervals E, or construct decision sub-spaces, to select the amount of work to be done in a single blast.

Dividing the interval [0, N] into sub-intervals will make the problem discrete, and the problem will be easier if we choose the same length Δ of the interval as shown in Figure 2. The length of the interval can be $\overline{V} = \frac{V_{\max} + V_{\min}}{2}$ as shown in Figure 2.

Thus, the modeling has been developed to manage the supply of shovels and dump trucks with the fragmented rock mass by dynamic programming, which allows reducing the downtime due to blasting of all mining equipment, thus ensuring the lowest cost and normal operation of loading, transportation operations. Accordingly, the above-explained task for determining the blasting period is a significant solution to determine how the process interacts with the excavation and hauling operations. This ensures that the digging and transporting process can be operated efficiently at the lowest possible cost.

4 Conclusions

According to a study at the Erdenet open-pit mine, as the mine's capacity enlarges, the stripping, extraction, and the volume of blasting work rises each year. As a result, equipment downtime increases, and performance losses increase. In particular, it has been defined that the downtime of the mining equipment increases linearly as the volume of the rock mass to be blasted per year increases.

Therefore, the study shows that the problem can be completely solved by managing the volume of one-time blasting and the time between explosions.

By optimizing the time between blasting through dynamic programming, it is possible to reduce the direct and indirect costs associated with blasting.

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Investigation of resistance and air leakage of auxiliary ventilation ducting in underground mine in Quang ninh

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Abstract. Ventilation when driving roadways is one of the most important considerations in coal underground mines. Ventilation efficiency depends on fan performance and ventilation ducting system. In recent years in Vietnam, ducts have often been produced domestically. However, parameters of the duct as duct leakage, duct resistance for designing auxiliary ventilation system are referenced from abroad handbook. This lead to inaccurate design results and needs to adjust efficiency of auxiliary ventilation during driving roadways. Determination of duct resistance; air leakage in ducting system have been undertaken. The research result has been used to optimize the auxiliary ventilation system.

Introduction

The auxiliary ventilation is carried out by bringing air to the work fronts, as the track is advanced, the amount of air that reaches the front gradually decreases due to the greater resistance of the conduit and the increase of the leakage [1]. Complete elimination of air leakage from, or to the duct system is impossible due to the duct quality and numerous joints in the duct system [2].

In Vietnam, studies on an auxiliary ventilation mainly aimed at finding solutions to improve the ventilation efficiency when mining roadways driven in coal mines. The number of these works is not much, especially there is no research on the resistance and air leakage in ducting being used in coal mines. Up to now, for designing auxiliary ventilation system, duct parameters were referenced from foreign handbook. In addition, these data are published long time ago, while at present, materials as well as duct technology are much different from before that affects the optimization of the auxiliary ventilation system.

Therefore, investigation of air leakage and resistance of auxiliary ventilation ducting in underground mine in Quang ninh has been undertaken. The research result is necessary for optimizing the auxiliary ventilation system.

The parameters of the duct as duct resistance; air leakage play an important role in the design of the auxiliary ventilation.

1 Measurement of duct resistance used in coal underground mines

1.1 Fundamentals of duct resistance

Air leakage through in ducting system flows in turbulent flow mode [3]. In turbulent flow mode, airflow energy loss for overcoming viscosity of the air due to turbulent vibrations, so this level of energy loss is much higher than that in laminar flow. Pressure loss due to frictional resistance in a round duct is determined by:

$$\Delta P = H = \lambda.\frac{L}{D}.P_v = 32.25.\alpha.\frac{L}{D}.\rho v^2 \qquad (1)$$

Where:
ΔP: Pressure loss (head loss) due to frictional resistance in duct L long, mmH_2O;
P_v: Velocity pressure in duct, mmH_2O;
λ: Friction coefficient, dimensionless coefficient;
L: Distance between two cross sections of duct, m;
α: Friction factor for the duct, $KgF.s^2/m^4$;
D: Diameter of the duct, m;
ρ: Air density, kg/m^3;
V: Average velocity at the duct cross-section, m /s.

A relationship between pressure loss and friction factor in duct is given by:

$$\frac{H}{L} = \frac{P_1 - P_2}{L} = 65.4.\frac{\alpha}{D}.\frac{\rho}{2} \qquad (2)$$

Where:
P_1: Pressure of air at section 1
P_2: Pressure of air at section 2

However, at present, there is not expression for calculating friction factor α. It has been determined experimentally.

One of the most basic ventilation equations describes a relationship between pressure loss and airflow volume in a duct is $H= \Delta P= R.Q^2= R.(v.S)^2$ [4] so that friction resistance in ducting system can be obtained by the following equation:

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$$R = \frac{H}{v^2.S^2} \qquad (3)$$

Where:
R: Friction resistance, kμ;
S: Cross sections of duct, m^2:

From equation (3), the specific resistance - r and friction factor of the duct can be found:

$$r = \frac{R}{L} \text{ And } \alpha = 0.25.\frac{H.D}{v^2L} \qquad (4)$$

2 Experimental procedures

Laboratory set-up. Experimental model for determination of duct resistance was set up at Institute of Mining Science and Technology - Vinacomin (IMSAT), Uong Bi, Quang Ninh.

Fig. 1. Experimental apparatus for determination of duct resistance.

For the model to determine the resistance of the duct with diameter D = 0.6m and air flow Q = 3.4 m^3 / s, the velocity in the duct

$$v = 3.4:\left[\pi * \left(\frac{D}{2}\right)^2\right] = 12.02 \ m/s$$

Reynolds number:

$$R_e = \frac{v.D}{\nu} = \frac{12.02 * 0.6}{14.4 * 10^{-6}} = 500833$$

Where: ν is the viscosity coefficient of the air ν = 14.4 x 10^{-6}

Duct length between two cross sections of duct section must be satisfied:

$$L = 0.639 * R_e{}^{0.25} * D = 10.2 \text{ (m)}$$

Thus, for the duct with diameter D = 600mm, duct length is set 15m. Measurements were conducted on a fabric duct of 600mm diameter, 15 m length.

Fig. 2 shows the schematic diagram for determination of duct resistance.

Fabric duct is connected directly to rigid steel ducting and carried as straight in the horizontal direction.The ducting system must be stretched tight during installation. Hence, the pressure loss on the ductwork is caused by frictional resistance [5]. Since the duct from PL_1 to PL_2 has no joints, local resistance does not appear.

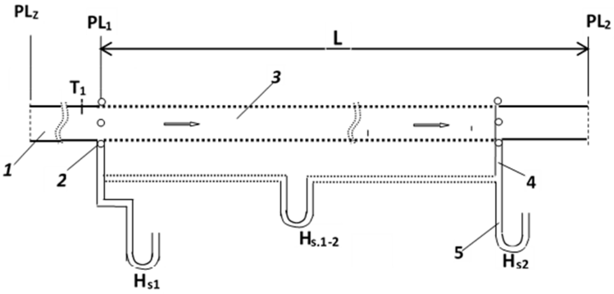

Fig. 2. Schematic diagram for determination of duct resistance: 1 - rigid steel ducting; 2 - holes for measurement; 3 - flexible fabric ducting; 4 – pitot-tube; 5 - U tube.

Velocity v at the center of each section was measured by a pitot tube. The cross sectional area of the duct was equally divided into four areas, 16 points traverse as shown in Fig. 3 [6].

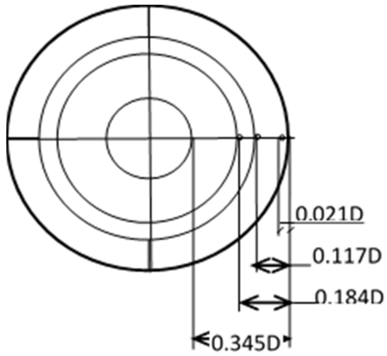

Fig. 3. Diagram position of traverse points in a circular measurement section for 4- area, 16 point traverse.

The average velocity V in the duct was calculated from the arithmetical mean value of v. At the same time, the pressure difference between the pressure PL_1 and PL_2 was measured and related with the average velocity V [7].

From that the average velocities at the measuring of the pressure drops along the ducts can be obtained.

Fig. 4 shows cross sectional area for pressure measurement and pitots in practice.

Fig. 4. Cross sectional area for pressure measurement and pitots.

3 Test results

Experimental data for determining duct resistance R, specific resistance r and friction factors are shown in Table 1. Average values of the resistance R, specific resistance r and friction factors calculated for test ducting are as:

$$\bar{R} = 4.041\ \text{k}\mu;\ \bar{r} = 0.0269\ k\mu.m^{-1};$$

$$\bar{\alpha} = 0.00030\text{KgF}.s^2.m^{-4}$$

Table 1. Experimental data and results for determining duct resistance.

Measurement	1	2	3	4	5
Airflow Q, m³/s	7.33	7.42	7.42	7.42	7.43
Pressure at section PL_1, Pa	785	784	781	780	777
Pressure at section PL_2, Pa	558	569	553	564	555
Resistance R, kμ	4.224	3.902	4.138	3.921	4.0201
Specific resistance r, kμ/m	0,02816	0,02602	0,02759	0,02610	0.02680
Friction factor α KgF.s²/m⁴	0.00034	0.0031	0.00033	0.0003	0.00032

The values for the measured friction factor is small compare with published values calculated by others as shown in Table 2 [8]. However, the measured friction coefficient (0.0003 kgF.s^2 / m^4) is much smaller with the value using the auxiliary ventilation design in Vietnam (0.00048 kgF.s^2 / m^4).

Friction factor depends on the smoothness of the duct material, diameter as well as the tension level of the ducting system.

Table 2. Quoted friction factors for flexible duct.

No	Friction Factor, KgF, s²/m⁴	Reference
1	0,00054 0.00046- 0.00048	Telyakovsky and Komarov, 1969 Burtrakov and Ushakov
2	0.00030	Le Roux, 1979
3	0.00037- 0.00046	Hartman and Mutmanski, 1982
4	0.00051	Baret and Wallman, 1983
5	0.00023	Jones and Rodgers, 1983
6	0.00038	Vutukuri V., 1983
7	0.00030	Institute of Mining Science and Technology - Vinacomin , Vietnam

2. Estimation of air leakage of duct used in coal underground mines

Level of air leakage is mainly influenced by the following factors: total length, diameter of the ducting and airflow in the ducting system. The experimental data are made on 0.6 m diameter ducts over sections of ducts installing towards the working face in actual field conditions in Quang Ninh coal mine as shown in Tab.3. A conceptual prediction model has been proposed based on experimental data at Quang Ninh Coal mine [9].

$$p = f(L, Q) \qquad (5)$$

Let p, L and Q represent leakage coefficient, duct length and quantity of airflow in the ducting system respectively. It is assumed to express p in the form:

$$\ln(p-1) = lnc + b_1 lnL + b_2 lnQ \qquad (6)$$

Where: p : Leakage coefficient;
L: Duct length, m;
Q: Quantity of airflow in the ducting system, m^3/s;
lnc, b_1, b_2, constants.

Each set of data: ln (p_i), ln (L_i) and ln (Q_i) under given data – duct diameter, with i=1, 2…n.
With ducting length L_i, the quantity of airflow in the ducting system Q_i is measured; the air leakage coefficient p_i is calculated as $p_i = \frac{Q_0}{Q_i}$;
Where: Q_0 the quantity of airflow beyond the fan, m^3/s;
Q_i the quantity of airflow reaching the end of the ducting length - L_i.

Table 3. Experimental data for the duct of 0.6m diameter.

Q(m³/s) / L(m)	1.5	2	2.5	3	3.5
100	1.022	1.025	1.028	1.030	1.032
200	1.081	1.091	1.100	1.108	1.115
300	1.173	1.195	1.214	1.230	1.245
400	1.296	1.333	1.365	1.394	1.420
500	1.448	1.505	1.554	1.597	1.636
600	1.630	1.709	1.778	1.839	1.894
700	1.839	1.945	2.037	2.118	2.192
800	1.455	2.213	2.330	2.434	2.529
900	2.341	2.511	2.657	2.786	2.904
Q(m³/s) / L(m)	**4**	**4.5**	**5**	**5.5**	**6**
100	1.033	1.035	1.037	1.038	1.040
200	1.122	1.128	1.133	1.139	1.144
300	1.259	1.272	1.284	1.296	1.307
400	1.443	1.466	1.486	1.506	1.524
500	1.672	1.706	1.737	1.767	1.795
600	1.945	1.000	2.036	2.078	2.117
700	2.259	2.322	2.381	2.436	2.489
800	2.615	2.696	2.771	2.843	2.910
900	3.012	3.113	3.207	3.295	3.379

Let y_i, x_{i1}, x_{i2} and b_0 represent ln (p_i -1), lnL_i, lnQ_i and lnC respectively. Equation above can be rewritten:

$$y_i = b_0 + b_1 x_{i1} + b_2 x_{i2} \qquad (7)$$

Least-squares regression is to fit these experimental data that minimizes the sum of squared residuals [10]:

$$\sum_i^n e_i^2 = \sum_{i=1}^n \left(y_i - b_0 - \sum_{j=1}^2 b_j x_{ij}\right)^2 \qquad (8)$$

Take derivatives with respect to the model parameters b_0, b_1 and b_2 set them equal to zero and derive the least-squares normal equations that our parameter estimates b_0, b_1 and b_2 would have to fulfil.

Normal equations of two independent variables can be written in matrix form as:

$$\begin{vmatrix} \sum_{i=1}^n x_{i1}^2 & \sum_{i=1}^n x_{i1}\, x_{i2} \\ \sum_{i=1}^n x_{i1}\, x_{i2} & \sum_{i=1}^n x_{i2}^2 \end{vmatrix} \begin{vmatrix} b_1 \\ b_2 \end{vmatrix} = \begin{vmatrix} \sum_{i=1}^n x_{i1} y_i \\ \sum_{i=1}^n x_{i2} y_i \end{vmatrix} \qquad (9)$$

Solve the above matrix to obtain the regression coefficients. Therefore, the air leakage coefficient for the duct of 0.6m diameter can be obtained based on data at Quang Ninh mine:

$$p= 1 + 3.5078.10^{-6}.L^{1.865}Q^{0.4135} \qquad (10)$$

Use the F-test can evaluate Pro (F) = 0.0000 with significance level is 0.5. This low a value would imply that the regression parameters are nonzero and the regression equation does have some validity in fitting the data.

Conclusion

The resistance and air leakage of the duct depends on many factors, in which the ducting material and size play an important role.

For designing auxiliary ventilation system, duct parameters were referenced from foreign handbook that causes results in lack of confidence.

Factors such as duct size and diameter, aerodynamic parameters in duct airflow influence on duct air leakage.

A conceptual prediction mode can be determined duct air leakage based on the experimental data at Quang Ninh mine. Also, the research result has been used to optimize the auxiliary ventilation system. Optimization of the auxiliary ventilation system can save cost and energy.

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Defining the information flows for DLT of a transport company in the mining industry according to the criteria for sustainable development

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Abstract. The application of information technologies leads to the improvement of the companies’ production parameters in each sector according to the criteria for sustainable development. Naturally, in order to achieve efficiency, they must be tailored to the specifics of the industry, in this case the mining industry. The article proposes a methodology for the introduction of Distributed Ledger Technology (DLT) for the transport information flow at a mining company. Based on the chosen organizational structure, the participating actors and the data they share, the information channels are determined. According to the necessary rights of the participants to modify the transactions and the number of channels of the transport information flow, a consensus mechanism Practical Byzantine Fault Tolerant and the so-called smart contract have been chosen. Different DLT platforms are analyzed. Hyperledger Fabric was selected as an appropriate platform in order to ensure the continuity of the system, the asynchronous control of the various channels and the ability to include different actors.

1 Introduction

In the second half of the XXth century there is an increase in population along with global economic growth, which is associated with excessive, intensive and uncontrolled use of natural resources [1]. In order to meet the needs of present and future generations on the Earth, the Brundtland Commission published a report on the sustainable development in all areas of life and human activity [2]. This means that the implementation of measures in one area must not be at the expense of deteriorating performance in another area. In addition, the measures taken should not be temporary initiatives, but long-term management decisions that have a positive effect on all areas affected.

Dubinski defined the following main pillars of sustainable development in the mining sector [1]:

- technical and economic activities for continued economic growth;
- introduction of ecological measures for environmental protection and appropriate use of natural resources;
- social events to improve working conditions, care for employees and personal development in the mining community.

With the growth observed in the quantities of extracted minerals from ancient times to present days, the main aim of the economic and technical means is the reasonable acquisition of natural resources. Therefore, according to the first pillar of economic growth, it is recommended to undertake measures for long-term sustainability in terms of planned production and sales volumes, which is directly related to the improvement of the technical means for extraction and processing of mineral resources.

In recent years, measures have been taken worldwide to reduce harmful emissions of waste products into soil and water generated by the mining, chemical and pharmaceutical industries [3, 4]. The reclamation of the excavated land masses and the improvement of the working conditions with reduced amounts of industrial accidents, dust and noise are considered with regard to the environmental measures [5]. The reduction of industrial accidents and occupational diseases, due to the presence of harmful substances are the main target for improving the working conditions, typical not only for the mining, but also for the chemical industry and agriculture. They have the highest share in countries with low innovation potential and in developing countries [6].

According to [7], the measures become effective with government support and this is proved by the enactment of many directives for reclamation and waste recycling [8, 9] from the mining activities, reduction of carbon emissions, efficient use of energy sources, etc.

At the same time, measures for staff training with new technologies, introduction of leisure activities, practices for the development of the innovative concept "Shared values", the “Got it” system for collection, evaluation and implementation of ideas from the employees, communication programs with the community and others are recommended [10, 11].

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An essential element for achieving the recommendations for sustainable development is the life cycle assessment (LCA) for each production process.There are two aspects with regard to the mining industry [12]. On the one hand, this is the impact assessment of the products from the activity on the environment and comparison of the indicators of different types of mining per kilogram. On the other hand, the mining industry can use LCA to assess the impact of its activities on nature in order to improve the technology.

2 Sustainable development and information technology

The introduction and evaluation of production activities according to the criteria for sustainable development can be done through new technical means for data management and processing, related to the complexity of the links among the individual sectors in each company. The implementation of an information system would not only lead to traceability and security of information flows, but would make progress in increasing the innovation potential in the mining sector. At the current stage of production, Bulgaria is the only EU member state with the lowest innovation index [10]. Therefore, process management, assessment of the state and raising the innovation index would not be possible without modern information technologies.

The introduction of information technologies in industrial production is associated with positive and negative aspects. Initially, financial resources, training, infrastructural changes, and sometimes even layoffs, recruitment or retraining of staff are needed. On the other hand, remote control, improved security and accountability, traceability of the information flow, etc. could be achieved by using them.

Firstly, the implementation of DLT implies security in data transmission, which will first increase trust among partners and therefore improve the working atmosphere. Secondly, it will contribute to the efficient consumption of fuels and resources, which will have an economic effect. Thirdly, the automatic sending and archiving of reports increases the accountability and traceability of all documents to the point of impossibility of theft by third parties.

Naturally, each new technology is built on the basis of a previous one. For example, when upgrading databases with DLT, it was found that the information could be compared and evaluated. On the other hand, data are shared among nodes more slowly compared to the SCADA system, which is designed to manage production processes. The advantage of DLT is the security, non-modifiability and traceability of the transmitted data, which makes it a suitable system not for managing production processes, but for sharing confidential data among commercial, production and regulatory organizations. With the implementation of this new information technology, different communication channels appear among subjects which exchange data of mutual interest.

Therefore, to assess production support measures according to the criteria of sustainable development, DLT is suitable for sharing information flows in mining enterprises. These are electricity, production, waste, transport, security. As a new technology, whose legislation is from 2019, it is necessary to develop an algorithm for implementation, definition of information channels and definition of the attributes in the blockchain for the described sharing channels. At present, such do not exist yet.

The purpose of this article is to determine the stages of the method for implementing DLT and achieving improved communication by clearly defining the communication channels and the type of transmitted information for the transport sector in a mining enterprise.

3 Methods

As a new information technology, the regulations for blockchain and DLT are respectively from 2017 and 2019, which necessitates a brief definition of their functions, advantages and disadvantages. The methods for building DLT are based on different platforms - Ethereum, Hyperledger Fabric, Corda and others. These platforms differ according to the method of data transmission, the rights of the participants to modify the data, the transmission speed, etc.

Given the history of DLT, the main research and development of the above-mentioned platforms are for cryptocurrency management [13, 14], trade and economic flows, as well as their protection against cyberattacks [15]. In recent years, there has been a study on the implementation of the technology in ticket sales in rail transport [16] and fleet management.

With the isolation due to the COVID-19 pandemic, the real applications of the technology are increasing.The already implemented and working solutions prove the possibilities for tracking cryptocurrencies to various commercial products. Although the DLT regulation is from 2019, there are already successful commercial applications such as tracking the origin of eggs from Farmers Hen House via QR shared codes, authentication of COS sweaters via My Story™ labels by H&M and VeChain [17, 18]. The most visible effect is to the transparent and unmodifiable tracking of supplies of medicines and food, encompassing the companies Deloitte, Maersk, the World Bank and the World Food Program [19].

In the industry, as a representative of the transport sector, Volkswagen has implemented DLT to track parts and origins of materials for the manufacture of batteries for electric vehicles [20], management and settings of cars in the construction of smart cities [21]. An analysis of the platforms shows that the Hyperledger Fabric is preferred in the transport sector, as can be seen from the website [22].

At a round table in Toronto, leading IT and mining experts have identified the following streams as leading directions for the implementation of DLT in the mining industry [23]:

1. Management of the financial resources in communication with banks and suppliers;
2. Communication with state institutions;
3. Human resources management;
4. Repair system when reporting accidents.

The management of vehicle traffic is not explicitly mentioned, but haulage is a major activity in large and distributed mining companies and area 4 - the repair and accident system is part of it. For this reason, the article is aimed at defining the channels of the transport information flow and the shared data.

In order to define the stages for implementing a blockchain-based DLT for transport channels for sharing, these concepts have to be defined first.

Since the organizational structure of each enterprise is the framework for reporting the relationships in an organization, the first step of the proposed methodology is to consider the main organizational structures. The values for measurement and transmission to the respective actors are determined according to the structure of the organization and with regard to the selected information flow. The number of channels for the respective information flow is then determined, as not all data are transmitted to all participants in a given communication scheme.

In order to achieve consensus, decentralization and equality in data transmission, it is necessary to define a consensus mechanism. The following is a design for smart contracts to set sharing rules and a platform selection.

4 DLT and Blockchain

DLT is a decentralized database containing information visible to all actors in real time. The system allows the sharing of the necessary information among the network's participants through the respective synchronization. To achieve security, the data is encrypted and changes by each participant are authenticated with their own key. On different platforms, participants' rights to modify the data may be different, but the common denominator is that once modified, the data cannot be deleted. Thus, the system ensures unmodifiability, traceability and transparency of information flows [24].

The blockchain [25], as the name suggests, is a chain of blocks (codes) connected by cryptographic algorithms, containing identical information. The management of transactions in the network is through a consensus mechanism that validates the allowed transactions when adding them to a block. This is a method of authenticating and validating a value or transaction without the need for explicit trust or reliance on a central institution, i.e. on a third party. Thus, the recommendation for economic optimization of expenditures according to the criteria for sustainable development is implemented by eliminating the need for an intermediary and giving the possibility to each participant to be both a provider and a user of data.

The transmission and recording of the information among these participants in the blocks takes place after its verification as genuine through the so-called smart contracts.

The choice of blockchain, smart contract and consensus mechanism depends on the parameters of the organizational structure, the rights of the participants to modify the transactions, the number of information flow channels and the type of information flow.

It has been established in previous studies that the information flows in the mining industry are the supply and reporting of fuel or repair equipment, the monitoring of energy parameters by shifts and departments, the quantity and quality of the extracted or processed product, the monitoring of emissions [26]. These information flows include data from the measures and laws introduced in recent years to reduce harmful emissions, optimize production, introduce new technologies for extraction and transport.

The development of information technologies has necessitated a remote or GPS system for tracking the routes of vehicles. In addition, methods are being developed to study their technical serviceability or efficiency. To carry out the above-mentioned activities, specialized information management is required [27]. In order to improve the efficiency of vehicle management in a mining company through DLT, the transport sector will be analyzed. Due to the differences in mining companies, the options are many and specific, but the information flow in all cases depends on the organizational structure of the company, which requires a brief overview of the main structures.

5 Organizational structure

Different organizational structures are characteristic for the mining industry and they depend on the functional peculiarities of production, the history of the organization, and the geographical features. Since mining production includes various activities such as extraction, processing, reclamation, there are different types of companies - Ltd., JSC, holding, industrial group and outsourcing. All these companies are characterized by a hybrid type of organization, which combines functional and geographical type of structure.

5.1 Holding

The holding company is a business entity that combines the assets of various subsidiaries and performs supervisory functions. It is characteristic that it generally does not carry out specific business activities and does not actively participate in the management of the day-to-day operations of its subsidiaries. Therefore, this type is not considered in the present study.

5.2 Industrial group

The industrial group includes companies that can work in various fields - construction, consulting, mining, energy, environment, haulage, security, etc. The companies in the industrial group can interact among themselves, but they can also have projects with external companies and partners.

5.3 Outsourcing

Outsourcing is the business practice of hiring a firm outside the company to provide services or create goods that are traditionally done internally by the company's own employees and staff. It was first recognized as a business strategy in 1989. This way of transferring tasks is undertaken as a cost reduction measure. This is a method for companies to allocate resources where they are most efficient, according to the criteria for sustainable development. It helps to preserve the nature of free market economies worldwide. This way of transferring tasks allows the companies to focus on key aspects of the business, allocating less critical operations to external organizations.

In the present study, the communication channels in a given outsourcing company are defined, because in the communication among companies it is possible to reduce the security in data transmission, to lose trust among the partners. Therefore, a need for protection arises when transmitting confidential data without disrupting the communication among the suppliers and the company, etc. The implementation of DLT will further facilitate the efforts of the legal teams of the companies when signing contracts in which the type and the way of sharing confidential data must be precisely mentioned.

With the implementation of Internet technologies, in all companies, amorphous parts of the structure have emerged, which can lead to confusion in the management and executive staff. This further reaffirms the need for a DLT, which will clearly define the ways in which the information required is transmitted to each participant.

The object of analysis is the transport information flow, as the communication channels proposed in the article can be modified according to the parameters and organizational features of a specific production process. They can also be used by smaller companies.

6 Main parameters

The implementation of each database as well as DLT begins with defining the transmission data [28]. For a transport company working in the mining sector, it is necessary to differentiate the data according to the actors involved.

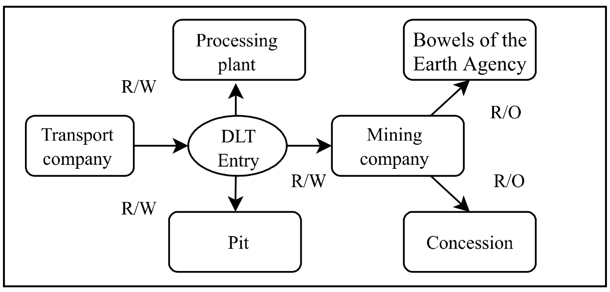

Fig. 1. Scheme of production.

The actors interested in these data are the Pit, the Processing Plant, the Transport Company, the Mining Company. It communicates and shares data with state-owned companies, agencies and regulatory bodies in accordance with the legislation. It is obvious that there are many participants and sharing all the information would complicate the work of each of them. Therefore, the following information flows are defined for the transport sector:

1. The amount of ore. In this information flow among the participating companies are shared data on the parameters: amount of development, amount of ore transported, number of courses of vehicles, fuel consumed, stope (working face). The actors interested in these data are the Pit, the Processing plant, the Transport Company, the Mining Company. They all share the measured values and confirm the received records. The mining company sends official reports to the Bowels of the Earth Agency and the concession, which only accept these data, i.e. their rights are read-only. The conceptual model for communication in this case is visualized in Fig.1.

2. Technical condition. The technical condition of the vehicles of the transport company depends on the working hours, the number of courses of full vehicles, the number of courses of empty vehicles, the distance traveled. In the presence of electric vehicles, the company may have implemented a system for remote diagnostics according to the temperature of certain parts or other parameters. In order to reduce carbon emissions [11], the share of electric vehicles in all sectors of production is expected to increase [29], and the information flow can be supplemented with parameters such as tire condition, battery condition, battery voltage of the individual vehicles, charging time, number of charging cycles, LCC, management or optimization of PV renewable source for charging [30] and etc. Information flows in the management of electric vehicles are not discussed in the article. The data about the technical condition are transmitted by the transport company to the repair company and to the mining company. The conceptual model for communication in this case is visualized in Fig. 2.

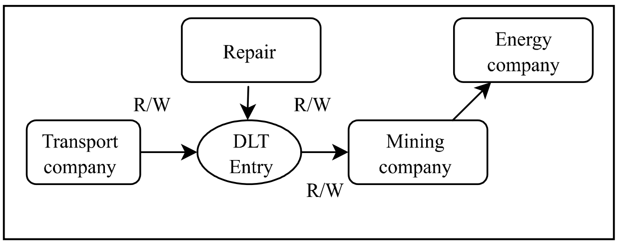

Fig. 2. Scheme of repair flow.

3. Delivery of repair equipment and parts. Every company has repair parts in stock, but each repair is also related to the delivery of new ones. In this information flow, the main data are the number and type of parts in stock and the number and type of parts to be ordered. Therefore, when registering a repair event, the transport company contacts the repair company and the mining company. For its part, the repair company contacts all the

suppliers. It has information about the technical condition of the fleet and can pre-order the elements necessary for maintenance. The conceptual model for communication in this case is visualized in Fig. 3.

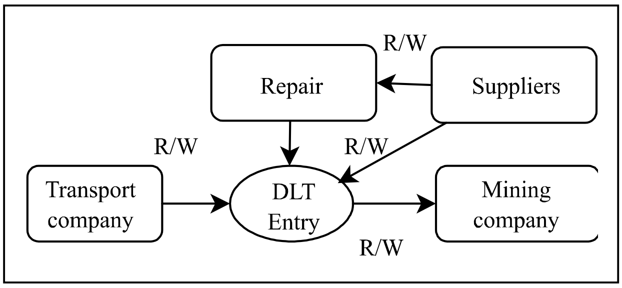

Fig. 3. Scheme of suppliers.

4. Financial flow. The transport company has employees and a fleet. It pays salaries, insurances, trainings to the employees, and buys fuel and energy for the fleet, takes over the repairs. The conceptual model for communication in this case is visualized in Fig. 4.

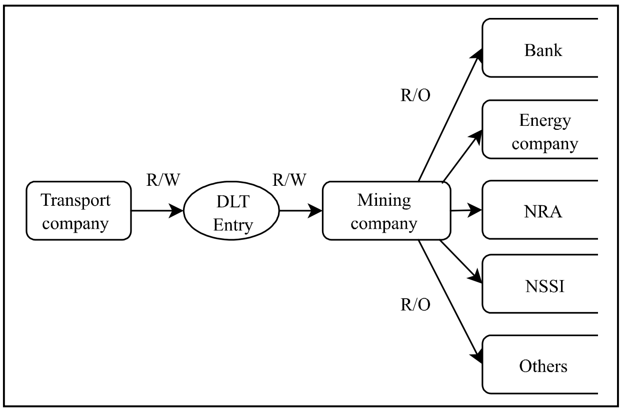

Fig. 4. Scheme of finance flow.

In Figure 4, The Mining company submits data to all external organizations, and they only have the right to view it.

The funds for the financial servicing of the fleet and the employees are received by the Mining Company after reporting on the work performed. In addition, the Transport Company submits a report about its expenditures to the Mining company, which is in contact with the government agencies (National Revenue Agency (NRA), National Social Security Institute (NSSI)), the electricity distribution company and the regulatory authorities.

The only organization that can verify the information sent is the electricity distribution company. This happens when monitoring the parameters of electricity, for example if the transport company has a large number of electric vehicles, which is not reported in the scheme. If it is necessary to halt the activity of the mining company, which is a big consumer of electricity, it warns the electricity distribution company. The same process is repeated at start-up, with the electricity distribution company allowing the start-up of a mining company's activity. If it is necessary to monitor the parameters of electricity, it is necessary to make a separate scheme of information flow related to the quality of electricity, which is among the future tasks of our team.

The study is useful for the mining industry, but the defined flows can be applied to trace hazardous substances in the chemical and pharmaceutical industries, hospitals [4], automotive [20], engineering, agriculture, etc. The results of the study can be applied in other activities after the identification of the following flows:

Characteristics - composition of the flow, source, purification (treatment), discharge - qualitative and quantitative composition, time;

The Supply chain – spare parts, fuel and lubricants – quantity, supplier, quality etc.;

Maintenance – regular vehicle checks, distance travel, tracking of the lifetime engineering cycle;

Documents flow – tamper resistance, redundancy, non-repudiation, tracking etc.;

Operational data – drivers working shifts, quantity of raw material transported, regular vehicle position checks.

7 Consensus mechanism

The data from the defined information flows are validated when added to a block and transmitted to the network of ledgers by a consensus mechanism. It is not necessary for all participants to see all the information in this structure, which is one of the main criteria for choosing a consensus mechanism. In the event of a software issue or another problem in one of the communication channels, it is necessary for the system to continue to operate, without requiring high speed data sharing.

Analyzing all these features for the case under consideration, the suitable consensus mechanism is the Practical Byzantine Fault Tolerant, in which the management is centralized and carried out by the Mining Company. This mechanism allows a clear definition of the participants without excluding the addition of new ones, for example when signing a contract with a new supplier. It provides protection against Byzantine faults [31]. Although Hyperledger Fabric (v 2.2) ordering service is still not ready with PBFT implementation (RAFT CFT is used), it is marked as the milestone for next releases [32, 33]. In addition, its advantages are that there are no initiatives on the nodes, there is no requirement of hash power.

8 Smart contracts

The business logic of the channel is implemented by Smart Contracts, which are computer programs or frameworks that automatically take over tasks and responsibilities in the shared ledger. This is a computer code that recreates the contractual logic of the real world. Acting at the node level under a specific regulation among the participants and the proper functioning of the principle of consensus, they validate and record the shared data. Examples of such platforms are Ethereum, Hyperledger Fabric, etc. The following table 1 provides a comparative analysis of the main platforms.

8.1 Ethereum

Ethereum uses the Proof-of-Work consensus algorithm, in which all participants must reach a consensus on the order of transactions. It lacks confidentiality because any user can see any type of information, which is inapplicable in this case.

Table 1. Comparative analysis of the main platforms

DLT platform	**Type**	**Block creation time**	**Energy consumption**	**Consensus**
Bitcoin	public	10 min.	high	PoW
Ethereum	public	15 sec	high	PoW
EOS	public	0,5 sec	no data	DPoS
Cardano	public	20 sec	no data	Ouroboros
Fabric	private	0,5-2 sec	very low	Modular
Sawtooth	private	no data	very low	PoET (Intel SGX)
IOTA	private	settings	very low	Tangle
Multichain	private	settings	very low	Distributed consensus
Corda	private	0,5 – 2 sec	very low	Notary nodes
Walton-chain	public and private	30 sec	low	WPoC

8.2 Corda (R3 CEV)

Corda was created for financial institutions, with participants agreeing in advance on a set of rules. The Node-to-Node (N2N) consensus algorithm is used, which allows control over the access to the network records. It is suitable in case of a request of a regulator to make a detailed and comprehensive check of the transactions in the network. Achieving security and indisputability of the records is related to the requirement for all participants to be online. For the mining sector, the use of a consensus mechanism suitable for the banking sector is inappropriate.

8.3 Hyperledger Fabric

It is designed for corporate use and all peers maintain one ledger for the channel to which they are subscribed (channels can be more than one). However, unlike other blockchains, in Hyperledger Fabric not all nodes are the same and this arises as a result of the different roles of the representatives of the organizations in the network, which is appropriate for the considered information flow - fleet management.

Hyperledger Fabric allows each network member to identify its representatives, which are configured in appropriate cryptographic materials, such as a Certificate of Identity. There is an opportunity to enter individual settings and preferences when building solutions for shared ledgers, which allows multi-channel communication of the transport company when sharing essentially different information flows.

The main shortcoming which is documented is the requirement to develop a list of participants in the network and give them access through membership of a centralized institution. In this case, however, this is an advantage because it coincides with the peculiarities of the considered organizational structure of an outsourcing mining company. Therefore, for the analyzed information flow, this has already been done and Hyperledger Fabric is the appropriate platform. The constraints of the research are the usage of non-permissive DLT platform Hyperledger Fabric in the management of the information flow in a transport company in the mining industry.

The implementation of DLT to the mining industry is an even more controversial issue. We were unable to find research papers on the application of DLT in the mining industry. Examining the maturity of technology, there is a rapid development of the legislative and regulatory framework, as well as the number of companies that have implemented the system. However, this involves costs, organizational changes, staff training, an increased attack area and the need for new cyber defense methods [15]. Despite Deloitte's estimates that by 2025, about 10% of global GDP will be based on blockchain structures [34], categories of standards applicable to the DLT and the blockchain have not been developed yet. These are framework standards, technology standards, platform-specific standards and industry-specific standards. The above-mentioned shortcomings are typical not only for DLT, but also for most information systems for data transmission.

Despite these limitations in the implementation of DLT as an ever-changing legal framework, the high electricity costs for data transactions, the need for staff training and more, the team believes that applications will increase worldwide. According to [35] DBMS should provide:

- Data storage, retrieval and update;
- User accessible catalog or data dictionary describing the metadata;
- Support for transactions and concurrency;
- Facilities for recovering the database, should it become damaged;
- Support for authorization of access and update of data;
- Access support from remote locations;
- Enforcing constraints to ensure data in the database abides by certain rules.

Thus, data confidentiality, processing logic, irreversibility, non-repudiation, and data redundancy aren't any part from an initial DBMS fully fledged solution. However, they can be partially achieved with additional explicitly added IT procedures which are out of scope of our research. DLT solutions implicitly add an additional layer that provides the described missing properties on the top of the DBMS solution.

9 Conclusions

According to the criteria for sustainable development in the mining sector, fleet management through a new information technology has been proposed. The article presents an algorithm for implementing DLT in an outsourcing company for sharing data by a transport company.

According to the methodology, the directions for sustainable development of the mining sector were

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initially clarified and the peculiarities of the organizational structure of an outsourcing mining company were analyzed. In order to build information management, it is necessary to define variables for data sharing for a transport company and a description of the main information flows. Conceptual models of the main information flows are proposed. The variables in the described information flows are not final and depending on specific features of each mining company, changes in the regulatory requirements and in the activity can be made or new ones can be added.

Based on the participants in the communication channels, the presence of a centralized management organization, the required level of security and data transfer speed, the consensus mechanism Practical Byzantine Fault Tolerant was chosen. It ensures continuous operation, even in the presence of a software problem and the ability to add new participants.

A platform for regulating the contractual data sharing policy has been chosen. Hyperledger Fabric was chosen because it is the closest to the considered organizational structure which needs multi-channel data sharing. The suggested solution provides a fast transaction finality time – e.g. in Hyperledger Fabric it varies from 150 – 200 ms to 2 sec. Exposition of new attack vectors, thanks to increased attack surface. This platform is suitable not only for the transport sector in a mining company, but also for the transport sector as a whole. In addition, Hyperledger Fabric is suitable for other information flows in the mining industry - tracking of resources, electricity, etc.

New perspectives for further research are the classification of the data passed to the DLT system and maintenance of the DLT system.. The attributes of the block are not determined for the defined information flows of the transport company for an outsourcing company, this will be among the future tasks of the team.

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Increasing efficiency of iron ore magnetic separation by using ultrasonic technologies

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Abstract. The research is aimed at solving the topical problem of enhancing efficiency of iron ore magnetic separation by applying ultrasonic technologies to identify optimal technological parameters of magnetic separation, improving controlled structural parameters of a magnetic separator and pretreating slurry by high-energy ultrasound to clean the ore material surface from fine-dispersed particles of minerals and slime, as well as disintegrate ore aggregates fed to the magnetic separator. The main tasks involve identifying regularities of influence of slurry pretreatment by high-energy ultrasound on properties of iron ore magnetic separation, determining regulations of improving technological and controlled structural parameters of the magnetic separator using ultrasonic methods, developing and substantiating methods to enhance efficiency of iron ore magnetic separation by applying ultrasonic technologies.

1 Introduction

Sustainable industrial development calls for solving the topical problem of reducing costs and energy-intensity of iron ore mining and processing [1-5]. Energy intensity of Ukraine's mining and metallurgical complex greatly exceeds that of advanced industrial countries [2, 3}. Power consumption of iron ore concentration processes and equipment substantially depends on properties of ore subjected to processing [6-8]. Nowadays, about 5-8 mineral and technological types of ore are processed simultaneously at Kryvyi Rih mining and concentration plants [2, 7]. It is worth noting that each mineral and technological type of iron ore demands such grinding rate to maintain certain granulometric composition in compliance with the size of useful component inclusions, thus ensuring the best ore-grain release and enhancing efficiency of subsequent sorting and separation [9, 10].

Application of ultrasonic technologies to nondestructive control is one of promising methods to enhance efficiency of iron ore concentration, this involving attainment of operative data on technological processes and treatment of ore particles by controlled high-energy ultrasound, in particular, by forming cavitation processes in iron ore slurry [11-13].

The research is aimed at solving the topical problem of enhancing efficiency of iron ore magnetic separation by applying ultrasonic technologies to identifying optimal technological parameters of magnetic separation, improving controlled structural parameters of a magnetic separator and pretreating slurry by high-energy ultrasound to clean the ore material surface from fine-dispersed particles of minerals and slime, as well as disintegrating ore aggregates fed to the magnetic separator. The main tasks involve identifying regularities of influence of slurry pretreatment by high-energy ultrasound on properties of iron ore magnetic separation, determining regulations of improving technological and controlled structural parameters of the magnetic separator using ultrasonic methods, developing and substantiating methods to enhance efficiency of iron ore magnetic separation by applying ultrasonic technologies.

[14-15] suggest applying the ultrasonic method to controlling suspension velocity and accumulating magnetic material inside the wet magnetic separator of low-intensity. To do this, [14] uses the acoustic system of back-scattering and the ultrasonic method to profile flow velocity. Simultaneously, intensity of the back-scattering signal is used to obtain data on local concentration of solids in the flow and accumulation of magnetic materials.

[16] deals with dynamics of slurry magnetic particles in the magnetic separator of low-intensity. The research suggests modelling dynamics of magnetic particles by tracing individual trajectories by means of the COMSOL Multiphysics software package. The research results reveal various distribution of the block of constant magnets and percentage of coupled particles affecting efficiency of separation. [17] considers the simulation model of the dry rotary drum magnetic separator with distribution of probable trajectories of particles leaving the magnetic separator drum. *Empiric relationships* are used to combine particles' trajectories after their discharge from the drum by its rotation and magnetic field.

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[18] is aimed at investigating into the influence of ore particles accumulated in the magnetic separator on separation processes. There are presented research results on profiles of accumulation of particles and their parameters. It is ascertained that pulsating suspension affects the areas of paramagnetic seizure of particles. *At the same time*, increased magnetic induction within a certain range can also increase particle accumulation to a great extent. [19] deals with researches into ore material separation in various types of magnetic separators. It indicates that a complex system of interrelated factors and structural parameters of magnetic separators greatly impacts efficiency of the latter. The research is aimed at studying the influence of external factors on efficiency criteria of magnetic separation. *Meanwhile*, the researches of the mentioned scholars neglect technologies of pretreating solid particles of ore slurry, in particular the ultrasound-based ones.

[20] suggests a magnetic separator model that considers mineralogical data of ore flows when treating *three ore types* depending on their content of the useful component. There are suggested efficiency indices of magnetic separation ranked by their significance that also take into account the mentioned ore classification. The research testifies to the impact of ore mineralogical characteristics on indices of magnetic separation.

[21, 22] investigate into ore material properties affecting separation in the magnetic separator. However, the above researches consider only a limited range of properties, this not allowing reliable recognition of mineralogical and technological types of ore materials.

[23, 24] describe the experiment results of separating ore materials of various mineralogical properties during magnetic separation. There are determined optimal mode parameters of separation depending on certain mineralogical characteristics to increase Fe content in concentrates. However, the mentioned researches do not focus on nondestructive control of solid slurry properties aimed at improving efficiency of magnetic separation.

Thus, analysis of foreign and national researches on the issues under study reveals a great number of scientific works dealing with methods of enhancing efficiency of technological parameters of ore concentration, improving controlled structural parameters of technological aggregates. On the other hand, it is worth indicating that little attention is paid to the issues of slurry pretreatment by high-energy ultrasound to clean the ore material surface from fine-dispersed mineral particles and slime and disintegration of ore aggregates fed to the magnetic separator. Considering this, integrated application of mentioned methods and means requires development of a relevant mathematical apparatus and engineering designs. It is necessary to conduct researches, improve available mathematical models of technological processes and elaborate a set of ultrasonic methods of operative control over iron ore properties and its pretreatment.

2 Materials and methods

The research aims to improve efficiency of iron ore magnetic separation by integrated application of ultrasonic technologies to enhancing technological and structural parameters of the magnetic separator as well as cleaning the ore material surface and disintegrating ore aggregates.

The research idea implies improved efficiency of iron ore magnetic separation due to identifying technological parameters of the process under study (efficiency, solids concentration, granulometric composition, useful component release), optimal controlled structural parameters of the magnetic separator (the angle of the magnetic unit, the rotation speed, distances between the overflow and the separation drum) and slurry pretreatment by high-energy ultrasound to clean the ore material surface from fine-dispersed particles of minerals and slime and disintegration of ore aggregates fed to the magnetic separator.

The working hypothesis involves integrated application of ultrasonic technologies to investigating into regularities of iron ore magnetic separation that will enable substantiating complex methods of improving efficiency of iron ore magnetic separation, enhancing controlled structural parameters of the magnetic separator and pretreatment of slurry by high-energy ultrasound to clean the ore material surface from fine-dispersed particles of minerals and slime and disintegration of ore aggregates fed to the magnetic separator.

Specific features of the research structure and components imply the fact that achievement of the project aim provides for complex investigations comprising identification of regularities of impacts of pretreating slurry by high-energy ultrasound on characteristics of iron ore magnetic separation; determination of regularities of improving technological and controlled structural parameters of the magnetic separator using ultrasonic methods; development and substantiation of methods to enhance efficiency of iron ore magnetic separation by applying ultrasonic technologies.

Thus, it is required to combine research results in the following directions: theoretical and practical research into iron ore magnetic separation; methods and means of operative control over physical-mechanical and chemical-mineralogical properties of iron ore slurry, as well as methods of improving indices of iron ore magnetic separation.

The mathematical model of dynamic effects of high-energy ultrasound impacting solids in the slurry flow is the key element of the research methods. The given model enables formation of conditions for pretreatment of the ore material surface and disintegration of ore aggregates fed to the magnetic separator. Simultaneously, the model considers dependency of the state of fine-dispersed slime, particles of ore grains of ferromagnetic slurry and flocculated unreleased ore aggregates on parameters of ultrasonic oscillations. The integrated system of methods of measuring ultrasonic dynamics of all technological variables enables improved substantiation of the concept of influence of technological factors on qualitative characteristics of magnetic separation of magnetite quartzite of Kryvyi Rih iron ore basin. The method of identifying processes of separation, delivery and dehydration of materials directly inside the magnetic separator under various operating modes will be

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developed on the basis of ultrasonic measurements of changes in concentration, velocity and sizes of ore slurry solids.
The method is noted for application of the first and the second harmonics of volume and surface ultrasonic oscillations propagating in the slurry and along contacting surfaces as measuring parameters of intensity. Also, the research methods include the method of increasing efficiency of iron ore magnetic separation that encapsulates slurry pretreatment by high-energy ultrasound to clean the ore material surface, from fine-dispersed particles of minerals and slime and disintegration of ore aggregates fed to the magnetic separator, determination of optimal technological parameters of magnetic separation (efficiency, concentration of solids, granulometric composition, the release rate of the useful component) and optimal controlled structural parameters of the magnetic separator by using ultrasonic measurements.

3 Results and discussion

To simulate the ultrasonic pressure source which is time-variant, the k-wave software package for MATLAB is used in the two-dimensional heterogeneous medium of propagation [25, 26]. The initial distribution of pressure is determined by adjusting parameters of the source.p0. To identify the pressure time-variant source, there can be established both a source mask (that identifies the model net points belonging to the source), and the input of the time-variant source. The source mask is determined by assigning of the binary matrix of the same sizes as the calculated net where 1 is presented by the net points forming part of the source [27].

When acoustic waves reach the edge of the calculated area, they are absorbed by a specific type of the anisotropic absorbing boundary layer [28, 29]. Effects produced by this layer can be observed when propagating waves approach the edge of the calculated area. By default, this layer occupies a band of 20 net points around the domain edge inside the calculated domain identified by kWaveGrid. To avoid side effects, one should not place the source or the sensor points inside this layer. As an alternative, to obtain a perfectly coordinated layer, it can be established *outside* the calculated domain set by the user.

The absorbing boundary layer possesses four properties each of which can be controlled by additional input parameters [28, 30].

Sizes of the absorbing layer on each domain edge are conditioned by the parameter PMLSize in units of the points. By default, there 20 net points in one- and two-dimensional spaces and 10 net points in the three-dimensional space. If the size is a single value, it is used for all Cartesian coordinates. Optionally, the size for each direction can be established separately by setting the *Size* value [x_size, y_size] in the two-dimensional space and [x_size, y_size, z_size] in the three-dimensional one.

Absorption inside the absorbing layer is set by the parameter *Alpha* in the Napier units on the net points. By default, the parameter equals 2 for all the sizes. If absorption is indicated as a single value, it is used for all Cartesian directions. Besides, absorption for each direction can be established separately by setting the *Alpha* value [x_alpha, y_alpha] in the two-dimensional space and [x_alpha, y_alpha, z_alpha] in the three-dimensional one.

The absorbing layer can be located so that it is inside or outside the calculated net created by the user while changing the value of the logic flag *Inside*. If *Inside* is established as *false*, the net inputs increase on each edge by the size set by *Size*.

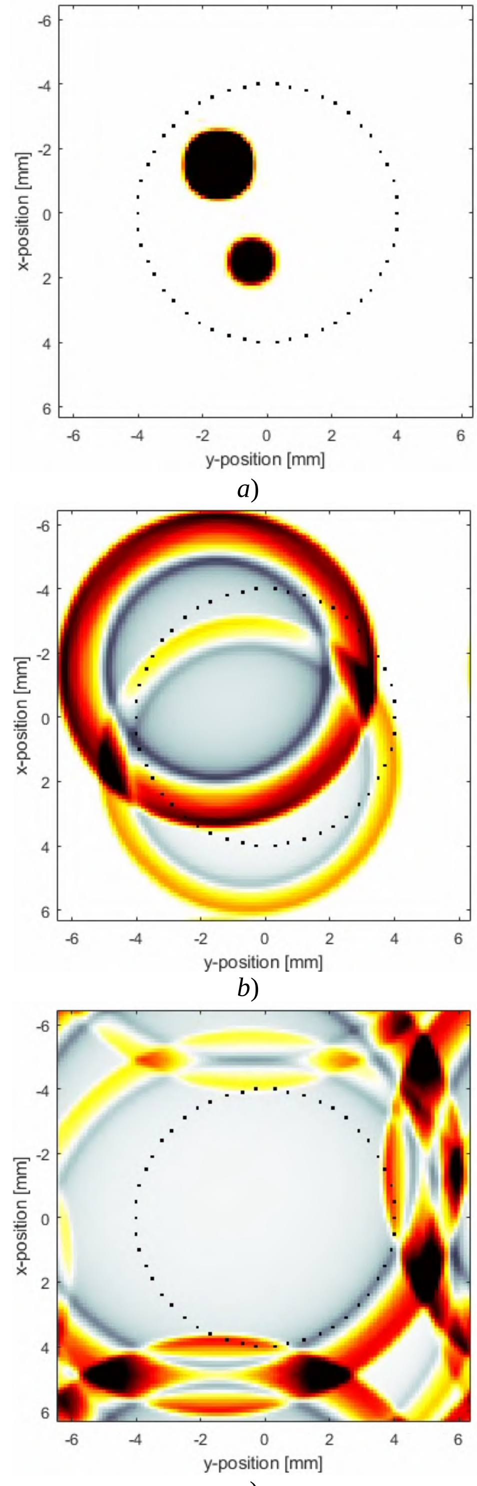

Fig. 1. Dynamics of the acoustic pressure field propagating with the absorbing boundary layer switched off.

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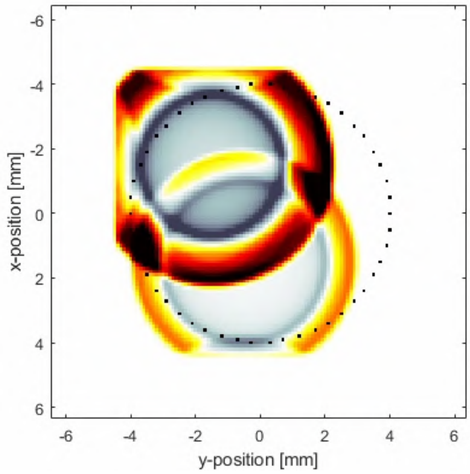
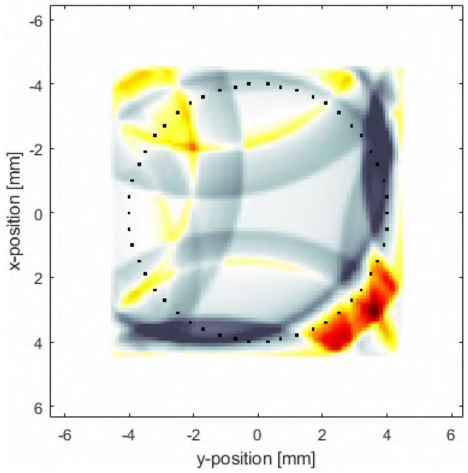
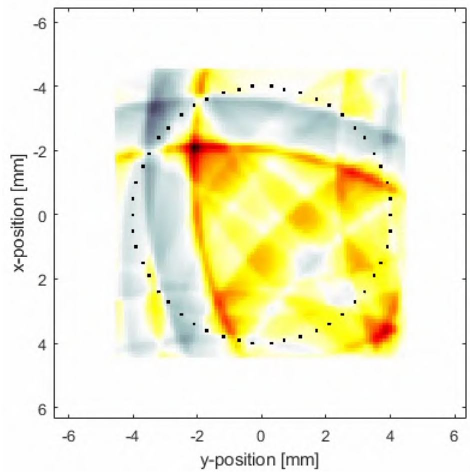
Visibility of the absorbing layer within the simulated space that is reflected during simulation is controlled by the logic input parameter *Plot* (by default set as *true*).



a)



b)

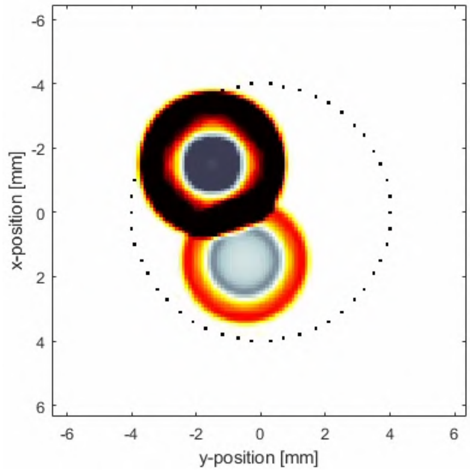


c)

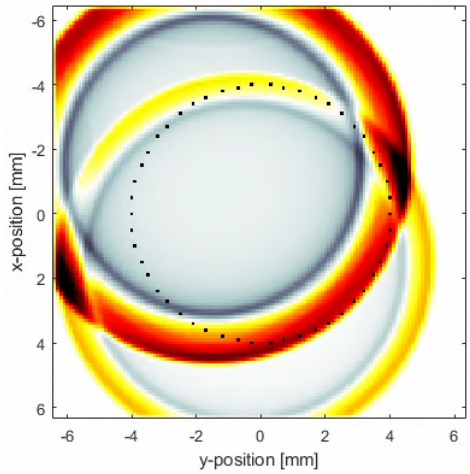
Fig. 2. Dynamics of the acoustic pressure field propagating with the propagation parameter value being too high

To make simulation more accurate, one should make sure the initial pressure distribution and the sensor mask are not within the boundary layer. This can be avoided by setting *Inside* to be *false*. Yet, calculation time will anyway depend on the general size of the net including the boundary layer (i.e. calculations will be the fastest for the nets where the total number of net points in each dimension is given twice).

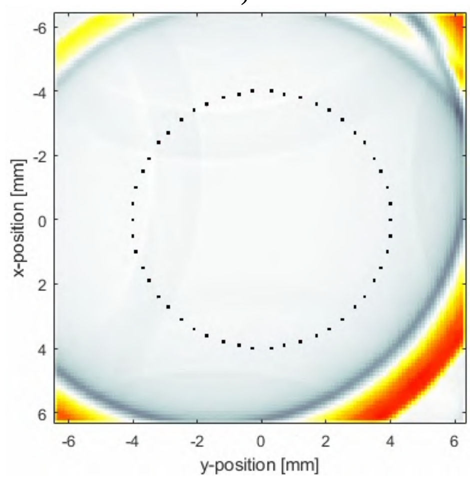
Let us consider some specific cases of adjusting the absorbing boundary layer – without absorption, with too high absorption, the partially effective boundary layer, and the boundary layer set outside the calculated domain.



a)



b)



c)

Fig. 3. Dynamics of the acoustic pressure field propagating with partially effective boundary layer

In software, certain parameters of the absorbing boundary layer are selected by the conventional operator where the variable of choosing the model characteristics is set manually and can take the value from the pre-established totality.

The effect of the absorbing boundary layer can be visualized by switching it off completely. To do this, the parameter *Alpha* is initiated by 0. In such a way, the zero absorption is established inside the layer and the waves leaving one side of the domain reappear on the opposite side. Fig. 1 visualizes dynamics of the acoustic pressure field propagating.

A similar effect is observed if the Alpha value is set too high. It makes the waves reflect from the boundary layer (Fig. 2).

Efficiency of the absorbing boundary layer depends on its size and absorption as well the time step used for modelling: the more time intervals a wave spends in the boundary layer, the more it is absorbed.

An effective absorbing boundary layer can be partially simulated by reducing its size, i.e. setting 2 for the additional input *Size*.

The boundary layer absorbs part of the waves approaching boundaries of the simulation area. Part of reflected waves watched in the previous example can still be perceived by sensors (Fig. 3).

By default, the absorbing boundary layer will be in the net determined by the user, so the source and the sensor should not be determined in this area.

Conclusions

Thus, the working hypothesis of the project implies the integrated application of ultrasonic technologies to investigating into regularities of iron ore magnetic separation that enables substantiation of integrated methods of improving efficiency of iron ore magnetic separation by enhancing technological parameters of magnetic separation, improving controlled structural parameters of the magnetic separator and slurry pretreatment by high-energy ultrasound to clean the ore material surface from fine-dispersed particles of minerals and slime and disintegration of ore agglomerates fed to the magnetic separator.

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Technological basis of processing of serpentinite copper-gold ores in the Kyrgyz Republic

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Annotation. The article is devoted to the development of an effective technology for processing serpentinite ores from the Bozymchak deposit in the Kyrgyz Republic. Based upon the analysis of mineralogical, physical and chemical parameters of the ore, the authors set reasons for the decrease in technological indicators of the existing concentrator and determine concentrating properties of the reviewed serpentinite resistant material by applying methods of intensifying the flotation process by using additional flotation collectors/depressors and introducing the process of mechanochemical activation of the pulp before flotation. In the proposed technological flowsheet, main requirements for the technological flowsheet and reagent suite of processing serpentinite ores are formed and it is acknowledged that an increase in the grinding size, introduction of the selective copper collector and additional depressor determines the prospects for improving the "reagent" component of determining factors of the set task. Materials of the article can be useful for mining and processing enterprises while involving resistant copper bearing, magnesian serpentinite ores in the processing in order to increase the raw material base of the existing mining and processing complex.

1 Introduction

The subject of research is serpentinite ores of the Bozymchak deposit in the Kyrgyz Republic. Serpentinite ores are composed of serpentine minerals (antigorite, chrysotile), carbonates, pyroxene, amphibole, and quartz. The main target copper mineral in this type of ore is chalcopyrite. The grade of secondary and oxidized copper minerals in some samples can reach 50% of the total amount of copper bearing minerals. The grade of serpentine reaches 70-71%. Main components in the ore are copper, gold, silver [1, 2].

According to the geological exploration, main reserves (up to 70%) of the Bozymchak gold and copper deposit are accounted for by serpentinite ores, which, in turn, determines the priority of developing processing technology for this type of raw material.

The ore mineral composition of the deposit is predetermined by the complex tectonic environment of their formation: introduction of granitoid intrusion – contact metamorphism with formation of marbles, corneas, serpentinites and skarns – pre-ore discontinuous tectonics – superposition of hydrothermal processes.

In this regard, two types of ores are developed at the deposit: skarn and serpentinite. Rock-forming minerals of ore skarns are represented by wollastonite, garnet (andradite), pyroxene (augite), quartz, slightly epidote, chlorite, and carbonates. Sulphide minerals are represented by chalcopyrite, bornite, chalcosine, covelline, pyrite.

Serpentinite is a rock consisting mainly of minerals of the serpentine group: lizardite, antigorite, chrysotile, chrysotile-asbestos that have a common chemical formula: $X_{2\text{-}3}Si_2O_5(OH)_4$, where $X = Mg, Fe^{2+}, Fe^{3+}, Ni, Al, Zn, Mn$. Serpentinite is the host rock of many minerals or frames deposits and therefore is a multi-tonnage waste of the mining industry and processing industry [3]. Serpentinite consists mainly of magnesium hydrosilicates, the processing of which makes it possible to obtain magnesium oxide and silicon dioxide.

When processing serpentinite, along with magnesium, concentrates of non-ferrous metals are obtained. Serpentine is leached with hydrochloric acid to obtain chlorinated magnesium solution and silicon dioxide. Chlorine-magnesium solution is purified from impurities by neutralization to obtain an iron-nickel concentrate. Carnallite is synthesized from purified chlorine-magnesium solution [4].

Serpentine-bearing ores can be an unconventional source of magnesium salts, white soot, iron-bearing pigments, and chromite concentrate and chromium compounds. It is proposed to use sulfuric or nitric acid methods for processing of serpentinites. Unlike sulfuric acid, serpentized magnesium and iron-magnesium silicates containing serpentine anthophyllite, talc, quartz, aluminum silicate, clinochlor, and the mineral nontronite, pimelite are leached with the participation of Bacillus bacteria, and nickel sulphides are not leached [5, 6].

The low quality of the copper concentrate is due to the presence of serpentine in it, the mass fraction of which reaches 43%, and presence of intergrowth of iron oxides with chalcopyrite. Losses of copper with dump tailings are associated with its losses with chrysocolla (losses of this mineral with dump tailings are 100%), malachite and azurite (losses of free copper oxides with dump tailings are 90%), and with intergrowth of chalcopyrite with iron oxides [7-9].

For enrichment of serpentinite asbestos ores, friction enrichment, air separation and wet processes are used [10]. To preserve the natural length of high-grade asbestos fibers and maximize their extraction, staged crushing is widely used with the extraction of asbestos fibers as they are released from their connection with the host rocks.

Main difficulties in concentrating of serpentinite ores are associated with the complexity of the ore mineral composition of the waste, among which easy-to-float serpentine minerals predominate.

2 Methods of experiment procedure

The study of the mineral composition of ore and concentrating products was performed using an Axio Imager A1m optical microscope equipped with automated Mineral C7 analyzer and EVO-MA 15 electronic scanning microscope. X-ray phase analysis of ore was performed on ARL PERFORM’X wave x-ray fluorescence spectrometer.

XRD analysis of the initial ore was performed on x-ray diffractometer of powder materials XRD-7000S. Weight parts of valuable components in the initial ore and its processed products were measured using Arcos, inductively coupled plasma emission spectrometer, Solaar, atomic absorption spectrometer, CS-800 sulfur analyzer, Titration Excellence T-70 automatic titration system, and Specord 250 Plus scanning spectrophotometer.

Sample preparation and technological studies were performed using MShL-7 ball mill, ultrafine bead mill, Pulverisette-5 planetary mill, flotation machines FMP-L3, FMP-L1 and FMP-L0.3.

According to the program of works, liberation of ore minerals in serpentinite samples was studied when the samples were grinded to 86.8% – 71μm.

In order to determine preliminarily technological indicators of the processability of serpentinite ore samples, flotation tests were performed according to the existing engineering report and with the use of new collectors. A number of traditional (liquid glass, carboxymethylcellulose) and new generation reagents (modified polysaccharides) were considered as depressors. Considering the work on copper bearing ores with the flotation-active rock-containing component, a series of experiments with the collector/depressor combination using Aero 9863 collector were carried out.

Options with regrinding of the foam product by combined (mechanochemical) activation of the feed before cleaner flotations are considered – as a softened option of grinding to ensure access of reagents to the “fresh” surface. Sulfuric acid was used as a chemical agent. Fig. 1 shows flowsheet of experiments.

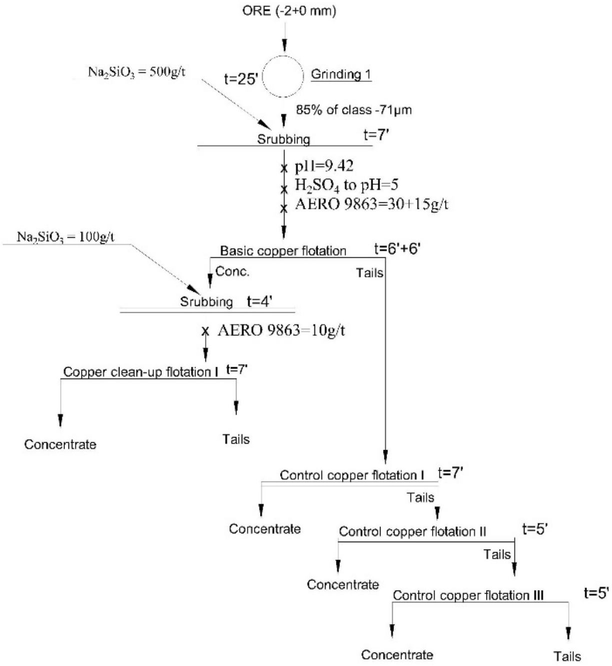

Fig. 1. Flotation flowsheet with mechanochemical activation of flotation feed.

Based upon the results of flowsheet studies, serpentinite ore flotation was carried out in closed cycle (Fig. 2).

Total reagent costs in closed cycle:
* Lime to the recommended pH values;
* Na_2SiO_3 – 1000 g/t;
* Aeroflot butyl – 40 g/t;
* ACC – 100 g/t;
* Aero 9863 – 10 g/t;
* CMC – 150 g/t
* MIBC – 44 g/t

The material composition of on-balance products of serpentinite ore flotation in closed cycle is determined.

3 Experiment results

The results of complex mineralogical analysis, including XRD, optical micro and macroscopic analyses are presented in Table 1.

According to mineralogical analysis, samples consist of magnesium silicates, among which serpentine predominates. Fe oxides and carbonates are present in significant amounts in the sample. The content of sulphide minerals is 10.6% by weight, of which pyrite predominates (8.1% by weight); chalcopyrite accounts for 2.2% by weight. The sample also contains 0.28% of oxidized copper minerals, represented by malachite and chrysocolla in approximately equal amounts.

According to chemical analysis, the main rock-forming elements are MgO and SiO2. Table 2 provides the chemical and phase composition of samples.

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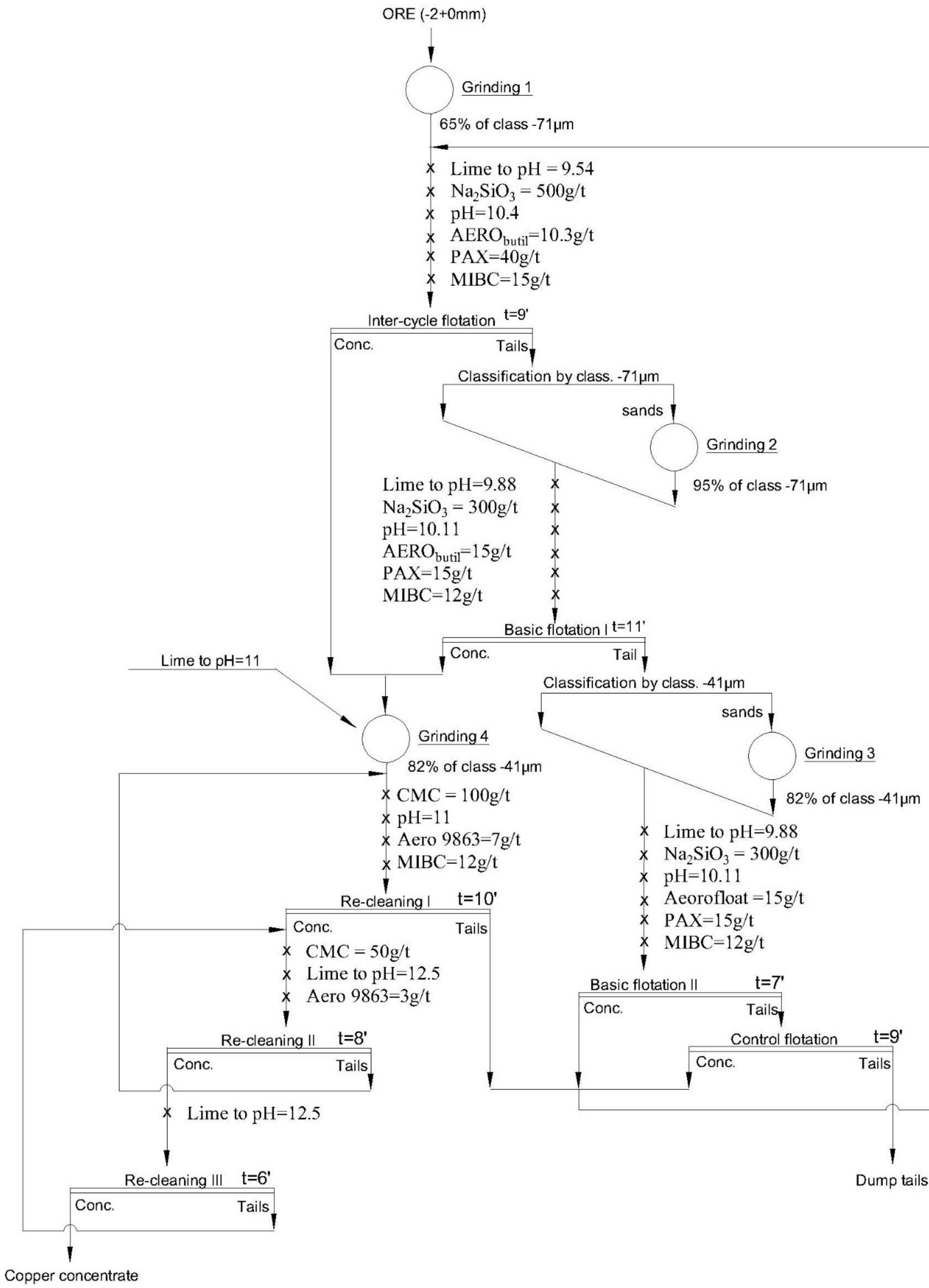

CMC - Carboxymethyl cellulose
$AERO_{butil}$ - Butyl aeroflot
MIBC - Methylisobutylcarbinol
AERO 9863 - collector AERO 9863 Promoter.

Fig. 2. Flowsheet of carrying out closed cycle with regrinding of the rougher concentrate.

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Table 1. Mineralogical composition of samples.

Minerals/groups of minerals	**Sample 1**	**Sample 2**
Rock-forming:	weight %	weight %
Serpentine $Mg_6[Si_4O_{10}](OH)_8$	50.0	72.5
Pyroxenes $Ca(Mg, Fe, Al)[(Si, A1)_2 0_6]$	14.0	5.0
Amphiboles $Ca_2(Mg,Fe)_5[Si_4O_{11}]_2(OH)_2$	7.0	6.5
Magnesium silicates (chlorites)	5.0	8.0
Mica (biotite, phlogopite) $K(Mg, Fe)_3[AlSi_3O_{10}](OH,F)_2$	5.0	i .5
Oxides *Fe* (magnetite, hematite, goethite)	4.5	3.0
Calcite	2.3	1.1
Total	88.8	97.6
Sulphides:		
Pyrite (marcasite)	8.1	1.0
Chalcopyrite	2.2	0.61
Wallerit $CuFeS_2(Mg,Fe,Al(OH)_{2\text{-}3})$	0.1	0.2
Total	10.6	1.9
Oxidized copper minerals (malachite, chrysocolla)	-	0.28
Other (rutile, sphene, apatite)	0.6	0.2
TOTAL	100.0	100.0

Table 2. Chemical composition of samples.

Item	**Sample 1**		**Sample 2**	
Element	**abs. %**	**rel.**	**abs. %**	**rel. %**
Cu oxidized	0.064	6.7	0.16	31.4
Cu secondary сульфидов	0.086	9.1	0.07	13.7
Cu primary сульфидов	0.8	84.2	0.28	54.9
Cu_{total}	0.95	100.0	0.51	100.0
Fe_{total}	8.8		3.88	
$S_{sulphide}$	5.12		0.80	
S_{total}	5.19		0.88	
CO2 (carbon)	0.99		0.51	
C_{total}	0.33		0.19	
Pb	0.006		<0.005	
Zn	0.056		0.028	
Mo	0.0026		0.0014	
MgO	27.3		37.5	
SiO_2	33.1		34.8	
CaO	6.68		2.91	
AI2O3	1.81		0.88	
K2O	0.31		0.084	
Na_2O	0.023		0.035	
TiO_2	0.13		0.1	
MnO	0.09		0.1	
P2O5	0.014		0.008	
Au, g/t	1.12		0.44	
Ag, g/t	4.91		3.15	

There is a noticeable difference in the phase composition of copper (Fig. 2).

According to XRD analysis (Fig. 3), main mineral phases in samples are minerals of the serpentine group $Mg_6[Si_4O_{10}](OH)_8$. Samples also contain significant amounts of pyroxenes (diopside, augite), calcite.

Figure 3 shows intergrowth of sulphide minerals in the initial serpentinite ore.

Microscopically the bulk of serpentinites has the fibrous, thin-scaled structure characteristic of serpentine minerals, sometimes cellular with *Fe* oxides and rare inclusions of sulphide minerals. Serpentine develops along sinuous fractures with formation of the very characteristic cellular structure. The process of serpentinization of olivine is often so intense that it is almost completely replaced by the secondary mineral. Only small relic grains of unchanged olivine are usually preserved in the mass of serpentine. Rare sulphide minerals in serpentinite samples are represented by cobaltine, arsenopyrite, and cobaltpentlandite, which are closely associated with main sulphides, and are found in the chalcopyrite-pyrite fine-grained mass.

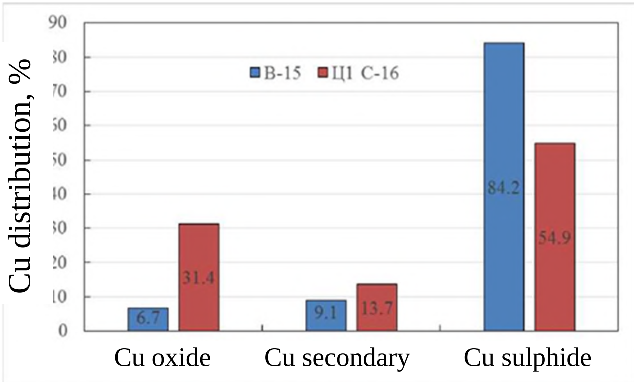

Fig. 2. The phase composition of copper in the original samples of the serpentine type.

According to the studies results on liberation, the liberation of the main sulphide mineral of copper-chalcopyrite in the initial sample is 64.3% rel., when it is grinded to 86.8% - 71 µm. Moreover, the size of free grains of chalcopyrite on 55.1% rel. is concentrated in the size from 10 to 71 µm. The significant share is free grains of chalcopyrite in size less than 10 µm (31.0% rel.). Main intergrowth of chalcopyrite is with non-metallic minerals (24.6% rel.), where the main copper sulphide is represented by 73.3% rel. in size from 10 to 40 µm. The significant part of chalcopyrite is concentrated in polymineral intergrowths (6.1% rel.), where it is mainly in the form of very thin inclusions. Pyrite liberation is 64.2% rel. Free pyrite grains are mainly concentrated in the size from 10 to 71 µm. It is noted that the significant part of free pyrite falls on the size less than 10 µm (32.3% rel.). Pyrite is characterized by intergrowths with iron oxides (17.7% rel.), where they represent the subgraphic structure of intergrowth in each other. Pyrite is 12.5% rel. represented in polymineral intergrowths and 4.9% rel. in intergrowths with non-metallic minerals.

Under flotation according to the existing engineering report, first of all, the change in the visual characteristics of flotation should be noted: process of rougher and scavenger flotation is accompanied by excessive frothing and its resistance, froth color is mainly gray, there is no contribution of copper minerals to the color gamma. The mass pull of the rougher copper concentrate is 20.3% (vs. 3.6% for sulphide ore) with metal grade of 3.69% (vs. 25.5 for sulphide ore). The selectivity of the process is broken due to the flotation-active rock-forming component. In addition, copper losses with dump tailings were 23.19%.

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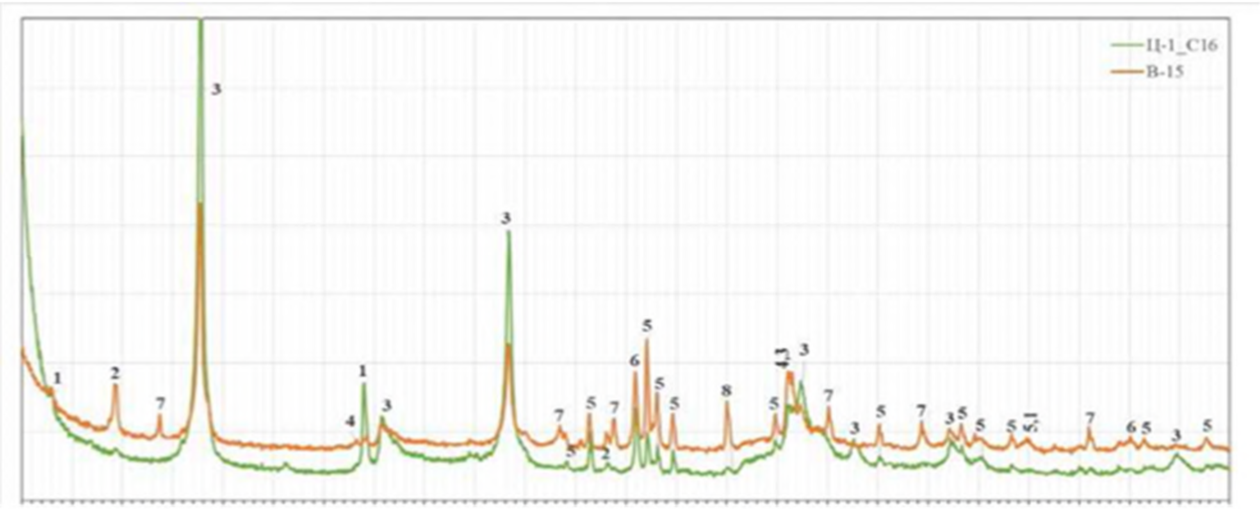

Fig. 4. Diffractograms of serpentinite samples with the designation of main mineral phases: 1 – chlorite, 2 – mica, 3 – serpentine, 4 – magnetite, 5 – pyroxenes (diopside, augite), 6 – calcite, 7 – amphiboles (actinolite), 8 – pyrite.

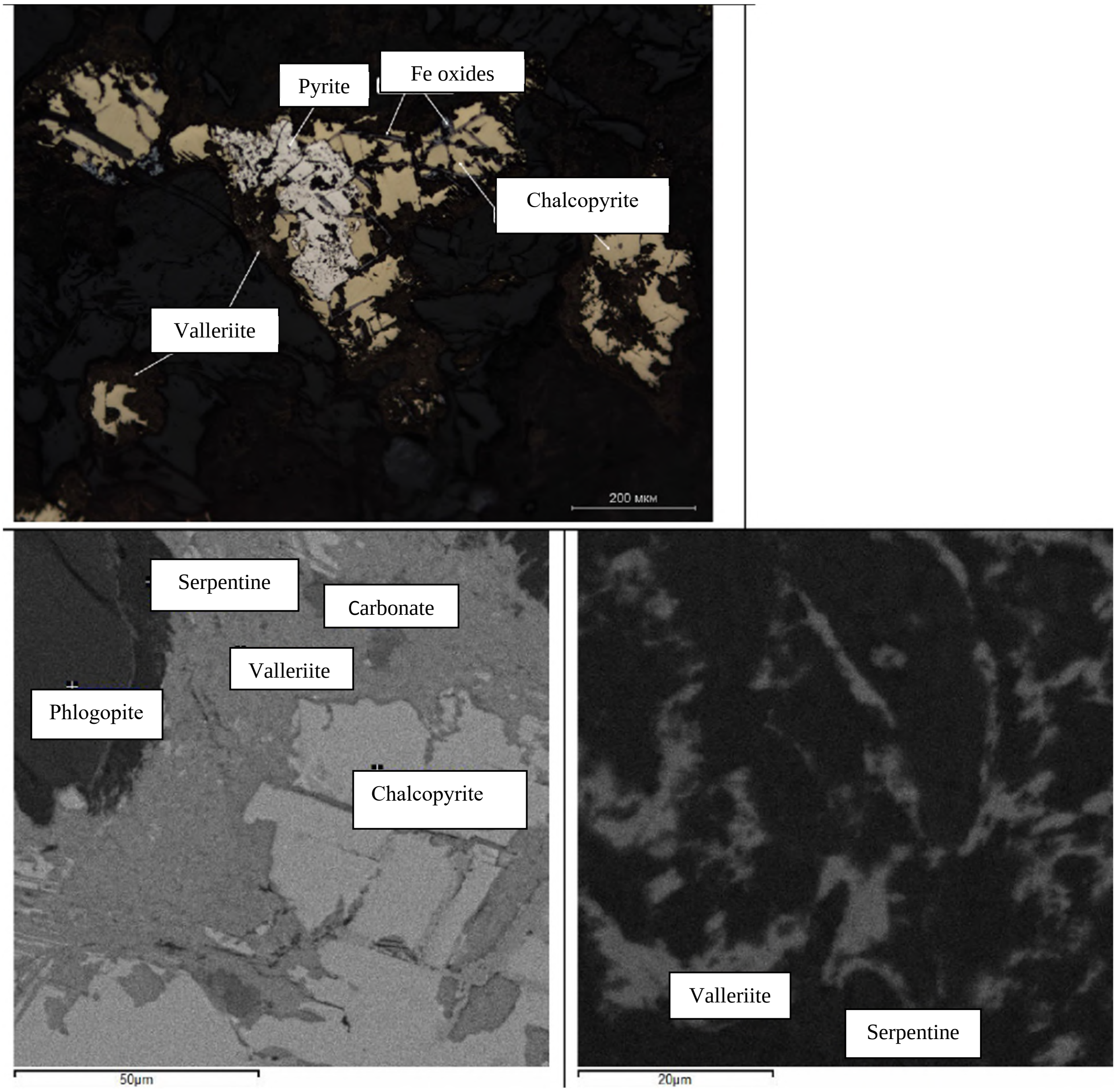

Fig. 4. Characteristic intergrowths of sulphide minerals in the original serpentinite ore.

Mineralogical analysis of flotation products showed that main metal losses are associated with the under-liberation of chalcopyrite and its thin intergrowth.

Table 3 shows the results.

Table 3. The results of flotation on the existing engineering report.

Experience conditions	Product name	Yield	Content, %				Recovery, %			
		%	Си	Fe	SiO2	CaO	Си	Fe	SiO_2	CaO
85% of class - 71µm; PAX - 70 g/t; MIBC - 10g/t; PAX - 25+20 g/t; t = 6 min	Basic copper flotation concentrate	20,3	3,19	15	23,94	4,2	70,4	37,6	14,13	13,16
	Concentrate control copper flotation I	2,2	1,82	19	22,66	4,4	4,36	4,93	1,45	1,49
	Concentrate control copper flotation II	1,34	1,37	16	21,8	3,6	2	2,64	0,85	0,75
	Tails	76,15	0,28	5,9	37,75	7,2	23,2	54,8	83,57	84,6
	Руда	100	0,92	8,3	34,4	6,48	100	100	100	100

A certain effect is achieved when using organic reagents DLM62 and CMC 55C as a depressor, and liquid glass with the constant consumption (200 g/t).

Table 4. The results of flotation using depressors.

Experiment condition	Recovery to total concentrate, %				
	Cu	*Fe*	AlO_3	SiO_2	*MgO*
without depressor	76.81	45.2	17.32	16.43	19.29
liquid glass - 200 g/t	82.64	51.61	13.65	15.54	17.01
CMC 55C - 200 g/t	83.48	52.58	17.27	15.19	18.03
AERO 8860 - 200 g/t	83.22	52.74	19.82	19.19	21.8
DLM 62 - 200 g/t	82.66	50.61	15.08	14.93	16.92
DLM 263 - 200 g/t	82.93	53.1	21.52	17.97	18.29

The main increase in metal recovery (about 6%) is due to redistribution of the share of *FeO* and Al_2O_3, i.e. mainly aluminosilicates are depressed.

Based upon the carried out experiment with the use of Aero 9863 collector, the rougher concentrate is received with copper grade of 5.61% and recovery of 64.94%. With similar consumption of liquid glass at the concentrator combination of amyl xanthogenate and MIBC, rougher concentrate performance is copper grade of 7.18% with metal recovery of 39.67%.

The introduction of (stage) attritioning operations shows "synergistic effect" that contributes to the maximum cleaner of the mineral surface and, as consequence, to the high quality of the received concentrate. This process let reducing losses with dump tailings by almost half (copper loss decreased from 35.50% to 17.37%). The concentrate of the first recleaner achieved copper grade of 15.1% with recovery of 47% at combined mechanical activation with sulfuric acid treatment of the product. At the same time, the combined method of pulp preparation allows to reduce copper losses with dump tailings up to 8.68%.

In closed cycle experiments, the experience of working on high-magnesia talcose ores is taken into account, and approaches tested on ores of this type are implemented in flowsheet solutions. Operations of mechanical activation and regrinding were used as pulp preparation operation. Table 5 shows the results of closed cycle experiments.

Table 5. The results of the locked cycle flotation.

Products	Mass pull %	Grade, %			Recovery, %		
		Cu	*Au*	*Ag*	*Cu*	*Au*	*Ag*
Concentrate	4.32	18.2	17.0	58.00	80.84	82.77	52.20
Tails	95.68	0.195	0.16	2.40	19.16	17.23	47.80
Ore	100.0	0.97	0.89	4.80	100.0	100.0	100.0

The following is noted visually: "dirt" nature of the froth, its increased persistence, and absence of "visible" copper. It is obvious that the froth product is formed by intergrowths with waste rock. As grades of *Fe* and SiO_2 are approximately equal, and *CaO* has decreased by ~10%, the quality of the concentrate mainly suffered due to transition of magnesium-bearing minerals (serpentinite) to the froth product.

The concentrate of the third cleaner consists mainly of copper sulphides (chalcopyrite) by 41.7% and iron (pyrite, marcasite) by 24.7%. The main part of chalcopyrite is in free form, or in intergrowths with pyrite and iron oxides.

Table 6 presents the chemical composition of scavenger flotation tailings received from the initial sample of serpentine ore, and Figure 4 shows the particle size distribution of this product.

Table 6. Chemical composition of flotation tailings.

Element	Grade, %	Element	Grade, %
Cu_{total}	0.195	K_2O	0.4
$Cu_{oxidized}$	0.071	Na_2O	0.038
$Cu_{secondary}$	0.026	TiO_2	0.033
$Cu_{primary}$	0.083	*Zn*	0.015
Fe_{total}	6.04	*Pb*	<0.005
S_{total}	4.0	*As*	<0.001
SiO_2	40.0	*Sb*	<0.002
Al_2O_3	2.18	*Au*, g/t	0.16
CaO	7.7	*Ag*, g/t	2.40
MgO	31.2		

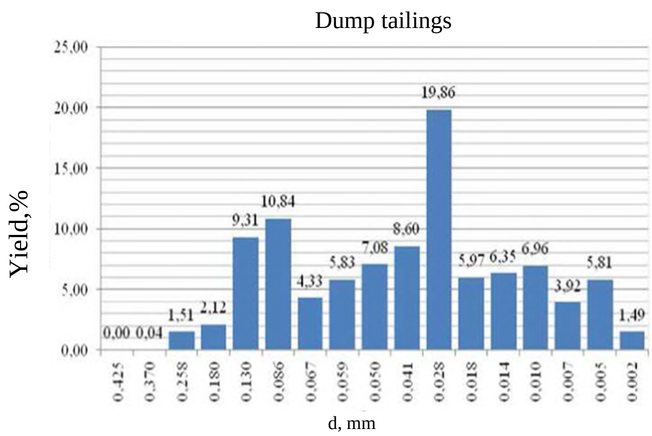

Fig. 4. Particle size distribution of dump tailings in a closed cycle.

4 Conclusions

Main copper losses are associated with chalcopyrite, which is found in intergrowths with non-metallic minerals and polymineral intergrowths together with pyrite and iron oxides. The size of chalcopyrite in such intergrowths is 20-30 µm, with rare exceptions the chalcopyrite grains with the size of about 70 µm are found. Copper losses are associated with presence of complex sulphide hydroxide-valleriite $CuFeS_2(Mg, Fe,Al(OH)_{2-3})$ in tailings, which is in close intergrowth with serpentine and thin chalcopyrite (3-5 µm). The total grade of copper minerals is 0.3%, pyrite and pyrrhotite – 7.3%, iron oxides – 4.0. Non-metallic minerals (88.4%) are represented by serpentine, pyroxenes, and carbonates.

When assessing the recoverability of individual phases of copper, it can be stated that if recovery of sulphide forms of copper into concentrate was practically preserved at the level of sulphide ores, then recovery of oxidized copper was reduced to 24%. This is mainly due to losses of efficiency of the sulfidizer at the stage grinding, which requires special attention to the formation of the sulphidization regime.

Stage grinding allows increasing total recovery of copper on froth products by 10%. However, the issue of obtaining the high-quality concentrate is not solved – the copper grade remains at the same level, while the copper oxide grade is increased to 40%, which confirms the need to introduce the operation of regrinding of rougher concentrate.

Based upon results of traditional approaches [3-9], it is established that increase in the grinding size, introduction of selective copper collector and additional depressor will allow to assess the prospects for improving the “reagent” direction, and main requirements for the technological flowsheet and reagent suite of processing resistant copper bearing, magnesian serpentinite ores are formed:

– stage grinding to fineness of 95% – 74 µm;

– introduction of the depressor for magnesium aluminosilicates;

– introduction of selective collectors for sulphide and oxidized copper;

– finding of the collector for valleriite.

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Relation between basic coal seam parameters and their gas saturation for Dobrudzha coal field, NE Bulgaria

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Abstract. One of the main natural gas contained in the coal seams is methane. Most of it is adsorbed on the surface of the coal matrix, another is in free state in different in size and morphology pore spaces or dissolved gas in the waters that associate with the coal seams. The form of presence and the degree of gas saturation depends on the rank of the carbonization process, the petrophysical and physicochemical parameters of the environment. Methane in coal seams is accepted to be categorized as an unconventional energy resource. From this point of view, it is of interest in the Dobrudzha coal basin, located in the North-eastern part of Bulgaria. The specific geological conditions of the basin, the limited study, the presence of a thick covering aquifer make it difficult to extract coal by traditional methods. This requires the use of non-popular for the country methods for energy extraction and establishing relation between the basic parameters of coal seams and their gas saturation. The existing geological-geophysical, drilling and laboratory information is combined in a detailed petrophysical model, which extends over the best presented and studied coal seam (m5) from the field. The basic parameters that reflect the amount of adsorbed gas and are the subject of study are the content of moisture, carbon, ash and the degree of carbonization, expressed by the vitrinite and its reflectance.

1 Introduction

Coal bed methane (CBM) is an integral part of the coal formation process. It is one of the main unconventional resources which became very important for the energy supply in last 20 years. CBM has attracted major attentions worldwide because it is considered as a potential clean source of energy in sustainable future [1]. Coalbed methane is different from conventional natural gas, mainly due to the predominant form of presence adsorbed on the matrix. A relatively small part of it is in a free, concentrated space of different size and morphology or gas dissolved in coal waters. The ratio between the forms of presence of the gas mixture largely depends on the amount of coal substance. Methane reaches 60-80% of the total gas content in coal [2-4].

In the catagenic transformation of coal from brown to black, the formed methane is in the range of 30-40 to 120-150 m^3/t, and in the transition from black to anthracite coal it reaches 200 m^3/t [5]. The accumulated large amounts of methane are under significant pressure and as a result of many factors (geological structure of the basin, properties of the reservoir rocks, water in reservoirs, petrographic composition and coal rank) explosions, gas emissions, its expulsion into tectonic fractures or in adjacent porous rocks are possible. The adsorption capacity depends on the degree of carbonization. It improves upwards - from shiny, brown to black gas and semi-anthracite to super-anthracite [6]. At greater depths, however, the sorption capacity decreases, even with increasing pressure to values above 10 MPa. Coal seams have considerably different characteristics from normal gas reservoirs, especially in gas storage and permeability features. Most gas storage in coal is by sorption into the coal structure, while the permeability is mainly produced by cleat (fracture) or joint controlled. It is also evident that there is a wide variation in coalbed permeability during production phases due to stress effect, which increases with fluid pressure reduction and shrinkage of coal. Coal seams have been described by two main porosity systems including: cleats (uniformly distributed network of natural fractures) and matrix blocks. The cleat (fracture) system of coal seams is divided into the face cleat and the butt cleat [7]. The most important property of coal beds is the permeability, which is mainly created by natural fractures. Coal formation may shrink on desorption of gas and may expand again on resorption. During the primary production phase of methane, two main phenomena are identified to associate depletion of reservoir pressure causing reduction of coal permeability. These two phenomena include: (1) reservoir compaction, which causes an increase in the effective horizontal stress while the reservoir is confined laterally; and (2) gas (mainly methane) desorption from the coal matrix; it causes coal matrix to shrink, reduce horizontal stress, and increase cleat permeability. Economical coal bed methane production depends on four important coal-seam characteristics including gas pressure, gas content, coal-

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seam thickness and permeability [8]. The knowledge of coal seams properties and behaviour are the key for successful production process and for increasing the produced volumes of natural gas.

2 Geological settings

Dobrudzha coal field is located in NE Bulgaria, within the eastern slope of the North Bulgarian High, which underwent three structural transformations, manifested with different intensity: through the Carboniferous - of weakly manifested placative and well-defined fault tectonics; in Perm - with a bright manifestation of block tectonics and in the Jurassic and Neogene - with weakly manifested block tectonics (fig 1). It covers area of approximately 200 sq.km. with significant proven coal reserves of about 2 billion tons [9]. Coals are with Carboniferous Age and the commercial reserves has been estimated in Upper Carboniferous Series. The field is non-mineable because of the existence of 900 m thick aquifer above. The field is covered by wells grid with dimensions of 500x500 m with average depth of well – 2000 m. There is conducted 2D seismic survey in volume of 600 km, but the presence of thick highly cavernous aquifer made the results poor and useless in intervals with Carboniferous Age. This is the main reason to investigate wellbore and log data during the drilling process.

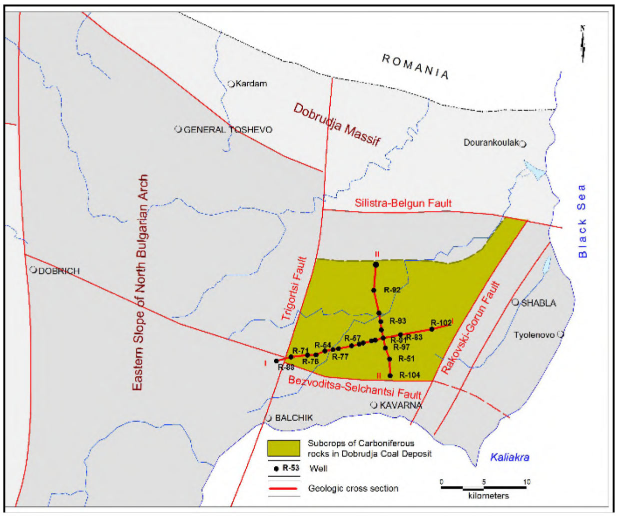

Fig. 1. Dobrudzha coal field location and location of some wells, used for the study.

The field is characterized with complicated geological settings, caused by several tectonic events with Triassic, Cretaceous and Eocene Ages. The major tectonic event, forming the nowadays view of the field is this one with Triassic Age. There are two type of faults in the field – buried one, related to Carboniferous Age and covered by Lower Triassic sediments and younger one, and faults affecting whole sedimental section. The filed is divided by fault to 28 separated areas (blocks) with different coal seam properties. All of the faults have been located using drilling data, because of the poor seismic quality in the area. Fault geometry and influence radius has been investigated using drilling and logging data. Every wellbore in the field have standard for its time logging data such are Calliper, Deviation surveys, Electrical methods (shallow and deep lateral log), Neutron gamma ray, Gamma ray and Density log. With consideration of made lithological and stratigraphical division and correlation of the formation of Upper Carboniferous, the division made before is being confirmed later [10], which is with clearly separation of four main coal formation arranged geochronological as follows: Mogilishte, Macedonka, Krupen and Gurkovo (fig. 2).

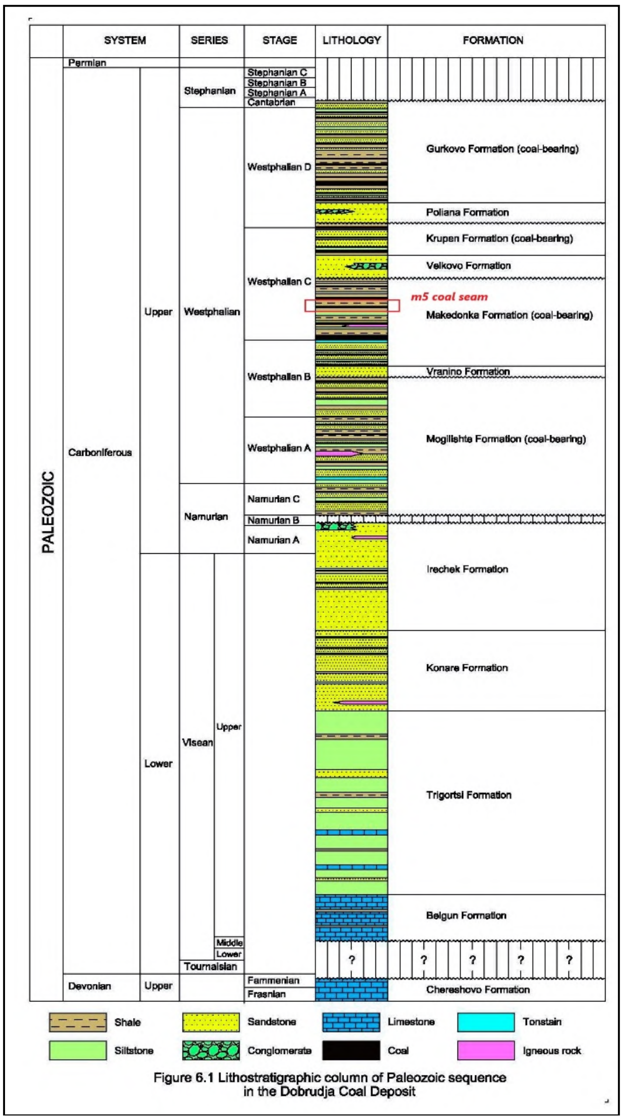

Fig. 2. Litho-stratigraphy of the Carboniferous System of Dobrogea coal field.

The Upper Carboniferous field contain a total of over 86 coal seams, of which 16 are of industrial importance. Coal is black from all classes to anthracite in most of the formations. The rocks containing them are relatively uniform in lithological composition with predominant terrigenous (sandstones, siltstones, argillites, in some places gravelites) lithotypes - products of lake-swamp sedimentation. The total thickness of the coal field exceeds 1300 m. This new updated lithostratigraphic correlation, formations boundaries identification and updated correlation of coal seams from the Upper

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Carboniferous section [10] is establish by using modern software products and available above-mentioned log records for most of the wells. For identification of coal seams data from core, log records and laboratory analysis of samples in the field are used.

3 Materials and methods

Finding the actual gas content in coal seams can be done directly – in the laboratory, or indirectly. The direct method of determining sorption isotherms involves drilling and cutting core that is immediately placed in canisters, followed by measurements of the volume of gas evolved from the coal over time.

The basic coal seam properties, which are chosen to investigate their relation to the gas saturation are as follows:

– ***Moisture*** - Moisture is an important property of coal and its presence and quantity are directly related to the processes of carbonization and subsequent transformation of sediments. Groundwater and other extraneous moisture are known as adventitious moisture and is readily evaporated. Moisture held within the coal itself is known as inherent moisture and is analysed quantitatively. Adventitious moisture is removed in the laboratory by evaporation in air. Moisture may occur in four possible forms within coal: *surface moisture*: water held on the surface of coal particles or macerals; *hydroscopic moisture*: water held by capillary action within the micro-fractures of the coal; *decomposition moisture*: water held within the coal's decomposed organic compounds; *mineral moisture*: water which comprises part of the crystal structure of hydrous silicates such as clays. Moisture content in a coal decreases the sorption capacity. Because coal loses moisture at a variable rate subsequent to removal from the borehole, a standard moisture content is used when measuring sorption isotherms.

– ***Fixed carbon content*** of the coal is the carbon found in the material which is left after volatile materials are driven off. This differs from the ultimate carbon content of the coal because some carbon is lost in hydrocarbons with the volatiles. Fixed carbon is used as an estimate of the coke yield from a sample of coal. Fixed carbon is determined by subtracting the mass of volatiles, determined above, from the original mass of the coal sample.

– ***Ash content*** of coal is the non-combustible residue left after coal is burnt. It represents the bulk mineral matter after carbon, oxygen, sulphur and water (including from clays) has been driven off during combustion. Analysis is fairly straightforward, with the coal thoroughly burnt and the ash material expressed as a percentage of the original weight. The lower ash content is indicator for more gas content.

– ***Vitrinite*** is the most common component of coal. It is also abundant in kerogen, derived from the same biogenic precursors as coals, namely land plants and humic peats. Vitrinite forms diagenetically by the thermal alteration of lignin and cellulose in plant cell walls. It is therefore common in sedimentary rocks that are rich in organic matter, such as shales and marls with a terrigenous origin. Conversely, carbonates, evaporites, and well-sorted sandstones have very low vitrinite content. Vitrinite is absent in pre-Silurian rocks because land plants had not yet evolved.

– ***Vitrinite reflectance*** was first studied by coal geologists attempting to determine the thermal maturity, or rank, of coal beds. More recently, it is used to study sedimentary organic matter from kerogen. It is sensitive to temperature ranges that correspond to hydrocarbon generation (60 to 120°C). This means that, with a suitable calibration, vitrinite reflectance can be used as an indicator of maturity in hydrocarbon source rocks. Generally, the onset of oil generation is correlated with a reflectance of 0.5 to 0.6% and the termination of oil generation with reflectance of 0.85 to 1.1%

All of the performed logging data was used for coal seams properties estimations applying modern software and approaches. During the drilling process, all wells were cored for all carboniferous section. There is available multiple laboratory test of the core focused on measurements of coal seam properties such as moisture, ash content, Sulphur content, violates. Some core samples were measured for gas content, but their number is very limited. The poor knowledge of coal seam gas content requires performing multiple investigations on log data and calculations based on the laboratory measurements. A number of petrophysical tests have been performed to establish and prove the results obtained synthetically from the available logging data with these laboratory tests. The information is entered into tables and converted into specialized digital formats, which are loaded into software products for geological modelling and interpretation.

4 Result and discussion

After loading the data and their implementation in the already created geological, tectonic and hydrogeological models [11], maps of the distribution of the various parameters by area within the locality for each layer were made. Several coal seams are suitable for gas extraction – those one with abbreviation ***m5***, ***m6***, ***m9***, ***n1***, ***n4***, ***p3*** located in above mentioned formations. The current investigation is focused on ***m5*** coal seam (Fig. 3.) buried on depth interval 1300 – 1900 m in Makedonka formation.

The minimum depths are in the easternmost parts of the locality, and in most of its area of distribution the depth of occurrence is over 1600 m (Fig.4). The average thickness of coal seam is about 5 m, but in the field, there is places where its thickness reaches 13 m. Coal seam ***m5*** is with one of the largest thickness in the field. In the wells in the western and central parts of the field there is a complex structure of the layer - from 2 to 10 layers. The reason for choosing this coal seam is that it is low interbedded, with a large area distribution and a relatively large thickness and has average gas content from 18 to 28 m^3/t of hard coal [12].

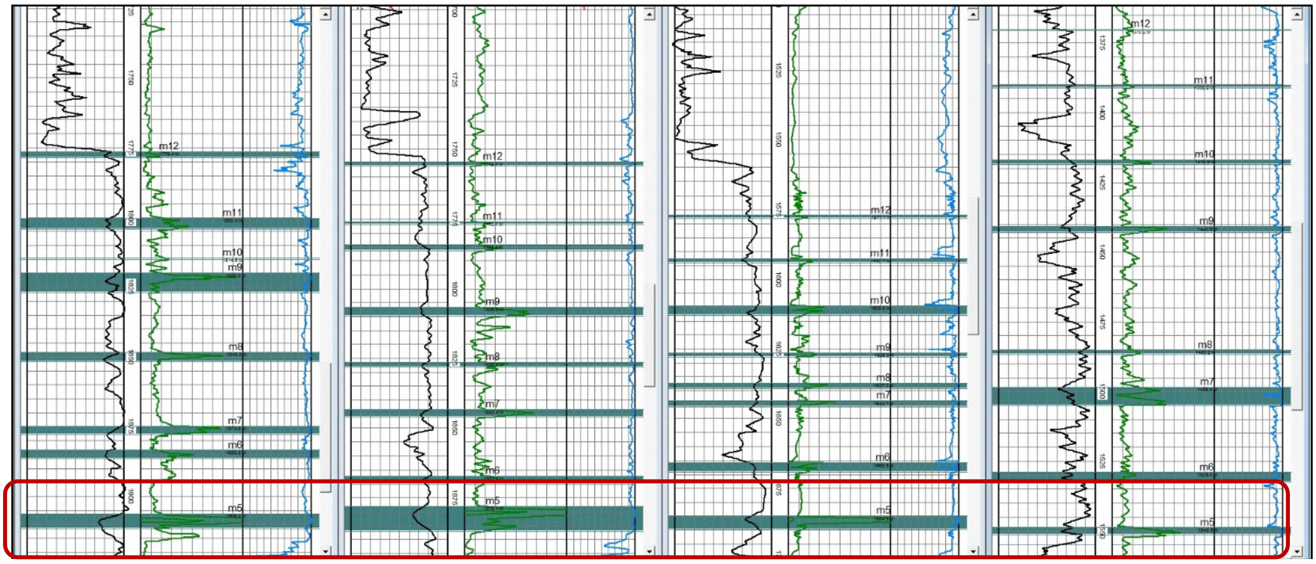

Fig. 3. Correlation scheme of m5 coal seam.

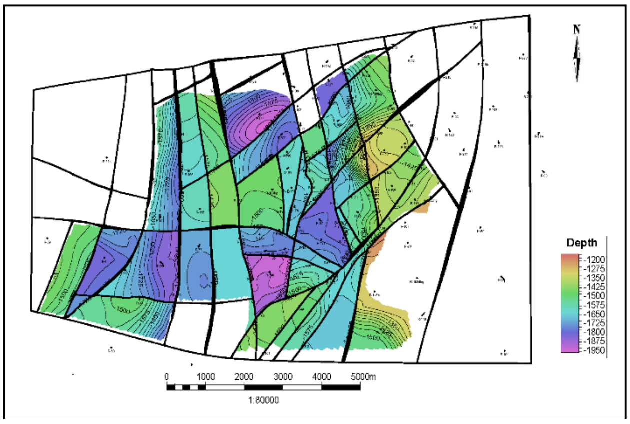

Fig. 4. Depth map of m5 coal seam.

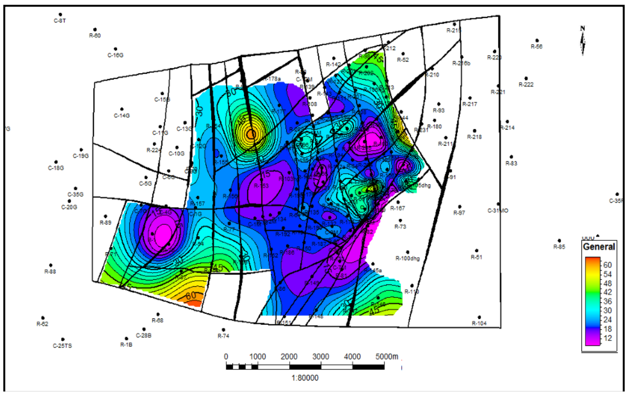

Fig. 5. Ash content (%) map of m5 coal seam.

Using the result of the laboratory tests detailed petrophysical model of the formation which includes ***m5*** coal seam was created. The average ash content is not very high, but its values in different parts of the field vary widely. The ash is unevenly distributed over the area of the layer, as the minimum values are in the central parts of the field. The results are showing higher ash content in coal field edges and low ash content in the middle of the field (Fig. 5). Using data from the investigation it can be conclude that the most suitable part for coal bed methane extraction is the central part of the field. The results from some laboratory test shows 28 m^3/t gas content for this particular area.

The moisture content of the coal varies widely. There is a tendency to decrease the value of this indicator from northwest to southeast. (Fig. 6).

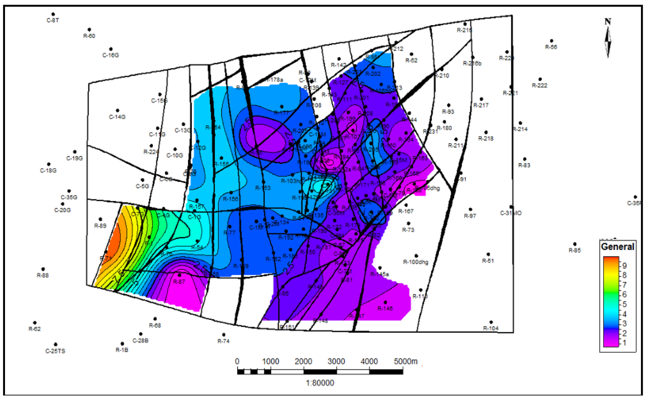

Fig. 6. Moisture content (%) map of m5 coal seam.

The gas content of layer ***m5*** varies in a very wide range, which depends on the depth of formation in different parts of the field. At shallower depths (up to 1600 m) the gas content is the lowest and the composition of the gases is dominated by nitrogen. The layer with the highest gas content is characterized in the range of depth from 1700 to 1800 m, which outlines the so-called methane zone. The composition of the gases is dominated by methane [9]. As the depth of deposition increases, the gas content of the formation decreases, and in the gas phase the amount of methane decreases at the expense of increasing the hydrogen content, especially at depths above 1900 m (Table 1).

Based on the analyses and petrophysical modelling, it can be said that layer ***m5*** is one of the main layers in the Dobrudzha coal field, which are extremely suitable for CBM in almost all key indicators - area and distribution; layer thickness; amount of resources; degree of

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carbonization; high yield of volatile substances, moisture; relatively low ash content, petrographic composition dominated by vitrinite macerals, with a significant amount of inertinite; low sulphur content, high gas content and methane content, especially in some parts of the field, low density and relatively high porosity (Table 2).

Table 1. Composition and volume of the gas components distributed in depth in ***m5*** coal seam.

Depth, m	Gas component composition, %							Gas component volume, cm^3	
	H_2	N_2	CO_2	CH_4	C_2H_6	C_3H_8	C_nH_{2n+2}	C_nH_{2n+2}	Total gas content
1400-1600	-	99.5	0.1	0.1	-	-	0.1	0.02	23.0
1600-1700	-	-	-	-	-	-	-	-	-
1700-1800	1.6	9.4	3.9	84.6	0.3	0.2	85.1	5263	6167.5
1800-1900	0.6	28.5	4.3	66.1	0.3	0.1	66.5	2277	3070
1900-2000	63.85	13.6	1.1	20.2	0.9	0.4	21.5	738	3919

Table 2. Basic ***m5*** coal seam parameters.

Parameters		Unit	Value		
			Min	Max	Average
Area of distribution		km^2	57.0		
Depth		m	1288	1906	1746.00
Thickness		m	1.70	12.90	4.80
Moisture, W^a		%	1.0	4.6	2.82
Ash content, A^d		%	7.5	54.0	25.05
Yields of volatile substances, V^{daf}		%	30.3	42.1	37.08
Composition	Vitrinite	%			60
	Exinite	%			15
	Inertite	%			25
Mineral impurities		%			10
Vitrinite reflectance, r_o		%	0.71	1.10	
Bound carbon content, C (ar)*		%	32.06	58.45	43.91
Gas components volume	Total gas content	cm^3	23.0	6551.8	
	C_nH_{2n+2}	cm^3	0.02	5815.2	
Gas component composition	He	%	0.0	0.3	
	H_2	%	0.0	83.2	
	N_2	%	6.1	99.5	
	CO_2	%	0.1	7.2	
	CH_4	%	0.1	88.2	
	C_2H_6	%	0.0	1.3	
	C_3H_8	%	0.0	0.6	
	Total C_nH_{2n+2}	%	0.1	88.8	
Bulk density		g/cm^3	1.28	2.53	1.49
Porosity	Total	%	4.00	16.10	10.02
	effective	%	1.55	10.45	4.81

5 Conclusions

Based on the research conducted on the relationship between basic coal seam parameters and gas saturation, it follows that:

– A direct relationship between the studied parameters and the gas saturation of the coal exists;

– A relationship between faults and the distribution of moisture content, ash content and the degree of variation in vitrinite reflectance is observed;

– According to its main indicators, coal seam ***m5*** is suitable for application of CBM technology for methane gas extraction;

– The demonstrated approach finds application for clarification of the interdependence between the studied parameters for the other layers as wells.

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Implementation of the cascade waste use principle by application of sewage sludge on lands disturbed by mining operations

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Abstract. Object of research - disturbed lands of Ingulets Iron Ore dressing Work (Ingulets GZK) The purpose of work - development and substantiation of technology of realization of principles of cascade waste use. Research methods – field experiment, comparative analysis, systems analysis. As part of the implementation of the cascade waste use principle, the results of research on the impact of the application of sewage sludge on formation of protosoils on the rocks of Ingulets GZK dumps are presented. The application of sewage sludge significantly increases the absorption capacity of overburden. A secondary soil absorbing complex is formed, which is able to accumulate and retain mineral nutrients of plants, especially calcium and magnesium cations. In the conditions of field research the influence of treatment of rocks with organic matter of sewage with introduction of seeds of perspective species was studied. Comparative analysis of vegetation shows a positive effect of the treatment of overburden with organic matter on productivity and morphometric performance of trees and shrubs. A comparison of the average condition of plant objects after treatment with organic matter and control studies shows the following: the vitality of herbaceous and tree species increases; the total projective cover and average height of plants increases; biodiversity.

Introduction

Implementation of the sustainable development strategy involves solving complex environmental problems. The problem of land desertification is becoming increasingly acute around the world and is recognized as global in international instruments ratified by Ukraine: Agenda 21, United Nations Convention to Combat Desertification. Desertification can be both natural and man-made. Desertification is facilitated by the extraction of minerals, which has led to the appearance of disturbed lands in Ukraine on an area of more than 160 thousand hectares. Creation of external dumps, dips and sludge storages contributes to the land degradation.

At the same time, huge amount of waste containing nutrients contributes to environmental pollution, exacerbating environmental problems of climate change. The negative impact of these objects on the environment is manifested in the form of destruction of fertile lands, changes in the hydrogeological regime and other forms. Thus, it is necessary to find non-traditional solutions, the main approaches to which are formed by the theory of sustainable development.

The main idea is the maximum use of natural energies, forces and phenomena. In his report to the Club of Rome, Gunter Pauli proposed that this approach should be considered as the only way of civilization development. It got a figurative name – the "blue economy". Such an economy should be based on technological processes that copy natural physical phenomena, and the waste from one industry should become raw material for another. Thus, the natural cascade principle of waste use in the environment is realized. Unfortunately, there is a shortage of scientific research in this direction.

Traditional notions of land restoration in Ukraine are limited to reclamation, which was widely used in Soviet times. However, because of the need to invest significant funds without real return, often unsatisfactory results of restoration and organizational problems, the traditional reclamation is basically no longer used.

Analysis of its results shows that the main reason for low efficiency is the attempt to create a quasi-natural technosystem based on simplified formal models that are not able to function as primary. The aim of the work is to develop new methods of rehabilitation of lands disturbed by mining operations on the basis of the cascade organic waste use principle.

The development of methods for the formation of secondary ecosystems which meet the requirements of sustainable development on the basis of resource and energy conservation is becoming increasingly important, especially for regions with high human impact. It is known that in energy and resource conservation the leading positions are occupied by the processes of functioning of living systems. In this regard, their involvement in solving technological problems, especially related to the elimination of environmental imbalances, is the most promising area of environmental harmonization.

The main tasks are as follows:

- to review of available methods of organic waste processing,
- to research of content of heavy metals, pathogens in technobiogeocenoses,
- to determine the impact of organic waste on the development of secondary vegetation.

Materials and methods

The research was carried out on the disturbed lands of Kryvbas at the Ingulets GZK. Studies of the structure of the surface and the state of ecosystems were performed using Landsat remote sensing data and ArcView and Google Earth services, which are publicly available.

The following scientific methods were used to solve the set tasks: graphoanalytical; analysis and generalization of statistical and cartographic data; mathematical modeling; system analysis.

Determination of heavy metals content was performed by atomic absorption method, determination of pathogens was performed by direct microscopy, humus content in technosols was determined by the Turin method. The method of squares was used to determine the projective vegetation cover. Its subject is a two-dimensional territorial element. A square with a side of 1 m has been used in geobotany since 1837.

Results and discussion

According to the European Parliament Directive and Council Directive 2008/98/EC (EPOC 2008) on waste, the following waste management hierarchy is proposed: prevention, preparation for re-use, recycling, other recovery, such as energy recovery, recycling. In many countries, the principle of preferential recycling of waste, rather than other ways of disposal, is declared at the legislative level. In Luxembourg, agriculture uses 90% of sewage sludge generated annually, in Switzerland – 70%, in Germany – 38%, in France – 23%, in Belgium – 10%, and the average for European countries and the United States is 32.4% [1]. The use of sludge in agriculture is regulated by Council Directive 86/278/EEC. Sludge should be used taking into account the nutritional needs of plants, and its use should not impair the quality of soil, surface water and ground water. Member states should regulate the use of sludge in such a way as to avoid exceeding the limit values due to the accumulation of heavy metals in the soil. The required rates of sludge application also depend on sludge fertilizer and soil properties. In Germany, liquid sewage sludge can be used in agriculture without dehydration, but the amount of sludge introduced into the soil is strictly controlled to protect groundwater from contamination. In Norway and the Netherlands, sewage sludge is treated by drying and granulating before being applied to the soil as a fertilizer. Prerequisites for the preparation of sewage sludge for disposal as fertilizer are the preliminary disinfection of sludge, as well as the cessation or significant restriction of acceptance by municipal sewage of industrial wastewater containing a significant amount of toxic substances [2]. According to [3], the most common method of sludge processing in the EU-15 in 2014 and 2015 was incineration (47.3% and 61.5% respectively) with subsequent reuse of sludge, including direct agricultural use and composting (48.2%, 38.2%). In Ireland alone, more than 70% of total sludge was disposed of in agriculture, in 7 countries the value ranged from 70% to 20% (over 50% in Bulgaria), in 10 countries less than 20% (0% in the Netherlands, Slovenia and Malta). Malta, the Netherlands and Slovenia belong to the group of countries with the strictest limit values for the main group of heavy metals in sludge. In Italy, disposal methods are distributed as follows: incineration – 20%, burial – 44%, use in agriculture – 36%; in the USA: incineration – 35%, burial – 30%, use in agriculture – 35%; in Poland: incineration – 44%, burial – 33%, use in agriculture – 23%; in Russia: incineration – 20%, burial – 74%, use in agriculture – 6% [4].

The European Union has adopted “End-of-waste criteria for biodegradable waste subjected to biological treatment (compost & digestate): Technical proposals” developed by the Joint Research Center, where sludge was excluded from organic waste allowed for compost production “from waste”.

In Ukraine by the Order No. 342 from 12.12.2018 “On approval of the Procedure for reuse of treated wastewater and sludge subject to compliance with the maximum permissible concentrations of pollutants” the use of sewage sludge is regulated by the DSTU 7369:2013 “Requirements for wastewater and its sludge for irrigation and fertilization”. In accordance with the requirements of current legislation, it is recommended to provide for the use of treated wastewater and decontaminated and dewormed sludge in agriculture (as organic fertilizer) [5]. The design of treatment facilities does not include the final stage of disposal and application of treated sludge. The use of sludge in agriculture is a recommendation, so in Ukraine the most common method of waste management is placing sewage sludge in holding ponds or landfills. Facilities for the disposal of sewage sludge are sources of environmental pollution and require large territories. In this regard, in some European countries, such as Germany, it is prohibited by law to deposit sludge on drying beds [6]. Sludge can be classified as follows: coarse, retained by grates; heavy (sand), caught by sand traps; floating (fatty substances) accumulated in settling tanks; suspensions deposited in primary settling tanks; activated sludge of secondary settling tanks (microorganisms with adsorbed and partially oxidized contaminants removed from wastewater during biochemical treatment); anaerobic sludge fermented in metatanks; stabilized aerobic activated sludge or its mixture with sediment from primary settling tanks in structures such as aeration tanks; activated sludge or sediment in thickeners or concentrators; sludge dehydrated on mechanical devices, dried on sludge beds or thermally dried. The main part of dry residue in the sludge of the primary settling tanks (60–75% on average) and activated sludge (about 70–75%) are organic substances. The organic part of the activated sludge is mainly represented by substances of protein origin (up to 50%) with a fat and carbohydrate content of 30 and 10%, respectively. It contains about half as many proteins and 2.5–3.0 times more carbohydrates than in activated sludge. Possibilities of disposal of waste (changes of some derivative characteristics to receive a product suitable for the further useful application) are determined by its qualitative structure. The composition of sewage sludge largely depends on the composition of wastewater, but most of their components are traditional. Based on the composition, the most common worldwide is the use of sewage sludge as organic fertilizers. Value of such fertilizers in many cases is equivalent to manure and sapropels. The content of plant nutrients in the dry matter of sewage sludge is: 2–7% of N; 1.5–7% of P_2O_5; 0.15–0.35% of K_2O. The content of mummified organic matter improves the soil-forming qualities of disturbed lands. Under the influence of sewage sludge in the soil there is an increase in humus content, improvement of water-physical properties and provision of the main nutrients — nitrogen, phosphorus, potassium, etc [7]. Despite some negative claims, the use of organic sludge as a non-traditional fertilizer to increase soil fertility is one of the possible ways to solve the problem of their placement, as the return of processing waste to agricultural and urban lands is a significant factor in closing the cycle of substances in nature [8]. In Ukraine, out of 6–12% sludge, which is recycled, no more than 1/3 is used in agriculture. In addition to use for growing food plants, sewage sludge and compost from this sludge are used as fertilizers on lands set aside for planting trees and shrubs, creating nurseries, parks, growing perennial grasses for pastures, forage, silage, industrial crops, and also for the restoration of reclaimed lands. Utilization of sewage sludge for the purpose of restoration and cultivation of forests is promising, as the probability of getting heavy metals and pathogenic microorganisms into food chains is minimal [9]. For the forest industry, detailed methods of preparation of a number of organic fertilizers from various components of industrial, communal and agricultural wastes have been developed and recommended for implementation in nursery production [10]. The effectiveness of sewage sludge and the lack of negative impact on grass and woody plants have been proven during field studies in nurseries in the Moscow region [11].

Returning to the qualitative composition of sewage sludge, it should be noted that its disposal in Ukraine is limited by two main factors: sanitary-epidemiological and sanitary-chemical. The epidemiological danger of sludge can be eliminated in many known ways, including such simple ones as drying on sludge drying beds according to DBN V.2.5-75:2013. But agro-ameliorative use of sewage sludge is also associated with the risk of contamination of soil and agricultural plants with chemicals, especially heavy metals, such as Cd, Cu, Ni, Pb, Cr, Zn, Hg, As, Mn, and in some cases Mo, Se, Co, Sr, B, Be, Ba. The content of the above elements in sewage sludge may exceed the background content in natural objects (soil, peat, bottom sediments). It depends on the level of development and profile of industry in the settlement, the technical culture of production, the characteristics of the geochemical province, the presence and area of technogenic landscapes. Sludge from domestic wastewater in cities and other settlements is a fertilizer that contains biogenic elements (nitrogen, phosphorus, potassium, their compounds), as well as micronutrient elements necessary for plant development. The most valuable organic fertilizer, especially rich in nitrogen and phosphorus, is activated sludge. Before use as a fertilizer, the sludge is dehydrated and disinfected. Dehydration is performed by mechanical means (vacuum filters, filter presses, centrifuges) and on sludge drying beds. The following methods are used for disinfection: thermal drying (at 80°C); three-day heat treatment at 55°C; composting at 55°C for 15 days; anaerobic fermentation at 35°C; alkaline treatment for 72 hours at pH 12 and a temperature of 50°C. The most effective disinfection of mechanically dehydrated sludge is achieved by their thermal drying. Drying can be direct (by flue gases, hot air, superheated steam) and indirect (through the heat transfer surface). Direct drying prevails and is carried out in units of various types, for example drum (diameter 1.0–3.5 m; length 4–27 m; direct flow of material and drying agent), fluidized (with mechanical stirring), vibrofluidized and spouted bed, combined. To eliminate the smell of emissions when drying sewage sludge, this operation is often preceded by the application of deodorizing additives. These can be, in particular, ground activated soft lignite coal and/or potassium chloride in the amount of 0.1–0.4 and/or 0.1–0.25 parts per unit mass of dry matter of waste, respectively [12]. To eliminate unpleasant odors, pre-liming of the fermented sludge before dehydration, in particular, by centrifugation, is also used. Additives not only suppress odors, but also destroy pathogenic bacteria by increasing the temperature of the mass to 50–55°C, as well as increase the power of centrifuges by 1.5–2.0 times (N-Niro method). A similar effect is achieved by mixing already dehydrated sludge with lime. The same deodorizing effects are obtained using a mixture of calcium carbide (CaC_2) and lime. Thermally dried sludge does not rot. It is a loose material free from helminths and pathogens with a moisture content of 20–50%, convenient for transportation and application to the soil. However, to avoid dusting, granulation is recommended. In the USSR, "Temporary specifications for thermally dried sludge" were developed. In order to prevent the accumulation of toxicants in the soil and plants, these specifications recommended to apply sludge once every 5 years assuming doses of 10–40 t/ha for sludge with moisture content of 50% or 5–20 t/ha for absolutely dry matter.

Compared to thermal methods, disinfection of sewage sludge in natural conditions on sludge beds is less effective. It requires a lengthy period of time — at least 3.5 years since the last filling. In addition, the distribution of such sediment (with a humidity of 75–80%) on the fertilized areas causes significant difficulties. A new method of disinfection using solar energy is the drying of sludge in greenhouses, which has been used in Germany since 1994. The pre-dehydrated sludge is evenly distributed on the surface of the greenhouse (8–10 m wide) and moved along it by means of an automatic unit of constant agitation and longitudinal movement of the sludge along the front equal to the working width of the greenhouse. The final humidity of the material is close to 10%. On the evaporated moisture specific productivity is 700–800 kg/m2 of the greenhouse at an electric power consumption of 20 kWh/t and prime cost of 100–180 German marks for 1 t.

Along with thermal disinfection and disinfection at sludge drying beds, iodine radiation is used (USA, 1979). The sludge is disinfected in an underground room in stainless steel containers. The source of gamma radiation is cesium-137 (dose of 1 MKu). As a result, all pathogenic microorganisms die, while the nutrients of the sludge are preserved. The total cost of processing 1 ton of dry or combined sludge did not exceed $9.

After dehydration and disinfection, sewage sludge is taken to agricultural fields. Its agronomic application is one of the old and widespread types of disposal. In Germany, when using sludge as fertilizer on arable land, the rate is 5 t/ha per year, and on pastures it is 2.5 t/ha (on a dry matter basis). The experience of joint application of mineral fertilizers with sewage sludge shows a significant increase in the yield of sugar beet, wheat, oats in comparison with the application of only mineral fertilizers. In Australia (Adelaide) sludge from aeration treatment plants is used as fertilizer for gardens and orchards located on sandy soils: application up to 24 t/ha on a dry matter basis increases the yield of vegetables in greenhouses and open ground, improves the structure of soil. Experiments by Polish experts have shown that with the annual introduction of optimal amounts of sludge into the soil, the yield of grass crops increases by 30% and rice by 18%. The predominant use of sludge in urban wastewater as a fertilizer also occurs in other countries (France, Canada, Great Britain, Finland, Japan, etc.).

Sediments can also be processed to obtain soil substitutes. For this purpose, they are placed on sites where reeds and other species of higher aquatic vegetation were planted, and which are equipped with systems for drainage, wastewater separation and its disposal to treatment facilities. The processing depends on the specific conditions and lasts up to 6 years or longer. The obtained material is not inferior in quality to natural soils, has physical and chemical stability and can be used in land reclamation in horticultural farms, etc. [13]. After five years of storage on sludge beds, sewage sludge becomes a soil-like mass with a moisture of 50–60%, which contains 36% organic matter (on a dry matter basis), up to 2.24% of total nitrogen, up to 1.26% of gross phosphorus (P_2O_5), up to 0.3% of potassium (K_2O), a rich set of micronutrient elements. Special requirements apply to the content of heavy metals in sediments in accordance with DSTU 7369:2013 "Requirements for wastewater and its sludge for irrigation and fertilization".

In the USSR, municipal sewage sludge was successfully used in agriculture until the 1990s. For example, the application to the soil of thermally dried sludge of the dry fertilizer shop of the treatment facilities of Orekhovo-Zuyevo in the amount of 30–40 t/ha increased the yield of winter wheat from 3.9 to 33.3 q/ha on raised-bog peat quarry soils. A number of collective farms and state farms in the Moscow region when using sludge as fertilizer increased crop yields by 1.5–2.0 times. There also was an improvement in soil structure. For more than 15 years, the garden and park administration of Moscow has widely used fermented sludge with a moisture content of 80%, removed from the sludge beds: 40–80 t/ha for perennial and annual crops, 100–200 t/ha when laying lawns. Thermally dried lime-containing sludge has become effective means for soil deoxidation. In the areas of development of former peat quarries with the application of thermally dried sludge in doses, which were gradually increased up to 80 t/ha at a humidity of 50%, the reaction of the medium in the soil during the year varied from pH 2.7–3.3 to neutral. Similar results were observed on other less acidic soils at lower doses of sludge. In some southern regions of the USSR, fermented sludge, dried on sludge beds, was used to fertilize vineyards and tea plantations.

In the early 1990s in Russia, the use of urban wastewater as fertilizer in agriculture was prohibited by law. The reason was the increase in the amount of heavy metals and their compounds in sludge.

Studies of substrate properties of overburden dumps have shown the prospects of their use for soil formation. The electrical conductivity of the aqueous extract does not exceed 10 mSm/cm (indicates the absence of salinity), pH values are close to the neutral (6.5–7.0). The absence of phytotoxic properties of rocks is evidenced by the results of biotesting of overburden by germination of radish seeds. The availability of the P and K nutrients promotes self-restoration of biogeocenoses. The development of natural growth processes of communities is inhibited by nitrogen deficiency (N), which underlies the mineral nutrition of plants. The application of organic fertilizers can compensate for the lack of mineral nitrogen and at the same time ensure the stability of its content in the substrate. The source of all forms of mineral nitrogen is the organic matter of sewage sludge. Due to microbiological processes at soil moisture of 25–30% and a temperature exceeding +10°, mineralization of organic matter occurs. Such conditions in the soils of Kryvbas are formed with the beginning of the growing season (early April) and persist for 2–3 months depending on climatic conditions. Sewage sludge has huge reserves of organic matter, the mineralization of which without mixing with rocks less saturated with organic matter can take decades. The main limiting factor in the restoration of biogeocenoses in the steppe zone of Ukraine is soil moisture. Plants experience a lack of moisture for most of the growing season. The formation of secondary biogeocenoses on the dumps of Kryvbas quarries begins with the stages of the "industrial desert". Optimization of humidification conditions is a key task in activating self-healing processes. The study of water-physical constants of the considered substrates shows that rocks of dumps have the lowest volumetric moisture content of withering, which can provide them with the largest range of active moisture. At the same time, the ability of rock dumps to condense moisture from the air significantly exceeds similar abilities of sand, which makes it possible to meet the minimum needs of plants in the dry season. The ability of dump rocks to condense moisture is determined by their mineralogical composition, which is dominated by quartzites. The accumulation of organic matter in the process of self-renewal should promote the aggregation of rocks and the accumulation of moisture. Based on the known equation of water balance, there is an obvious need to ensure the advantage of inflow values over outflow. Excluding from consideration cases of influence of ground waters which on the disturbed lands apeear at depths of more than 5 meters and do not influence development of soil-forming processes, we compare outflow and inflow. Then, based on the fact that in the steppe zone the total amount of precipitation is equal to the sum of evaporation and desuction, by simple transformations we obtain:

$$A = I_{surf} + I_{sub} + I_c - O_{surf} - O_{inf} - O_{sub} \quad (1)$$

where A is the amount of moisture accumulation; I_{surf} is the amount of inflow due to surface runoff; I_{sub} is the amount of inflow due to subsurface runoff; I_c is the amount of inflow due to condensation of moisture; O_{surf} is the amount of outlflow due to surface runoff; O_{inf} is the amount of outflow due to infiltration; O_{sub} is the amount of outflow due to subsurface runoff.

Obviously, the right part of the equation contains values that can be regulated by engineering methods by creating the necessary geological conditions and reclamation structures. Protosoils formed on rocks of degraded lands have porosity indicators significantly lower than natural analogues (light chernozems by 2.8 times, chernozems in eluvium of sandstones and shales by 2.5 times). Due to this, the filtration coefficient is significantly lower in protosoils: 0.2 mm/min. With such water permeability, the formed soils cannot ensure the absorption of all precipitation that falls, and lose some of them with surface runoff. Analysis of particle size distribution according to the classification of N.A. Kachinskiy allows to classify protosoils as strongly granitic. Granitic soils are most common in mountainous areas. They have several features (short profile, gritty consistency), however, which did not prevent them from forming their fertility, the ability to self-restoration, self-regulation. Protosoils of degraded lands, as a rule, develop from coarse clastic soils, which are a mixture of various mechanical elements of stones and boulders (200 m), gravel (40–400 mm), rotted rock (2–4 mm), loam. Humidity of coarse clastic soils is determined by the humidity of the clay aggregate. The accumulation of moisture can help plan the artificial relief of moisture accumulation. On flat areas it is necessary to evenly plan porous accumulative forms in the form of holes, rollers on the edge of the slope, etc. On the slope cracks and furrows along the horizontal relief should be formed. Stimulation of moisture accumulation in the protosoils of degraded lands is one of the promising areas for activating the self-restoration of biogeocenoses. In stony soils, processes of dew formation (absorption of moisture from the air) are created. Limestone rocks, having hygroscopicity, absorb moisture from the air, and then gradually release it into the soil. The movement of atmospheric air brings atmospheric moisture from the seas and water bodies. Changes in atmospheric pressure, the difference in temperature of stones and air led to condensation of water and its accumulation in the soil. Condensation allowed to receive from air in stony soils up to 60 mm of precipitations annually during the growing season. Such moisture reserves allowed the plants to overcome the dry season and maintain their viability in harsh conditions. Application of organic waste (wastewater, sewage sludge, crop biomass, etc.) significantly increases the possibility of protosoil formation on the rocks of dumps, quarries and tailings, organic matter helps to aggregate the soil surface and reduce the rate of water and wind erosion.

In the conditions of field research the influence of treatment of rocks with organic matter of sewage with introduction of seeds of perspective species was studied. It turned out that sewage sludge with an organic matter content of more than 30% can inhibit the development of vegetation, seed germination processes, growth and development of plants [14, 15]. Excess organic matter led to a significant increase in the content of nitrates in soils and their migration in the environment under the action of surface and infiltration runoff.

Analysis of the obtained results and literature data shows that the optimal content of organic matter in soils should not exceed 10–20%. Thus, in order to create optimal conditions for the restoration of disturbed land ecosystems, it is necessary to ensure the mixing of organic waste with weathered (soft) overburden and their application to the surface of the restored soil cover. Traditional means of applying organic fertilizers to the soil cannot be provided due to the lack of tools, the working bodies of which could withstand the processing of stony technical mixtures, which predominate on the lands disturbed by mining operations. The application of sewage sludge contributed to the formation of a kind of mulch on the surface of the soils, which allowed to minimize the loss of moisture through evaporation, contributed to the formation of a lumpy macrostructure. The application of sewage sludge significantly increases the absorption capacity of overburden. A secondary soil absorbing complex is formed, which is able to accumulate and retain mineral nutrients of plants, especially calcium and magnesium cations. The formation of the soil absorption complex significantly improves the water and air regime of soils.

Studies of the chemical composition of overburden have shown a low content of mobile forms of heavy metals.

The content of heavy metals is shown in Tables 1-5.

The content of gross forms of heavy metals in the shales of Ingulets GZK overburden dumps is less than 0.2% for manganese, 0.02% for cadmium, 0.1% for lead, 0.2% for zinc, 0.2% for copper, 0.1% for chromium, 0.2% for nickel of their relative abundance in Earth's crust. The content of gross and mobile forms of heavy metals does not exceed threshold limit values.

The content of gross forms of heavy metals in the clays of Ingulets GZK overburden dumps is less than 0.4% for manganese, 0.02% for cadmium, 0.1% for lead, 0.002% for zinc, 0.2% for copper, 0.0001% for chromium, 0.1%

for nickel of their relative abundance in Earth's crust.

Table 1. Contents of heavy metals in the shales of Ingulets GZK overburden dumps.

Form	Contents of heavy metals, hazard class, mg/kg						
	Pb (1)	Cd (1)	Zn (1)	Mn	Cu (2)	Cr (2)	Ni (2)
gross;	10,0	<0,1	100,0	200,0	32,0	100	68,0
mobile: t=25°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
t=40ºC	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
water soluble t=25°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
t=40°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1

Table 2. Contents of heavy metals in the clays of Ingulets GZK overburden dumps.

Form	Contents of heavy metals, hazard class, mg/kg						
	Pb (1)	Cd (1)	Zn (1)	Mn	Cu (2)	Cr (2)	Ni (2)
gross;	12,0	2,8	1,0	522,0	32,0	<0,1	40,0
mobile: t=25°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
t=40ºC	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
water soluble t=25°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
t=40°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1

Table 3. Contents of heavy metals in the loams of Ingulets GZK overburden dumps.

Form	Contents of heavy metals, hazard class, mg/kg						
	Pb (1)	Cd (1)	Zn (1)	Mn	Cu (2)	Cr (2)	Ni (2)
gross;	13,0	<0,1	61,5	312,0	10,0	<0,1	17,0
mobile: t=25°C	<0,1	<0,1	<0,1	5,6	<0,1	<0,1	<0,1
t=40ºC	<0,1	<0,1	<0,1	5,6	<0,1	<0,1	<0,1
water soluble t=25°C	<0,1	<0,1	<0,1	5,6	<0,1	<0,1	<0,1
t=40°C	<0,1	<0,1	<0,1	5,6	<0,1	<0,1	<0,1

The content of gross forms of heavy metals in the loams of Ingulets GZK overburden dumps is less than 0.3% for manganese, 0.02% for cadmium, 0.1% for lead, 0.1% for zinc, 0.1% for copper, 0.1% for chromium, 0.1% for nickel of their relative abundance in Earth's crust.

Table 4. Contents of heavy metals in the limestons of Ingulets GZK overburden dumps.

Form	Contents of heavy metals, hazard class, mg/kg						
	Pb (1)	Cd (1)	Zn (1)	Mn	Cu (2)	Cr (2)	Ni (2)
gross;	12,0	<0,1	19,6	200,0	5,7	<0,1	10,0
mobile: t=25°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
t=40ºC	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
water soluble t=25°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
t=40°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1

The content of gross forms of heavy metals in the limestones of Ingulets GZK overburden dumps is less than 0.2% for manganese, 0.02% for cadmium, 0.1% for lead, 0.1% for zinc, 0.1% for copper, 1% for chromium, 0.1% for nickel of their relative abundance in Earth's crust.

Table 5. Contents of heavy metals in the quartzites of Ingulets GZK overburden dumps.

Form	Contents of heavy metals, hazard class, mg/kg						
	Pb (1)	Cd (1)	Zn (1)	Mn	Cu (2)	Cr (2)	Ni (2)
gross;	15,0	<0,1	8,5	112,0	4,0	<0,1	17,0
mobile: t=25°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
t=40ºC	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
water soluble t=25°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
t=40°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1

The content of gross forms of heavy metals in the quartzites of Ingulets GZK overburden dumps is less than 0.1% for manganese, 0.02% for cadmium, 0.1% for lead, 0.1% for zinc, 0.1% for copper, 0.1% for chromium, 0.1% for nickel of their relative abundance in Earth's crust.

In general, for overburden, the content of heavy metals is less than their relative abundance in the Earth's crust and less than the regional values established for Kryvbas. That means that waste can be applied on these rocks without endangering the environment, even if the content of heavy metals in the waste exceeds threshold limit values. According to our research, sewage sludge does not exceed threshold limit values for heavy metals, so its application will not harm secondary ecosystems due to toxic effects, but only bring them closer to the regional relative abundance.

The study of the gross chemical composition of overburden shows that the rocks have enough calcium and manganese, which are plant nutrients, to ensure the fertility potential of secondary soils. Analysis of particle size distribution was performed by screening. According to its results, the technical mixture can be attributed to the coarse clastic soils. Statistical processing of materials indicates the diversity of the particle size distribution of the technical mixture.

Soil formation can be carried out only under the condition of vegetation formation. The development of the latter is constrained by a shortage of diaspore stocks (seeds). The state of the phytocenosis was managed by introducing seeds of tree and shrub species. Pioneer plant colonies had spatial and relief peculiarities. A knotgrass colony with explerent species was formed on flat areas. There were dominated by common knotgrass, or doorweed (*Polygonum aviculare L*). Species that implement the life strategy of explerents have low competitive power, but quickly capture the ecological niches of dump territory. Late annuals predominate among them. In the wet year, yellow sweet clover (*Melilotus officinalle L*) and honey clover (*Melilotus album L*), whose height reached 150 cm, prevailed on flat areas. On the slopes coltsfoot grows, which can occupy up to 5% of the area. Ecological features of the coltsfoot species (*Tussilaga farfara L*) allow to withstand lack of moisture, soil erosion, poor nutrient content of substrates. On the slope there were seedlings of ash-leaved maple, field elm and walnut due to self-restoration processes. In the first year after the implementation of technological actions, seedlings of tree and shrub species were obtained. Formed pioneering communities show a balance between ecological, economic and botanical groups and families. Legumes, represented by several species, have the ability to initiate nitrogen fixation and promote the accumulation of nitrogen of biological origin. The terrace was dominated by an annual plant (common knotgrass), and the stability of such a colony remained low. The slope was dominated by a rhizomatous perennial (coltsfoot) and ash-leaved maple. The development of the root system, the possibility of both seed and vegetative means of plant reproduction determine the prospects for stabilization of emerging ecosystems. The development of vegetation during the application of wastewater has led to the formation of colonies of Chenopodioideae plants on the terrace and on the slope: their biodiversity (52 flora species) and productivity increased. The development of populations of tree and shrub species indicates that the plants have developed and successfully overcome harsh living conditions. Analysis of morphometric parameters shows that the best vitality is still demonstrated by the silver berry (wild olive), apricot and walnut.

Treatment of rocks with organic matter of domestic wastewater has led to a positive dynamics of soils, which is reflected in the enhanced development of vegetation of secondary ecosystems. Comparative analysis of vegetation shows a positive effect of the treatment of overburden with organic matter on productivity and morphometric performance of trees and shrubs.

Morphometric parameters of plants that grow on soils treated with organic matter exceed the control values: by 29% for average height, by 5.9% for mean increment, by 22% for average diameter of the root collar. A comparison of the average condition of plant objects after treatment with organic matter and control studies shows the following: the vitality of herbaceous and tree species increases; the total projective cover and average height of plants increases; biodiversity and total biomass of colonies increases; seed germination is enhanced. The application of organic matter on the surface of the dump allows to provide ecosystems with nutrients, to create a valuable soil structure, to promote the formation of moisture reserves for the scarce summer months.

But the application of sewage sludge promotes the restoration of ecosystems only when they are transferred to a state where the parameters of chemical composition, physical and biological properties are in the optimal range for plants and soils.

When sewage sludge is applited to disturbed lands, they are exposed to natural agents (surface runoff, wind, etc.), which promote the migration of sludge substances in the environment. In order to avoid negative impact on the environment, it is necessary to achieve the safety of sludge during application, or to apply special measures that would exclude the possibility of migration of hazardous substances after application (disinfection, preservation, remediation).

Obviously, the main problem that hinders the use of sewage sludge as organic fertilizers is their contamination with heavy metals. Even with an average content of heavy metals below the threshold limit values, the risk of uneven sedimentation and local pollution, contamination by re-introduction as a result of the accumulative effect, volley pollution of wastewater and sludge, which is not detected by means of control, is not excluded. Under such conditions, the use of sewage sludge as fertilizer on chernozems is associated with the risks of contamination of fertile soils and irreversible changes in their use. Practice shows that the owner prefers to lose the ability to use additional nutrients than to risk losing everything. The urgency of this problem persists with the use of sludge in green construction, when hazardous substances can get into the immediate environment of population of cities and villages.

Sanitary and hygienic problem is one of the key problems. It lies in the content of pathogens (microorganisms, helminths, etc.) in the sludge. Despite various safety measures, it is known that in Japan, a country that has long used municipal waste as fertilizer, infectious diseases, especially ascariasis, are very common. Sludges are very diverse in condition and properties, penetration of substances that carry out disinfection is uneven, the formation of areas in which disinfection does not work is possible. Artificial disinfection methods (infrared and ultraviolet radiation, chlorination, ozonation, etc.) require significant energy consumption and can only be effective for a short period of time. The most effective methods are those that are formed naturally and last for a long period of time. They are achieved by the creation of uniform conditions in which the pathogens die from dehydration, by the formation of an alkaline or acid reaction, and so on.

The problem is the ability to move sludge and substances contained in them. Sewage sludge enters natural ecosystems from the technosphere, has no place in the ecosystem, is not integrated into the natural cycle of matter and energy, and is not a stable element. Sewage sludge, or the substances that make it up, can migrate in space, not appearing where it was applied. Migrations occur under the action of gravity, convection effects, laminar and turbulent flows. Thus, the positive effect of ecosystem restoration can be offset, and in some cases become negative (pollution of surface and groundwater, the spread of infectious diseases).

Organic matter in sewage sludge is in raw form, and at the initial stage of formation is poisonous to most living organisms. To convert to a state suitable for use by soil and plants, it is necessary to carry out the transformation when the raw organic matter is either mineralized or converted into humic and similar substances that are able to form a soil absorbing complex, quickly give nutrients in mobile forms (anions and cations) to the soil solution. The problem of organic matter conversion stems from the need to adapt the artificial element to the needs of the ecosystem.

Wastewater sludge has a concentration of organic matter that is almost non-existent in nature. To include this organic substance in natural cycles, it is necessary to dilute it with inert materials. This dilution when applying organic fertilizers is achieved by scattering on the surface of the field and mixing with the soil in the process of tillage (plowing, cultivation, harrowing). When composting sludge using earthworms, sludge is mixed with waste paper, rags, soil, etc. Dilution of organic matter can be achieved in the process of natural migration under the action of natural agents with surface runoff, wind. The use of natural distribution processes can significantly reduce costs and make recycling processes attractive from an economic point of view.

All these problems of sewage sludge application also occur when it is used to activate ecosystem restoration. In various conditions of disturbed lands, these problems are exacerbated or weakened under the influence of natural factors.

The basic principles of technology should determine the methodological basis of their development, which allows to solve the problems of their application.

Studies of overburden have shown a generally low content of heavy metals compared to modern soils. The content of only some of them exceeds threshold limit values set for soils. This generally coincides with the theoretical generalizations about the biogenic origin of anomalies in the content of heavy metals observed on the earth's surface. According to this hypothesis, plants “pump” heavy metals to the surface, where they are distributed by natural agents (surface runoff and wind). In deep layers of the earth there is no high content of heavy metals, especially in layers that correspond to epochs deprived of the organic world (plants and animals). Based on this, the use of sewage sludge on overburden is environmentally justified. The application of excess heavy metals on the overburden in the general case will help the soils to reach the regional relative abundance.

Thus, for most heavy metals the following is true:

$$C_r = F + B + T \tag{2}$$

$$S < B + T \rightarrow F + S < C_r$$

where C_r is the regional relative abundance of heavy metals in the Earth's crust (regional clarke); F is the content of heavy metals in the soil-forming rock; B is the content of heavy metals of biogenic origin; T is the content of heavy metals of technogenic origin; S is the content of heavy metals in sewage sludge.

If there is a high content of certain heavy metals in the overburden, the genesis of this anomaly has its origins in the special conditions that developed on Earth during their formation in ancient times. This anomaly cannot coincide in time or space with the content of heavy metals in sewage sludge. Therefore, sewage sludge cannot contain the amount of heavy metals that would significantly increase their content in secondary soils.

In natural conditions, pathogens are present in the environment in certain quantities. It is impossible to achieve the complete absence of pathogens. The environment cannot be completely sterile. Sewage sludge after disinfection and pasteurization procedures contains a minimum number of pathogens that does not exceed natural levels. Thus, when overburden that has no biological contamination, almost sterile, comes to the surface of the earth, it is inhabited by either the microflora of sludge or the microflora of the environment. It is obvious that biological pollution from sewage sludge poses the least danger to humans on dumps and tailings in comparison with agricultural, recreational, urban lands, where contact with humans is direct (through the respiratory system, food). Sewage treatment plants are usually located on the terriroty near the industrial site and cannot be completely isolated from the facility employees. Pathogens move with the dust under the action of wind, posing a threat to employees. Dumps, quarries and tailings are located at a considerable distance from the places of concentration of the population (settlements, industrial facilities). They are guarded, which prevents people from accessing them. Therefore, the probability of disease spread when applying sewage sludge to them is the minimum of all possible ways of usage. Contamination of overburden can occur in two ways: by invasion, that is the reproduction of pathogens to the natural level, or contamination, i.e. the application of sludge that already has a natural level of contamination (the presence of invasive pathogens in the environment). Thus the following equation holds:

$$k_p = k_d \times k_0 = k_r \times I \tag{3}$$

where k_p is the value of contamination of overburden and technical mixtures (the number of pathogens per unit volume of sludge — microbes per liter); k_d is the disinfection rate; k_0 is the value of contamination in fresh sludge (number of pathogens of each species per unit volume of fresh sludge — microbes per liter); k_r is the reproduction rate; I is the value of the initial invasion (the number of pathogens at the beginning of the invasion per unit volume — microbes per liter).

The main agents that move sludge and substances are surface runoff and wind. To prevent the movement of sludge, it is necessary to block access of these agents or to minimize their activity. In the first case, a radical solution is achieved; in the second case the solution is partial.

A modified universal equation of water erosion can be used to describe the processes of soil movement under the action of surface runoff:

$$A = R \times L \times S \times C \times P, \tag{4}$$

where A is the loss of the substance; R is the factor of erosion force of precipitation; L is the indicator of slope length; S is the surface slope index; C is the indicator of the surface factor; P is the indicator of technological impact on overburden.

It is obvious that the values of L, S, C, P can be adjusted at the mining stage of dump formation. Access of agents can be blocked by creating an insulating layer between them and the sludge. One can use film, layer of soil, mulch, etc. At present, innovative methods of creating artificial soil, the properties of which can be predicted, are already used. Artificial soils can cover sewage sludge, achieving conservation and isolation.

The conversion of organic matter must be achieved naturally. It takes from 1 to 3 years for raw sludge to ferment under the influence of local microflora. This process can be sped up by the application of active strains of microorganisms, animals that process organic matter in nature (millipedes, worms, etc.).

Dilution of organic matter is very difficult to achieve on stony technical mixtures of disturbed lands. Only surface treatment can be carried out on them. The application of mulch or artificial soil looks much more promising. Artificial soil is formed in the process of mixing weathered overburden with dry ground sewage sludge.

The main methods of application of sludge:

1. Application of small volumes of fermented sewage sludge (0.5 dm^3) into holes during planting of tree and shrub seeds. Such discrete application of organic matter in the norms of 150 mg/dm^2 does not require large amounts of waste (up to 5 m^3/ha). The use of this technique allowed to stimulate the germination of common oak seeds. This technique is difficult to apply on the slope of the dump, where the steepness can reach 45°. Any movement of people and mechanisms on this slope is a threat to occupational safety.

2. Application of a mixture of seeds and fermented sewage sludge on the soil surface in the norms of 100 m^3/ha. After application in the autumn, organic matter has time to penetrate into the soil and to begin its action in the spring to increase nutrient content, soil aggregation and accumulation of moisture. The use of such huge amounts of sludge simultaneously solves the problem of their disposal.

3. Raw sewage sludge with a moisture content of 80% requires surface disinfection with chemicals, such as 10% ammonia solution after loading on a PTS-4 tractor trailer. After transportation to the dump, the sludge is unloaded into the holding pond. After unloading, the surface is disinfected again. Raw sludge with a moisture content of 80% must be kept in holding pond for 3 years to disinfect and ferment the raw organic matter. After holding, the sludge is used by applying in the norms of 100 m^3/ha with a coating by vegetable mulch. Steppe plant sod, rolled lawn, etc. can be used to fix organic matter. Application of sewage sludge from food enterprises to intensify restoration of ecosystems is the most promising area for their disposal.

4. Macroencapsulation is a new way of growing forest zoochories and their crops. Sewage sludge treatment allows the production of multilayer capsules that contain nutrients, micronutrient elements, biologically active substances that stimulate plant development, and biosorbents that allow the transfer of heavy metals to a safe state. Seeds (acorns, drupes) are placed in the capsule and covered with soil.

The effectiveness of such macroencapsulated seeds in agriculture is due to: increased seed germination, accelerated sprout growth and higher plant yields, as well as a significant reduction in the total consumption of organo-mineral fertilizers in field crops, especially on poor soils.

Conclusion

1. Application of sewage sludge significantly increases the absorption capacity of overburden. A secondary soil absorbing complex is formed, which is able to accumulate and retain mineral nutrients of plants, especially calcium and magnesium cations. The formation of the soil absorption complex significantly improves the water, nutrient and air regime of soils.
2. Studies of the chemical composition of overburden have shown a low content of mobile forms of heavy metals.
3. Treatment of rocks with organic matter of domestic wastewater has led to a positive dynamics of soils, which is reflected in the enhanced development of vegetation of secondary ecosystems.
4. In the conditions of field research the influence of treatment of rocks with organic matter of sewage with introduction of seeds of perspective species was studied. Comparative analysis of vegetation shows a positive effect of the treatment of overburden with organic matter on productivity and morphometric performance of trees and shrubs. A comparison of the average condition of plant objects after treatment with organic matter and control studies shows the following: the vitality of herbaceous and tree species increases; the total projective cover and average height of plants increases; biodiversity and total biomass of colonies increases; seed germination is enhanced.

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Investigation of technogenic deposits of phosphogypsum dumps

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Abstract. The article contains research materials on the storage of man-made deposits, including phosphogypsum dumps. The consequences of long-term operation of phosphogypsum dumps and their negative impact on the environment have been established. The quantitative content of microelements to the soil within the storage of technogenic phosphogypsum deposit was determined. Graphical dependences of phosphorus, manganese, fluorine, mobile sulfur, zinc, nickel content depending on the depth of sampling and distance from phosphogypsum dumps to settlements and the Goryn River are presented. The directions of processing and utilization of the given waste are offered. The elemental composition of phosphogypsum dumps of PJSC "Rivneazot" has been established, in particular, the presence of a group of valuable rare earth elements.

1 Introduction

Mining is the basis of the economy of any country [1, 2]. Since minerals are exhaustible, there is a need to process existing raw materials, including processed products of other industries [3, 4].

The problem of reduction and utilization of waste from various industries is very acute at the present stage of existence of the population around the world [5, 6].

According to the Rivne Geological Exploration Expedition, about 1,200 stationary landfills for soil and groundwater pollution have been identified in the Rivne region. Among the latter, a man-made phosphogypsum deposit poses a significant threat to human life and health, as well as a negative impact on environmental systems. It was formed as an inevitable multi-ton waste as a result of many years of production of phosphoric acid at PJSC "Rivneazot" [7].

Man-made deposit from phosphogypsum dumps of PJSC "Rivneazot", located in Rivne district at a distance of 1.5 km northeast of the village of Metkiv, and at a distance of 1 km east of the village of Rubche (Fig. 1) [8].

There are a significant number of such man-made phosphogypsum deposits in Ukraine and around the world. Most of them are not used, but only constantly accumulated [9].

Significant areas of agricultural land are allocated for phosphogypsum storage [10, 11]. Thus, phosphogypsum dumps of PJSC "Rivneazot" cover an area of 58 hectares and their total volume is 15.2 million tons [7].

It is known that when stored outdoors, under the influence of atmospheric factors, acid residues and large amounts of impurities, phosphogypsum enters groundwater and affects the ecosystem. Among these impurities are found rare earth elements (REE), the extraction of which does not occur [7, 12, 13].

Fig. 1. Man-made phosphogypsum deposit of PJSC "Rivneazot" (photo taken from open sources).

Rare earth elements are widely used in the production of high-tech products. REE includes chemical elements:

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Sc, Y, La and 14 elements of the lanthanide family. The total demand for these materials in 2013 amounted to 136 thousand tons [14] and now it is about 200.000 tons, which indicates an increase in demand by 47% [15]. New energy-saving fluorescent lamps, which include: yttrium, lanthanum, cerium, europium, gadolinium, terbium, have become widespread. Due to their low toxicity, REE are used in the manufacture of rechargeable La-Ni-H batteries, which will eventually be able to displace lead-acid batteries in automobiles and nickel-cadmium batteries in computers. Elements of the lanthanide family are used in the glass industry to create optical glass in the charge is injected lanthanum oxide (from 5% to 40%) which increases heat resistance and acid resistance, such glass is used for the production of lenses and prisms of telescopes, cameras, film cameras and laboratory glass [16]. Lanthanum nickel hydride is widely used as the basis for high-capacity batteries for hybrid cars, and the cerium dioxide catalyst is widely used in the petrochemical industry.

Therefore, it is already possible to consider man-made deposits of phosphogypsum as a raw material for the extraction of valuable rare earth elements. According to research, phosphogypsum waste contains up to 1% REE.

The use, processing and utilization of phosphogypsum waste is an urgent scientific and applied problem, the solution of which will improve the ecological situation in the storage areas of man-made phosphogypsum deposits and bring significant economic effect for the national economy [17, 18].

2 Materials and methods

The object of the study is the phosphogypsum dumps of PJSC "Rivneazot" and the adjacent territory (Fig. 2). This is a waste of the fourth class of danger, which is represented mainly by phosphorus oxides that accumulate in the dumps of phosphogypsum [7].

Phosphogypsum refers to calcium sulfate dihydrate. It mainly consists of gypsum ($CaSO_4 \cdot 2H_2O$), impurities P_2O_5 (undecomposed phosphate, unwashed phosphoric acid, crystallized P_2O_5 and water) and other inclusions of trace elements, including REE [19, 20].

Phosphogypsum is a polydisperse material that has a grayish-white color. It is represented by aggregates of particles, lumps with interunit cavities. The density of phosphogypsum is 2.2…2.4 g/cm^3, relative humidity 25…30%, bulk density 0.67… 0.93 g/cm^3, porosity 71.5… 76.3 [21, 22].

Hunting canals have been designed to intercept surface runoff and prevent contamination of soils and groundwater around the perimeter of the facility, and a pumping station has been designed to pump water from the site. Water is diverted to the treatment facilities of PJSC "Rivneazot". Currently, the pumping station is out of order. The water in the canals is highly mineralized, as evidenced by the results of research and dry trees in the riverbed, the water pressure in the canals is 0.5 m. To the object from the side of the village Metkiv there is a concrete road that connects PJSC "Rivneazot" and man-made dumps of phosphogypsum [7].

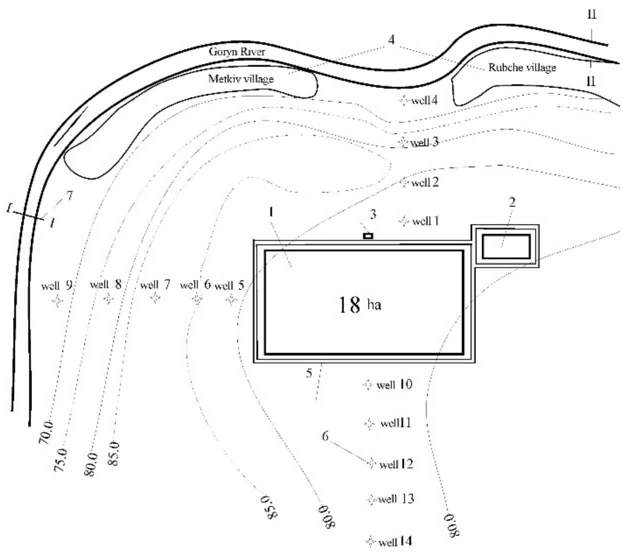

Fig. 2. Experimental area - phosphogypsum dumps of OJSC "Rivneazot": 1 - phosphogypsum dumps; 2 - storage of solid toxic substances; 3 - pumping station; 4 - settlements; 5 - system of channels for interception of surface runoff; 6 - wells for soil sampling; 7 - places of water sampling from the river Goryn, 8 - treatment facilities;w.1 - w.14 - wells for soil sampling; I, II - create for water sampling in the river Goryn.

To determine the content of contamination in soils and in the Goryn River, the study was conducted in two stages: at the first stage, soil and water samples were taken at the Goryn River, and at the second stage, the study results were processed.

To take soil samples, the experimental plot was divided into three sights, which were projected on the lowest points of the terrain. The first line west of the warehouse in the direction of the village. Rubche 1 km long; the second to the south of the object is 1.5 km long; the third to the east of the object towards the forest, 0.9 km long. The total number of wells is 14 pcs.

In Fig. 3 shows a longitudinal section of the target №1.

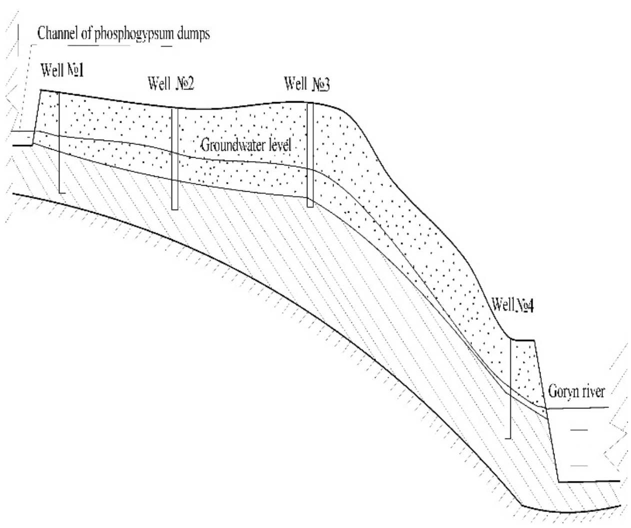

Fig. 3. Scheme of longitudinal section on the target №1: 1 - sand; 2 - loam; 3 - water resistance.

Wells for sampling were drilled by hand drill (geological drill, diameter 50 mm) to a depth of 6 m. Soil

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samples were taken every meter, starting from the surface with three repetitions of each sample. The distances between the wells in the first three lines are 50, 250, 300, 400 m, respectively. Along the first line there is a decrease of the territory towards the river Goryn. The distances between the wells in the second line, respectively, 50, 250, 300, 400, 500 m

Processing of data of field measurements was carried out jointly with specialists in the laboratory of the State Department of Ecology and Natural Resources in Rivne region [23, 24].

The raw material for the extraction of rare earth elements was phosphogypsum from the dumps of PJSC "Rivneazot" [7, 8, 25]. Sampling points on the territory of the dump were determined for research (Fig. 4).

Fig. 4. Location of technogenic deposit and place of phosphogypsum sampling on dumps of PJSC "Rivneazot".

Graphical coordinates of the points were determined using a Garmin GPSMAP 64 navigator: sample 1 (50°44'47.9"N 26°10'53.5"E), sample 2 (50°44'45.8"N 26°10'56.4"E), sample 3 (50°44'43.4"N 26°10'60.0"E), sample 4 (50°44'40.8"N 26°11'04.1"E), sample 5 (50°44'38.2"N 26°11'08.2"E), sample 6 (50°44'33.4"N 26°11'15.3"E), sample 7 (50°44'29.6"N 26°11'17.8"E), sample 8 (50°44'29.9"N 26°11'07.9"E), sample 9 (50°44'34.4"N 26°11'01.2"E), sample 10 (50°44'39.0"N 26°10'53.3"E) , sample 11 (50°44'43.1"N 26°10'47.9"E). A total of 11 samples were taken, with a total of 25 kg.

Before the research, a quantitative chemical analysis was performed to determine the elemental composition of raw materials [26, 27].

3 Results and discussion

3.1 Research of phosphogypsum storage landfill

As a result of chemical analysis of water and soil samples taken on the territory of the experimental site, the content of microelements in the experimental samples was determined. The content of nitrates NO_3, fluorine F, mobile phosphorus P_2O_5, mobile sulfur S, zinc, iron, cobalt, nickel, lead, manganese, copper and chromium in soil samples in mg/kg was determined. The pH of the water extract was determined. Graphical dependences of the content of microelements in the soil on the length of the target for each depth of sampling are constructed.

The results are presented for the target №1. It is directed towards the village Rubche and Horyn river, therefore, the obtained data are of the greatest value in terms of impact on soil and groundwater pollution due to the storage of man-made phosphogypsum deposits.

In fig. 5. and fig. 6. graphical dependences of phosphorus and manganese content on the length of the line, respectively, are presented. Samples were taken at a depth of 1 to 6 m.

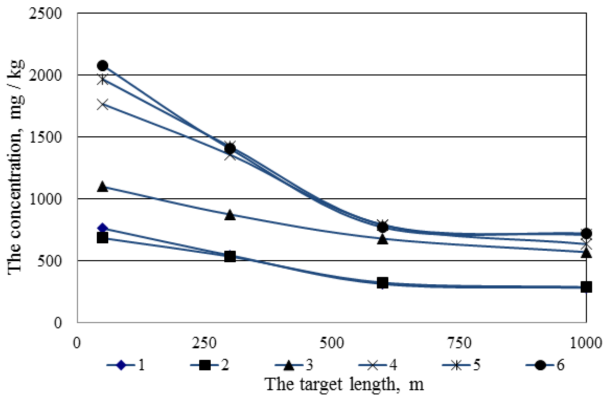

Fig. 5. Dependence of phosphorus content on the length of the target:1 - h =1 m; 2 – h=2 m; 3 – h=3 m; 4 – h=4 m; 5 – h=5 m; 6 – h=6 m.

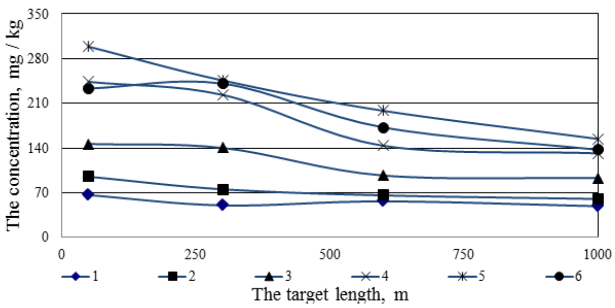

Fig. 6. Dependence of manganese content on the length of the target: 1 - h =1 m; 2 – h=2 m; 3 – h=3 m; 4 – h=4 m; 5 – h=5 m; 6 – h=6 m.

As a result of the analysis of the presented graphic dependences it is established that the concentration of phosphorus varies in the range from 286 to 2078 mg/kg. It is also seen that the concentration of phosphorus in the soil decreases depending on the distance from the phosphogypsum dump, and increases with increasing depth.

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The nature of the dependences of the manganese content in the soil is similar to the dependences for phosphorus. Numerical characteristics vary from 48.9 to 298.7 mg/kg.

Studies of the content of microelements from the length of the target at a depth of up to 6 m were also carried out. In Fig. 7 the results are presented at a depth of 3 m, and in Fig. 8 - 5 m.

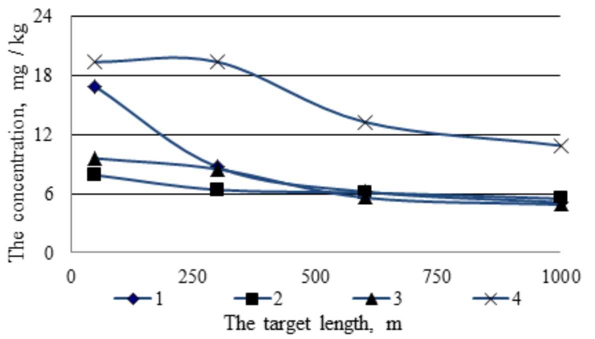

Fig. 7. Dependence of the content of microelements on the length of the target at a depth of 3 m from the soil surface, mg/kg: 1 - fluorine; 2 - mobile sulfur; 3 - zinc; 4 – nickel.

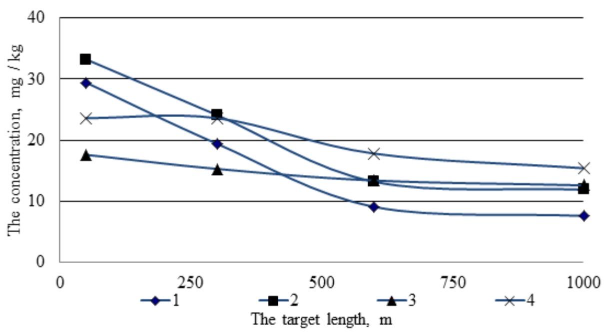

Fig. 8. Dependence of the content of microelements on the length of the target at a depth of 5 m from the soil surface, mg/kg: 1 - fluorine; 2 - mobile sulfur; 3 - zinc; 4 - nickel.

The result of the obtained data showed that the content of such microelements as fluorine, mobile sulfur, zinc and nickel increases with depth, and decreases with distance from the man-made phosphogypsum deposit.

When comparing the data obtained experimentally and the data of the State Department of Ecology and Natural Resources in Rivne region, there is a tendency of significant accumulation in time of harmful chemical elements in the soil. The content of lead, zinc, copper, cadmium, nickel, cobalt, nitrites, manganese, phosphorus exceeds the maximum allowable norms. Thus, in samples taken at a distance of 500 m to the west in 2000, the content of mobile phosphorus in the soil is 332 mg/kg, and in 2019 - 670 mg/kg. As a result, it can be concluded that it is necessary to reconstruct the system of protection of soils and groundwater from pollution by harmful substances on the territory of phosphogypsum dumps near the production site of PJSC "Rivneazot", or the introduction of new more effective methods, which will ensure high-quality interception of pollutants at the outlet of the facility and will not cause an environmentally unfavorable state of the environment. Another way to reduce the negative impact on environmental systems is to develop a project for integrated disposal of phosphogypsum dumps.

3.2 Investigation of man-caused phosphogypsum deposit

From the raw materials obtained for research from phosphogypsum dumps, a quantitative chemical analysis was performed, the results of which are presented in Table 1. For comparison, the results of quantitative chemical analysis of phosphogypsum OJSC "PhosAgro-Cherepovets" (Russia) are presented [28].

Table 1. Quantitative analysis of raw materials from phosphogypsum dumps.

Element	Phosphogypsum of OJSC "PhosAgro-Cherepovets", wt.%	Phosphogypsum PJSC "Rivneazot", wt.%
Sulfates	54.4	52.5
Aluminum oxide	0.2	0.15
Boron oxide	0.0092	0.01
Cadmium	0.00032	0.003
Cobalt	-	0.0012
Chrome	0.002	0.018
Copper	0.0014	0.0018
Iron oxide	0.025	0.034
Potassium oxide	0.055	0.064
Magnesium oxide	0.17	0.187 th most common
Manganese	0.0012	0.013 th most common
Molybdenum	0.00016	0.0056
Sodium oxide	0.27	0.294
Nickel	0.00016	-
Lead	0.00098	-
Strontium oxide	2.04	1.4
Vanadium	-	0.0014
Zinc	0.0018	0.002
Titanium oxide	0.014 ± 0.3	0.016
REE oxides:		
Cerium oxide	0.27	0.26
Oxide dysprosium	0.0042	-
Europe oxide	0.0023	-
Gadolinium oxide	-	0.0015
Lanthanum oxide	0.17	0.205
Neodymium oxide	0.12	0.116
Praseodymium oxide	0.018	0.02
Samaria oxide	-	0.0012
Terbium oxide	0.0014	0.0014
Yttrium oxide	0.016	0.015
REE concentrate	0.6019	0.629

In fig. 9 the content of REE oxides of light group of technogenic phosphogypsum deposit of PJSC "Rivneazot" is presented.

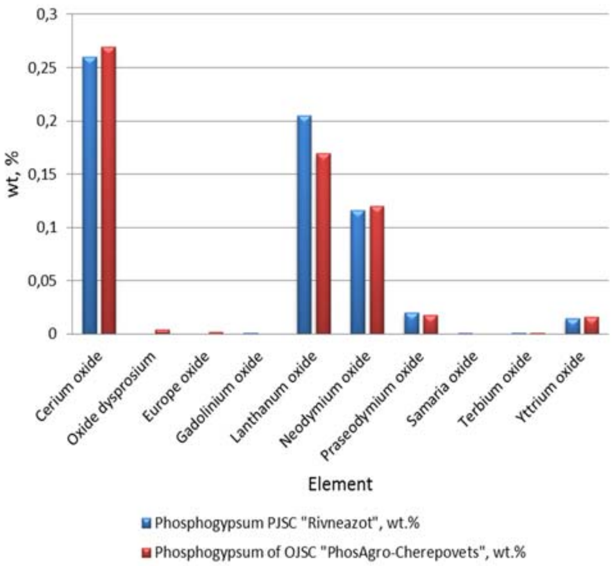

Fig. 9. Oxides of rare earth elements of the light group.

As can be seen from Table 1 and Fig. 9 in the dumps of phosphogypsum PJSC "Rivneazot" presents 8 rare earth elements. The main mass fraction is REE oxides of the light group. These include four elements: lanthanum, cerium, neodymium, praseodymium, the different content of which in concentrates of enrichment determines their commercial value.

3.3 Areas of use of phosphogypsum

The main areas of use of phosphogypsum in the national economy include [29, 30]:

- agriculture, as fertilizers and for reclamation of acid soils;
- use as pavements;
- as creation of X-ray protective designs;
- use as mineralizing additives in the firing of cement clinker;
- in the construction industry, for the production of building materials, production of gypsum binders and production of hydraulic additives;
- as a filler: in the production of paper instead of kaolin, in the paint and varnish industry and in the production of plastics, glass, ammonium nitrate instead of traditional materials (heat-treated phosphogypsum instead of sodium sulfate, etc.);
- mines of coal and other industries - to fill the fastening space and calculation of security strips;
- extraction of rare earth elements.

Conclusions

Solving the problem of processing or utilization of waste that forms man-made deposits of phosphogypsum is an important application, the solution of which will significantly improve the ecological state of the environment.

The research was carried out on the example of a man-made phosphogypsum deposit of PJSC "Rivneazot", located in Rivne region.

According to research, the parameters of micronutrient distribution in the soil around phosphogypsum dumps have been established. The content of lead, zinc, copper, cadmium, nickel, cobalt, nitrites, manganese, phosphorus exceeds the maximum allowable norms. The concentration of these trace elements in the soil decreases with distance from the dumps.

The main areas of use of phosphogypsum in the national economy are agriculture, the manufacture of X-ray protective structures, the extraction of rare earth elements.

According to the results of quantitative chemical analysis, it was found that phosphogypsum dumps contain 0.629% of REE oxides.

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The use of the construction with a digital camera and GPS receiver while researching dangerous areas

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Abstract. The purpose of the study is to select an effective methods and equipment for observing deformations in dangerous areas of the terrain, such as areas that are undermined by underground mining. It is known that the topical task of the mine surveying service is to improve remote sensing methods for the state of movement zones with craters, dips, cracks. The research methodology is based on the results of the performed analysis of methods for observing deformations using modern devices and technologies, and experimental work using the developed methodology, which provides for the combined use of digital methods and GPS technologies. Experimental work was carried out at the facilities of the Ordzhonikidze mine using various remote sensing methods, including those developed by the authors. The research used a design consisting of a digital camera and a GPS receiver. The performed analysis of the obtained survey results, using the proposed design of two devices, has shown its effectiveness in remote methods of observing the objects deformations located in areas undermined by mining operations. The scientific novelty of the results obtained lies in the methods development for remote observation of deformations of the ground's surface and objects, based on the structure use from a digital camera and a GPS receiver. This method was developed to increase the efficiency of performing research on objects deformations located in places that are dangerous for finding a person. The efficiency of using terrestrial digital stereo survey when the coordinates of the photographing points are determined with the help of GPS has been proved. The practical significance of the study lies in increasing work efficiency the on monitoring deformations of the earth's surface, buildings and structures located in areas dangerous for field work by traditional methods, which are performed using leveling and measuring the distances between the benchmarks of profile lines, which are usually used on areas undermined by underground mining. The use of terrestrial digital stereo photography with the coordination of photographing stations using GPS allows remote determination of the spatial position of the observed points with the required accuracy. Key words: ground stereoscopic survey, collapse zone, digital camera, GPS.

Introduction

When developing a mineral, a large range of works is envisaged, which also includes the study of the properties of the mineral, the study of the stress-strain state of the field massif and other measures that ensure the most complete and efficient extraction of the mineral with the least losses for the environment [1-8]. However, when mining a mineral, both open and underground, there is a violation of the ecological balance and damage to the environment. As a result of the activities of the mining enterprises, the atmosphere is polluted and the fertile layer is disturbed. As a result, zones with craters, dips and cracks, etc. are formed on the ground's surface. All these negative manifestations are observed by mine surveyors and surveyors in order to take timely measures to reduce their harmful effects on industrial and residential facilities, as well as to protect the environment [9-12].

Therefore, when developing minerals, one cannot do without competent mine surveying. The mine surveying service provides all the work on the extraction of minerals, develops measures for the rational use of subsoil and land, and performs work on the observation of the rocks movement and the ground's surface [13-16].

Ukrainian and foreign scientists are engaged in the development of more efficient systems for the development of minerals and methods of mine surveying support, including measures for their safe production.

An important type of mine surveying, from the entire complex, is mine surveying, the results of which are used to solve many problems. The introduction of modern instruments for their implementation, as well as digital technologies for obtaining and processing data, contributes to the improvement of mine surveying. Many works are devoted to the introduction of photogrammetric methods of shooting using digital cameras and unmanned aerial vehicles (UAV) [17-19]. These methods are effective when observing the state of objects located in areas where it is dangerous for finding a person. Such work is carried out for various similar objects, including for the objects of

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mining enterprises, where deformation processes are observed.

When choosing a surveying camera and an aircraft, they are guided by the requirements for the accuracy of solving a particular problem. It is known that the accuracy of a document created from the results of a digital survey carried out with a UAV is influenced by the surveying parameters and the characteristics of the survey equipment. This work is devoted to the study of these questions.

1 The use of software in photogrammetry

The modern photogrammetric methods are characterized by a high level of automation. Most of the operations that were previously performed by highly skilled performers can be performed by ordinary operators [20-22]. In many cases, the operator does not even need special knowledge of photogrammetry, since special programs are used to perform the survey and process the obtained material. Almost all software tools use ready-made processing templates, for example, Pix4D has 3D Maps, 3D Models, Ag Multispectral templates. In turn, templates are divided into those that carry out processing with low requirements for detail and accuracy and those that allow processing with high values of detail and accuracy. Some templates are designed to process data from different thematic cameras Ag Modified Camera or Agrgb, Thermomap Camera, etc. Nowadays such works as orientation of images on special photogrammetric devices (mutual, external orientation), which required a high qualification of the performer, are no longer performed. Even the construction of phototriangulation, the creation of photocircuits is carried out using software products. When designing and performing aerial photography of an area or an object, a minimum of knowledge about longitudinal and transverse overlaps, camera resolution, etc. is required. Calculations for the design of the survey are carried out according to the program using a computer, taking into account all the necessary parameters of the camera and the requirements for the scale and accuracy of the document (plan or orthomosaic), which is created based on the results of the survey. The initial data is set by the operator. However, to perform some work, special knowledge and experience is still required, for example, when drawing up situational and topographic plans for complex objects, which are deep quarries, when it is necessary to correctly position the recognition signs, select shooting parameters, and show elements on the plan with the required accuracy career, not just horizontal lines [23,24].

As a result of the automation and computerization of most processes, some photogrammetric methods have changed significantly or disappeared altogether. First of all, this concerns the methods in which a lot of routine field and office work was used, and some methods have turned from high-precision to survey. In support of this, we can consider phototheodolite photography, which has now changed and uses handheld or tripod photography, and is used to create overview digital models and presentations, or is an addition to aerial photography from unmanned aerial vehicles (UAV). In programs such as Photomodeler or Agisoft Metashape, the operator can build a digital model in a conditional coordinate system from any images (images) that have overlapping. Nowadays, amateur 3D models of architectural monuments, museums and other objects are often used in everyday life, tourism, and other spheres. Nowadays, professional ground surveying is rarely used to solve high-precision tasks. A significant number of programs and software complexes have been developed for the widespread use of unmanned aerial vehicles and digital imaging technologies.

2 The simultaneous surveying research

Phototheodolite photography, in the form in which it was used earlier, was much more accurate than aerial photography. A number of factors contributed to this:

- high binding accuracy of photographing stations and images;
- close-up of the image;
- lack of "blurring" of the image;
- high resolution of photographic plates that were used for photographing;
- the presence of a reference device made it possible to orient the camera relative to the photographing basis.

With the use of modern technologies when performing field work, the first factor that concerns the binding of photographing stations still exists in the form of determining the point coordinates from which the survey is performed, using standard autonomous GPS devices that can be installed on shooting cameras (for example, on Canon EOS 6D camera), or using separate GPS modules that work through the camera's hot shoe, such as the GP-E2 receiver. GPS devices of this class do not have the ability to receive differential corrections.

As a result, the camera positioning accuracy is from 5 to 8 meters in the planned position, and up to 10 meters in height. In many cases, this accuracy is sufficient to create a 3D-scene of an object.

The lack of "blur" in the image is explained by a technological leap in the creation of high-quality digital matrices for cameras, automatically or in manual mode is corrected and corrected by raising the ISO speed. Nowadays, cameras with wide-angle lenses that are mounted on UAV have found widespread use. When using them, in contrast to the narrow-angle (long-focus) ones, the amount of “blur” is insignificant and is not a critical factor. Increasing the ISO speed contributes to the appearance of "noise", but this does not significantly affect the accuracy of measurements on the model, that is, this factor is not critical either.

It is known that phototheodolite photography differed from aerial photography in higher accuracy; this was facilitated by the availability of a reference device. In the implementation of modern digital photography, this factor, which made it possible to obtain a high accuracy of terrestrial phototheodolite photography, replaces the use of a large number of images, the use of reverse photogrammetric intersection and high accuracy of pattern recognition [25-27].

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The presence of one control point allows you to replace the process of camera orientation relative to the baseline. Another reason for not using camera orientation is the inappropriateness of software for this type of surveying.

It is known that the initial deformations studies of mining facilities objects, it is necessary to begin with the reconnaissance process of the area. When examining an object, for example, a displacement zones, it is necessary to determine the deformation values, velocities, volumes of extinguished voids, identify areas for special attention, etc [28,29].

On the territory that is located in the zone of displacement from the work of the Ordzhonikidze mine, the previous study was based on the results of aerial photography using the Sensefly drone with the following shooting parameters:

- flight altitude 203 m;
- coverage area 1.87 km²;
- shooting positions 844.

A camera mounted on a drone has the following characteristics:

- focal length f = 18.5 mm;
- pixel size 3.91 x 3.91 microns;
- the number of pixels is 24 million;
- shooting resolution: 3.89 cm/pix.

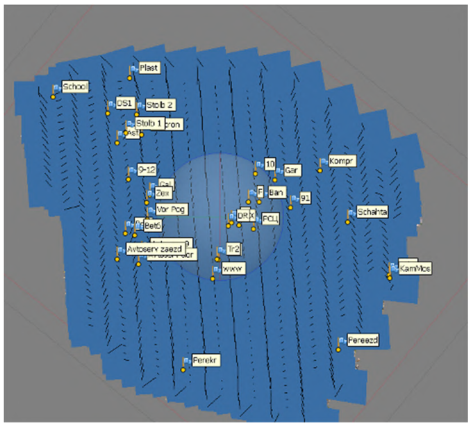
In addition, 975134 tie points, 2582845 projections with a reprojection error were used: 0.391 pix.

When aerial photography of mining facilities objects with significant differences in altitude, such as open pits, multi-tiered dumps, sinkholes zones, recognition signs should be located on them much more often than on a flat territory. Therefore, it is necessary to mark points on areas dangerous for a person, which is undesirable. But when creating a network of identification marks, you can get rid of the need to mark points in dangerous places Today, finding a person in a dangerous place can be replaced by the use of remote sensing and coordination methods. For this, it is advisable to determine the point coordinates from a line of intersection, built from four fixed points, or to determine them using the "reflectorless" mode of electronic devices.

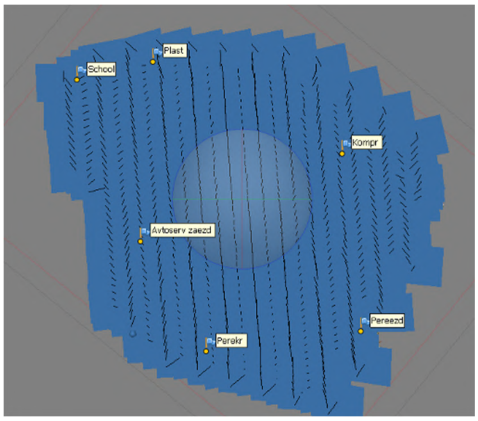
The authors investigated the influence of the location of identification marks on the determining accuracy the spatial coordinates of the studied points. In the first case, all identification marks were included in the processing (Fig. 1*a*), and in the second, only identification marks located along the outer contour of the site (Fig. 1*b*).

The deformation values in the displacement trough, which is formed from the influence of underground mining of the Ordzhonikidze mine, can have values from several centimeters to several tens of meters. Therefore, when exploring this dangerous territory, it can be divided into sections for which definitions can be used with varying accuracy.

If for a funnel with a depth of several tens of meters, in the center, the deformation values can be determined roughly, with an accuracy of 1 m to 1.5 m, and then it is possible not to mark the points directly in the funnel. But if it is necessary to ensure the accuracy of determining the position of the points of 0.1-0.3 meters, then marking is mandatory.



a



b

Fig. 1. Layout of identification marks: *a* - over the entire area; *b* - along the outer contour.

In fig. 2 shows a raster image of the funnel (Fig. 2*a*) and the distribution of errors in the values of deformations over the funnel field (Fig. 2*b*). The distribution of deformation values is shown in different colors, where they are more than 1.3 meters, they are indicated in red.

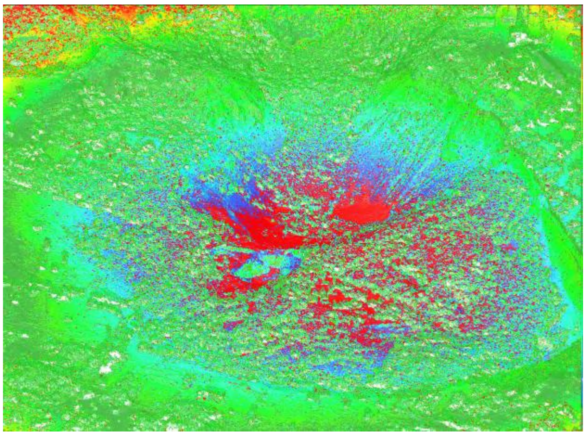
Root mean square errors on identification marks are shown in the graph (Fig. 3). The results of the analysis made it possible to exclude identification marks, the errors of which are more than 0.25 meters, from the use for orienting images.

3 The joint use of a digital camera and a GNSS receiver

The accuracy that aerial photography guarantees is sufficient for general surface monitoring, but for surfaces that have significant elevation differences, it gives large errors. Examples of such surfaces are the quarries sides, dumps and the surfaces of funnel-forming zones. To improve the observations accuracy of deformations, it is advisable to use ground stereotopographic survey.

It is shown in [30,31] that it is expedient to study the areas deformations where the deformations are from 50 to 100 mm and more by the method of ground stereotopographic survey. But the method of ground stereotopographic survey considered earlier by the authors has a number of disadvantages, which consist in the mandatory presence of identification marks and in the need to fulfill the requirements their layout. Also, a significant drawback was the impossibility with the required accuracy to link the images in the areas dangerous for finding a person.

a



b

Fig. 2. Image of the funnel (*a*) and the distribution of deformations (*b*).

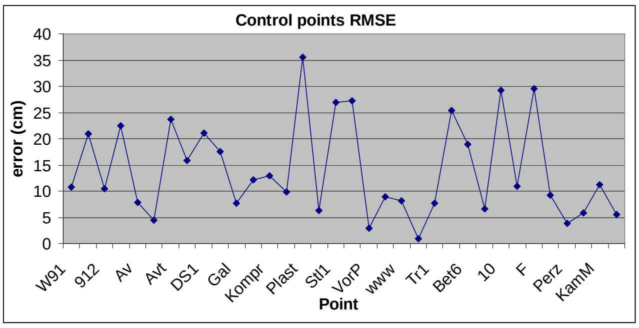


Fig. 3. Errors on identification marks.

When studying the deformations of quarry sides and dumps, as well as other mining enterprises objects, using ground digital survey, it became necessary to increase its accuracy [32]. For this, a design of the device was developed, which allows determining the coordinates of the photographing station with an accuracy of 5 to 15 mm, depending on the observation time, PDOP and distance to the base.

The device is designed on the basis of a Canon EOS 750D digital camera and a Topcon HIPER Plus GNSS receiver (Fig. 4).

Fig. 4. Device design appearance, consisting of a digital camera and a GNSS receiver.

The design has an optical plummet (3), which is attached to a standard three-pin tribrach (1) through an adapter (2). Thanks to this, the adapter can be easily removed and an electronic total station is installed in its place. The GNSS receiver is attached with four pins (4) that allow you to adjust (decrease or increase) the distance to the camera. The hole in the plate (6) has a larger diameter than the bushing (5), which allow the GNSS receiver to be accurately centered over the camera (Fig. 5).

Fig. 5. Elements of the device.

With the help of this device, in May 2020, survey work was carried out from six stations, the distance between which was from 55 to 65 meters. The distance between the first and last photographing stations was 230 meters, and the distance to the base was approximately 200 meters (Fig. 6).

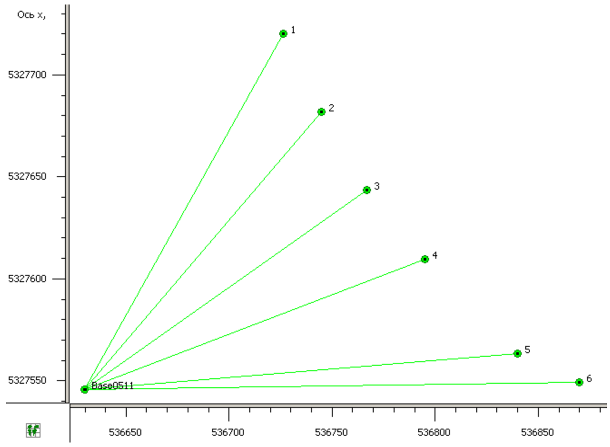


Fig. 6. Location of photographing stations and bases.

The studies were carried out on the territory, which is characterized as a zone of funnel formation from the activities of the Ordzhonikidze mine Central GOK. There are many mined out space in the mine take boundary; therefore the surface and subsoil are in a constant dynamic process. The speed of deformation processes on the day surface depends on the location in the depths of the areas with intensive mining works; therefore, work on predicting its further state is complicated by the fact that the mine is working.

To increase the accuracy of the survey results using device structure appliances, the survey parameters were pre-selected and the elements of the internal orientation of the camera were investigated, the accuracy of which significantly affects the accuracy of determining the position of survey points.

When using modern software for processing photographs (images) with standard settings, the focal length mode "Approximate" is used and the approximate focal length of the camera is taken. After adjustment, this value changes, and for each image its own focal length value is obtained. This also applies to other elements of interior orientation (distortion, main point coordinates). In addition, for each photographing station, coordinates X, Y and Z are determined, which characterize its spatial position. Approximate mode is used for most landmark surveys.

When the position of the photographing point is known with sufficient accuracy, the “Fixed” focal length setting mode is usually used.

In this case, the focal length was determined by photographing the KL-1000 reference ruler and determining the distance to the object using a Sokkia SET630R electronic total station. The defined focal length was 785.521 mm.

Also, in the process of calibrating the camera, the dimensions of the matrix of the Canon EOS750D camera were refined, which amounted to 22.657 mm x 15.104 mm.

The work investigates the research results of the influence of the determination accuracy of the focal length of a professional digital camera on the determination accuracy of the single point positions (Fig. 7) and their mutual position (Fig. 8) according to the digital model obtained from the survey results. In this case, the surveying was carried out without the use of recognition signs.

If, during surveying, the coordinates of the photographing station position are determined with an accuracy of 5 mm, and the focal length is determined with an error of 1 mm, then one can expect an error in determining the position of the studied points in the range from 0.7 m to 0.9 m.

With a rough determination of the coordinates of the photographing station position, for example, with an accuracy of 5 m, and with an error of 1 mm in the value of the focal length, the error in determining the position of the studied points can range from several to tens of meters.

Conclusion

The proposed method for performing ground-based digital surveys, with the coordination of photographing stations, using a GPS receiver installed on them, makes it possible to increase the efficiency of monitoring the objects deformations located in dangerous zones of rock movement and the ground's surface.

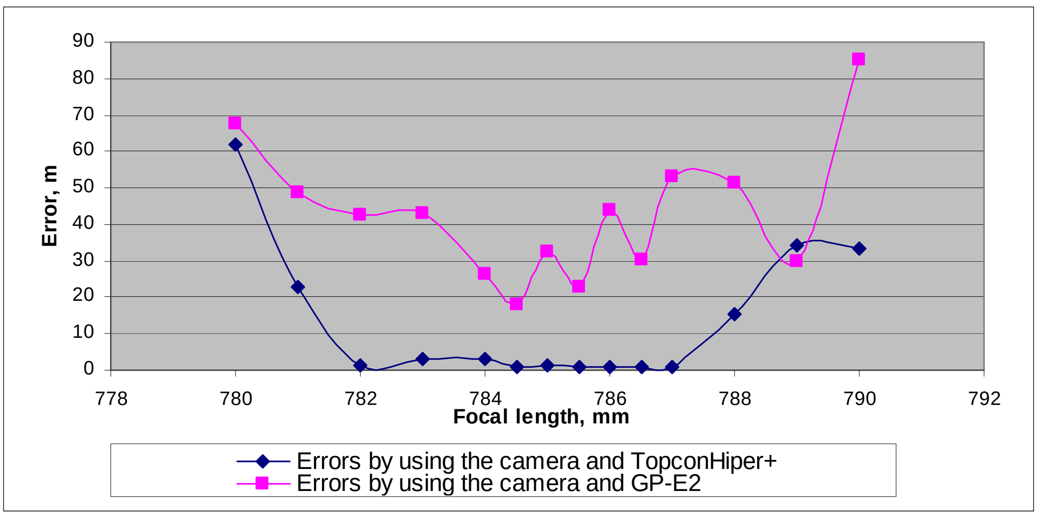


Fig. 7. Dependence of the accuracy of determining the position of points on the accuracy of the focal length.

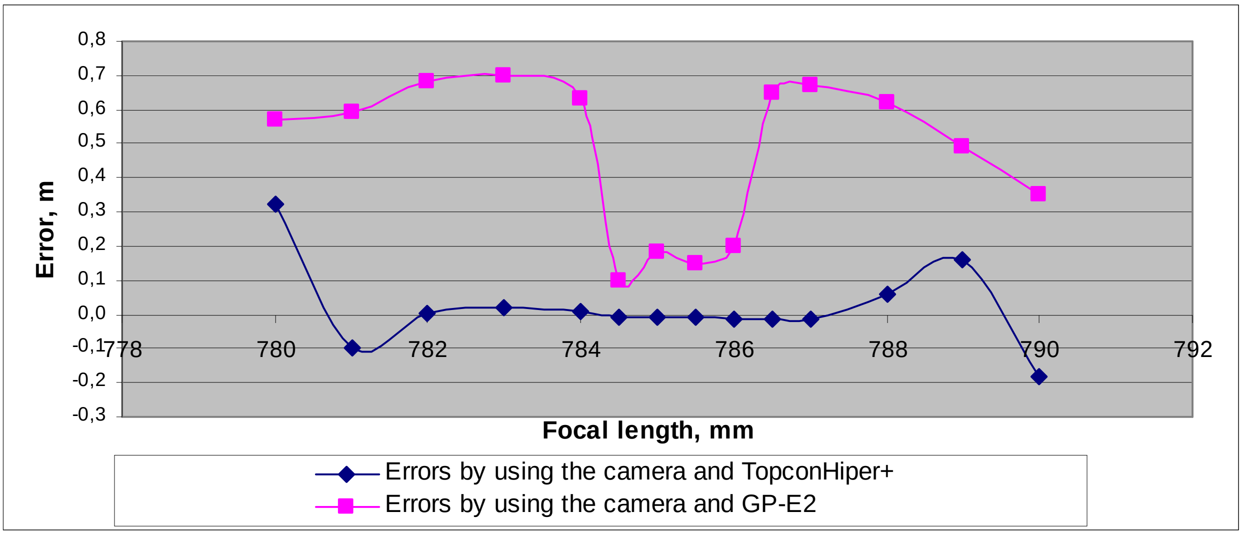


Fig. 8. Dependence of the accuracy of determining the relative position of points on the accuracy of the focal length.

At the same time, the accuracy of determining the coordinates of the studied points, without the use of identification marks, which are necessary for orienting images, increases 10 times or more. It is clear that the proposed technique will also improve the accuracy of work in which identification marks are used to orient the images. But such studies have not yet been carried out by the authors.

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Technological measures to enhance efficiency of mining ore from stopes applying self-propelled equipment

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Abstract. The work analyzes current technologies of ore mining applying self-propelled equipment in underground conditions; studies practices of using the equipment in general and for broken ore transportation only; considers performance of mining enterprises in similar mining-geological and mining-technical conditions; analyzes and generalizes causes of high ore loss and dilution rates in underground mining in Kryvyi Rih iron ore basin, thus revealing a problem of providing high efficiency and increased ore extraction with minimal quality deterioration. Marketable ore production is affected by decreased quality and high broken ore losses. Incomplete balance ore extraction when breaking and drawing ore from the stope results in deterioration of mining indices. Ore dilution with waste rocks leads to decreased ore content in the mined mass as compared with that in the ore massif. The research enables development and substantiation of the rational technology of ore drawing and transportation as well as designing a new structure of the loading face to ensure increase of the drawn ore quality indices.

1 Introduction

In Kryvyi Rih iron ore basin, iron ores have been mined for over 150 years [1,2,6,7]. At first, mining operations were performed in open pits and later – in underground mines. First underground mines were only several dozens of meters deep. Main equipment applied was a pickaxe for breaking and horses for ore transportation.
Nowadays, underground mines are more technologically developed, efficient and secure. Complete mechanization of stoping, namely principal and auxiliary processes, has become the main trend of their development [6,37-39].

At present, a high level of stoping mechanization is demonstrated by foreign mines which are more technologically developed than national ones due to the fact that complex implementation of self-propelled equipment as well as mechanization of technological processes started there in the middle of the 20th century. Implementation of self-propelled equipment and mechanization had a comprehensive character [6,7,40,41].

In Ukraine, introduction of self-propelled equipment was not large-scale. In the Soviet Union, this type of equipment was mainly introduced at uranium deposits and, to some extent, at the ZZRK underground mines [7,42-44].

In Kryvyi Rih, self-propelled equipment was used on a trial basis in 1980s-1990s. Its implementation at Kryvbas underground mines was a forced decision caused by the fact that obsolete machines were not able to provide high-technology mining. This necessitated implementation of advanced underground mines' practices [1,2,45,46].

2 Methods

The research aims to study and enhance basic stoping processes, develop technological measures to increase efficiency of mining ore from stopes applying self-propelled equipment.

To reach the set objective, the following methods are used:

- analysis and study of underground operations with applied self-propelled equipment;
- enhancement of drilling and blasting operations applying self-propelled equipment;
- development of efficient structures of the draw level when applying load-haul- machines;
- enhancement of stoping methods and technologies when applying self-propelled equipment at Kryvbas underground mines.

3 Results and Discussion

In mining ore deposits by underground methods, all the underground mining operations are divided into main and auxiliary ones [1-4].

Main underground operations include: ore breaking, broken ore drawing, transportation and loading, rock pressure control.

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At present, one of the most widely applied schemes consists in breaking ore by vertical blasthole rings on the vertical compensation space [4-8]. As a rule, it is used for ores with insufficient stability of horizontal, or even inclined, exposures of compensation rooms [1,47,49,50].

Here, blasthole rings are drilled from drill drifts. Ore is broken by layers with a millisecond delay between the adjacent layers necessary for forming additionnal exposure areas [2,12,48,51].

People, materials and equiment are transported along the block raise.

In ores of medium and over medium hardness and stability where significant exposures may occur, breaking can be performed on the horizontal compensation space, or the horizontal undercut.

At this breaking scheme, vertical blasthole rings are drilled from drill orts. To clearly contour the stope, drill orts are driven on the block boundaries. Ore is broken on the horizontal undercut. Primarily, blastholes of the lower layer are broken, then blastholes of the overlying level with a millisecond delay and so on bottom up [1,13,52,53].

In case of insufficiently stable iron ores with no horizontal exposures and with the vertical compensation space being impossible due to technical reasons (e.g. insufficient dip angle and ore body thickness), there are applied schemes of breaking with vertical blasthole rings on the inclined compensation space [6,7,9,10].

The suggested scheme of drilling the block is applied in similar conditions. Its application is mainly aimed at decreasing impact of detonation products on workings of the draw level. In addition, the inclined exposure of the compensation room is more stable than the horizontal one when forming the horizontal undercut. The inclined compensation space is formed for the full width of the stope (panel). Then from the drill ort (drift), vertical blasthole rings are drilled and broken on the inclined undercut [43,54-56].

Breaking is performed in sequence starting from the lower row of boreholes. To reduce the impact blow of the broken ore on workings of the receiving level, part of the broken but not drawn ore is left on the draw level to create a kind of cushion that reduces negative impacts of detonation products on workings of the receiving level. With the same purpose, adjacent ore layers are broken with a millisecond delay.

Historically, application of self-propelled load-haul machines started with their introduction at foreign mines in the middle of the XX century [11-14].

When choosing parameters of self-propelled equipment, it is necessary to consider technological tasks first. It is its reliability, not price, that matters.

For Kryvbas, these factors are a problem, too, that requires immediate study and solution. According to the research data [2,13,15,16], the value of a diesel machine is 1.5-fold less than that of an electric one with similar characteristics.

However, comparison of traditional mining technologies and those applying self-propelled equipment speaks in favor of the latter. The authors of [12,17-19] state that with self-propelled equipment the average monthly meterage per syndicate is 160-170 m, a drifter's efficiency being 9 m. Yet, at Kryvbas, monthly crosscut driving does not officially exceed 70 m according to official designs. This is a very low rate even for traditional drifting methods. Application of self-propelled equipment can help accelerate it.

So, selection of a technology of driving workings is of great importance. Choice of highly efficient machinery and technology is conditioned by both mining and geological conditions and required rates of drifting operations and their costs.

Main mining and geological factors include: ore rock hardness and stability, deposit dimensions along the strike, dip and thickness, deposit morphology, hydrogeological conditions, sometimes gas conditions, explosion risks, spontaneous ignition, radioactivity, etc.

At present, Kryvbas has started the second experiment of introducing self-propelled machinery in underground conditions. Let us consider the case of the underground mine "Oktiabrskaya", the PJSC "Kryvbaszalizrudkom", where the ore body "Osnovnyi" is mined applying self-propelled equipment in compliance with the "Project of development and stoping operations in the block between axes 45-50 on the level 1190/2265 m".

The ore body site within these axes is situated in the central part of the field of the underground mine "Oktiabrskaya" and limited to rocks of the V ferruginous and V schistose stratigraphic horizons.

The deposit is represented by the seam-like ore body which is uniform along the strike and weakly varying to the dip with inter-mineral impurities. Horizontal thickness of the ore body varies within 15-25 m. The ore body dip varies from 46˚ to 50˚. Its dimensions and shape refer the ore body to group "I", subgroup "b". Required prospecting intervals are 12-15 m along the strike, 25-30 m to the dip.

This part of the deposit is represented by: martite ore of the V ferruginous horizon, steel blue, fine-grained, thin-layered, badly fractured, with hardness of 5-7 and low stability; red dirt and martite ore of the V ferruginous horizon, grey-brown, represented by alternation of martite layers and dirt bands, of medium bedded structure, badly fractured, with hardness of 5-6 and low stability; red dirt of the V schistose horizon, dark-brown, coarsely-stratified, badly fractured, with hardness of 4-6 and low stability. Due to their instability, large hang-ups and rockfalls are possible. The ores do not tend to stick or drift, they are not rock-bump hazardous, cavities are not expected [15,57-59].

Many researchers note that mining enterprises use various type-dimensions of self-propelled machines. Main types of mining and transportation machines are used for mechanizing principal mining processes [13,20-22]. Efficient haulage length makes 250-300 m. The haulage workings dip is 10-15˚.

Most of sources mention dip angles of 10-15˚. In our opinion, such angles are borderline for now. The technological radius of roundings is 8-12 m.

As a rule, self-propelled load-haul machines are used in ore underground mines for preparatory operations and stoping.

At present, at underground mines of Kryvbas, broken ore is transported in stopes by scraper winches. They are

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also used when driving horizontal and inclined workings, especially on sublevels.

When it is not expedient to use scraper winches, self-propelled equipment is applied, e.g. on main haulage levels.

Scraper winches are obviously more advantageous in loading and hauling broken ore due to their relative structural simplicity and reliability in complicated mining and geological conditions.

Disadvantages of scraper winches include low efficiency and restricted haulage distance as well as quick rope wear and insufficient mechanization of operations.

For conditions of the underground mine “Oktiabrskaya”, scraper haulage is an obsolete technology that does not allow implementation of innovative ones and, therefore, decrease of mining costs.

Scraper haulage operations mechanization is beneath criticism.

That is why, mechanization of underground mining processes require self-propelled machinery for most difficult and labor-intensive operations. At advanced mines, this type of equipment is used for less labor-intensive auxiliary processes.

Highly efficient loading machines with large bucket capacity are used for mining large deposits.

Swedish mines, which are the most advanced in Europe, prove expediency and high efficiency of applying SCOOPTRAM to underground stoping operations.

The problem of enhancement of leading mines with the most promising mining systems applying self-propelled load-haul machinery is considered in [23-26].

Most advanced mining countries of the world tend to change over to stoping systems with backfilling of the mined space with a solidifying mixture. Room-and-pillar systems with backfilling are the most promising ones. The systems enable undisturbed daylight surfaces and enhanced environment due to possible disposal of mining wastes in dead areas of underground mines.

Modern load-haul machinery is often equipped with remote control systems. Remote control stations can be located at any distance from the place of mining operations. Automated operation of self-propelled load-haul equipment is applied at underground mines of South Africa.

Technologies of remote control application are described in many works [6,12,27,28, etc.]. Remote control of self-propelled machinery is implemented at advanced mining enterprises, including broken ore loading and transportation to discharge points.

Productivity of load-haul machines depends on their parameters and may reach 350-400 t/h with transportation for up to 50 m.

At world’s advanced underground mines, processes of ore loading and haulage are automated with modern equipment with dedicated hardware and software, thus increasing efficiency of self-propelled mining machines. Here, a mining engineer’s task consists in safe, efficient and profitable delivery of useful minerals to the daylight surface.

Describes use of underground haulers with 50t capacity in gold mining. The authors stress the necessity of implementing high-level mechanization of all ore mining operations [29-32]. Thus, according to the authors, the tunneling speed of up to 150 m/month is achieved due to application of three “Boomer” drilling rigs. The authors note that the latest models of the rigs are shortened from 4.2 m to 3 m. This enables the rigs to drill anchor holes in roofs with subsequent anchoring.

It should be noted that in conditions of highly intensive work, maintainability of mining equipment and ease of maintenance of self-propelled mining machines are of great importance.

Let us select and substantiate rational stoping parameters for sublevel-and-room mining at the u/m “Oktiabrskaya”, the PJSC “KZRK”. Considering mining and geological conditions of the ore body “Osnovnyi”, physical and mechanical properties of ore and country rock, the sublevel-and-room mining system is accepted for mining the ore body “Osnovnyi” of the u/m “Oktiabrskaya” minefield. Ore breaking is performed by vertical blasthole rings on the vertical slot. The sublevel-and-room mining system is designed for use of self-propelled mining machinery.

The input data for calculating block geometry are given in Table 1.

Table 1. Input data for calculating block parameters

No.	Input data	Parameters
1	Ore body class	II
2	Order of priority	I
3	Ore hardness, average	5.86
4	Hanging wall ore hardness	8-10
5	Ore body dip angle, degrees	42-50
6	Horizontal thickness, m, average	23
7	Normal thickness, m, average	18
8	Mining depth, m	1220
9	Sublevel height, m	40
10	Compensation room life	1.1

To determine geometry of the sublevel-and-room system, the following conventional signs are accepted:

$H_г$ and $H_в$ are the depth of horizontal exposures (crown) and vertical exposures (intervening pillars), m;

$f_р$ and $f_{пп}$ are ore hardness and rock hardness coefficients respectively;

$m_г^0$ is the boundary value of the equivalent span of the horizontal exposure in the stope, life of which in the set mining and geological conditions makes t months, m;

t is the exposure life;

$m_В^0$ is the boundary value of the equivalent span of the vertical exposure in the stope, life of which in the set mining and geological conditions makes t months, m;

η_1 and η_2 are the coefficients considering time impacts on stability of exposures and pillars;

η_3 is the coefficient describing relations between boundary values of equivalent spans of horizontal and vertical exposures;

$\ell_н^0$ is the boundary value of the equivalent span of the inclined exposure of the hanging wall rocks in the stope, life of which in the set mining and geological conditions makes t months, m;

$A_Н^0$, A_I^0, A_P^0 are the boundary values of dimensionless functional characteristics for determining horizontal (inclined) thickness of the crown and width of the intervening pillar, life of which in the set mining and geological conditions makes t months.

Let us determine boundary values of calculated functional characteristics: with the mining depth $H_г$ = 1180 m and hardness f_p = 6; $m_г^0 = 15.3$ m at $t = 6$ months.

At $t = 2$ months and $\eta_1 = 1.24$ (according to the chart by curve 1), Fig. 1:

By the formula:

$$m_г^0 = m_г^0 \cdot \eta_1 = 15.3 \cdot 1.24 = 19 \text{ m}$$

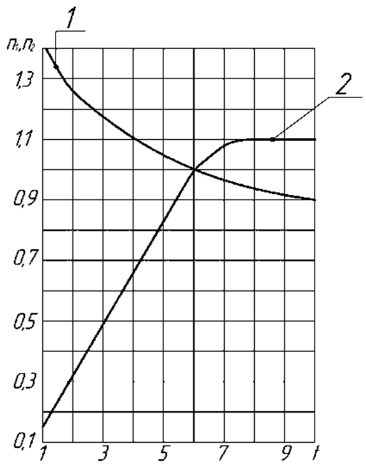

Fig. 1. Dependency of the coefficients η1 and η2 on life of exposures and pillars.

For $H_г$ = 1180 m and f_p = 6 (according to the chart, Fig. 2):

$$A_{ПР}^0 = 1.28 \text{ at } t = 6 \text{ months}$$

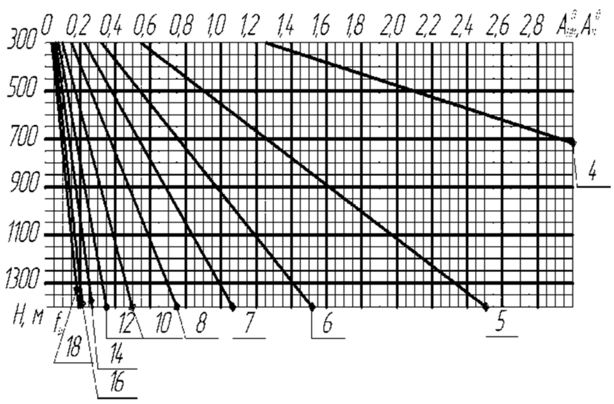

Fig. 2. Dependency of the boundary values of calculated functional characteristics $A_{Ц}^0$ and $A_{ПН}^0$ on the mining depth at t = 6 months.

At $t = 2$ months and $\eta_2 = 0.32$ (by curve 2)

By the formula:

$$A_{ПН}^0 = \eta_2 \cdot A_{ПН}^0 = 0.32 \cdot 1.28 = 0.41$$

To determine $m_В^0$ according to the formula:

$$m_В^0 = \eta_3 \cdot m_г^0$$

we find $m_г^0$ for $H_В$ = 1200 m and f_p = 6 at $t = 6$ months

$$m_г^0 = 15.1 \text{ m}$$

At $t = 6$ months, at $t = 2$ months and $\eta_1 = 1.24$

$$m_г^0 = \eta_1 \cdot m_г^0 = 1.24 \cdot 15.1 = 18.7 \text{ m}$$

$\eta_3 = 1.28$ then:

$$m_В^0 = 1.28 \cdot 18.7 = 24 \text{ m}$$

To determine $\ell_н^0$ by the expression:

$$\ell_н^0 = 1.35 \cdot m_г^0$$

we find $m_г^0$ for $H_В$ =1200 m and $f_{пп}$ = 9. From the chart $m_г^0$ = 20.5 m at $t = 6$ months. At $t = 2$ months and $\eta_1 = 1.24$

$$m_г^0 = \eta_1 \cdot m_г^0 = 1.24 \cdot 20.5 = 25.42 \text{ m}$$

$$\ell_н^0 = 1.35 \cdot 25.42 = 34.3 \text{ m}$$

By the formula:

$$A_п^0 = \frac{A_{пн}^0}{0.75} = \frac{0.41}{0.75} = 0.55$$

we determine geometric parameters of the mining system.

Dimensions of the stope along the strike are calculated applying the found value $m_г^0 = 19$ m and the known value of the horizontal thickness $M_г$ = 23 m from the left part of the chart a = 34 m; let us assume a = 30 m.

Dimensions of the stope to the dip are calculated applying the found value $m_В^0 = 24$ m and the known value of the normal thickness $M_н$ = 18 m; $в = \infty$.

The equivalent span of the hanging wall exposures in the stope is determined by the expression:

$$\ell_Н = \frac{a \cdot в}{\sqrt{a^2 + в^2}} = \frac{30 \cdot 23}{\sqrt{30^2 + 23^2}} = \frac{690}{37.8} = 18.25 \text{ m}$$

On comparing it with $\ell_н^0 = 34.3$ m, we obtain $18.25 < 34.3$; thus, the parameters *a* and *в* remain unchanged.

In this case, sublevel-and-room and level-and-room mining systems can be applied.

According to the functional characteristics of the designed block, the crown thickness is accepted equal to $h = 15$ m.

As at the level of 1220 m the block is mined first, the width of the pillar is not determined.

The obtained dimensions of the constructive elements of the system are given in Table 2.

Table 2. Dimensions of the constructive elements of the sublevel-and-room system.

Block elements	Accepted	Calculated
Stope dimensions along the strike	30	34
Stope dimensions to the dip	23	∞
Trench undercut width, m	30	-
Compensation space volume, m3	2632	-
Stope volume, m3	10526	-
Hanging wall rock exposure area, m2	690	782
Ore massif thickness above stope (crown), m	15	15

For drilling, it is expedient to use self-propelled longhole drilling machines SIMBA of Atlas Copco. The massif is broken by vertical blasthole rings on the horizontal compensation space (trench undercut), Fig. 3.

According to the suggested circuit and considering the ore body thickness, which is 20-25 m, it is reasonable to start drilling from the drill drift driven in the footwall rock.

After forming the trench undercut, part of the broken ore is left on the draw level. The broken ore will further serve as a compensation cushion to prevent workings of the draw level from failure.

Ore is broken by layers with a millisecond delay between the adjacent layers.

Drilling and blasting parameters are calculated in compliance with the instructions [33-36].

Drilling and blasting parameters for mining a block with average ore hardness $f = 6$ are given in Table 3.

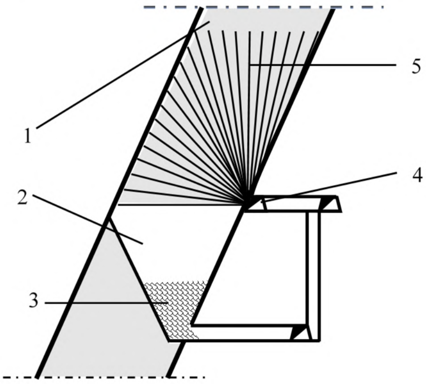

Fig. 3. The circuit of breaking the massif by vertical blasthole rings on the horizontal compensation space (trench undercut): 1 – the ore body, 2 – the trench undercut, 3 – the broken ore cushion, 4 – the drill drift, 5 – the blasthole ring.

The blasting and drilling parameters are calculated based on the practice of the underground mine "Oktiabrskaya". The LLR equals 3 m. The distance between hole ends is 3.5 m. In our opinion, such parameters will decrease oversize yield and losses of explosives for secondary fragmentation.

Table 3 Drilling and blasting parameters for mining the block under study.

Indicator	Units of measure-ment	By rock hardness	Conside-ring stress state
Rock blasting indicator	C_0	36.867	34.964
LLR value	m	3.5	3.38
Distance between blasthole ends	m	3.85	3.65
Boundary consumption of explosives for breaking	kg/t	0.318	0.302
Diameter of average ore fragment (fragmentation quality)	m	0.184	0.178
Oversize yield	%	13	12.6
Specific consumption of explosives for secondary fragmentation	g/t	75	74

The process water from drilling blastholes is gathered in the sludge trap of the drill drift. Then, it goes in metal and rubberized pipes of 2-3 inches in diameter to the sludge settler of the access ort where it is clarified. The clarified water runs to the drainage ditch of the haulage ort and then to the mineshaft into the water reservoir.

When drilling the ore massif above the trench undercut level from the drill drift, the process water from drilling blastholes is gathered in the sludge settler in access orts above the area of blasthole drilling for clarification. The clarified water is drained into the drainage ditch of the haulage drift and then to the mineshaft into the water reservoir.

Two versions of the rational draw level structure are suggested.

The first version of the draw level with application of modern load-haul machines for transporting broken ore is developed for the ore body thickness l of over 25-30 m, Fig. 4.

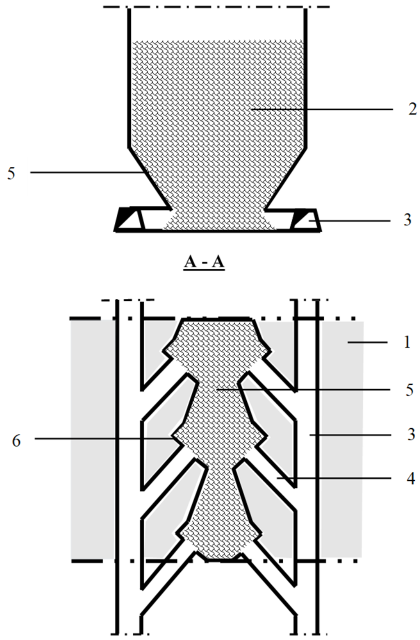

Fig. 4. The draw level structure for the ore body thickness of over 25-30 m with application of modern load-haul machinery for broken ore transportation: 1 – the ore body, 2 – the stope, 3 – the supply ort, 4 – the loading face, 5 – the trench undercut, 6 – the frontal loading face.

In this case, the stope 2 is located across the strike.

Block supply orts 3 from which loading faces 4 are driven at the angle to the stope are located on the boundaries of the block.

Block undercutting is trench. The trench 5 is created on the transportation level across the strike. The trench width should provide broken ore loading from the opposite loading faces.

The main disadvantage of loading broken ore from loading faces driven at the angle is that the bucket goes into the broken ore at the angle as well, thus deteriorating the bucket fill factor and resulting in one side wear of the bucket.

To eliminate this disadvantage, we suggest formation of the loading face 6 in the way that enables frontal fill of the bucket through its entering the muckpile perpendicularly.

The other option of the draw level with application of modern load-haul machines for transporting the broken ore is developed for the ore body thickness l of less than 25-30 m, Fig. 5. In this case, the stope 2 is located along the strike.

Block undercutting is trench. The trench 3 is created along the strike for the full width of the stope. The trench height depends on the thickness of the ore body and the angle of the trench slope dip which should provide broken ore rolling down the trench slopes by gravity.

In the footwall of the block, the block supply drift 4 is driven from which loading faces 5 are driven at the angle to the stope.

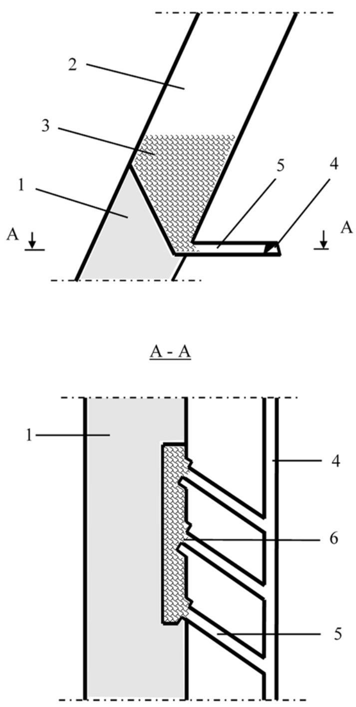

Fig. 5. The draw level structure for the ore body thickness of less than 25-30 m with application of modern load-haul machinery for broken ore transportation: 1 – the ore body, 2 – the stope, 3 – the trench undercut, 4 – the supply drift, 5 – the loading face, 6 – the frontal loading face.

The frontal loading face 6 is formed to enable frontal loading of the bucket through its entering the muckpile perpendicularly.

Considering the fact that the number of blocks at Kryvbas underground mines applying self-propelled equipment is limited, it is recommended to use self-propelled load-haul machines, previously used to drive workings, for broken ore transportation. With this purpose, we plan to use ST1030 SCOOPTRAM of Atlas Copco.

Ore can be discharged into both ore passes and electric railway haulage cars.

4 Conclusions

The work presents analysis of literature sources dealing with application of self-propelled machinery in stoping in general and for underground mining operations only and considers practices of mining enterprises' performance in similar conditions.

Geometry of block elements at stoping applying the sublevel-and-room system in compliance with the instructions "Determination and control of permissible dimensions of structural elements of mining systems at Kryvbas mines" is calculated to ensure stability of stopes throughout the block life.

The article suggests efficient versions of drilling the massif and determines their advantages and disadvantages.

The main disadvantage of loading the broken ore from loading faces driven at the angle is that the bucket of the machine enters the muckpile at the angle as well, thus deteriorating the bucket fill factor and resulting in one side wear of the bucket.

To eliminate this disadvantage, the authors suggest new versions of the draw level structure with formation of the loading face in the way that enables frontal fill of the bucket through its entering the muckpile perpendicularly and provide drawings of the versions.

The suggested enhanced technology of stoping considers the recommended parameters of underground operations on the basis of the research conducted.

The conducted research proves the viability of the developed technology and enable recommending its implementation.

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On the issue of determining the main factors of gas hazard in coal mines of Ukraine

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Abstract. The main sources of methane emission are located in the undermined coal-bearing strata, which is not taken into account by the requirements of regulatory documents when determining the category hazard of coal mines. Gas emission from each undermined source is not equally dependent on the tons of coal mined. The relative gas emission changes during the cleaning work and cannot be a criterion for assessing the gas hazard of the entire mine. The volatility of the gas emission index per unit area of the underworked space, which was formed because of monthly movements of the working faces, was established. In essence, this indicator repeats the dependence of the relative gas content per ton of coal mined, since the area of the underworked space is functionally related to the amount of coal mined for a certain period. Without coal mining, the rate of movement of the working face is equal to zero, and gas emission from a unit area continues for several months. As a result, the considered indicators do not have their specific meaning and, due to their inconstancy, they cannot reliably reflect the gas hazard of mines.

1 Introduction

The regulatory framework for safe mining of gas-bearing coal seams was laid down in the 1960s. This concerns the establishment of hazard categories of mines [1] and predictions of gas emission during mining operations [2]. The development of the requirements of these documents was based on the assumption of a direct proportional relationship between the level of gas emission and the amount of coal produced. To some extent, this approach was justified by the fact that the main source of gas emission during the treatment was the underworked reservoir. The share of gas emission from the broken coal and the exposed surface of the working face, during that period of development of the Donbass coal deposits, was 60 ÷ 80% of the total gas balance of the mining area. Over the past several decades, mining operations have been forced to move to deeper levels. This caused a significant change in the gas balance of the working areas during the cleaning work. In modern mines when mining at a depth of 500 ÷ 1500m the main gas release up to 90% and more comes from the coal-bearing strata undermined by the workings. The level of gas emission from these sources (adjacent seams and enclosing rocks), in addition to coal mining, is influenced by other factors. These, first of all, include the processes of displacement of underworked rocks during the cleaning work [3]. Over the past, not only the main sources of methane emission have changed in quality and quantity, but also the factors that determine its level and methods of safe mining of gas-bearing coal seams [4-8]. Such changes in the conditions of mining operations have practically not been adequately reflected in the regulatory framework [1, 2], the provisions of which have not been revised for many years. For example, the gas hazard is confined only to the level of coal production, and the degree of development of cleaning work within the excavation area and the wing of the coalfield is not considered. Unfortunately, accidents with serious consequences associated with the ignition of gas-air mixtures and their explosions in coal mines recur periodically. This indicates the relevance of the works aimed at establishing the factors that determine safe development of gas-bearing coal seams.

2 Purpose, idea and research methodology

The aim of this subsection is to establish the main factors that determine methane emission throughout the entire period of mining areas exploitation. This makes it possible to determine the influence of the degree of cleaning works development on the associated processes of undermined coal-bearing strata displacement and gas emission. To develop proposals in terms of improving the forecast of gas emission and establishing the category hazard of mines.

The idea is that the level of methane emission and the total amount of gas emission from undermined sources depends both on the size of the extraction pillar and on the speed of moving the active face. Monitoring throughout the entire period of the mining operation allows to assess the change in gas emission during the cleaning operations (removal of the face from the open pit) at all characteristic stages of coal mining - reaching targets, stable operation and reducing the load before stopping the face.

The indicators of gas emission for a certain movement of the active faces for a fixed period of time, including the official monthly average data for establishing the category of mines by their gas hazard, are considered.

The well-known experimental data [4,5], obtained respectively in the conditions of the A.F. Zasyadko mine, and the Newspaper "Izvestia" mine, as well as monthly average data for establishing the category hazard of the "Sukhodolskaya-Vostochnaya" mine and the D.F. Melnikov mine over the past four to five years. Basic information about the objects of observation is summarized in Table 1. In all cases, the roof was controlled by the complete collapse of the rocks. Experimental data made it possible to establish the amount of gas emitted per time interval.

3 Research results and discussion

In all cases, in the initial period of the mining areas exploitation, as the working faces were removed from the split furnaces, an increase in the amount of emitted gas was observed (Fig. 1). The increase in methane emission during this period is due to an increase in the underworked space and the development of displacement processes of underworked rocks to the settlement of the main roof with the subsequent development of these processes. After the formation of a constant height of the zone of rock displacement with a rupture of their continuity, stabilization of gas emission occurs at a certain level. In most cases, before stopping the working face, its speed decreases.

As a rule, the minimum rates of the active faces' movement correspond to the initial and final periods of exploitation of extraction areas, which is due to the specific features of technological processes when mining coal seams with long faces. They are characterized by the need for grinding in mechanisms and identifying possible defects in equipment installation. For these reasons, sometime is required to ensure the planned performance of the extraction areas.

A decrease in the speed of moving the active faces before stopping them is determined by the transition period associated with the need to commission the next extraction pillar. For the organization of cleaning work in the newly commissioned face, additional material and human resources are required, as well as a certain period of time for reaching the planned indicators.

Table 1. Information about geological and mining-engineering conditions of extraction areas mining.

Face, seam	Seam capacity, m, m	Face length, $L_л$, m	Length of underworked extraction pillar, L_{cm}, m	Depth of cleaning works, H, m	Moving speed of active faces, $\upsilon_{оч}$, m/month	The amount of gas released within the extraction pillar, million m
A.F. Zasyadko mine [9]						
16th eastern, m_3	2.10	270	1918	1195	18÷132	57.2
Newspaper "Izvestia" mine [10]						
1st western, $\ell_2^в$	0.90	111÷185	1422	300	9÷64	4.7
1st western, $\ell_2^в$	0.90	68÷100	775	300	6÷63	2.5
2th western, $\ell_2^в$	0.90	200	1186	300	27÷139	13.6
2th bis western, $\ell_2^в$	0.90	185	279	300	9÷41	4.7
3th western, $\ell_2^в$	0.90	215	1559	300	31÷144	16.7
4th western, $\ell_2^в$	0.90	210	1491	300	52÷153	15.5
5th western, $\ell_2^в$	0.90	216	1421	300	56÷149	22.0*
6th western, $\ell_2^в$	0.90	230	1169	300	25÷95	23.0*
7th western, $\ell_2^в$	0.90	230	1309	300	21÷118	16.4
8th western, $\ell_2^в$	0.90	215	787	300	0÷131	12.8
9th western, $\ell_2^в\ell_2^в$	0.90	250	329	300	0÷73	4.4
'Sukhodolskaya - Vostochnaya' mine						
24th eastern, i_3'	2.20	240	1112	1016	5÷70	50.5
25th western, i_3'	2.20	265	700	1198	15÷47	26.0
12th bis eastern, i_3'	2.20	240	879	965	12÷36	34.8
34th eastern, i_3'	1.20	180	813	948	22÷53	11.6
37th western, i_3'	1.20	180	1316	911	18÷88	10.1
D.F. Melnikov mine						
1-я northern, ℓ_6	1.30	220	1210	853	0÷58	11.4

* - in total with the amount of gas emitted from outside the extraction areas during the activation of rock movement

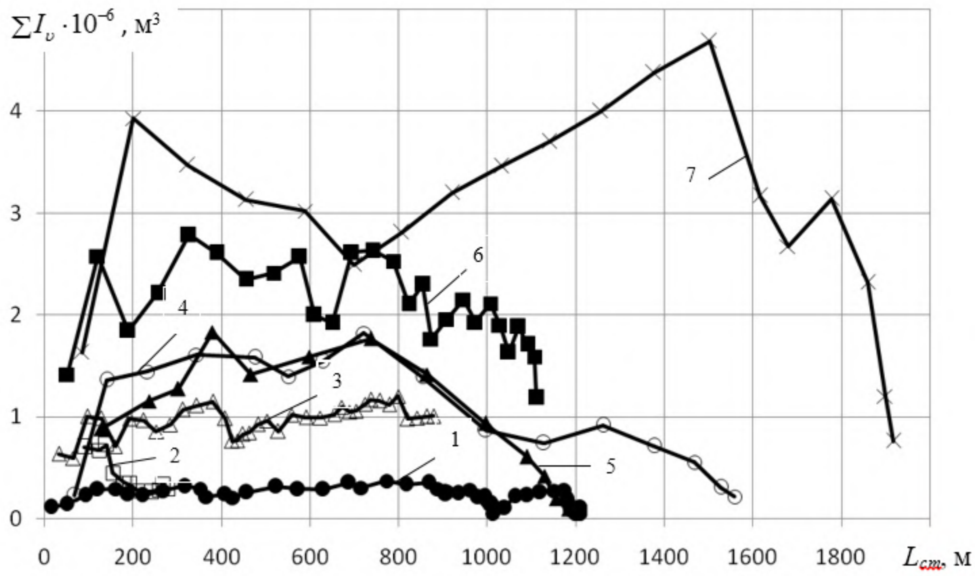

Fig. 1. Change in average monthly volumes of gas emission ($\sum I_{\upsilon}$) depending on the removal of active faces (L) from cut workings. 1, 2, 3, 4, 5, 6, 7 - graphs of changes in gas emission, respectively, for the D.F. Melnikov mine (1st northern face layer ℓ_6), the Newspaper "Izvestia" mine (2nd bis, 2nd and 3rd western faces of the seam $\ell_2^{в}$), "Sukhodolskaya-Vostochnaya" (12th bis and 24th eastern facfes of the seam i_3'), the A.F. Zasyadko mine (16th eastern seam m_3m_3); ●, □, ■, ○, ▲, Δ, × - experimental data.

Experimental data (Table 1, Fig. 1) shows that the volumes of the emitted gas depend on the dimensions of the extraction pillars. They are characterized by their length (L_{cm}) and the length of the exploited longwalls ($L_{л}$), as well as by the speed of active faces. This can be seen in the example of the Newspaper "Izvestia" mine faces. In the section of the 2nd bis of the western face (curve 2) with a pillar length of 279 m. and the speed of moving the active face 9÷41 m/month. much less gas was emitted in comparison with the 2nd (curve 3) and 3rd (curve 4) western faces, for which the value of L_{cm} was 1186 and 1559 m, respectively, and $\upsilon_{оч}$ -27÷139 and 31÷144 m/month.

The influence of the active faces movement rate on the values $\sum I_{\upsilon_{\text{очі}}}$ is also confirmed by experimental data for the 12th bis (curve 5) and 24th (curve 6) eastern faces of the "Sukhodolskaya-Vostochnaya" mine. With the same length of faces (240m) in the section of the 24th eastern face and $\upsilon_{оч}$ = 5÷70 m/month, 50.5 million m^3 of gas was emitted (Table 1), and in the section of the 12th bis eastern face at $\upsilon_{оч}$ = 12-36 m^3/month only 34.8 million m^3 of methane was emitted.

The above facts indicate that gas emission is associated both with the size of the area of the underworked face space (S_{cm}= $L_{л}$×L_{cm}), and with the speed of the active faces movement ($\upsilon_{оч}$). In addition to the specified technological parameters (S_{cm}, $\upsilon_{оч}$), other factors also affect gas emission from the undermined strata. First of all, they should include the reserves (resources) of methane, which is in the coal-rock strata before the cleaning works. Preliminarily, the estimated gas reserves can be judged by the gas content of the coal in the developed seams. Natural gas content of seam m_3 (the A.F. Zasyadko mine) is 35 m^3/t.m.a.m., seam i_3' (the "Sukhodolskaya-Vostochnaya" mine) - 33 m^3/t.m.a.m. When underworking the $\ell_2^{в}$ seam, the Newspaper "Izvestia" mine, its natural gas content decreased from 35 to 3÷8 m^3/ t.m.a.m. as the pillars were underworked along the uprising and the active faces approached the zone of gas weathering and geological disturbance (Karlovsky discharge). The natural gas content of the ℓ_6 seam (the D.F. Melnikov mine) did not exceed 8 m^3/ t.m.a.m. This ratio of natural gas content of the underworked seams obviously influenced the amount of gas emitted from the undermined coal-rock strata (Table 1, Fig. 1). The question of the possible volumes and forms of gas occurrence in the coal-bearing strata requires a separate detailed study.

The influence of the active faces movement rate ($\upsilon_{оч}$) on the amount of gas emitted from the undermined strata (I_{υ}) manifested itself in the form of differing dependencies for different objects (Fig. 2, a). During the development of the m_3 seam, a directly proportional dependence was observed (straight line 2), and during the extraction of the i_3 and ℓ_6 seams, an exponential dependence (curves 1 and 3, respectively).

When underworking the $\ell_2^{в}$ seam, the trend of dependence $I_{\upsilon} = f(\upsilon_{оч})$ also approaches exponential (Fig. 2, b). Large deviations of the experimental data from the averaging curve are caused by significant differences in gas resources in the undermined massif during the development of individual pillars due to the influence of geological disturbances, different degrees of cleaning works in the wing of the mine field, and the presence of gas emission outside some extraction areas under the influence of the activation of rock displacement.

In the presence of additional sources outside the extraction areas, ventilation schemes were used, which contributed to an additional flow of gas into the area workings. The given results of mine observations indicate that in order to ensure the safe development of gas-bearing coal seams, along with technological factors (L_{cm}, $L_{л}$, S_{υ}', $\upsilon_{оч}$) and natural gas resources in the undermined strata, it is necessary when designing ventilation schemes for extraction areas to provide for the exclusion of gas from external sources under the influence of general mine depression.

a)
b)

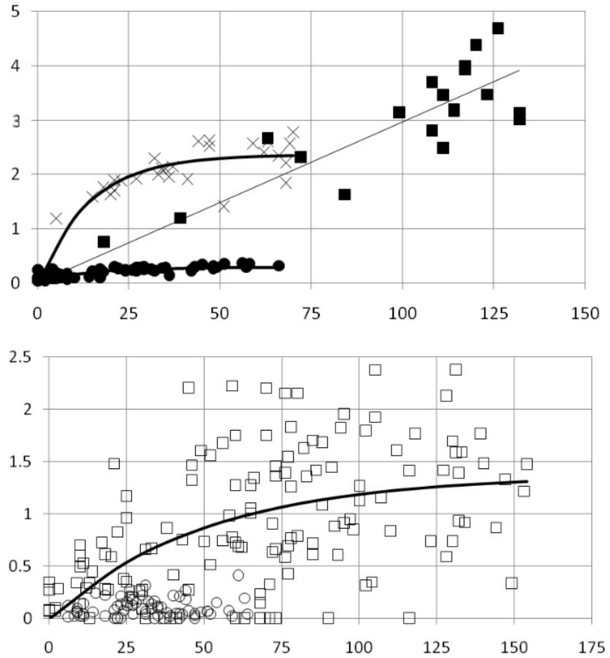

Fig. 2. Dependence of the released amount of gas (I_υ) from the undermined coal-rock strata on the active faces movement rate ($\upsilon_{оч}$) under conditions of different mines. 1, 2, 3, 4 - averaging lines, respectively, for the experimental data of the “Sukhodolskaya-Vostochnaya” mine (24th eastern face, seam i_3'), the A.F. Zasyadko mine (16th eastern face, seam $т_3$ [9]), the D.F. Melnikov mine (1st northern face, layer ℓ_6), the Newspaper “Izvestia” mine (2nd bis and 2-9th western faces, seam $\ell_2^в$ [10]); ×, ■, ●, □ - experimental data for averaging lines; ○ - experimental data for the 1st and 1st bis of the western faces of the Newspaper “Izvestia” mine located directly in the zone of geological disturbance; *R*, *r* - correlation ratio and correlation coefficient, respectively.

Of scientific and practical interest is the dependence of gas emission per unit area of undermined space ($\frac{I_\upsilon}{S_\upsilon'}$) on the active faces movement rate ($\upsilon_{оч}$). The $\frac{I_\upsilon}{S_\upsilon'}$ indicator is insufficiently studied to date. The graphs of such dependencies (Fig. 3) show the variability of this parameter for each object of observation. In essence, the $\frac{I_\upsilon}{S_\upsilon'}$=*f*($\upsilon_{оч}$) dependence repeats the dependence of the relative gas abundance per ton of coal mined, since the area (S_υ') for each mining area is functionally related to the amount of coal mined for a certain period of time. In the absence of coal mining ($\upsilon_{оч}$=0), gas emission per unit area of the worked-out area does not have its specific meaning, since the value of this parameter tends to infinity. This is due to the presence of gas emission from underworked sources for a long time (several months) when the active face is stopped ($\upsilon_{оч}$=0). The above circumstances do not allow the $\frac{I_\upsilon}{S_\upsilon'}$ indicator to be used as a criterion for gas hazard in the course of cleaning work.

For practical purposes, the most suitable parameter for assessing the gas hazard may be the gas e4mission indicator $\sum I_{cm}^i$, which characterizes the total amount of gas emitted from the undermined sources from the start of operation of the extraction area to the current moment.

The main advantage of the $\sum I_{ст}^i$ indicator is its functional dependence for specific extraction areas. The $\sum I_{ст}^i$ parameter unambiguously increases as the working faces (*L*) move away from the split working (Fig. 4, a). In a similar way, the $\sum I_{cm}^i$ indicator depends on the area of the underworked space (Fig. 4, b).

The given graphs indicate that under unchanged geological and mining-engineering conditions, the total amount of emitted gas changes in direct proportion as the length of the underworked pillar increases (Fig. 4, a) or the area of the underworked space (Fig. 4, b). This dependence was unambiguously characteristic of the extraction areas of the D.F. Melnikov mine (line 1) and the A.F. Zasyadko mine (line 3), where mining and geological conditions did not change as the mining pillars were worked out. In the conditions of the mine. The Newspaper “Izvestia” mine found a deviation of experimental data (curve 2) from a directly proportional relationship (line 2 '), which is caused by a decrease in gas reserves in the underworked strata as the active faces move away from cut workings and approach the zone of gas weathering or geological disturbance. Despite the changes in the mining and geological conditions of the working areas during the development of the $\ell_2^в$ seam, a close correlation was established (r = 0.97) of the amount of emitted gas on the area of the underworked space of individual working areas (Fig. 5).

As the active faces of the 12th bis and 24th eastern faces moved away from the split furnaces (“Sukhodolskaya-Vostochnaya” mine), the experimental data $\sum I_\upsilon^i$ (curve 4) deviated from the directly proportional relationship upward (Fig. 4, line 4). This indicates a change in mining and geological conditions and an increase in the amount of gas per unit of undermined area. Knowing the $\sum I_\upsilon^i$ change, when removing stope from cut workings (*L*) or an increasing area of undermined space (${S'}_\upsilon^i$), it is not difficult to reliably predict gas emission for any stage of development of the next extraction pillars. The obtained results of experimental data processing indicate that for specific geological and mining-engineering conditions, a reliable indicator of gas hazard can be the ratio of the total amount of emitted gas, referred to the area of the extraction pillar being underworked at the current time or the end of the cleaning work in the extraction pillar. The change in the $\frac{\sum I_\upsilon^i}{\sum {S'}_\upsilon^i}$ indicator in the initial period of the excavation areas operations is associated with the removal of the active faces from the cut workings (*L*) and the development of the processes of displacement of the undermined rocks with subsequent precipitation of the main roof. With sufficient removal of the active face (*L*), stabilization occurs, if the geological and mining-engineering conditions of the excavation areas exploitation do not change (Fig. 6). This type of change $\frac{\sum I_\upsilon^i}{\sum {S'}_\upsilon^i}$ was observed for the faces of the D.F. Melnikov (curve 1) and the A.F. Zasyadko mines (curve 6).

In the conditions of the Newspaper “Izvestia” mine,

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this kind of dependence was established for the extraction pillars of the 3rd (curve 3) and 2nd (curve 4) western faces (Fig. 6). The length of these extraction pillars was, respectively, 1559 and 1186 m, which made it possible to stabilize the processes of rock displacement when the active faces were removed from the cut workings at a distance of more than 250÷350 m, and together with them to reach approximately constant values for the indicator $\frac{\sum I_\upsilon^i}{\sum S'^{i}_\upsilon}$.

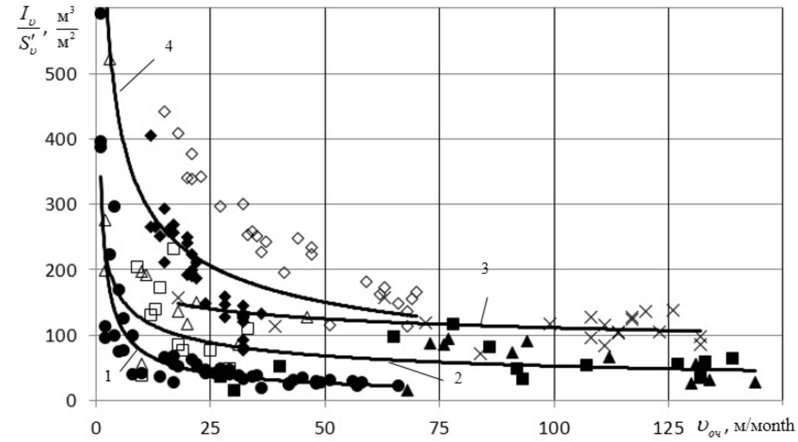

Fig. 3. The dependence of the specific gas emission in relation to the unit of area of the worked-out space ($\frac{I_\upsilon}{S'_\upsilon}$), corresponding to the monthly rate active faces movement ($\upsilon_{оч}$). 1, 2, 3, 4 - averaging curves, respectively, for the D.F. Melnikov mine (1st northern face, seam ℓ_6), the Newspaper "Izvestia" mine (2nd bis, 2nd, 3rd, 9th western faces, same $\ell_2^{в}$), the A.F. Zasyadko mine (16th eastern face, seam $т_3$), "Sukhodolskaya-Vostochnaya" (12th bis, 24th eastern face, seam i_3').

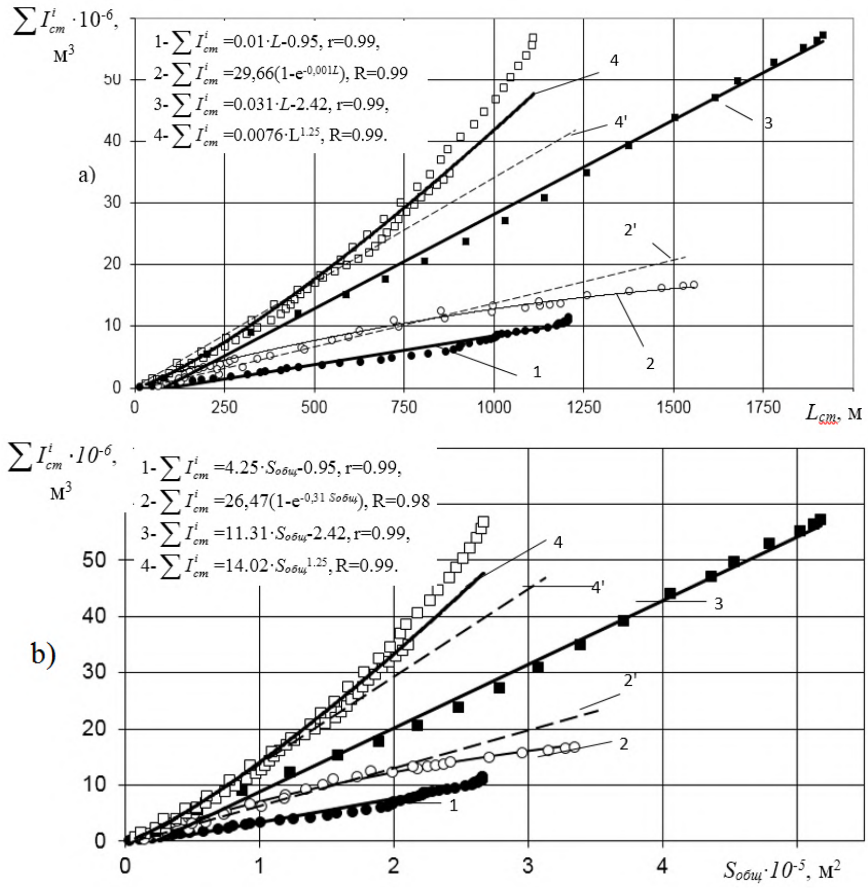

Fig. 4. Dependence of the total amount of gas emitted from the undermined coal-rock strata ($\sum I_\upsilon^i$) as the active face (a) moves (L) and the area (S_{cm}) of the worked-out space (b) increases. 1, 2, 3, 4 - averaging lines, respectively, for the D.F. Melnikov mine (1st northern face, seam ℓ_6), the Newspaper "Izvestia" mine (2nd bis, 2nd, 3rd western faces, seam $\ell_2^{в}$), the A.F. Zasyadko mine (16th eastern seam $т_3$), and the "Sukhodolskaya-Vostochnaya" mine (12th bis, 24th eastern faces, seam i_3'); 2', 4' - predicted direct $\sum I_{cm}$ dependencies for unchanged mining and geological conditions in comparison with the beginning of the exploitation of extraction areas, respectively, for the faces of the Newspaper "Izvestia" and "Sukhodolskaya-Vostochnaya" mines; ●, ○, ■, □ - experimental data; r, R - correlation coefficient and correlation ratio, respectively.

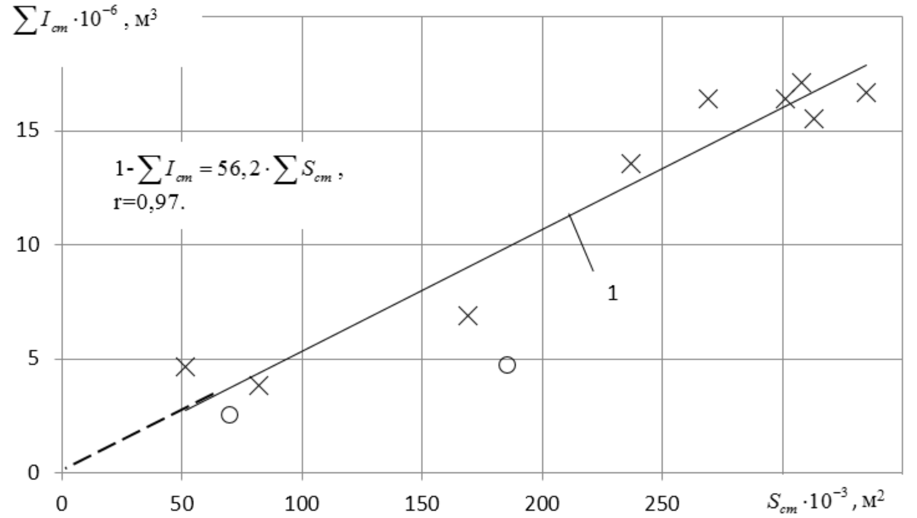

Fig. 5. Dependence of the amount of released gas ($\sum I_{cm}$) within the excavation areas of the Newspaper "Izvestia" mine from the area of underworked spaces of stopped faces (S_{cm}). 1- averaging line for faces located outside the immediate zone of geological disturbances; r - correlation coefficient; × - experimental data for faces (2nd, 2nd bis, 3rd, 4th, 5th, 6th, 7th, 8th, 9th) outside the zone of direct influence of geological violations; ○ - experimental data for faces (1st and 1st bis) in the immediate zone of influence of geological disturbances.

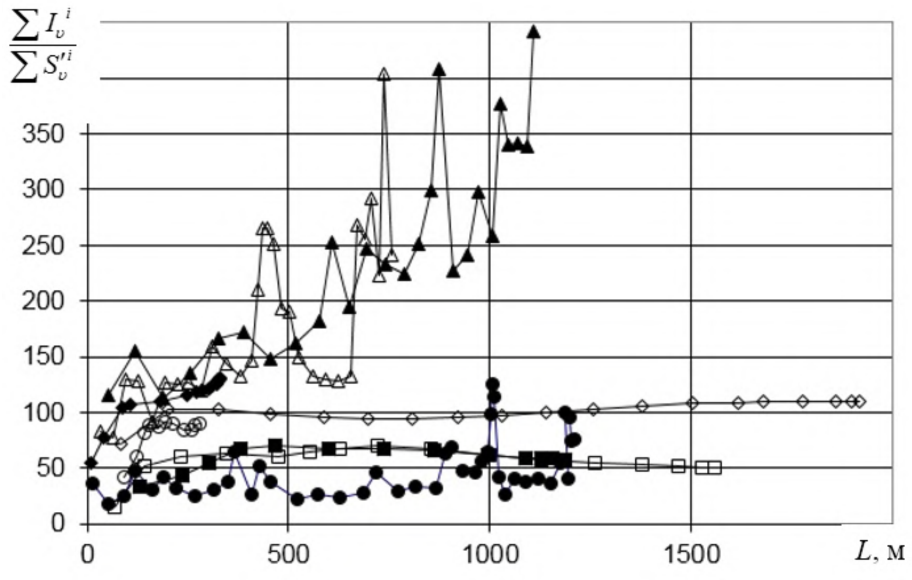

Fig. 6. Change in the specific gas emission relative to a unit area of the underworked space of the extraction pillars ($\frac{\sum I_{\upsilon}^{i}}{\sum S'^{i}_{\upsilon}}$) when removing ($L$) the active faces from the cut workings. 1,2,3,4,5,6,7,8 - curves of the $\frac{\sum I_{\upsilon}^{i}}{\sum S'^{i}_{\upsilon}}$ indicator change, respectively, in the conditions of the D.F. Melnikov mine (1st northern face, seam ℓ_6), the Newspaper "Izvestia" mine (2nd bis, 2nd, 3rd, 9th western faces, seam $\ell_2^{в}$), the A.F. Zasyadko mine (16th eastern face, seam $т_3$), the "Sukhodolskaya-Vostochnaya" mine (24th, 12th bis eastern faces, seam i_3'); ●, ○, ■, □, ♦, ◊, ▲, Δ - experimental data.

During the operation of the 2nd bis (curve 2) and 9th (curve 5) western faces, there was no opportunity for the development of rock displacement processes to such an extent, since the length of their extraction pillars was, respectively, only 279 and 329m. For this reason, during mining of faces with short pillars only showed an increase in $\frac{\sum I_{\upsilon}^{i}}{\sum S'^{i}_{\upsilon}}$ values to a certain level without their further stabilization. It should be noted that the average advance velocity of the 2nd bis and 9th western faces for the entire period of their mining was insignificant and amounted to 0.7 and 0.9 m/day, respectively. In the mining areas of these faces, during the period of operation, 4.7 and 4.4 million m^3 of methane were emitted into mine workings and degassing wells, respectively. At approximately the same rate of movement ($\upsilon_{оч}$) and the amount of emitted gas ($\sum I_{\upsilon}^{i}$), the change in the $\frac{\sum I_{\upsilon}^{i}}{\sum S'^{i}_{\upsilon}}$ parameter curves (Fig. 6, curves 5 and 2) as the working faces moved away from the cut workings significantly differed from each other.

After stopping the faces, the $\frac{\sum I_v^i}{\sum S'^i_v}$ indicator for these faces was respectively 90.4 and 53.9 m^3/m^2. This difference is explained by the distinctive features of face exploitation. The length of the 2nd bis of the western face was 185 m, and the 9th western face was 250 m. With little differing average rates of moving faces (0.7 and 0.9 m/day) and the length of the pillars (279 and 329 m), the area the underworked spaces of the considered faces differed by more than 1.5 times (51.6 and 82.3 thousand m^2). The natural gas content of the underworked seam during the operation of the 2nd bis of the western face was 24.0 м^3/t.m.a.m., and during the development of the 9th western face - 35.0 м^3/t.m.a.m. This indicates that the gas resources in the undermined coal-bearing strata of the 9th western face should have been approximately one and a half times higher than the $\frac{I_{ст}}{S'_{ст}}$ indicator for the 2nd bis of the western face. If, in addition to the natural gas content of the developed reservoir, we also consider the area of the underworked pillars, then the total gas emission $I_{ст}$ in the 9th western section should have been 2.3 times higher than this indicator for the 2nd bis of the western face. The experimental data did not confirm such a relation between $I_{ст}$ and $\frac{I_{ст}}{S'_{ст}}$. The $I_{ст}$ indicator for both faces was approximately the same, and $\frac{I_{ст}}{S'_{ст}}$ for the 2nd bis of the western face it was almost 1.7 times higher than its value for the 9th western face. The obtained experimental data can only be explained by the sequence of mining of these faces. The extraction pillar of the 2nd bis of the western face during its mining was isolated from all sides by a coal mass, and the extraction pillar of the 9th western face was adjacent to the underworked area of the previously mined ten faces. In the first case, gas was emitted only within the mining area, and in the second, due to the direction of the depression, it was carried out from the local workings to the general mine. In the conditions of the "Sukhodolskaya-Vostochnaya" mine when the active faces of the 24th (curve 7) and 12th bis (curve 8) eastern faces of the seam i'_3 (Fig. 5) were removed from the cut workings, the change in the values of the $\frac{\sum I_v^i}{\sum S'^i_v}$ indicator was approximately the same. This indicates that for these faces, geological and mining-engineering conditions change in approximately the same way during the development of cleaning works.

If the area of the underworked space (S'^i_y), which was formed during the monthly movement of the active face ($v^i_{оч}$), is less than the area of the underworked space $\sum S_v^i$, which determines the gas emission $\sum I_v^i$, then the $\frac{I_v^i}{S}{'}^{i}_{v}$ value will always be greater then $\frac{I_v^i}{\sum S'^i_v}$. The equality of these indicators is possible only for cases when the monthly rate of active faces movement ensures the extraction of the formation in an area corresponding to the size of the gas emission zone. The dimensions of the gas emission zone above the active face are determined by the zones of active movement of the undermined rocks. The projection of the size of such a zone behind the active face according to [3] is 0.466 of the depth (*H*) of the cleaning work. For example, for the conditions of the Newspaper "Izvestia" mine, the gas emission zone behind the active face is about 140 m, and for the conditions of the A.F. Zasyadko mine - about 550 m. The maximum speed of active faces movement of about 140 m/month was provided in some months only for several faces (2nd, 3rd, 4th, 5th western) of the Newspaper "Izvestia" mine. For these cases, the values of $\frac{I_v^i}{S}{'}^{i}_{v}$ and $\frac{I_v^i}{\sum S'^i_v}$ in all cases were close to each other, which confirms the reliability of determining the size of active movement zones of underworked rocks and the corresponding dimensions of the underworked space, which determine gas emission from the coal-rock strata.

On the site of the 16th eastern face of the m_3 seam of the A.F. Zasyadko mine the reached speeds (132 m/month) of the active face (Table 1) were significantly less than the projection of the active movement zone of rocks behind the active face. This, obviously, predetermined higher $\frac{I_v^i}{S}{'}^{i}_{v}$ values in all cases compared to $\frac{I_v^i}{\sum S'^i_v}$ after removal of the active face from the cut working at a distance of more than 550 m. Confirmation of the coincidence of the sizes of gas evolution zones with zones of active rock movement requires additional research.

4 Conclusions

Based on the generalization of the results of the studies carried out to establish the main factors of gas hazard in coal mines of Ukraine, the following conclusions have been drawn:

- the regulatory framework for safe mining of gas-bearing coal seams is based on research carried out 50÷60 years ago. Over the past, due to the transition to deeper layers, the gas balance and the sources of methane emission during the cleaning work have changed significantly. In modern mines, the main share of gas emission comes from the undermined coal-rock strata, and the requirements of regulatory framework for the establishment of gas hazard are focused on directly proportional dependence on the level of coal production from the underworked seam. The change in the gas balance and the share of the main sources of methane emission of its constituents led to a change in the factors that determine the danger of mining operations based on the gas factor. The provisions of the regulatory framework regarding the determination of the gas hazard and the forecast of gas emission have not been revised for several decades;
- the total amount of gas emitted from the undermined coal-rock strata, all other things being equal, directly depends on the area of the undermined space of the mined extraction pillars;
- the current level of gas emission depends both on the resources of methane in the undermined sources, and on the rate of the active face movement. The total amount of emitted methane remains constant for the specific dimensions of the mining field;

- the indicator of the amount of gas emitted per unit area of the undermined space, formed in the process of a monthly movement of the active face, is not a constant parameter for specific mining and geological and mining conditions. This is due to the non-coincidence, in most cases, of the active faces movement speed for a certain period of time (a month) with the sizes of the gas emission zones from the undermining array after the passage of the active face. The change in this indicator is similar to the dependence of gas emission per ton of coal mined. For this reason, it cannot be a criterion for assessing the gas hazard in mines;
- with sufficient development of cleaning works in the mine field, additional sources of gas emission appear outside the exploited working area under the influence of the activation of the undermined rocks movement. This phenomenon must be taken into account when designing ventilation schemes for mining areas and the direction of action of a general mine depression.

The scientific results obtained make it possible to develop a new methodology for assessing the gas hazard in coal mines and predicting gas emission from the undermined coal-rock strata based on the existing production experience and technical documentation for establishing the hazard category of coal enterprises in previous years in accordance with the regulatory framework in force at that time.

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Models and data quality in information systems applicable in the mining industry

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Abstract. The purpose of this article is to present modern approaches to data storage and processing, as well as technologies to achieve the quality of data needed for specific purposes in the mining industry. The data format looks at NoSQL and NewSQL technologies, with the focus shifting from the use of common solutions (traditional RDBMS) to specific ones aimed at integrating data into industrial information systems. The information systems used in the mining industry are characterized by their specificity and diversity, which is a prerequisite for the integration of NoSQL data models in it due to their flexibility. In modern industrial information systems, data is considered high-quality if it actually reflects the described object and serves to make effective management decisions. The article also discusses the criteria for data quality from the point of view of information technology and that of its users. Technologies are also presented, providing an optimal set of necessary functions that ensure the desired quality of data in the information systems applicable in the industry. The format and quality of data in client-server based information systems is of particular importance, especially in the dynamics of data input and processing in information systems used in the mining industry.

Introduction

Modern databases, which are the basis of information systems, operate with different data models. The aim is to represent them to describe the described real objects as accurately as possible, and the challenge is at the same time for the data form to allow their online processing in real time (Fig. 1).

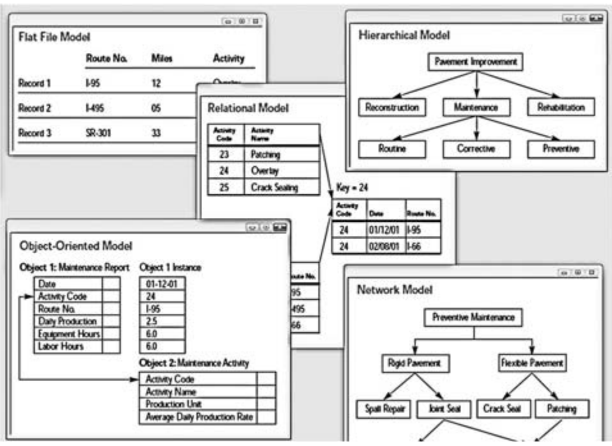

Fig. 1. Database models.

In general, the evolution of database management systems (DBMS) can be described in three stages:

- Navigation systems - those were used in the 1960s and represented hierarchical and network models of data description;
- Relational - those were created in the 1970s and are used to this day. They are based on set theory and on relational algebra. The objects are described in the form of two-dimensional tables allowing for connections (relations) between them. They use the SQL programming language;
- Post-relational - this category comprises a wide variety of data description methods. The object-oriented model was introduced in the 1980s, and the NoSQL and the NewSQL models have become popular in the recent decade.

Over the past 10 years, NoSQL and NewSQL models have become popular, which are targeting for a specific problem, such as short-term OLTP (Online Transaction Processing) operations.

At the same time, the information in them should be as high-up to date, accurate and sufficiently comprehensive as possible to enable maximum effective solutions.

In the mining industry, the processes are in continuous dynamics, mutually connected, and each of them can affect the operation of the whole system, depend also on the natural resources and require large investments in resources and funds. Moreover, the majority of the tasks in the modern mining industry are characterized by a pronounced uncertainty, non-linearity and multifactorial. [1] In this case, an unfortunate decision taken based on poor quality information can lead to huge losses for the particular enterprise.

In order to avoid such situations, it is especially important to obtain quality data, i.e. data meeting the

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requirements of the specific information system. The format and quality of the data is directly dependent on the purposes for which they will be used [2], and from the point of view of information systems the format and quality of the data is part of the whole process of data management.

Modern data models

Standard relational databases were not designed to handle the scale (Big Data), flexibility and real-time operation that are required by modern information systems. In addition, they do not take full advantage of the low cost of storage devices, nor of the high performance of the machines we have at our disposal nowadays.

NoSQL encompasses a wide variety of database technologies that have been developed in response to the increasing amount of data stored for users, objects and products, the frequency with which this data is accessed, as well as the need of high performance in their processing.

The first NoSQL software appeared in the early 21st century: MongoDB (2009), Redis (2009), Cassandra (2008), etc. Today there is a wide variety of data models used in NoSQL systems. The most popular are shown in Fig. 2:

- Key-value: here, information is stored in records of the “key-value” type and complex data structures, including XML, can be stored as “value”. The search is performed via a key. Dynamo, Riak, Azure, Redis, Cache are such NoSQL databases;
- Document: the work data and related information are stored in documents, most often in the XML or JSON formats. This model resembles the key-value model, with the “value” being the document itself. Such models are MongoDB, CouchDB, Raven, BaseX, etc.;
- Wide column stores: again, a "key" is used, but this may point to a family of columns. Each record can have a different number of columns and can be placed in other columns called super columns. BigTable, Hbase, Cassandra, Accumulo are popular examples of column family database software;
- Graph: this works with graph structures. Data is modeled as a network of links between particular elements. Neo4J, Allegro, Virtuoso, Bigdata are such models;
- Multidimensional: Globals, SciDB, Minim DB.

Among the main advantages of NoSQL databases are:

- flexibility - they do not work with static schemes;
- scalability - they also allow for horizontal scaling;
- facilitated database transfer across multiple servers.

The biggest drawback to NoSQL systems is that they are not transitive.

Typically, NoSQL databases are used in distributed systems information systems, where the emphasis is on productivity in processing large volumes of data, which makes them applicable to information systems in the mining industry.

In such systems, the CAP theorem (Brewer's theorem) is observed [3]: “In a distributed system, at most two of the categories can be satisfied:

- Consistency (C): all database clients see the same information, even with competitive updates;
- Availability (A): all database clients can access any version of the information;
- Partition tolerance (P): The database can be partitioned over multiple servers.

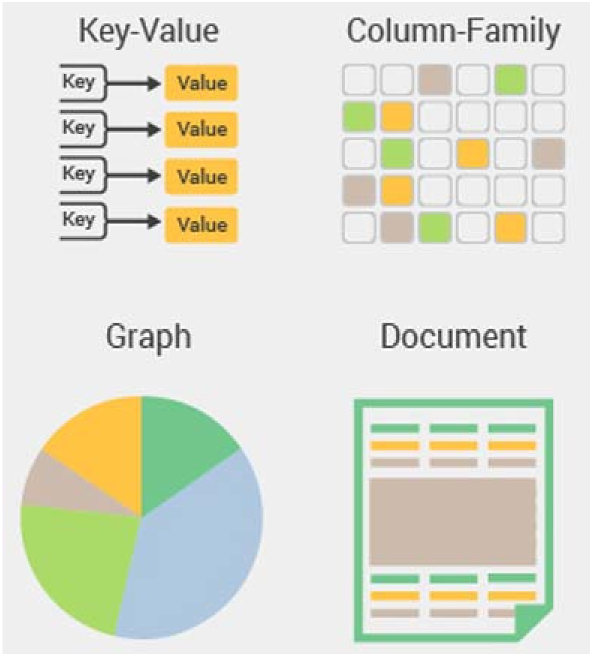

Fig. 2. Popular NoSQL models of data.

The simultaneous provision of all three guarantees is impossible (Figure 3).

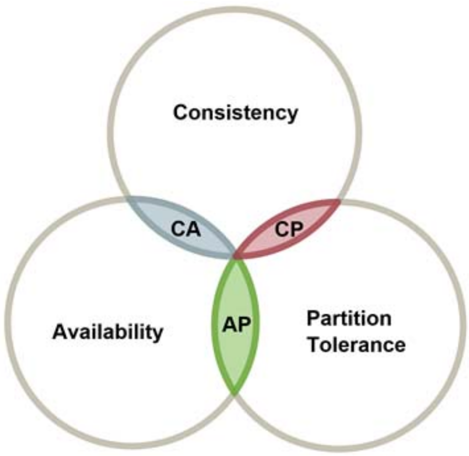

Fig. 3. CAP theorem.

The theorem proves that only two of the three pillars can be used to create such a system, i.e. we may have a system with high consistency and expandability, a system with high data availability and expandability, or a system with high consistency and high availability, but without expandability.

Most NoSQL databases operate on the BASE (Basically Available, Soft-state, Eventual consistency) principle: choosing availability and partitioning at the expense of consistency and looking for the fastest and most reliable synchronization among individual servers.

NoSQL databases still have limited application in specific areas, but the fact that they are used by IT giants like Google, Facebook, Amazon, and LinkedIn is a proof about their potential.

Numerous comparative analyzes of the performance of RDBMS and NoSQL have shown that, in general, NoSQL systems perform better when recording, deleting, and updating Big Data sets than are common to information systems used to manage mining processes.

NewSQL databases have been talked about for the last few years. The term NewSQL was first proposed by Aslett [4]. These are actually databases that combine the advantages of SQL and NoSQL databases (Fig. 3), as NewSQL are transitive and horizontally and vertically extensible.

Fig. 4. Comparison between SQL, NoSQL, and NewSQL.

The products described as NewSQL databases are very diverse, but three main types can be classified:

- SQL engines: highly optimized storage engines for SQL (examples MySQL Cluster, Infobright, TokuDB);
- New architectures: databases that were designed to operate in a distributed cluster (examples Google Spanner, Clustrix, VoltDB, MemSQL);
- Transparent sharding: they provide a sharding middleware layer to automatically split databases across multiple nodes (ScaleBase).

The coal of NewSQL databases is to provide a high-performance and affordable solution for processing large volumes of data without compromising data consistency and high-speed transaction capabilities, making them very efficient and applicable to some processes in the mining industry, which are almost completely automated.

They are best used in the control of enrichment processes, where the data are very high frequency - the sensors (express analyzers) continuously provide information at intervals of up to 2 minutes, which requires the supply of appropriate reagents to obtain the desired content of ore concentrate.

Although in recent years many analytical comparisons have been made between SQL and NoSQL databases [5, 6], today the choice of which data model to use is determined mainly by the specific conditions and tasks.

Data quality assurance technologies

Data quality is a characteristic that shows the extent to which they are analyzed and meet the needs of the business to make informed and effective decisions. From an information technology perspective, data quality is part of the whole data management process.

The criteria determining whether we operate with quality data can be considered according to the requirements of information systems and from the point of view of their users.

The requirement for the use of high quality data in information systems is that they meet at least five main criteria [7] - completeness, accuracy, validity, consistency and timeliness (figure 5).

Unlike standard data collection (on paper), information technologies make it possible to ensure the completeness of data by using functions that allow the input and digital storage of information only, where all attributes for the object, activity etc. have been introduced.

To ensure full quality data, additional features are introduced that check not only the correctness of the data provided but also the exact implementation of the data entry format defined by the particular information system.

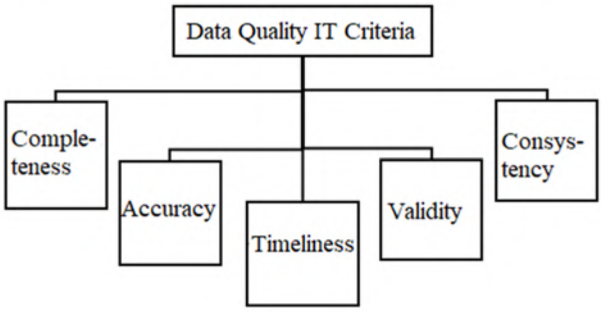

Fig. 5. Main criteria for data quality.

Accuracy of data criterion suggests that incoming data in the information system are correct and fully reflect the depicted object, process, etc. To avoid the risk of inaccurate data submission, the interference of the human factor in this activity should be minimised already at the design stage of a specific information system. Unfortunately, this is almost impossible, and therefore, the implementation of this activity must be done by competent and well trained specialists.

To ensure the data accuracy, especially in cases of a high volume or a continuous stream of data, additional features are being set in the information systems which check for inaccuracies at every step and eliminate admission of such.

The criterion validity of the data determines how data values are correctly measured according to the pre-set conditions. If we have received invalid data, this means that there is a problem in the process of collecting the data.

When you get values for specific data that are beyond the limits of the usual, it does not always mean that they are invalid. In such a case the values should be re-checked. In the flexible information systems this problem is easily solved by altering the defined limits for measured values and incorporating new values.

In information systems, especially in those with longer term of use, there are data about the same object, process, action, etc., that are introduced at certain periods and have different values. In other words, there are different versions of the data for an object or process.

The consistency criterion ensures that the data in the various versions are saved in the same format and in the most important this data format is not changed during processing.

In order for an adequate and efficient decision to be made, it is important that the data we need to analyse should be timely - i.e. there is no time interruption of the incoming data stream for various reasons.

The timeliness criterion is especially important in industrial systems, which manage continuous production processes because the lack of data for a specific segment of time can lead to incorrect management decisions.

From the point of view of data users, the criteria for data quality can be considered conditionally in four major groups - availability, usability, comprehensibility and security (figure 6).

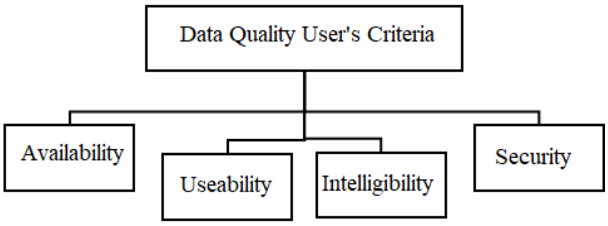

Fig. 6. Users' criteria for data quality.

Availability of data means that in every moment, when appropriate, users need, to have access to them and they are always available.

In information systems, basic characteristics about the availability of data are accessibility, authentication, authorisation, and timeliness of equivalence.

In the client-server technology used by modern information systems by design levels of access to a specific collection of data are defined and an access level is assigned to every particular user, which determines what kind of data to be submitted. Various collections (databases) available for specific levels may exist. An example in this respect are geographical information systems [8], where there is different accuracy (data quality) depending on the type and level of access.

Depending on the specific level of access, it is verified if that user has permission (authentication) to use the information resource (i.e. to a lower or higher quality data). Authorisation is performed by the information system itself, as it gives the user rights to perform the permitted set of actions.

Since a large part of the information systems, including industrial ones, are used by many users, and different users can enter information, the equivalence of data is of particular importance. It measures the extent to which equality (equal values) of the same data is guaranteed.

The timeliness guarantees users that data are timely (as timely as possible), which is essential in making effective decisions.

The usability criterion means that data incoming in the information system from different sources can be processed and analysed.

The data characteristics that determine their usability are documentation, validity, applicability, precision, flexibility and interactivity.

The most important feature of usability of incoming data is their ability to be converted into a digital format by the information system, i.e. they can be formalised by meeting their set conservation model [9].

The validity of the data is determined by comparing the relevance to the requirements set for the specific information system.

Applicability is a characteristic that determines how much data can be processed and analysed in support of specific targets. In order to have adequate solutions taken on the basis of the data it is necessary to have precise data – i.e. they need to have values in the range specified in the information system. Thus, the level of detail of the data, which is required by different groups of users and management levels, is defined. The too high level of refinement and detail of data often leads to difficulties in the operation of information systems and it is therefore necessary to find a level of balance that satisfies both these two characteristics.

Data security assures the users that they are provided with the requested information in an accessible form and the data origin is guaranteed.

The main features ensuring data security are standardisation, reliability, comprehensiveness, integrity, objectivity, comparability and stability.

Standardisation ensures that the data submitted and processed correspond to the rules set in each information system, which in some cases are valid for different information systems that share and exchange information. This data feature is set in the design process of the relevant information system and is monitored throughout its entire life cycle.

Nowadays, the reliability of data is a key feature not only for information systems but also for society as a whole. They give confidence about the source of the data and its reputation, which determines the degree of confidence in the data. Comprehensiveness is a complementary feature that determines to what extent the data is satisfactory and covers the user's request. Data integrity is one of the most important features of data, especially in an insecure environment such as the Internet, because it ensures that changes to data are made only by authorised users. The objectivity feature of the data ensures that the data are not modified under the influence of human emotions, i.e. only the specific facts about the data are reflected.

Naturally, one of the most important features of data is the ability to be permanently stored and accessible over a long period of time to ensure its stability.

Information technology uses many different techniques that guarantee the use of only high quality data. As particularly critical in this regard we can identify technologies that provide standardization, profiling, matching, control and cleaning of real-time data (Fig. 7), which are particularly important in ensuring the operation of information systems in the mining industry.

Data standardization is a technology that operates on the basis of established rules and criteria, ensuring the desired quality. The received data goes through various transformation processes in order to comply with the rules set in the specific information system. [10] Additional functions must be included, allowing automatic correction in the presence of minimal inaccuracies or rejection of data in case of significant discrepancies.

Data standardization is especially important in ERP systems, where information comes from different sources. This technology is also essential when we have data exchange between different information systems with diverse databases, such as those used in the management of various processes in the mining industry.

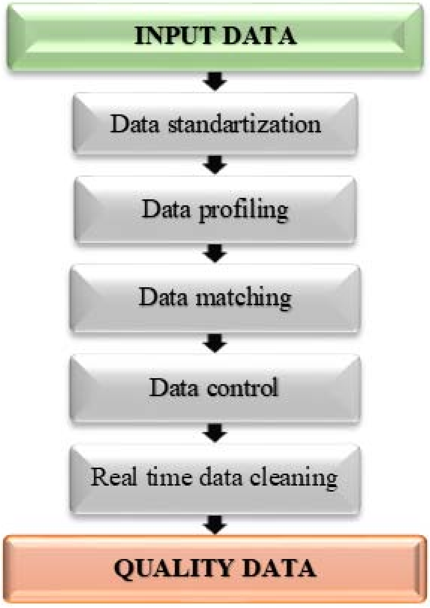

Fig. 7. Data quality assurance technologies.

Data profiling is a technology used to analyses the content, quality, and structure of output data, and is used in various criteria for data quality, such as determining their accuracy and completeness.

Data sources are considered, with an initial assessment of the data to identify potential and actual deficiencies. The goal is to find out the wrong areas in the data organization that can be found in user input, interface errors, data corruption when transferring, and so on. The use of this technique significantly improves data quality.

Data matching aims to find records that relate to the same object, process, individual, and so on. It can be done in many different ways, but the process is often based on algorithms or programmed circuits, where processors perform sequential analyzes of each individual data set, comparing it to each individual part of another data set or comparing complex variables for finding strings containing specific similarities. In the paper of I. Getova [11] present innovative test and evaluation model which gives a probability assessment obtained learning of the lectured material by the learners and provides information on how much the learner perceives the new material and how well the lecturer has presented it in a way can be readily understand it of students. The analysis in this article is performed on a set of data collected by two universities in Bulgaria using the IBM statistical analysis program - SPSS.

Data control is a set of technologies that monitor changes in data quality over time and report deviations from predefined quality indicators. The control of the data is realized through various software tools (drop-down menu, mandatory field, etc.), which monitor and guarantee the completeness, accuracy, validity, timeliness and other quality characteristics of the submitted data.

The timeliness of data in information technology is most easily ensured through cloud structures where all data about a particular object, process, individual, automatically transferred to the cloud once a process is complete and immediately available to all users authorized to work with them.

The data cleaning process monitors for incorrect, incomplete or inaccurate data and ensures that all obsolete or non-compliant data quality criteria are removed.

In modern information systems, software tools for quality control and data cleaning are built into the respective input modules, which allows them to work in real time. In this way, incomplete, inaccurate and outdated data are not allowed to enter, which maximally supports the making of the right management decisions.

This is the process that ensures that the data is correct, consistent and applicable. Data clearing is important because it improves data quality by removing any obsolete or incorrect data and leaving the highest quality information.

For the data to be used by different management levels (different user groups) and to be available on different devices (PC, Tablet, Smartphone), it is necessary to possess flexibility, which is particularly important in ERP systems in the mining industry. This means that they are subject to processes for different organizational changes or reengineering with minimal modification of the existing objects and relations in them. The use of information systems through the Internet or in a network mode requires the data to be interactive – that is, to have two-way communication between the data and users.

Conclusion

Although relational databases are still widely used in the mining industry, with the increasing volume of processed data distributed in the Web environment and the introduction of the Internet of Things, they are finding it increasingly difficult to handle large real-time data sets. NewSQL databases still offer partial solutions, but NoSQL has already established itself in certain areas as a better solution than classic RDBMS.

The information systems used in the mining industry are characterized by their specificity and diversity both for the type of mineral deposit (each deposit is unique) and compliance with the requirements of the specific company [9, 12, 13], which is a prerequisite for the integration of NoSQL data models in it due to their flexibility.

More and more mining companies plan, manage and control their activities, using specialized information systems adapted to their conditions and requirements. Since many large mining companies, incl. and in Bulgaria they are already building their own cloud structures, using information from different types and models of databases, the technologies guaranteeing the processing of high quality data are of special importance.

However, due to the diversity of the software tools used, the implementation of all criteria for high quality data proves to be a difficult problem to implement, as an optimal balance between all criteria is sought.

For this reason, each mining company, depending on its requirements and available software tools, determines which quality criteria are most important for its work at a particular time, and this process is dynamic with the introduction of new information technologies.

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Enhancement of the technology of mining steep ore bodies applying the “floating” crown

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Abstract. When mining ore bodies in Kryvyi Rih iron ore basin, underground mines apply open stoping or bulk caving systems in proportion of 55% to 45%. Most of underground mines prefer stoping with pillar caving. Yet, rock pressure contributes to growth of costs for workings maintenance and deterioration of extraction indices. Rock mass extraction indices can be enhanced by application of a protectve structure in the upper part of the block that will enable additional decrease in load on the draw level. There are a great many of methods for determining parameters of constructive elements of the protective structure that help keep its integrity for the whole period of block mining. The article suggests methods for determining parameters of the protective structure when mining steep ore bodies. The research conducted demonstrates that with the inclined protective structure, increase of unit load on it from 200 to 1200t/m^2 leads to decrease of its thickness from 6.3-20.9m to 5.5-18.4m and increase of the crown length from 40m to 60m. The developed block caving system with application of the protective structure when mining steep ore bodies enables overall decrease of ore dilution in the block by 3%, increase of iron content in the mined ore by 1.3% without significant mining costs growth and decrease of loads on the workings of the receiving level.

1 Introduction

Ore bodies of Kryvyi Rih iron ore deposit (Ukraine) house over 30.2 Bt of ferruginous quartzite with iron content of 24-65% [1-4]. These ore bodies are mined applying surface and underground methods. Underground methods are used to mine rich iron ores with iron content of 57–65% applying stoping systems and bulk caving of ore and overlying rock in proportion of 55% to 45% [5-8]. Most of underground mines prefer stoping with pillar caving. Yet, in complicated mining and geological conditions rock pressure contributes to growth of workings maintenance costs and deterioration of extraction indices [9-12].

Underground mining operations have reached the depth of 1350 m. Ore bodies stretch for 800-1200 m, their horizontal thickness is 30–120 m and the angle of slope is 45–85 degrees [13-16]. The authors of [17-20] state that ore bodies significantly differ from each other in not only physical and mechanical properties that influence mining and processing technologies but also their quality. Mining of agglomerated iron ores is the main type of activities of enterprises that are engaged in underground mining of naturally rich iron ores. In compliance with specifications, agglomerated ores are produced at grinding-sorting complexes of underground mines through grinding at several stages, screening and blending at surface stockpiles [21-25].

To enhance indicators of the final product, concentration complexes apply various technologies and methods of controlling the process of concentrating crude ore considering energy-efficiency indicators [26-29]. To settle resource saving issues, a modern complex approach of controlling environmental-economic systems applying the theory of administrative-engineering management is used. Yet, this results in increased mining costs and alienation of land for concentration waste storage.

When mining ore bodies in complicated mining and geological conditions, ore losses and dilution become higher by 3-5% as compared with the standards. Increased losses and dilution result in pre-schedule mining-out of the level, increased volumes of capital mining operations and ore mining costs [30-33].

The authors of [33-38] suggest various options of mining ore bodies that enable enhancement of ore mass extraction from stopes. However, rock pressure may lead to stope failures when forming a compensation space and, consequently, result in deterioration of extraction indices, decrease of labour efficiency and increase of time spent on mining a block.

At Kiruna mine, application of the bulk caving system without considerable exposures enables enhancement of ore extraction indices in unfavorable mining and geological conditions [39, 40]. Managers of Kryvyi Rih underground mines have made several attempts to implement the system. However, this has resulted in

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deterioration of labour conditions and increased mining costs due to complicated mining and engineering conditions (instable fractured ore and rocks).

To enhance extraction indices, the sublevel caving system with an artificial flexible metal layer was applied to extract polymetal ores at Bakyrchik mine (Kazakhstan). The developed option with a flexible metal layer in the upper part of the block and longhole blasting (Fig. 1) has proved to be efficient despite considerable economic indices of mining [41-43].

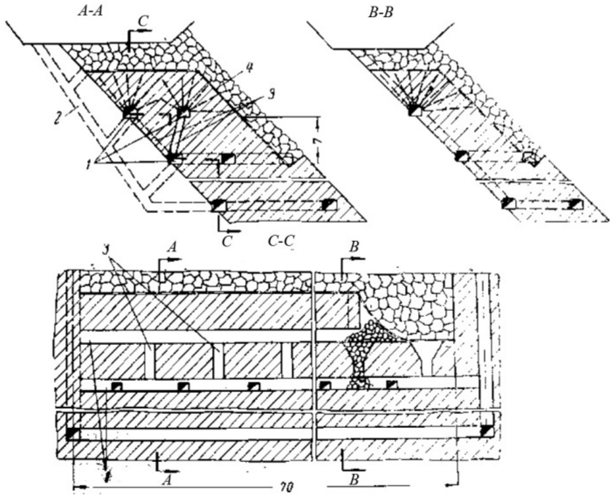

Fig. 1. Ore mining under a flexible layer: 1 – drill sublevel drifts; 2 – orepass; 3 – box raises; 4 – the flexible layer.

It should be noted that application of this mining system requires that flexible roofing should be sufficiently strong and withstand not only static but also dynamic loads when stoping. It has proved to be not only protecting against caved rock coming into the face space but also a load bearing support that creates safe working conditions.

The state research ore mining institute "SkhidNDGRI" has suggested the option for mining blind ore bodies with drawing the broken ore under the protective rock block-shield that separates caved rock and ore [44] (Fig. 2).

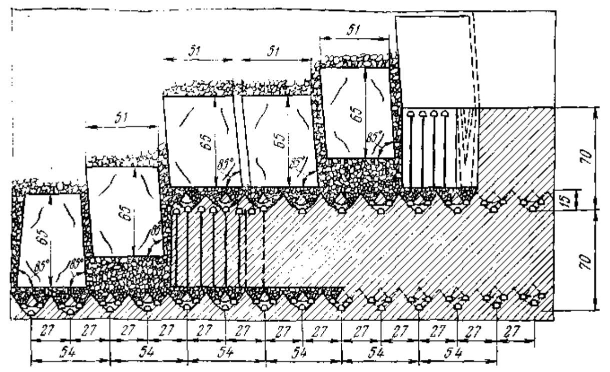

Fig. 2. The system of induced block caving under the protective rock block-shield.

Kuznetsk metallurgical plant (Russia) has tested this technology at its mine. The experimental block was formed in the 10-20 m thick magnetite ore body with sulphide inclusions at the depth of 130-150 m. The stope was mined applying block caving with layered ore breaking by a bunch of parallel contiguous boreholes on the "compressed environment". The caved ore under the rock block-shield was drawn applying scraper equipment.

Geometry of the stope was as follows: length – 36 m; width – 16-20 m; height of the caved ore layer – 32.5 m; length of the block-shield – 30 m, distance between block-shields – 2.5-3 m. Ore massif was broken by 10-13 m wide parts bunches of parallel contiguous boreholes. The ore was drawn successively from drawpoints until the block-shield moved vertically for 13 m. Then the ore was drawn from the previously broken adjacent block. Application of this technology enabled high ore extraction indices [44].

Thus, the technology of mining blind ore bodies applying a block-shield is rather promising. Yet, its application is possible for steep ore bodies only.

The sublevel caving system with creation of rock and ore moving protective structure (the "floating" crown) is suggested to mine parallel contiguous steep ore bodies [45] (Fig. 3).

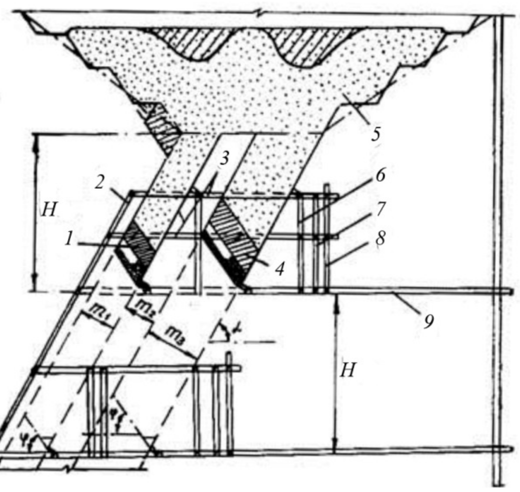

Fig.3. The flowsheet of forming "floating" rock and ore crowns (FC): 1, 4 – rock and ore FC; 2, 6, 7, 8 – ventilation, ore drawing, manway and service raises respectively; 3 – drilling sublevels; 5 – overburden rocks of the inside dump; 9 – the haulage level.

In this case, in the upper part of the stope, the FC is formed at a certain angle (Fig.3). To control vertical movements of the FC, a remote control circuit is developed. The authors suggest determining the FC thickness applying methods for defining structural elements of the room-and-pillar system for the inclined crown. Permissible dimensions of exposures and pillars are calculated depending on the level height and the FC thickness on the basis of methods developed by the research ore mining institute.

The FC is formed by drilling and blasting. Along the strike, the crown is formed from drill drifts of the footwall and the hanging wall with the help of short holes; across the strike – from a drill drift by longhole rings.

Ore stoping is performed until the FC is formed. For this, a drawing level is formed in the stope by a cut raise and the ore massif is caved by blasthole rings. After the mining block is filled with the broken ore, the FC is formed and the broken ore is drawn off from the stope

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under the crown, vertical movement of the crown being controlled.

To provide even movement of the FC, caved ore should be controlled, especially while drawing from a series of drawpoints. For this, it is necessary to create a single drawing zone (one drawing crater 7 and a loosening zone 2, 8) in the center of the block (panel) as when drawing from a single drawpoint (Fig. 3).

Even vertical movement of the FC with its integrity preserved for the whole period of mining depends on the following factors: physical and mechanical properties of ore, the draw level parameters, overlying rock pressure on the FC.

According to [46-49], uniform sequential drawing of caved ore from adjacent drawpoints shifts the centers of both drawing figures and results in intensive formation of one drawing figure out of two [49] (Fig. 4).

In [48], the author states that in case of non-observance of the uniform advanced mode of drawing, there may be formed two or even three and more craters under the FC. This will result in significant losses and dilution due to the craters running beyond the protective structure, and in more complicated control over the even FC movement

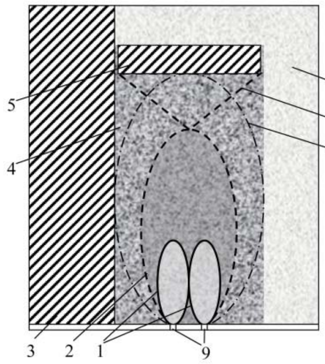

Fig. 4. Formation of drawing and loosening figures and a draw crater while drawing caved ore from a series of drawpoints: 1 – the drawing ellipsoid; 2 – the loosening ellipsoid; 3 – uncaved massif; 4 – caved ore; 5 – the FC; 6 – caved rocks; 7 – the draw crater; 8 – the loosening ellipsoid at the moment of reaching the FC; 9 – drawpoints.

To prevent the draw crater running beyond the FC, construction of the protective structure should be changed (Fig. 5). Thus, creation of the FC with protective brows in the lower part along its perimeter enables decreasing side dilution of the caved ore. Parameter of the protective brow are determined based on conditions of its formation (by drilling and blasting), compressive strength and the number of FC. The height of the protective brow (h_{br}) makes 3-5 m and it is determined by parameters of the drilling room.

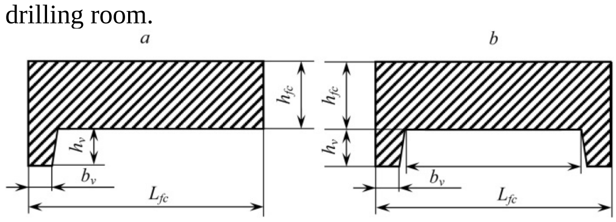

Fig. 5. The principle diagram of “floating crowns”: a – asymmetric “Г”-shaped; b – symmetric “П” – shaped.

Thus, enhanced extraction indices can be achieved through separation of broken ore and caved rock by the protective structure [36, 39, 43].

2 Methods

Application of the protective structure in the upper part of the block enables redistributing of loads on the draw level and enhancing indices of caved ore extraction from the stope. However, there is no technology for mining steep ore bodies by bulk caving and applying the protective structure. Thus, research into and enhancement of the technology of stoping under high rock pressure remains actual.

The work aims to enhance the technology of mining steep ore bodies applying the moving protective structure in the upper part of the stope.

The task of the work consists in developing the technology able to provide increased iron content in mined ore mass in complicated mining and geological conditions.

3 Results and discussion

In underground mining, calculation of pillars between underground rooms and the open stoping space is of great interest. These pillars can be treated as crowns.

The widely used method of calculating the crown thickness is based on the rock fragmentation factor at caving. This method is used for low stopes. If stopes are high, thickness of crowns would be inexpediently great. There are a number of constraints considering which safe dimensions of crowns should be calculated on the basis of cave arch parameters. Height of the natural arch is known to depend on the working width and physical and mechanical properties of rocks. Despite all advantages of this method of calculating the safe FC thickness, it is insufficiently reliable due to the fact that in conditions of large roof exposures, determination of cave arch parameters is rather difficult [44]. At that, it is practically impossible to determine the moment when formation of the dome of equilibrium is finished.

To calculate the safe thickness of a crown, the most reasonable are the methods of structural mechanics that are described in recent scientific works [5, 6, 44-46]. The authors of the works recommend to distinguish among three types of crowns: *a* – a long thick beam-like plate constrained along the contour; *b* – a plate constrained along the contour and with fixed corners if its length-to-width ratio equals or exceeds six; *c* – a plate constrained along the contour and with fixed corners if its length-to-width ratio is less than six.

Crowns of various types can be calculated with insignificant errors using a unified methodology, this facilitating such calculations in production conditions. As mentioned above, the FC thickness depends on the exposure span, physical and mechanical properties and rock loads. Along with that, it should be taken into account that unreasoned increase of the FC thickness in order to raise the factor of safety leads to increased losses of the useful mineral.

The FC is treated as a separately structured plate-like part of the massif moving together with overlying rocks. According to the above mentioned, the width and the length of the FC are equal, so let us treat it as a plate resting on a moving support ("support pillars") consisted of the caved ore and located near a draw crater. The FC undergoes loads from its weight and the weight of the caved rock [44, 45]. Bending moments in section points of the crown are calculated similarly to those for a plate freely abutting with its four sides. Stresses impacting the plate along the x-x and y-y axes are calculated by the expression

$$\sigma_x = \sigma_y = \frac{12M_{x\,max}}{h_{fc}^3} z = \frac{12M_{y\,max}}{h_{fc}^3} z\,, \qquad (1)$$

where $M_{x\,max}$, $M_{y\,max}$ are values of the maximum bending moment in the z part of the span of the "floating crown" exposure along the x and y axes respectively; h_{fc} is the thickness of the "floating crown", m; z is the distance on which the largest stresses occur in the plate, m.

According to [50]. The largest stresses occur at $z = \pm h/2$. Thai is why, stresses in the plate under load should satisfy the condition

$$\sigma_{x\,max} = \sigma_{y\,max} = \frac{6M_{x\,max}}{h_{fc}^2} = \frac{6M_{y\,max}}{h_{fc}^2} \le \left[\sigma_p\right], \qquad (2)$$

where $[\sigma_p]$ is the permissible tensile stress of rocks making the "floating crown", t/m^2.

As the FC length and width are equal, expression (2) will look like

$$\sigma_{max} = \frac{6M_{max}}{h_{fc}^2} \le \left[\sigma_p\right], \qquad (3)$$

where M_{max} is the total of bending moments in the middle part of the FC exposure span.

The value $[\sigma_p]$ in expression (3) is calculated as follows

$$\left[\sigma_p\right] = \frac{K_f\, f_p K_o}{K_z}\,, \qquad (4)$$

where K_f is the coefficient of converting rock hardness into stress; f_p is the Protodyakonov hardness ratio of rock including those of the "floating" crown; K_o is the factor of rock loosening caused by fissures (assumed from 0.5 to 0.85); K_z is the safety factor of rocks of the "floating" crown (changing from 1.5 to 2.5).

When mining steep ore bodies, [45] suggests forming the FC not horizontally but at some angle to the receiving level.

The crown should be inclined at the angle that will not allow its turning over in the stope from the hanging wall side, i.e. the angle between the stationary crown and the hanging wall does not exceed 80 degrees (Fig. 6).

The minimal crown inclination angle α_{fc} for steep ore bodies is generalized by the expression, degrees

$$\alpha_{fc} = 100 - \alpha_w\,, \qquad (5)$$

where α_w is the dip of the hanging wall rocks, degrees.

Formula (5) is true when the ore body dip changes from 40 to 80 degrees. Considering the fact that the FC is inclined, stress components will be redistributed according to the expression

$$\left[\sigma_p\right] \sin\alpha_{fc} = \frac{K_f\, f_p K_o}{K_z}\,. \qquad (6)$$

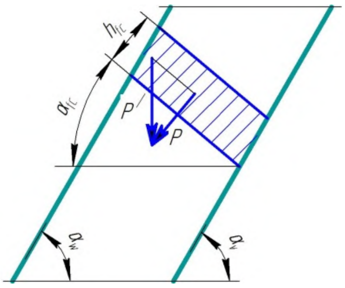

Fig. 6. The principle diagram of determining the FC formation angle.

Solving the equation (3) with respect to h_{fc}, we will obtain the general expression for determining the maximum permissible thickness of the "floating" crown

$$h_{fc} = \sqrt{\frac{6M_{max} K_z \sin\alpha_{fc}}{K_f\, f_p K_o}}\,. \qquad (7)$$

Taking into account independences of force actions, the value of the maximum bending moment is calculated as the total of moments of each load according to the expression

$$M_{max} = M_{max}^c + M_{max}^p\,, \qquad (8)$$

where M_{max}^c и M_{max}^p are values of the maximum bending moments on the span of the "floating" crown exposure depending on the weight of the crown itself and the weight of overlying rocks respectively.

The bending moment from the "floating" crown weight is determined as follows

$$M_{max}^c = \beta_m P_{cr} l_{sp}^2 \gamma_o\,, \qquad (9)$$

where β_m is the bending moment in the freely abutting plate ("floating" crown) equaling 0.0479 [50]; P_{cr} is the load caused by the weight of the crown on 1 m of its width, t/m^2; l_{sp} is the span of the exposure under the "floating" crown, m; γ_o is the volumetric weight of the crown rock, t/m^3.

Let us consider the FC lying on the caved ore as a plate [50]. The bending moment caused by the caved rock weight impacting the "floating" crown four sides of which rest on support pillars is described by the differential equation

$$\frac{\partial^4\omega}{\partial x^4} + 2\frac{\partial^4\omega}{\partial x^2 \partial y^2} + \frac{\partial^4\omega}{\partial y^4} = 0\,. \qquad (10)$$

Task (10) is solved considering boundary conditions. If the crown abuts freely with its four sides is freely supported, the boundary conditions will look like (11), and the task is solved by numerical methods

$$\begin{cases} \omega\big|_{x=0}^{x=a} = 0, \\ \left.\dfrac{\partial^2\omega}{\partial x^2}\right|_{x=0}^{x=a} = 0, \end{cases} \text{и} \begin{cases} \omega\big|_{y=0}^{y=a} = 0, \\ \left.\dfrac{\partial^2\omega}{\partial y^2}\right|_{y=0}^{y=a} = 0, \end{cases} \qquad (11)$$

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where a is the FC length (width), m.

As solution of equation (11) requires use of numerical methods which are cumbersome, the author of [50] suggests a simplified equation to determine the maximum bending moment in engineering calculations

$$M_{max}^{p} = C_1 P_{cr} l_{sp}^2 , \tag{12}$$

where C_1 is the adjustment coefficient of bending moments, [50]; P_{cr} is the load of overlying rocks on 1 m of the FC width, t/m^2.

Substituting the value of the bending moment calculated by formula (12) in expression (7), we obtain the final expression for determining the minimal permissive thickness of the FC

$$h_{fc} = 0{,}1437 l_{sp} \sqrt{\sin\alpha_{fc}} \left(\frac{l_{sp}\gamma_o K_z}{K_f f_p K_o} + \frac{\sqrt{\left(l_{sp}\gamma_o K_z\right)^2 + 290{,}65 C_1 P_{cr} K_f f_p K_o K_z}}{K_f f_p K_o} \right). \tag{13}$$

Vertical movement of the FC occurs during caved ore drawing due to destruction of the support pillar which the crown rests on. Let us assume that at the angle of the support pillar rocks shear, the shearing and holding forces are in bounding equilibrium. So, stability of bounding equilibrium is described by Coulomb's law and looks like

$$\tau = \tau_o + \sigma_n \, tg\rho , \tag{14}$$

where τ is the shearing stress in the support pillar, t/m^2; τ_o is the initial shear resistance which equals rock cohesion c at $\sigma = 0$, t/m^2; σ_n is the normal stress in the support pillar, t/m^2; ρ is the friction angle, degrees.

Normal and shear stresses are included in equation (14) and determined as follows

$$\sigma_n = \sigma \cos\theta , \tau = \sigma \sin\theta , \tag{15}$$

where σ is the effective value of the compacting stress, t/m^2.

The compacting stress σ is the ratio of the total weight of overlying rocks (P_{rock}) and the "floating" crown (P_{cr}) to the total area of the "support" pillar cross section (S_{max}) [51-54]

$$\sigma = \frac{P_{rock} + P_{cr}}{S_{max}} = \frac{P}{S_{max}} , \tag{16}$$

where P_{rock}, P_{cr} are loads caused by overlying rocks the FC respectively, t; S_{max} is the area of the cross section which the FC rests on, m^2.

On solving (16) with regard to S_{max}, we obtain the formula for determining minimal permissible areas of the "support" pillar that bears the FC

$$S_{\text{г}p} = \frac{P\left(\sin\theta - \cos\theta \, tg\rho\right)}{c} . \tag{17}$$

Then, when drawing ore from a series of drawpoints, the maximal exposure span under the "floating" crown is calculated by the formula

$$l_{sp} = 2\sqrt{\frac{ca^2 - P\left(\sin\theta - tg\rho\right)}{\pi \, c}} . \tag{18}$$

The research conducted enables the conclusion that the exposure under the FC depends on physical and mechanical properties of ore and the effective load P that consists of the weight of the overlying rocks and the weight of the "floating" crown. In its turn, the weight of the "floating" crown depends on its constructive parameters (width, length and thickness).

Based on calculations of the crown thickness considering the FC inclination angle, the dependencies of the "floating" crown thickness on the unit load on the FC at the ore body dip of 60° are built (Fig. 7).

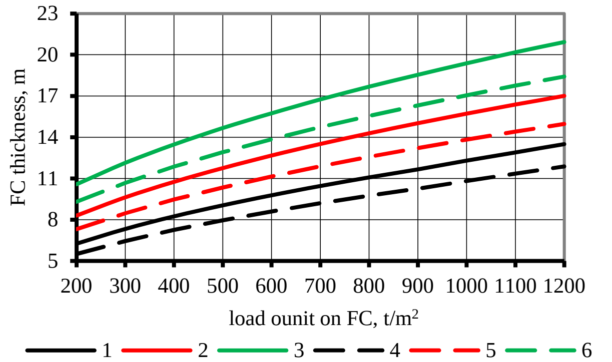

Fig. 7. Dependency of the "floating" crown on the unit load on the protective structure and its parameters at: 1, 2, 3 – the FC lengths of 40 50 and 60 m respectively at the angle of 0°; 4, 5, 6 – the FC lengths of 40, 50 and 60 m respectively at the angle of 40° to the receiving level.

Fig. 7 demonstrates, that if the unit load on the FC increases from з 200 to 1200 t/m^2 and the crown incline angle of 0° and 40°, the crown thickness grows from 6.3 to 20.9 m and to 5.5 to 18.4 m respectively. It should be noted that the character of crown thickness changes at the angles of 0° and 40° is similar. Thus, it can be concluded that calculations based on the enhanced methods provide reliable results.

The conducted research enables the conclusion that depending on the location of drawpoints, waste rock can get into the mining block. This happens when the caved ore is drawn under the FC inclined against the receiving level. (Fig. 8).

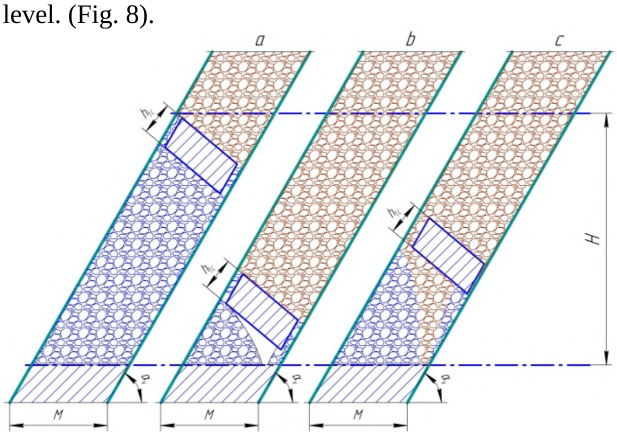

Fig. 8. Diagrams of the FC movements while ore drawing: *a* – the initial stage; *b* – the final stage of caved ore drawing; *c* – the final stage of caved ore drawing after the active drawing area moves beyond the protective structure.

Yu.P. Kaplenko and V.O. Kolosov state that after ore drawing from the stope, the FC will move as shown in Fig. 6*b*. However, according to S.V. Pysmennyi's research, the drawing area moves beyond the FC with the 50% probability and lets waste rock into the active drawing zone (Fig. 8*c*). To prevent this, it is suggested to create protective brows in the lower part of the crown (see Fig. 5).

Analysis of caved ore drawing under the protective structure when mining steep ore bodies enables the conclusion that it is reasonable to locate protective brows in the upper part of the FC from the hanging wall side (Fig. 9).

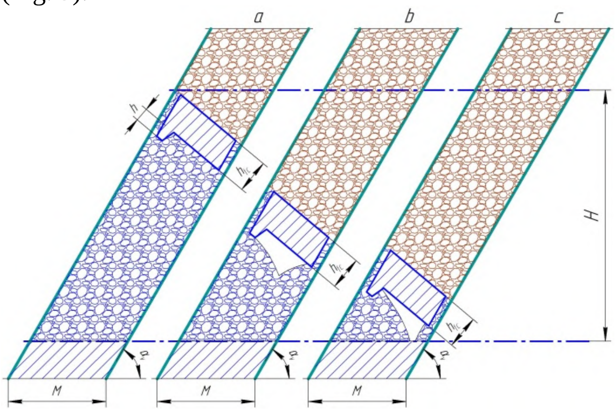

Fig. 9. The diagram of movement of the FC with a protective brow from the hanging wall side when drawing caved ore: *a* – the initial stage; *b* – the intermediate stage; c – the final stage.

Fig. 10 demonstrates that when forming a draw crater under the FC (the intermediate stage), the protective brow does not allow it to go beyond the protective structure that prevents waste rock from coming to the active drawing area.

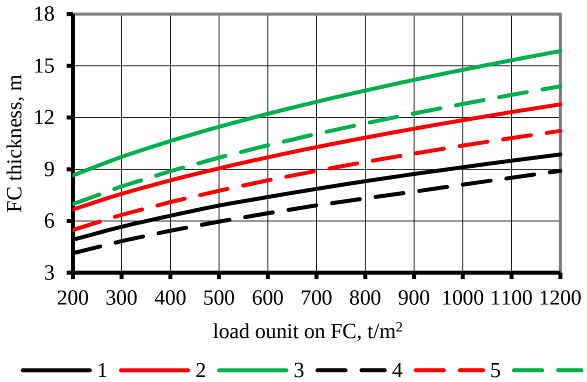

Fig. 10. Dependency of the “floating” crown with the protective brow on the unit load on the protective structure and its parameters at: 1, 2, 3 – the FC lengths of 40, 50 and 60 m respectively at the angle of 0°; 4, 5, 6 is the FC lengths of 40, 50 and 60 m respectively at the angle of 40° to the receiving level.

As is seen in Fig. 10, if the unit load on the FC increases from з 200 to 1200 t/m^2 and the crown incline makes 0° and 40°, the crown thickness grows from 4.9 to 15.9 m to 4.1 to 13.8 m respectively. It should be noted that the character of crown thickness changes at the angles of 0° and 40° are similar. Thus, it can be concluded that calculations based on the enhanced methods provide reliable results.

Analysis of calculations in Fig.7 and 10 shows that it is possible to decrease the crown thickness applying the protecting brow in the upper part of the FC. It should be noted that the crown thickness decrease leads to increase in general reserves in the FC at the expense of ore reserves in the protecting brow.

To reduce dilution of the caved ore and decrease rock pressure manifestations, we suggest a system with bulk caving of ore and overlying rocks applying the “floating” crown (Fig. 11).

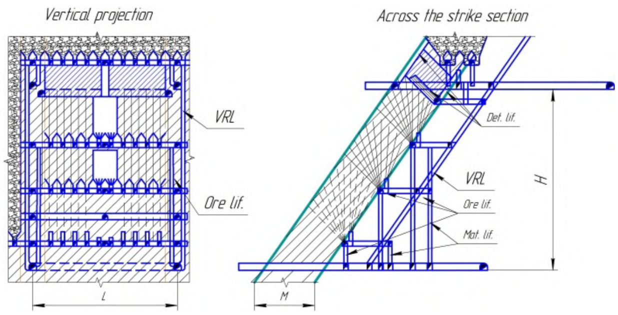

Fig. 11. The system of induced block caving with breaking ore on the vertical compensation room and applying the “Г”-shaped “floating” crown.

The suggested mining system consists in the following. In the upper part of a stope a FC is formed by breaking ore massif along its contour. The stope is conditionally divided into two or three levels where a scraper entry is located from which ore massif is broken on the vertical compensation room.

Geometry of the mining system is as follows: the level height is 10 m, the block length is 60 m, thickness is 25 m, the FC thickness is 15 m according to the calculations (Fig.10). Preparation of the block starts with driving access orts from the haulage entry and driving ventilation and manway raises on the flanks of the mining block. Then the level is conditionally divided into 25 m long sublevels; from ventilation and manway raises, ventilation and manway orts are driven to which service and ore discharge raises are driven up from the haulage level. A scraper entry is driven from the ventilation and manway orts in the footwall. 5-7 m high drawpoints go out of the scraper entry [55-58].

A 15 m thick FC is formed in the upper part of the stope. The FC is cut by driving horizontal and vertical cutoffs. To prevent the active drawing zone from going beyond the FC, the “Г”-shaped protective structure is suggested.

The ore massif of the main reserve is caved after creating the FC. For this, the ore massif is broken by blasthole rings. from the scraper entry on the previously created compensation room. After that, the blasthole rings are fired with delay.

Caved ore drawing begins at drawpoints located in the block center (according to Yu.P. Kaplenko) to create a single active drawing zone (according to S.V. Pysmennyi) until the fragmentation ellipsoid reaches the FC (this makes about 15-20% of the main block reserve). After the fragmentation ellipsoid reaches the FC in the ore massif, the fragmentation factor will be over 1.5. This will enable the FC to move vertically due to its own weight and the weight of the overlying rocks. After the FC movement, the fragmentation factor in the block will decrease to 1.3 and this will stop movement of the protective structure.

With further ore drawing, the factor changes to 1.5, this resulting in the FC movement.

As ore breaking is performed by stages, a pillar is left above workings of the receiving level. The pillar absorbs loads from the broken ore, the crown and caved rocks, thus limiting conditions of rock pressure manifestations in workings. After extracting 50% of ore mass, the lover part of the ore massif is drilled out and ore drawing continues [59-61].

General technical and economic data is given in Table 1.

Table 1. Technical and economic data by mining systems.

Parameters	Mining system	
	Traditional	**Suggested**
Balance ore reserve in block, t	420746	420746
Ore mass mined from block, t	401621	388577
Specific consumption for workings, m/kt	4,3	4,4
Per meter run:		
a) while forming compensation space, t	12.9	12.1
b) while bulk caving, t	18.4	18.4
c) with “floating” crown	–	15.2
Blasting ratio: kg/t		
a) packaged explosives	1.35	1.52
b) granular explosives	0.267	0.294
Labor efficiency, t/shift:		
a) at breaking	1052	898
b) at transportation	509	542
c) by mining system	52.1	50.9
Fe content, %:		
a) in massif	62.0	62.0
b) in ore mass mined	58.63	59.63
Ore loss, %	16.0	18.8
Ore dilution, %	14.0	9.85
Cost of 1t of ore	11.48	11.14

Table 1 demonstrates that application of the FC mining system results in mining costs reduced by 0.34 USD/t, ore losses increased by 2.8% (FC ore excluded), and ore dilution decreased by 4.15% as compared with traditional mining systems. Iron content in the mined ore increases by 1.0%.

Conclusions

The research conducted enables the following conclusions:

1. Based on the analysis of mining and geological conditions of mining under rock pressure in Kryvyi Rih iron ore basin, enhancement of ore extraction from the stope has been proved possible due to application of the protective structure.

2. The current methods of calculating the “floating” crown thickness enable determining its optimal parameters to ensure its integrity when stoping. However, there are no developed techniques of applying the FC when mining steep ore bodies.

3. The enhanced methods have been developed to determine the FC thickness considering the dip angle of the ore body. Based on the research conducted, there has been developed a system of block caving with application of the “floating” crown to mine steep ore bodies that enables decrease of ore dilution, increase of Fe content in the mined ore without considerable growth of ore costs.

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Determination of economically viable option of liquidation the consequences of external dump deformation

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Abstract. The safety factors for different variants of operation development were obtained, on the basis of which the technical and economic indicators were established and the most expedient way of restoration of dump operations in conditions of the formed landslide was chosen. The solutions were proposed for the external dump No 2 of the Central Ore Mining and Processing Enterprise (COMPE), that allow to continue its future operation. When working in the conditions of the formed landslide, three variants of the further dump operation are modeled: the first one - with landslide removal and unloading of the upper dump horizons, the second one - without landslide removal and involvement of disturbed lands in land allotment, the third one - with the landslide loading. Based on the built sections of the dump and defined physical and mechanical properties, the stability factors were obtained for different options of the operation development, which made it possible to determine the appropriate option to eliminate the effects of the dump slide deformations. As a result of the calculations, the cost flows for each of the proposed options of the formation of the end contour of the dump No 2 are determined.

1 Introduction

Practice and scientific research show that the overburden rocks during the development of deep open mines are stored in external dumps, which occupy large areas. Their systematic expansion and considerable distance from the open mines lead to a significant increase in the cost of field development as a whole. To place the dumps, in some cases, hollows and ravines are used, which are almost impossible to use in agriculture. When storing overburden rocks in such conditions, it should be accounted that the weight of the dump placed in the hollows effect the base and can lead to deformation of the sides. Such processes can be facilitated by the presence of ground and surface water, which moisten the rocks of the dump base. The formation of such deformations, as a rule, occurs outside the land allotment of the enterprise. In this regard, there are unforeseen costs to eliminate the effects of deformation, which in difficult economic conditions and reducing demand for iron ore concentrate is unacceptable.

2 Analysis of studies

The development of deep open mines in Ukraine is accompanied by the placement of overburden rocks in external dumps. Issues of dump formation have been considered in various scientific papers [1-8]. The volume of the overburden rocks extraction of and their storage in the external dump directly depends on the productivity of the open mine where minerals are extracted [9-17]. The placement of overburden rocks and the productivity of open mine equipment is an important task that affects the sequence of dump development and the stability of slopes. Many scientific works consider methods of strengthening berms and ledges and methods of construction of potential sliding surfaces and calculations of strengthening parameters, which is confirmed by considerable experience in strengthening unstable surfaces. Problems of stability of slopes of quarries and dumps were considered in many scientific works [18-21]. Solving the problem of stability makes it possible to increase naturally or artificially the safe operation of external and internal dumps.

3 Problem formulation

The Dump No 2 of the PJSC Central Ore Mining and Processing Enterprise (excavator) is located at a distance of 12 km from the open mine in the Oleksandro-Maryivska hollow (Fig. 1). Loose and rock mass are stored in the dump, which are delivered by rail transport. In fact, the dump is poured in succession in several tiers. At the dump No 2, the overburden rocks is accepted at 2 dump dead ends and is dumped with the help of ECG-8I and EK 10/70 excavators. Overburden rocks in the dump

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No 2 of the PJSC "COMPE" is delivered from the faces and reloading points of the open mine No 3. The transport development system is used in this open mine.

As a result of the landslide that occurred on the dump No2 of the Petrovsky open mine of the PJSC "COMPE", 1.42 hectares of arable land were disturbed. There was a need to take measures to eliminate the effects of the landslide. In this regard, options for further dump operation were considered.

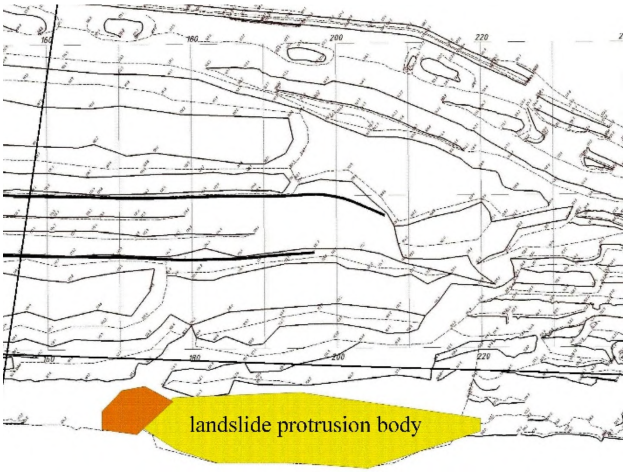


Fig. 1. Schemes of the formed landslide and placement of boreholes.

Deformations in the form of landslide with the following parameters appeared on the section of the south-western side of the dump No 2: the length of the landslide manifestation was 410 m; the depth on average was 7 m; the volume was 850 thousand m^3; landslide area is 85 thousand m^2. It should be noted that previously no deformations were observed in this part of the dump. In the area of the dump formation there is a complex relief with a hollow. The negative aspects include the very low strength of rocks placed into the dump (mainly clays, loams), which have a high plasticity at a natural humidity of 21 - 25%, the sole of which also contains different by their physical and mechanical properties loams.

Therefore, the following **tasks** need to be solved: using geophysical methods to determine the presence of aquifers and their impact on the dump, to consider possible options for the development of works on the dump taking into account the formed deformations, to determine the stability of slopes according to the proposed models of development, to choose the best technical and economic indicators.

4 Purpose

To solve the tasks it is necessary to determine the most economically feasible option for the development of works on the dump where the processes of landslide deformation and protrusion in its sole outside the land allotment of the enterprise.

5 Methodology

To solve the tasks set force in this work, the following research methods were used: geophysical method of the Earth's natural pulsed electromagnetic field (NIEMEF) - for the forecast estimation of the risk of formation of new centers of geodynamic phenomena and development of the measures to prevent them; the method of algebraic addition of forces - to establish changes in the stress-strain state of the rock array; computer modeling to substantiate technological solutions by options; graphical and analytical method - to calculate the stability of slopes by various options of the development of mining operations on a dump; economic comparison of accepted technological decisions - to define a rational variant of formation of the final dump contours.

6 Selection of initial data

The boundary of the dump No 2 is within the hollow and the dump occupies its entire area (see Fig. 1). The body of the protrusion in the plan is a complex isometric figure, the length of which is 490.6 m, and the maximal width from the outer boundary (on the arable field) to the boundary of the joint behind the sole of the protrusion with the ledge of the dump 111.9 m. The protrusion surface is presented by the complicated relief with atypical height differences complicated by violations (cracks). The body of the protrusion has: 46 thousand m^2 - the area of the base of the body of the three-dimensional model of the protrusion; 700 thousand m^3 is the volume of protrusion. In addition, there is a scree formed to the west of the protrusion due to a violation of the density of the ledge when moving rocks during the protrusion. It has the form of a dump ledge with an average height of 25 m and a length of 82.6 m, and a width of 78.5 m. The area of the scree base made 6.5 thousand m^2. The total volume (talus and protrusion) amounted to 850 thousand m^3.

Geo-mechanical studies of changes of the stress-strain state in the studied area were conducted in order to forecast the risk of formation of new centers of geodynamic phenomena and develop measures to prevent them. The geophysical method of the natural pulsed electromagnetic field of the Earth (NPEMEF), which was applied, is used in engineering and geological research to clarify the localization of processes and phenomena occurring [22]. An example of interpretation of measurement results is shown in the Fig. 2.

The rocks that form the basis of the dump: the modern division (q_{iv}) is represented by a soil-vegetation layer with a thickness of 0.1 - 0.5 m, upper quaternary sediments q_i are represented by two varieties: pale loams, pale yellow loess and brownish-yellow with the thickness of up to 4-4.5 m; middle quaternary sediments q_i are represented by two types of brown-pale and yellow-brown loams with a thickness of 0 to 8 m; brown and red-brown clays, which belong to the undismembered neogene-quaternary sediments lie in the form of lenses with a thickness of 1.6 to 13 m; below there are the primary kaolins with a thickness of 2.8 to 20 m.

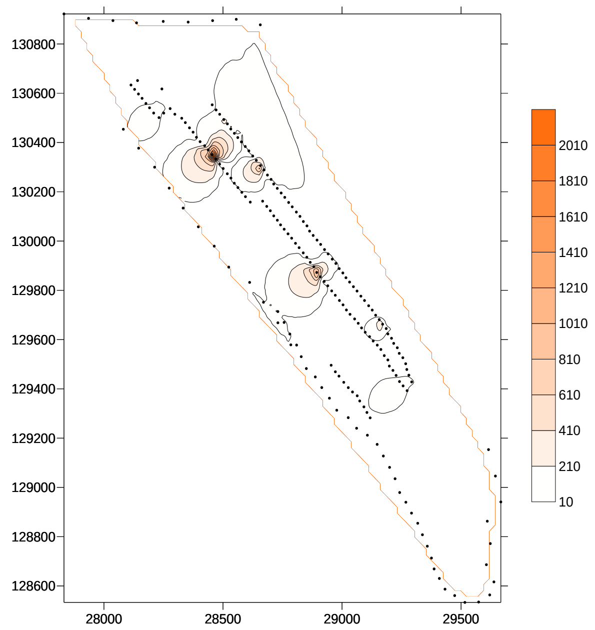


Fig. 2. Example of site interpretation of the study results using the NPEMEF method for creep zone (sliding rocks) at the dump No 2 in the Z plane (Color scale in mV)

7 Organization of calculations

As a result of geophysical studies of the dump No 2 of the Petrovsky open mine of the PJSC “COMPE” by the method of NPEMEF the following was established: the north-eastern side of the dump is currently stable, so the following description applies to the south-western side; cracking in the rock mass of the dump at the time of the study mainly occurs in the northern part; areas of rock landslides at the time of research are established in the northern part and in the area of deformation; the stress-strain state of the rock mass of the dump №2 is registered in the south-western section and at the workplaces of the equipment in the middle part of the dump; water migration is superficial; the groundwater mirror in some areas is in the range from 1.5 to 10 m; deep accumulation of moisture is not observed, as the modern and ancient relief promote drainage, and inflows of surface waters should be regulated by means of the water drainage channel.

The direction of groundwater migration along the axis of the hollow from the north to the south. It should be noted the possible presence of lenticular accumulations of water in the northern and middle part of the dump. The accumulation of groundwater in such lenses can lead to landslides in these areas.

To determine the stability of the dump the method is used proposed by the institute “VIOGEM”. From the upper edge of the slope shown in the Figure 3 in one of the scales adopted for surveying documentation, the value of the width of the slide prism *a* and the vertical value of H_{90} are set.

Studies have shown that the sliding surface of the slide prism for these conditions is smooth curvilinear, the form of which is close to round-cylindrical. The location of the most stressed surface in the rock mass adjacent to the slope coincides with the location of the calculated surface with a minimum safety factor. This surface is defined by stability calculations. Taking into account the obtained physical and mechanical properties of rocks, as well as when testing wells, it became clear that the rocks are not flooded. Therefore, the calculation is carried out under condition of limit equilibrium of forces.

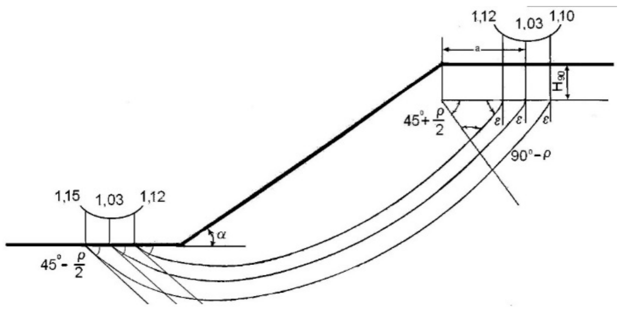


Fig. 3. The position of the calculated surfaces on the slope of weak rocks (ρ<13°, α<ε)

The condition of limit equilibrium in the algebraic addition of forces on the most stressed surface is written as follows:

$$\frac{\sum_{i=1}^{n} P_i cos\varphi_i \cdot tg\rho_n + \sum_{i=1}^{n} k_n l_n}{\sum_{i=1}^{n} P_i sin\varphi_i} = \frac{tg\rho_n \sum_{i=1}^{n} N_i + k_n L}{\sum_{i=1}^{n} T_i} \quad (1)$$

where P_i – the weight of the elementary blocks into which the prism is divided in the array, adjacent to the slope, limited by the most stressed surface, t;
l_i – square of the base of elementary blocks, m^2;
φ_i – incline angle of the base of elementary blocks, degrees;
ρ_n, k_n – features of resistance of sliding rocks, decreased by *n* times.

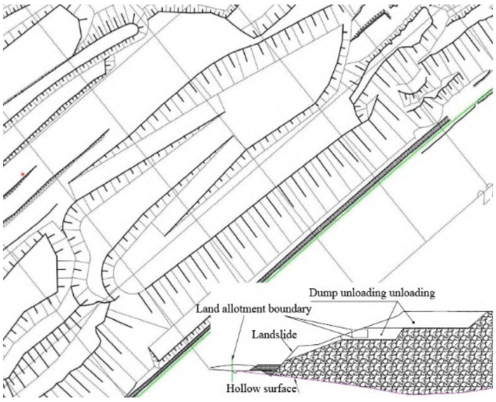
7.1 Options of the dump forming schemes

During the work performance it is offered to consider 3 variants of the decision of unscheduled works on the landslide liquidation (fig. 4).

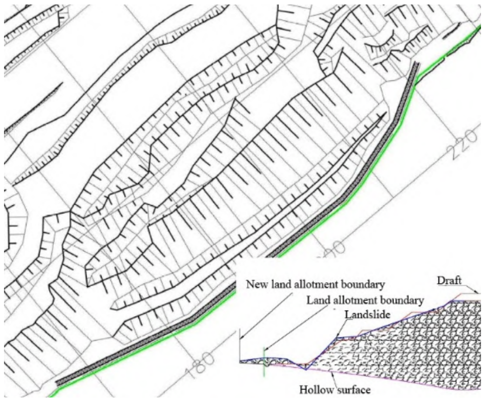
Option 1. Removing the landslide to the boundaries of the land allotment without allocating of additional land and determining the possibility of further storage the overburden rocks in this area (Fig. 4).

Option 2. To carry out land allotment on the slide section from slide action and to define possibilities of the further of overburden rocks in conditions of the formed landslide on the dump (Fig. 4).

Option 3. To carry out land allotment on a slide section in conditions of the formed landslide on the dump, to form a support prism from slide action and to define possibilities of the further storage of the overburden rocks (Fig. 4).



Option 1



Option 2

Option 3

Fig. 4. Technological schemes of the options for solving the problem of landslide.

Taking into account the determination of the residual capacity of the dump No 2, calendar plans for storage of the overburden rocks have been developed according to the options (Fig. 5), in thousand m^3.

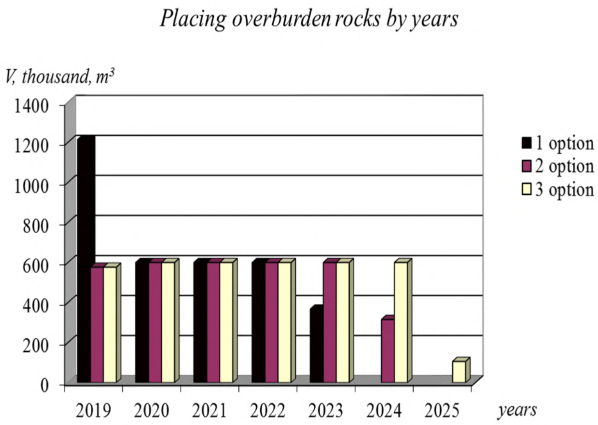


Fig. 5. Placing overburden rocks by years at the dump according to the work development options

7.2 Calculation of stability parameters

For different variants, taking into account the obtained sections, the safety factors were set. The calculation scheme for the option 3 is shown in the Fig. 6. Calculations were reduced to the search for sliding forces and restraint forces.

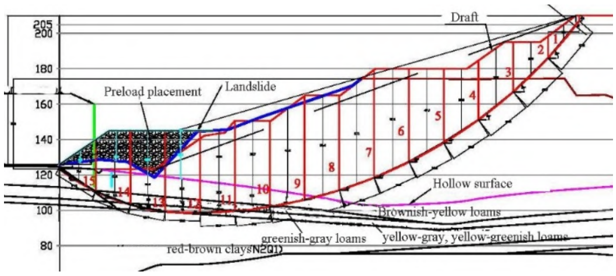


Fig. 6. Graphic part of the calculation of stability in the section surveying axis (s.a.) 180 (with loading)

At the initial stage, the following data on the safety factor were obtained (table 1) around the perimeter of the whole dump.

Table 1. Summarized table of the safety factors

	Current position	After slide removal	Draft state	Draft state with the loading by rock	Draft state with loading
Open mine 180(well PO-2, slide)	1.1	1.01	1.0	1.3	1.26
Open mine 180(well PO-7)	0.71	–	0.99	–	1.18
Open mine210(well PO-3, slide)	1.24	1.06	Almost current state	1.49	1.42
Open mine 210 (well PO-6)	–	–	1.24	–	–

Option 1 provides the removal of the landslide to the boundary of the land allotment. It is not possible to remve only landslide due to the reduction of the safety factor. To reduce the load on the dump, the option of removing a part of the rocks on the upper horizons between the marks +175 to +160 m is considered. According to the calculation data the safety factor at the survey open mine 210 s.a. for the dump after removal of the rocks with the formation of the resulting slope 15º makes 1.43 (Table 2). This figure is sufficient for a stable position.

When calculating the safety factor in the area between the marks +160.0 and +124.0 m, it was determined that this area is not stable (Ky = 0.87, Table 2). That is, significant volumes of landsliding are possible in this area.

Table 2. Summarized table of the safety factors

Open mine s.a.	**The total stability of the dump** after removal of the upper tier of the dump (+174.0 and + 160.0m) and bringing its slope to 15º	Stability of the **lower** tiers after removal of the upper tier	The stability of the lower tiers **after removal of the second tier** (+160.0 and +150.0 m) between s.a. 180 and s.a. 190	Stability of the lower tiers **after removal of the second tier** of the dump (+160.0 and +150.0 m) and **backfill of the support prism** between s.a. 180 and s.a. 190
s.a. 210	1.43	1.34	–	–
s.a. 180	1.62	***0.87***	***0.94***	**1.11/*1.24**

* – stability factor after laying a steep slope with the help of the excavator ESh-10/70 (between marks +150.0 m + 123.0 m)

The area that is prone to slide in the open mine s.a. 180 (Fig. 4, option 1) is marked with cells. To reduce the pressure of the upper rocks in the area of 160 m, it is necessary to remove a part of the rock mass on another horizon with marks from +160, 0 to +150.0 m. However, the stability in the area increases only to a factor of 0.94. Thus, this measure is also not enough. It is proposed to carry out backfilling with a prism at the base of this section after unloading the dump from the rocks of the upper horizons in the area between the surveying sections s.a. 180 and s.a. 190.

That is, according to the option 1, it is proposed to carry out a set of measures for removing the dump and return it in the boundaries of the land allotment in the area between the sections of the s.a. 180 and s.a. 190. Namely, the excavation of a part of the dump rocks in tiers with the marks of the first excavation tier +174.0 and +160.0 m and the second tier in the area between the sections s.a.180 s.a. 190 with marks +160.0 and +150.0 m. To increase the safety factor, it is proposed to move the slide rocks to the base of the dump and form a support prism with an upper mark of +129 m. The height of the support prism is 9.0 m. Landslide rocks are removed by excavator, are moved by auto dump trucks to the bottom of the dump and the supporting prism is formed by a bulldozer. The width of the top part of the prism is 20 m. The safety factor in the area of the dump between the marks + 1K50.0 and +129 m will be 1.11.

After removal of the part of the dump on the upper tiers where there was a landslide and the creation of a loading prism to the mark of +129.0 m to ensure the normative stability of the dump is proposed to laying down on the section with a steep slope using an excavator EK-10/70. 2. The summarized table on the safety factors with the removal of the dump landslide and the return of the dump in the boundaries of the land allotment is given below.

7.3 Recommendations for the obtained data on the stability of the dump slopes

According to the performed mining and geological studies, the rocks at the base of the dump do not have groundwater.

The calculated values of the open mines (see Table 1) indicate that it is possible to remove the landslide, but this will reduce the stability of the dump. Thus, the safety factor in the open mine s.a.180 under the current position is 1.1 and after removal works, it will be 1.01, which corresponds to the limit stability state. Thus, at some point the dump will be in a relatively stable state, but in the event of external factors, changes in the properties of the clays' rheologies at the base of the dump and in the dump, getting water and others, it will be prone to repeated landslides.

For open mine 180 in the area of drilling PO-7 will the stability adverse conditions will also appear. Measures to increase the stability is the reduction of the resulting slope inclination angle of the dump or the formation of the loading embankment at the base of the dump.

The data of the safety factor in the open mine 210 (Table 1) indicate that the current position in the sliding area of the dump is in a stable state (the safety factor is - 1.24), after removal works this figure will decrease to 1.06, i.e. the dump will be in a state of the limit equilibrium. At the moment of the slide removal at an unfavorable background (moisture, dynamic loadings, static loadings, change of clays' properties) repeated slide signs can appear. To increase the stability of the dump as well as when considering options for the open mine s.a. 180 it is proposed to load the dump in bulk at the base. The rocks removed from the open mine and stacked on the dump were taken into the calculations as the loading material.

Conclusions on the possibility of the option 1 (Table 2): It is proposed for removal the dump and returning it in the boundaries of the land allotment in the area between the sections of s.a. 180 s.a. 210 to implement a set of measures. To carry out excavation of waste rocks in tiers with the marks of the first excavation tier +174.0 and +160.0 m and the second tier in the area between the sections of s.a. 180 s.a. 190 marked +160.0 and +150.0 m. To increase the safety factor, it is proposed to move the slide rocks to the base of the dump and form a supporting prism with an upper mark of +129 m between the sections of s.a. 180 and s.a. 190, i.e. not along the entire length of the landslide, but only in the section with a length of approximately 160 m. The safety factor in the area of the dump between the marks +150.0 and +129 m according to the calculations will be 1.11. To increase the dump slope safety factor in the section, it is proposed to lay down the slope with an excavator EK-10/70. The EC excavator moves the rocks to the dump site with the mark +160.0 m, from where it is loaded into dump trucks with the help of an excavator and moved to the dump.

Option 1. Removal of the landslide, as well as the extraction of waste rock on the upper tiers is carried out by a hydraulic inverted shovel type excavator, and the laying down of the slope with EK excavator. Removal of the rock mass is carried out by the dump trucks to the dump where they are unloaded and placed by means of the bulldozer [23-25]. To remove the landslide, it is necessary to form a road, to lay down the power line and drive the EK excavator to the place of the landslide to the upper tiers. Landslide rocks are partially used to form the loading prism for this purpose a bulldozer must be used. When the landslide removal is finished with the help of an excavator, a trench of the water drainage ditch is formed and strengthening works are done with the placement of concrete slabs inside the ditch.

Option 2. The formed landslide remains within the existing limits. The works on construction a bypass ditch (see option 1) along the landslide with reinforcement works and the placement of concrete slabs are performed. Legislation regulates the issue of land allotment for the dump.

Option 3. The same works are performed as in the second option, but the road from the dump to the landslide is being reconstructed. A reloading point is organized at the dump. At the reloading point, the rock is shipped into dump trucks by an excavator and delivered to the landslide place. A pioneer embankment on the horizon of +145 m is formed in the area of the landslide site. The formation of pioneer and loading embankments is done by a bulldozer. The rock mass delivered by dump trucks is unloaded on the loading embankment and formed by a bulldozer.

From the point of view of technological decisions the third option is most effective, which allows to place in addition volumes of overburden rocks both in a loading embankment (385.14 thousand m^3), and to form a dump with a height within design contours providing the stability of the dump. Also, the technological solution is the formation of the dump with the landslide removal (option 1), for which it is first necessary to perform works to reduce the resulting slope angle by removing a part of the tiers of the dump and forming a loading prism at the base of the landslide.

Decisions on the effectiveness of options were made taking into account economic indicators.

To determine the economic indicators of options for the development of works on the dump the indicator *PVI* (Present Value of Investment) was used [26], which is calculated to obtain an idea of the current value of the total investment costs of the enterprise over the years. The decrease in this indicator against the background of an increase in discounted incomes from investments indicates an increase in their efficiency. The analytical expression of this indicator is as follows:

$$PVI = \sum_{j=1}^{m} \frac{I_j}{(1+i)^j} \quad (2)$$

where I_j – annual investments during *m* years.

To determine the amount of PVI per 1 m^3 of the rock mass, the costs were reduced to the initial moment of time, taking into account the discount rate of 15%. The reduced costs under the option 1 make only 68555.2 thousand UAH.

PVI per 1 m^3 of the rock mass will be:

68555.2 / 3381.675 = 20.27 UAH/ m^3

Thus, the net present investment costs under the first option will make 20.27 UAH per 1 m^3 of works related to the formation and reclamation of the dump.

Similar technical and economic indicators are determined under the 3 option. The net present costs under the option 3 make only 60081.03 thousand UAH. Thus, the net present investment costs under the option 3 will make 16.31 UAH per 1 m^3 of works related to the formation and reclamation of the dump.

60081.02 / 3682.985 = 16.31 UAH / m^3

Given that the target criterion for the effectiveness of the investment options is to minimize the cost of dump formation, it is the option 3 should be considered as one that provides a more rational use of investment resources.

According to the results of calculations in the table 3 the technical and economic indicators for the formation of the final contour of the dump No 2 on the CO MPE are shown.

The main operating costs for the formation of the dump over the years are shown in the Fig. 7.

Table 3. Technical and economic indicators

Name of indicators	Unit	Value for development	
		Option 1	**Option 3**
1. Dumping time	years	5	7
2. Total volume of overburden rocks stored	Thousand m^3	3381.675	3682.985
3. Mining and technical reclamation: -volume of cover soil	Thousand m^3	162.216	163.108
4. Biological reclamation: - Furrowing; Number of seedlings - trees - bushes	s.a., units	185248.0 63577 15578	195232.0 67005 16418
5. Mineral fertilizers	kg	6883	7260
6. Irrigation water during planting	m^3	1030	1086
7. Water for vegetative irrigation	m^3	4122	4344
8. Capital investments for the dump formation:	Thousand UAH	22792.752	15696.563
9. Operational costs - for mining and technical reclamation; - for biological.	Thousand UAH	15152.125 11505.066	15763.871 12150.998
10. Agricultural production costs	Thousand UAH	150.480	150.480
11. Net present total operating costs	Thousand UAH	68555.2	60081.02731
12. Total net present investments per 1 m^3 for forming and reclamation of the dump	UAH	20.27	16.31

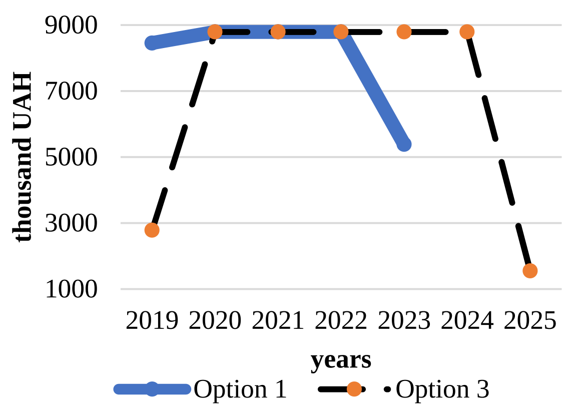


Fig. 7. Costs under the chosen options of the rock storage on the dump

8 Conclusions

1. As a result of the research of the dump No 2 of the Petrovsky open mine of the PJSC "COMPE" the following was established: the north-eastern side of the dump is currently stable, so the further description applies to the south-western side; cracking in the rock mass of the dump at the time of the study mainly occurs in the northern part; water migration is superficial.

2. During the operation of water-bearing communications (gutters) and the lack of the proper surface drainage, it is possible to soak the loess loams, which will reduce the deformation, strength characteristics and subsidence of the base soils, and as a consequence, negative processes of the rock mass extrusion [27-30].

3. Removal of the dump landslide to the boundaries of the land allotment can lead to repeated manifestations of rock slide. The dump will be in limit equilibrium, which is dangerous for machinery and people working at the bottom of the dump [31-34].

4. When forming the dump taking into account the formed landslide, there are two solutions for the further construction: the first one is the reduction of the dump height with observance of the angle of the resulting slope within 16 degrees and the second - construction of loading embankments in the formed landslide area. Loading embankments reduce the resulting angle and create additional load for the retaining forces.

5The calculation of costs for the formation of the final contours of the dump No 2: calculated costs for the creation of a drainage ditch, the land allocation costs, as well as operating costs for the formation of the main dump and its reclamation. It can be seen from the above calculations that the capital costs under the option 1 exceed the capital costs under the option 3 by 6918.549 thousand UAH. However, operating costs for the formation of the dump and the cost of reclamation are lower by 4434.19 thousand UAH and 1257,678 thousand UAH respectively. In order to be able to compare the costs of the projects, the net present investment costs for each of them are related to the formation and reclamation of the dump. Calculations have shown that the unit costs under the option 3 are UAH 3.96 less than the same indicator under the option 1. Thus, according to the criterion of minimizing the unit costs for the formation and reclamation of the dump No 2, the option 3 is more appropriate for implementation.

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Optimization of the drilling-and-blasting process to improve fragmentation by creating of a preliminary stress in a block

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Abstract. At mining and processing complexes, many parameters today are evaluated from the point of view of the total process from geology to the final product. Changes in certain mining parameters inevitable lead to the changes in the following downstream processes. In this article, the focus is on the ore fragmentation, which is one of the most important parameters in many mines as it affects the downstream ore preparation and processing efficiencies, productivities and costs. In most of the cases, the cheapest way to improve the fragmentation of the ore is by changing the drilling-and-blasting design parameters. It of course increases the mining costs, but at the same time decreases the costs of the following processes, which are normally significantly higher. Therefore, authors of this article propose a new way of optimization of the drilling-and-blasting process by introducing new blast design modifications. Based on the analysis, research of the scientific information and the mining practise, the authors discuss the way of creation of the preliminary stress in the block of the open pit and hence improving fragmentation. Physical experimental blasts in "Belaya Gorka" open pit were performed and shown positive results reflecting a potential for continuation of the research in this direction in the future.

1 Introduction

Mining industry is very competitive and requires mining companies to constantly improve their processes, costs and safety. From the sustainability point of view, there other environmental and safety issues at the existing mines and potential mining projects as well [1, 2]. From the technical point of view, many mines have problems with the decreasing grades of the components in their ores, increasing depths, more complex hydrogeological and geotechnical conditions and hence need new approaches to the processes of mining and processing, which today are not considered separately anymore as it was just one or two decades ago. One process affects the other due to their sequential link between each other and of course any implementation should be evaluated taking into account its complex effect on the company as a whole.

Today, the process of intensification of processing (including heap leaching) is done by applying various effects to the ore (physical, mechanical, chemical, biological), most of which are aimed at improving efficiency and reducing the cost of extraction of valuable components. Very often, ore fragmentation becomes one of the most important characteristics [3]. Therefore, for example, to obtain the required particle size distribution for heap leaching, ore coming from the open pit goes through several crushing stages. Of course, such mechanical crushing is expensive and sometimes makes from 8 to 18% of the total operating costs.

At the same time, the operating cost of the open pit mining is often several times lower than the cost of processing [4, 5], respectively, the cost of ore preparation during drilling and blasting operations is cheaper than mechanical preparation [6].

Therefore, it is obvious that the ore fragmentation during the drilling-and-blasting operations at the mining stage affects the following operations at the stage of processing and could give a positive economic effect to the company as whole.

Many technologies are used in the world today to improve the efficiency of blasting. For example, in works [7, 8], the authors describe the effect of empty blast holes on the nearest charged blast holes. In both cases, process modeling was performed to understand and describe the stress distribution in the mining block. Also, the authors of [6] do a calculation, where they show that more work done during the drilling and blasting process to improve fragmentation, save energy and work on the downstream processes, which further shows how the increase in the drilling and blasting cost leads to the decrease in the cost of the following crushing and grinding.

Considering that there are several ways to perform research on the new technologies, such as simulations [9], digital twins [10] or actual physical tests at the mines sites, where possible, authors of the work have performed physical blasting experiment at one of the

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open-pit mines. Of course, at the beginning, all the conditions and actual information on the performance of the mine were gathered for the future comparison with the research work's results.

2 Research

Blasting is a complex process, which is still not fully understood, even though a lot of research work is conducted to improve it. Many works are performed at certain conditions, which are hard to be replicated in the mining site, because every blasting block is different and it is impossible to consider the main parameters so that can be utilized as general ones. Knowing that the blasting process has many important characteristics affecting its efficiency, the research work has focused on one of the main ones, which is the stress wave that plays the main role in the mechanism of fragmentation of rocks by blasting.

2.1 Calculation methods

The method for calculating the parameters of stress waves was developed by the authors of [11, 12]. This technique was improved in works [13, 14, 15], while the author of work [13] tried to take into account the detonation velocity and the actual length of the charge. The considered algorithms and programs were strongly focused on the types of computer technology of that time and were not very suitable for carrying out a large amount of calculations.

He calculated the geometric parameters of the wave front arising around a charge of cylindrical symmetry, introduced and experimentally determined the rate of decrease in the conical section of the wave front. However, at the stage of determining the influence of the design parameters of a charge of cylindrical symmetry on the formation of a stress field in an unlimited medium, he did not take into account such an important parameter as the diameter of the charge. As a result, the calculation he proposed makes it possible to only qualitatively estimate the shape of the wave front, depending on the length of the charge and the detonation velocity.

The author of [14] eliminated these shortcomings, but considered the process of formation of a stress field from an elongated charge, which does not fully describe the real picture of the effect of stresses on the fracturing of a rock mass, since in practice, the blast holes are not blasted separately, but rather as a whole block of the blast holes.

In [15], a method for the numerical calculation of the parameters of the wave field of stresses from four blast hole charges is proposed. However, this technique did not take into account such important parameters of the blast-holes as the direction of initiation, the number of points of initiation. In addition, only radial stresses or stress wave components along the coordinate axes were calculated, which made it difficult to analyze over the entire calculated field.

To improve the quality of the ore to be broken and to reduce the cost of crushing it before leaching, a technology of crushing has been developed using the preliminarily created stressed state of the massif.

In our case, to study the influence of the preliminary stressed state of the massif on the quality of ore breaking, experimental blasts were carried out in the open pit, which has drilling-and-blasting process for the initial ore crushing.

2.2 Research site

The object of the study is the section of "Belaya Gorka" site, which is a part of the Rodnikovoye deposit, administratively located in the northern part of the territory of the Kokpektinsky district (on the border with the Zharma district) of the Eastern Kazakhstan region of the Republic of Kazakhstan.

Overall, the technological process at the site is fairly standard for the mining complexes. Mining and processing are performed with a cycle consisting of:

- drilling and blasting with the use SBU-100GA-50 drills;
- loading using backhoe excavators with the 2.2 m^3 bucket for waste and 1 m^3 bucket for ore;
- transportation of the mined ore to the ore stockpiles and waste to the waste dumps using 40 tonnes payload Belaz trucks;
- from the stockpiles the ore is sent to the crusher for preparation;
- prepared ore is sent to the heap leach pad for extraction of gold.

The mine has average grades of approximately 1.44 g/t. At the same time, because heap leaching is utilized the cost of processing is low, but the recovery is low as well (around 62%). Other geological and technical conditions of the mine are:

- Average uniaxial compression strengths of the rocks 78.2 MPa (46-111 MPa range) in the dry state and 55.6 MPa (5-97 MPa range) in the wet state respectively;
- Oxide and sulphide materials are present at the mine;
- Rocks are fractured, but pit walls are stable with some local failures;
- Batter face angles in the pit are 45-60º, with steeper parameters in the eastern (50-55º) and western walls (55-60º);
- Swell factors variate depending on the rock types from 1.27 to 1.75 (1.6 in average);
- Specific gravity also varies from 2.14 t/m^3 for the soft weathered material, 2.58 t/m^3 for the hard oxidized material and 2.72 t/m^3 for the primary hard rocks.

Based on the mining technical conditions of mine, the method of vertical blast hole charges with a short-delayed blasting was adopted. The blasting block that was chosen for the experimental blasts consisted mainly of sandstones and siltstones.

Drilling and blasting parameters were settled at the mine in the previous years of operation. However, some them, like burden, stemming and charge height are variable due to the presence of many different rock types.

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The list of the main blast design parameters are reflected in the table 1.

Table 1. Drilling and blasting design parameters.

Name	Unit	Parameter	
		ore	**waste**
Sub-bench or bench height	m	5	10
Blast hole diameter	m	0.11	0.11
Explosive density (grammonite used for the experimental blasts in the pit)	t/m^3	0.9	0.9
Specific gravity of the rocks	t/m^3	2.41	2.72
Burden of the first row of the blast holes along the bottom of the bench	m	4.8	6.6
Subdrilling	m	1.0	2.0
Blast hole depth (drilling depth)	m	6.0	12.0
Stemming	m	3.1-3.4	4.3-4.6
Charge height in the hole	m	2.9-2.6	7.7-7.4
Explosive specific consumption per volume of rock	kg/m^3	0.6	0.6
Burden	m	3.5-7.0	4.6-8.0
Spacing	m	3.2	4.1

The main explosives, which are used at the mine are:

– ANFO for the soft dry areas (mainly overburden and oxide ore);

– FortisExtra 70 for all the other ore and rock types;

– Grammonite is sometimes used as a replacement for the above-mentioned explosives.

SenatelMagnum with the cartridge diameter of 34 or 90 mm is normally used as a primer. However, in some cases, ammonite with the cartridge diameter of 34 or 90 mm and trinitrotoluene blocks (T-400) are used as well as a replacement to the SenatelMagnum.

For the conditions of this deposit, the blast holes in the ore blocks is drilled to the depth of 6 meters, so that the amount of explosive per 1m of the blast hole is P = 9.5 kg, the weight of the charge in the blast hole, taking into account stemming height of 3.1 m is Q_{bh} = 27.6 kg.

3 Discussion

It is known that the process of fragmentation of rocks by blasting occurs in very quickly and depends on many factors, which are not easy understand and research. There is still no internationally accepted exhaustive theory of the mechanism of fragmentation of rocks by blasting.

Assuming that during the process of blasting, the fragmentation of rocks is mainly determined by the energy of stress waves, the effect of blasting of a single concentrated charge in an unlimited homogeneous medium can be represented in the following form:

– During the blast, the walls of the charging block are instantly affected by the enormous pressure of the blasting products and a shock wave is generated;

– The compression stress at the shock front increases abruptly, the velocity of its propagation exceeds the speed of sound in the rock;

– The crushing resistance of even the toughest rocks is several times lower than the magnitude of the stresses arising at the wave front at the walls of the charged block;

– Particles of the rock receive radial movements and are displaced after the front of the shock wave;

– After the shock wave has passed, the pressure in the charged block drops, and the rock near the charge begins to expand towards the center of the charge and unload;

– As a result, a zone of highly deformed rock is formed;

– As you move away from the charge, the blasting energy is transferred to the ever-increasing mass of the medium, due to which the specific energy (J per 1 cm^3 of the block) decreases significantly. Compressive stresses drop rapidly with distance.

3.1 Rock crushing zones understanding

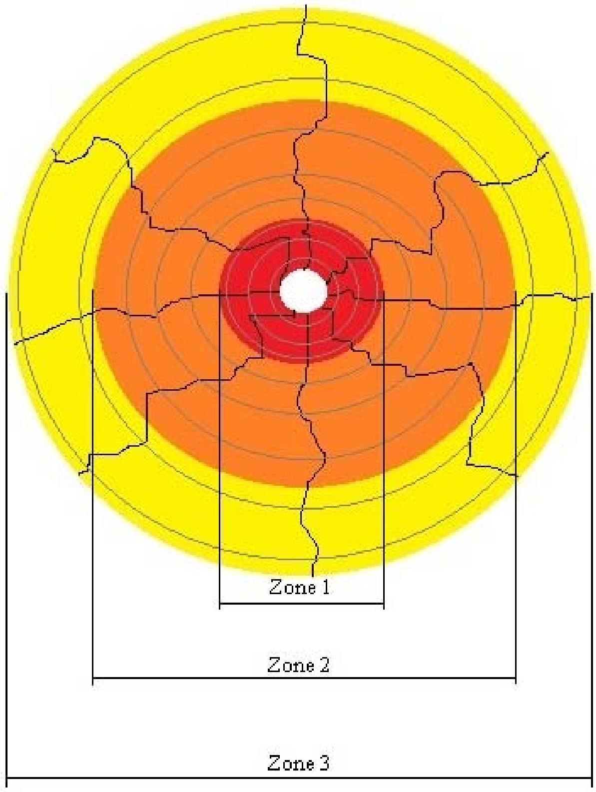

Fig. 1. Various zones arising from hole blasting (red – zone 1, orange – zone 2, yellow – zone 3.

Thus, when blasting holes in a quarry or pit where hard rocks are mined, several zones are distinguished [16]:

– the first zone is compression and plastic deformation, which, depending on various factors, is usually within 3-7 radiuses of the charge from the blast hole;

– the second zone - elastoplastic deformations and primary fracturing, in which rocks are crushed when subjected to tangential stresses creating tension. It is usually within 120-150 charge radiuses;
– the third zone is elastic deformation and fracturing, which, respectively, is outside the 150 radiuses of the charge.

All the above-mentioned zones are schematically reflected on the figure 1.

3.2 Blasting in a block

Thus, if we consider a theoretical block consisting of four blast holes located in a row, it can be understood that the least affected area is usually located in the center, at an equal distance from all holes, as shown in Figure 2.

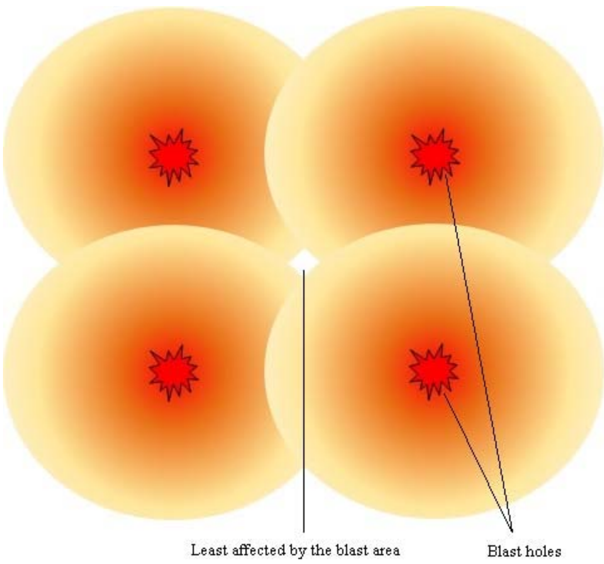

Fig. 2. Theoretical block, showing effect of the blast at the distance from the four holes, where color from red to white shows the intensity of fragmentation (white area in the center is the least affected by the blast)

Considering that, one of the major challenges in the production blasting is to have a rock mass with specific particle size distribution. The solution to this problem is possible by studying the above data, as hole as on the basis of a full research of the mechanisms of fragmentation of the rock, when impulsive loads are applied, which allows us to determine the optimal parameters of the pulse in specific mining conditions.

In our case, two or three rows of blast holes are used in the pit to fragment rocks. According to calculations, knowing the amount of the energy released by 1 kg of the explosive, and having the such parameters as the weight of explosive in one blast hole from the Table 1, the total potential energy of one hole is equal to:

$$E_p = E_e\, m_h\, 4.1868 \qquad (1)$$

where E_p – potential energy of the blast per one blast hole;
E_e = 1025 kcal/kg - energy released by 1 kg of the explosive;
m_h – mass of the explosive in one blast hole.

So, the total potential energy of the blast per blast hole equals to 118 444.57 kJ/kg, with a detonation speed of 3500 m/s, which is the rate of increase of the initial load on the hole walls.

On one side of the hole, this load is applied to the volume of the rock mass, one side of which is the bench face, i.e. free face, which is not loaded. On the opposite side, the blast shock wave coming from the blasting sets the momentum for the particles of rock. First, the particle velocity is calculated using the formula below:

$$\vartheta = \sqrt{\frac{2\eta q Q}{p}} \qquad (2)$$

where η = 0,05 – blast efficiency coefficient;
q = 0,6 – explosive specific consumption from the Table 1, kg/m^3;
Q = 4291 – specific heat of the blast of the specific explosive, kJ/kg;
ρ = 2410 – specific gravity of the rock, kg/m^3.

So, the particles velocity for our specific scenario is approximately 0.33 m/s.

Further, having calculated the velocity of the rock particles during the blast, it is possible to calculate the kinetic energy of the blast, required to throw away the first layer of rock with a volume of V = 227 m^3 using the following formula:

$$E_k = \frac{m\vartheta^2}{2} \qquad (3)$$

where m = 547 t – mass of the 227 m^3 of rock of the first row;
ϑ = 0.33 m/s – velocity of the particles of the rock during the blast.

The kinetic energy required to throw away the first layer of rock would be equal to E_k = 29.8 kJ. The amount of energy released from the blast hole charge is E_{bh} = 118 444.57 kJ, which means that a little energy is used for blasting of the first row and the rest of it is dissipated in the other blasting zones, used for the heat generation and etc.

Knowing this, blasting zones can be calculated using the known radius of the charge (55 mm as the hole diameter is 110 mm) for the specific conditions of the mine:
– Zone 1 is assumed to be 7 charge radiuses and equal to 0.385 m;
– Zone 2 is assumed to be 120 charge radiuses and equal to 6.6 m;
– Zone 3 is assumed to be 150 charge radiuses and more, and equal to 8.25 m.

Having studied in more details the technology of fragmentation of rocks in the open pit, we made a proposal for the classical technology of accounting for the initial stresses obtained from the blasting of the first row of holes, which made it possible for us to clarify the delay time of the second row of blast holes.

Further research of the process of fragmentation of rocks has shown that when the blasting of the second row with a delay, the initial stress is used, only in the section between the first and second rows of blast holes, and most of the area is fragmented by crushing the rock using the power of the blast wave, which several times exceeds the ultimate strength of the rock mass. The remaining part has mainly closed cracks, which, when blasting the next row of holes, do not contribute much to crushing. In the interval between the side of the open pit and the first row of blast holes, the rock is crushed by the tension wave, which occurs when the blast wave is reflected from the free surface of the pit wall.

4 Proposed technology

To use the initial stress for the purpose of crushing the rock during the blasting of holes in a block, an updated blast design layout of the holes shown in Figure 3 was proposed.

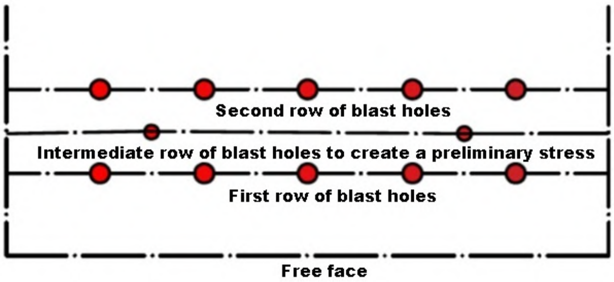

Fig. 3. Proposed holes layout (two standard rows of the blast holes and one intermediate).

In order to create an initial stress in the entire area of the breakage intended for fragmentation, an additional row of charging holes is created, and the blasting power of additional holes should not exceed the ultimate strength of the rocks being crushed. The burden is determined for each case separately, taking into account the mining and geological conditions of the field and the radiuses of the blasting zones. The distance to the additional row of holes and the distance between the holes are selected taking into account the burden of the first row of holes, and all holes along the surface must be at an equal distance from these holes. Thus, an elastic stress wave can be created, which will not fragment the rock, but rather create the initial stresses for the further more homogeneous fragmentation of rock by the main blast. Overall, the assumption is that the best place for the intermediate holes is at the border of the second and the third blasting zones.

The blasting of the first row of blast holes must be made at the moment, when the wave of the firstly blasted row of intermediate holes passes the first row of blast holes and creates an initial preliminary stress. In order to match the timing, the delay time between the intermediate row and the first row of the blast holes should be calculated. The effect obtained with such blast delay will provide interference of stress waves, which will facilitate their action and increase the effect of fragmentation produced in the block.

The delay time (interval) between the initiation of the intermediate and the first row of the blast holes is determined using the following formula: [17, 18]

$$t = \frac{\sqrt[2]{a^2 4\, W^2}}{\vartheta_s} \qquad (4)$$

where a – is the distance between charges, m;

W – burden of the blast holes along the bottom of the bench, m;

ϑ_s - velocity of shock wave propagation in the rock mass, m/s.

When using the proposed formula above, the average delay should be equal to 32 ms.

5 Results

To establish the influence of the initial or preliminary stress on the quality of ore crushing, a new blast design was proposed. The existing blast design of the “Belaya Gorka” site was adjusted with an addition of an intermediate row of blast holes, which were placed at the border of the second and the third blasting zones calculated for the specific conditions of the mine. The purpose of such intermediate row was to create a preliminary stress to improve the final block fragmentation.

After the changes in the blast design, in order to test its effect, limited amount of experimental blasts were carried out in the open pit with the fragmentation analysis of the crushed ore determined immediately after the blasts, at the block in the open pit using photos with the planimetric method of measurements.

As the result, the fragmentation analysis the crushed ore using standard blast design has shown that the amount of pieces of ore up to 300 mm in size averaged 48%, while the fragmentation with the proposed technology has shown that the amount of the same size pieces averaged at 73%, which meant that the fragmentation has improved by approximately 25%, which exceeded the expected results.

6 Conclusions

There is a new technology proposed to improve the efficiency of the fragmentation of rock during the drilling and blasting process in the open pit mines, which considers several important factors of blasting, like:

– zones of blasting;
– charge diameters;
– delays;
– other blast design parameters;
– properties of rock;
– geological and technical conditions of the specific mine.

In order to create an initial stress on the mining block intended for fragmentation, the following technology has been proposed:

– an additional row of charged holes with a certain spacing should be drilled in between the existing rows;
– the holes should be loaded so that the blasting power of them does not exceed the ultimate strength of the rocks to be crushed;
– these additional holes should be blasted first;

– blasting of the subsequent rows of holes must be carried out taking into account the level of the initial stress of the rock mass, which can be adjusted by the interval of deceleration of blasting depending on the physical and mechanical properties of the rock mass and the radiuses of the blasting zones;

– for the conditions of the "Belaya Gorka" site, the delay interval should be taken as 32 ms, for any other conditions the delay should be recalculated.

Once the intermediate row is blasted, the created by it elastic waves create an initial stress and open and closed cracks, but at the same time do not break the rock. Further, blasting of the first row of blast holes must be performed at the moment, when the wave of the blasted row of intermediate holes passes the first row of blast holes and creates an initial preliminary stress. In order to match the timing a delay time should be calculated. The effect obtained with such blast delay will provide interference of stress waves, which will facilitate their action and increase the effect of fragmentation in the block.

Approximate increase in the works required during the drilling and blasting process due to the addition of an intermediate row of blast holes is 15 to 20%, while as the experimental blast has shown the improvement in the ore fragmentation can be expected at an approximate level of 25%. So, if we take into account that the works during the mining processes are normally cheaper than the works performed during the mechanical ore preparation and processing, we can assume that the additional mining costs will eventually give larger savings in the costs of the downstream processes. So, the results obtained justify the further continuation of the research in this area and a necessity in a wider experimental work with more semi-industrial blasts in the operating mines, in order to perform a calculation of the full economic effect that this technology can provide.

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Application of membrane processes in mining and mineral processing

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Abstract. Sustainable mining and mineral processing is of paramount importance for producing metals needed for our society development. Membrane processes are able to contribute to the comprehensive extraction of metals from mined ores, while at the same time decrease the amounts of used water and reagents and ensure discharge to the environment of wastewater meeting the legislation requirements. Membrane-based technologies are still underused in metals obtaining although their development and price have made their application affordable. The paper presents in brief membrane processes and displays examples of their application in various areas of mining and mineral processing, such as coping with acid mine drainage and mine influenced water, recovery of metals, reagents and water in hydrometallurgy, recovery of lithium from brines, and treatment of wastewater. Emphasis is placed on pressure driven membrane processes, as well as on the very recent studies in the area. Advantages of membrane processes application in mining and mineral processing are pointed out as well as constrains to be overcome.

1 Introduction

The sustainable development of our society and our normal life needs metals - ferrous, nonferrous and minor. For the present, all metals can be ensured in required amounts only by the "chain" mining - extractive metallurgy (mineral processing, hydrometallurgy, pyrometallurgy and electrometallurgy).

Ores extraction by mining and metals extraction by mineral processing and/or hydrometallurgy are related with generation and /or use of different aqueous streams. When sulphide minerals, such as pyrite are disturbed by mining activities and exposed to oxygen and water chemical reactions take place - finally leading to formation of acidic water containing sulphates and ions of various metals in elevated concentrations, i.e. the so called acid mine drainage (AMD) is formed. When it is not treated, the AMD can result in a considerable pollution to both soil and groundwater [1].

Membrane technologies have been and are being studied for removing and concentrating different metals from AMD [2-5].

Generally, flotation is most effectively carried out with clean water. Changes in water quality are unwanted because this could affect the reagent regimes, finally resulting in compromise of the flotation performance. It is known that water quality impacts the flotation results and the following negative effects can be observed: loss of separation efficiency, loss of recovery, loss of concentrate grade, contamination of products [6]. At the same time the minerals industry is being requested to save freshwater by using recycled water and to minimize the discharge of wastewater into the environment. Since the flotation efficiency can be affected by the water quality, different approached have been and are being developed to cope with the problem. Among them membrane technologies are being studied to remove metal ions and improve the quality of water used in flotation [7].

Nowadays the shortage of many metals necessary for the modern economies, in combination with the increasing demand and the need to use low-grade ores, requires more efficient technologies for metals extraction. Hydrometallurgy plays a key role in processing and recovery of metals from challenging raw materials. Traditionally hydrometallurgical flowsheet includes i) ores leaching, ii) purification of the pregnant leach solution (PLS) by solvent extraction followed by stripping or by ion exchange followed by elution, and iii) metal recovery - where in many cases electrowinning is applied. In the latter case use of membrane technologies to pre-concentrate PLS is regarded recently as an way for lowering the energy consumption, enhancing the recovery of valuable metals and ensuring high recovery of reagents and fresh water [8].

Lithium (Li) is a very important metal in the production of rechargeable batteries, ceramics and glass, as well as lubricating greases. It is used in metallurgy (as casting additive, flux and alloying element) and in many other industries. Lithium can be extracted from either hard rock minerals and brines. Salt brines represent the most abundant lithium sources. They comprise approximately 60% of all known lithium deposits [9]. In the recent 10-15 years extensive work has been carried out to improve

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Li recovery from brines by applying membrane technologies.

Membrane technologies have been and are being widely studied and applied to recover valuable metals from wastewater from mineral processing and extractive metallurgy while at the same time ensuring high quality of treated water. Even more, they may be applied also to leachates from mining waste.

Figure 1 presents a summary of the possible applications of membrane technologies in metals extraction.

Membrane technologies have been existing for around 50 years, but they are still not widely used in the general mining industry. That is why this paper aims at shedding some light on the opportunities presented by the membrane processes for more profound use of resources and sustainable production of metals, with an emphasis on the recent (3-4) years.

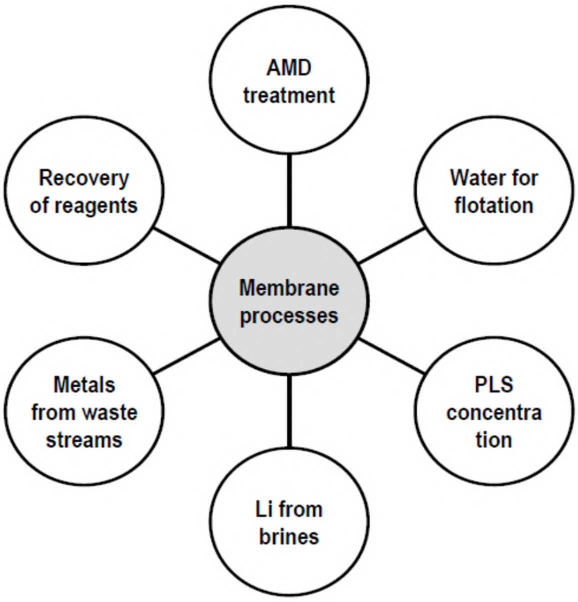

Fig. 1. Possible applications of membrane technologies in metals extraction

2 Membrane technologies in brief

Membranes are semi-permeable structures or films of materials that allow only certain species or substances to pass and prevent passage of others.

Different forces can drive substances to pass trough membrane - Table 1 [10].

Although there are some studies devoted to application of emulsion liquid membranes and supported liquid membranes techniques for extraction and recovery of metals from liquids (wastewater, waste liquids) the works on these applications are not so many and they are dealing with specific cases of extraction [13, 14].

Membrane distillation that can operate at low temperatures (60-90°C) enables the use of waste heat and thus seems a promising technology [15].

Forward osmosis is considered also a promising technology since it does not require a pressure application.

Table 1. Membrane processes classification based to the driving force

Driving force	**Membrane process**
Pressure difference	Microfiltration - MF, Ultrafiltration - UF, Nanofiltration - NF, Reverse osmosis - RO
Electric potential difference	Electrodialysis - ED, membrane electrolysis - ME, (membrane) electro-deionization -EDI, membrane electrophoresis
Chemical potential difference	Pervaporation, Per-traction, Dialysis , Vapour permeation, Liquid membranes - LM, Forward osmosis - FO
Temperature difference	Membrane distillation - MD

However, both MD and FO are evaluated as emerging membrane-based technologies and still enough studies and data are absent on their application [16].

Electrodialysis has been studied as a method for recovering the reagents and metals from stripping solutions [17], separating and recovering lithium from brines [18-20] and even in the mineral extraction from deep see water [21]. However these applications are still in the study stage.

The most studied and used membrane techniques, including in mining, mineral processing and extractive metallurgy, are based on a pressure difference between membrane feed and permeate sides - Table 2.

PDMPs performance generally is evaluated according to the following characteristics:

- Trans-membrane flux (J_v) [m/s]:

$$J_v = V_p / S_m \text{ x } t_p) \tag{1}$$

where: V_p - the volume of permeate [m^3], S_m - the surface of the membrane in contact with the flux [m^2], t_p - the time [s]

- Solute passage P

$$P = C_p / C_f \tag{2}$$

where C_f is the solute concentration in the feed and C_p - its concentration in the permeate

- Solute rejection (retention), in %

$$R = (1–P) \times 100 = (1–C_p/C_f) \times 100 \tag{3}$$

- Selectivity coefficient

$$(\alpha_{1/2}) = P_1 / P_2 = [C_p/C_f]_1 / [C_p/C_f]_2 \tag{4}$$

When retentate is concentrated to a small volume, the volume concentration factor (VCF) is determined

$$VCF = V_f / Vr \tag{5}$$

where V_f is the volume of the feed at the start of filtration and V_r is the retentate (concentrate) volume.

- Recovery

Table 2. Pressure driven membrane processes (PDMPs) [1, 10-12]

Process	Microfiltration	Ultrafiltration	Nanofiltration	Reverse osmosis
Membrane material[1]	CC, PP, PS, PVDF, CA	CC, PS, PVDF, CA, TFC[2]	CA, PVDF, TFC	CA, TFC
Membrane structure	porous, symmetric or asymmetric	microporous, asymmetric	tight porous asymmetric, thing film composite	dense, semi- porous, asymmetric
Retained diameter, μm	0,1 -10	0,01 - 0,1	0,001 - 0,01	< 0,001
MWCO[3], kilo Dalton	100 - 500	20 - 150	2 - 20	0,2 - 2
Operating pressure, bar	< 2	< 10	< 35	< 75
Separation mechanism	size exclusion	size exclusion	combination of size exclusion and solution diffusion	solution diffusion[4]
Permeate flux	high	high	medium	low
Usual module configuration[5]	tubular, hollow fiber	tubular, hollow fiber, spiral wound, plate-and-frame	tubular, spiral wound, hollow fiber	tubular, spiral wound, plate-and-frame
Examples of rejection	bacteria, micro-particles, fat, oil, grease, colloids	macromolecules - proteins, pigments, polysaccharides, detergents, viruses	high molecular weight compounds, polyvalent ions	high and low molecular weight compounds, poly- and monovalent ions

[1] CC - ceramic, PP - polypropylene, PS - polysulfonic, PVDF - polyvinilidene fluoride, CA - cellulose acetate, TFC - thin film composite membrane
[2] The RO and NF membrane presently of choice worldwide is the polyamide TFC. TFC membranes, composed of a strong asymmetric support membrane and a thin dense polyamide toplayer, have a higher permeability and can be used at higher temperatures at a broader pH range, compared to the others. Cellulose acetate membranes are chlorine resistant while TFC membranes have low resistance to chlorine.
[3] Molecular weight cut off range
[4] Solutes dissolve in the membrane material, then diffuse through it due to the concentration gradient. The separation is based on the differences in the solubilities of the solutes in the membrane and the different diffusion rates.
[5] There are four membrane configuration types for treatment systems: plate-and-frame (flat membranes sandwiched between membrane support plates which are arranged in stacks), spiral wound (flat sheet membranes separated by spacer screens and wrapped around a central core of a perforated collecting tube), hollow fiber, and tubular.

$$\text{Recovery, \%} = m_{P,end} / m_{F,\ ini} \tag{6}$$

where - $m_{P,end}$ - permeate mass at the end of the experiment, $m_{F,\ ini}$ - feed mass at the beginning of the experiment.

The permeate flux in membrane separation process, which determines its productivity, depends on the properties of the membrane, properties of the feed solution, trans-membrane-pressure, solute mass transfer coefficient (which influences the concentration polarization), membrane fouling.

The main factors influencing the selectivity and permeability of PDMPs are the pressure applied over the treated water (working pressure), the temperature and acidity of the treated water, the concentration and nature of the salts dissolved in the treated water.

The concentration polarisation and the fouling are the main factors affecting membrane performance. Concentration polarisation is the observed differential solute concentration between membrane surface and bulk stream. It is reversibly influenced by operation parameters. The fouling is formation of deposits on the membrane surface. It is irreversibly influenced by operation parameters.

3 Membrane technologies for treating AMD and mine influenced water

The high concentrations of sulfate ions and metals in AMD pose a severe risk to the environment.

Most often lime is added to AMD to raise its pH and precipitate the dissolved toxic harmful metals. However, the sludge produced by this process has no economic value and has to be disposed of, covering large areas of land. Acid mine drainage can be effectively processed and made satisfactory for discharge using membrane technology.

Studies on membrane processes application for treating AMD commenced at the 90-ties of the previous century with an emphasis mainly on RO.

Probably one of the earliest applications of membrane technologies was at Cananea de Mexicana where a full-scale RO - based plant was installed in 1997 to treat AMD - with copper recovery directly from concentrate - thus the process was paid back within 6 months [22].

NF and RO (single pass units) were applied successfully at the Kennecott Utah Copper's Bingham Canyon Mine Water Treatment Plant, now property of Rio Tinto Group, to treat AMD (pH 2,9 - 3,4, SO_4^{2-} - 73,8 g/L, Mg - 9,9 g/L, Al - 5,96 g/ L, and Ca, Cu, Fe, Mn, Zn - in the range of 0,150 - 0,599 g/L, TDS - 92 g/L) and contaminated groundwater. The solute retention for all pollutants was higher than 97 %. The main encountered problem was gypsum scaling [23].

Zhong and co-authors tested commercial polyamide ultra-low pressure reverse osmosis (ULPRO) and nanofiltration (NF) membranes for their ability to remove heavy metal ions from AMD. Rejections achieved were 97 % and 95 % respectively pointing at the possibility to recover metals from the concentrate obtained. In addition ULPRO removed also a major part of the dissolved monovalent ions thus decreasing the total water conductivity by 96% and rendering the treated water suitable for irrigation purposes [24].

Results from studies and applications of RO, ED, NF and UF for the treatment of AMD and mine influenced water (MIW), carried out till 2008, are comprehensively presented and discussed by Mortazavi [25].

A group of scientists at Freiberg University of Mining and Technology studied (2008 - 2010) the applicability of different RO and NF membranes for treating AMD. Experiments were carried out at two different pressures of 20 and 30 bar and at two different concentration levels in order to resemble the concentration range of actual AMD found in the mining industry. The results showed that NF membranes (NF99, DK, GE) successfully treated AMD, the heavy metals rejection was > 98% at higher fluxes and at lower pressure (consequently energy consumption) compared to RO. The DK membrane performed in the best way since it showed the highest rejection even at low studied pressure (20 bar) and high AMD concentration. The treatment has also been successfully conducted on a large scale in order to check its applicability at a commercial scale [3, 26, 27].

In 2010 the Interstate Technology and Regulatory Council (ITRC) at the Environmental Research Institute of the States announced that any one of the pressure driven membrane processes can be implemented to treat MIW, including surface and ground water [12]. According to ITRC the treatment goal(s) determine the process selection. The application of a given PDMPs generally depends on the: a) water quality requirements for the permeate (i.e., product water), b) location and source of water needing treatment, c) availability of utilities, d) options to dispose concentrates (retentate), e) quality of the water to be treated. Actually RO was successfully used to treat MIW rich in sulfates and TDS to achieve drinking water standards [28].

The EMalahleni water treatment plant (South Africa) was a solution for treating the coal mining industry influenced water in a reclamation project. AMD was collected from 3 mining sites, neutralized by lime addition which removed iron, magnesium and aluminium. After the clarification water was treated with UF and RO to produce potable quality water. The membrane separation step was repeated 3 times to maximize water recovery and minimize the concentrate volume. The feed water contained mainly calcium, magnesium and sulphate, with a small concentration of monovalent ions (sodium, chloride and potassium), and iron, manganese and aluminium [2, 29].

Dow NF 270 polyamide thin film and a TriSep TS 80 polyamide thin film nanofiltration membranes were studied for their ability to remove and concentrate ionic species from MIW in wide range of pH values of the polluted water [30]. The study proved that NF can be successfully used to achieve metal recovery objectives and meet discharge standards.

A study was carried out with the aim to assess the applicability of RO and NF to treat AMD from gold mines, as well as the main operational conditions. The results pointed that the NF had a higher potential to treat the AMD than the RO, since NF ensures higher permeate flux and satisfactory solutes retention efficiency. The best results were obtained with NF270 membrane at feed pH of 5,5 where the maximum water recovery rate was 60%. The estimated capital cost of the UF-NF unit at an effluent volumetric flow rate of 15 m^3/h was US$ 131250,00, and the operational cost was 0,263 US$/$m^3$ of effluent [31].

A very recent study has been carried out at a pilot-scale level with real AMD in order to determine and estimate the operating conditions for using a commercial NF membrane (NF270) to recover water and concentrate copper, as well as to find how NF can be coupled with SX for the selective copper recovery [32]. The water was acidic (pH 3,5) with high conductivity (5510 μS/cm) and high concentrations of some pollutants, in g/L: 4,67 SO_4^{2-}, 0,53 Cu, 0,38 Al, 44,70 Zn, 72,0 Mn. The study has proved that the combined NF-SX technology achieved a high recovery of water and copper from AMD. Thus, freshwater consumption can be reduced and wastewater treatment costs can be decreased.

Since UF works on low operating pressure (consequently energy consumption) and at high water recovery, studies have been carried out to use this membrane process to treat AMD and MIW. However, a means had to be found to modify the pollutants so that they could be retained by the larger pores of UF membranes. Here came to aid application of surfactants and polymers and micellar enhanced ultrafiltration (MEUF) and polymer enhanced ultrafiltration (PEUF**)** were proposed. PEUF is based on use of water-soluble polymer to complex metallic ions. The formed complexes possess a higher molecular weight than the MWCO of the membrane. The complex is retained by the UF membrane. Further, the retentate can be treated to recover metallic ions and polymeric agent for reuse. The polymers used (polyacrylic acid, polyethyleneimine, diethylaminoethyl cellulose and humic acid) achieved selective separation and high recovery of heavy metals with low energy requirements [33].

The MEUF is based on the use of a surfactant in the feed stream of the UF process. Dissolved ions which are intended to be separated are attracted by oppositely charged surfactant molecules. They attach to the surface of a micelle formed when the concentration of the surfactant exceeds the critical micelle concentration. Thus formed large ion-micelle complexes can be retained by the ultrafiltration membrane. Ions that are not attached to the surface of a micelle can penetrate through the membrane pores because of their small size. A drawback of MEUF is that it can cause secondary pollution to the environment if the used surfactants are leaked to the permeate. That is why, biosurfactants have been developed [15]. MEUF was successfully applied at pilot level to remove Cd and Cu from phosphorous rich real wastewaters [34].

Very recently a combination of FO and RO processes was proposed for treatment of mining wastewater [5]. Results from a pilot scale FO-RO (with a capacity of 1 m^3/day) pointed that this process could offer reduction in use of energy, chemicals, and piping infrastructure.

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4 Membrane technologies for PLS concentration

Mainly gold and copper mines have invested in membrane systems to concentrate their PLS **[4]**.

In the early 90-ties of the previous century HW Process Technologies, Inc. installed at Freeport McMoran Phelps-Dodge Rod Mill El Paso one NF and two RO systems to treat H_2SO_4-based Cu-bearing PLS from heap leaching in order to increase the feed copper concentration to the SX/EW plant, reuse the permeate from the second RO system as rinse water, while the concentrate from the 1st RO system is passed also through a NF system. The NF concentrate was directed to copper refinery, while NF permeate was sent to Cu dissolving. In this way a Zero-Liquid (waste)-Discharge was achieved [22].

In 1999 the same company obtained an US patent for method for separating gold and/or silver from copper or other contaminant metals in which a NF membrane is used to form a retentate containing most of the multivalent metal cyanide complexes and a permeate, containing most of the precious metal cyanide complexes [35]. In next stages the precious metal(s) can be recovered from the permeate and the other valuable but non-precious metals - from the retentate where they present as multivalent metal cyanide complexes.

Minera Yanacocha is the largest gold producer in South America. Its mining and processing operations are in the Andes Mountains at height in the range 3500 - 4100 meters. The gold is extracted by heap leaching with diluted cyanide solution (30 - 50 mg/L free cyanide). Seven RO modules are installed (initial installation in 2003) at Yanacocha complex (250 m^3/h each one) and five excess water treatment plants, two carbon plants for recovering precious metals, and two Merrill Crowe processing plants [4]. During the rainy season, the PLS is being diluted and RO plants are used to dewater the PLS making the Merrill-Crowe gold extraction process more effective. Additional RO plants are installed to remove the cyanide and metals left and to allow the permeate water to be discharged and the concentrate to be returned to the extraction process. At the same time chlorine consumption (for cyanide destruction) is reduced by 75% and overall operating cost is 70% less than that of a conventional precipitation plant [22].

Because of the harmful impact of copper-cyanide complexes on the gold extraction process, the use of NF for separating $Au(CN)_2^-$ from $Cu(CN)_3^{2-}$ has been studied. Soldenhoff and co-authors reviewed some patented NF processes for gold processing designed to ensure separation of $Au(CN)_2^-$ from $Cu(CN)_3^{2-}$ in copper-rich cyanide solutions [36]. This separation can be realized by treating either the PLS from cyanide leaching operations or the loaded eluate from activated carbon extraction.

Treatment of copper-gold cyanide PLS from heap leaching where it is fractionated into a small, 1/10th, volume copper concentrated stream and a large, 9/10th, volume gold-bearing stream has been proposed [37]. The copper stream is processed further by sulfide-acid-re-neutralization-treatment to recover copper and return cyanide back to the process. The gold-(or gold-silver) permeate stream is processed to recover gold and the cyanide (concentrated by a membrane process from the barren solution) can be returned to the leaching. Thus both permeates and concentrates from the applied membrane processes provide added value.

Studies have been conducted also on membrane processes application to PLS from a pressure-oxidation (POX) of refractory gold ores [38, 39]. POX represents a hydrometallurgical oxidation of concentrated ore pulp under high pressure (20 bar) and temperature (135–200 ºC). During the pressure oxidation process, the sulfide in the host mineral matrix is oxidized by oxygen, thus producing soluble metal sulfates and sulfuric acid. In this way, the gold originally occluded in the sulfide minerals is completely released, allowing further high gold recovery by cyanide leaching. POX is efficient process for refractory gold ores but it generates a large volume of liquid effluents, characterized by high acidity and substantial metal content, and some of metals (Cu, Co and Ni) are of great economic value. The aim was to concentrate metals, and recover acid and water by applying combination of UF, NF and RO. The UF process is used as a pretreatment to avoid presence of suspended solids in the feed to NF system. NF membrane concentrates Cu, Co and Ni. An average concentration factor of 2 was observed for metals in the NF retentate. This concentration was favorable to subsequent recovery processes of metals (Co, Ni and Cu). The NF permeate (a metals-free solution with a low concentration of acid) is passed to the RO stage. There the acid is concentrated in RO retentate (with 2,5 times higher concentration of the H_2SO_4 and low impurity content - totally 0,58 mg/L) and could be recirculated to control acidity in the POX process. The RO permeate was water with quality for industrial reuse in the company. The best performance at a pilot-scale operation was while operating at recovery rate of 90%, 40–50%, and 50% for UF, NF, and RO, correspondingly. The total estimated cost of the proposed treatment was US$ 1,137/m^3 of effluent, including the neutralisation of UF and NF concentrates. A long-term work in a mining company validated suitability of the proposed treatment scheme. The same working group conducted further studies to find the most chemically stable membranes in order to increase the process sustainability [40]. Commercially available NF membranes (NF90, NF270, MPF34, DK, Duracid) and RO membranes (BW30, LP, TFC-HR, XN45, and SG) were assessed in terms of key performance parameters. The DK (as NF) and SG (as RO) membrane showed the highest capability for application in POX effluent treatment.

Application of membrane process has been studied and proposed also for recovering nickel from spent nickel electrolyte after electrowinning of Ni from purified PLS of the base metal refinery in the PGM cycle (Bushveld Complex, South Africa) [41]. Energy costs limit the recovery of nickel in the electrowinning unit to 50% thus making the recycling of the spent nickel electrolyte significant for cost-effective nickel production. In the "classical scheme" four units are necessary for nickel concentration and sending back to the cycle. They are replaced by one NF unit. The retentate stream where nickel is concentrated is recycled back to the nickel electrowinning cells together with the sodium sulphate to ensure the needed conductivity while the permeate is recycled back to the leaching circuit in order to reduce the overall sulphuric acid consumption of the base metal refinery.

Very recently a study has presented a promising process chain for the separation of Ge and Re from an acidic multicomponent PLS obtained by bioleaching [42]. The proposed treatment chain includes consecutively MF, NF, and RO. For the MF pretreatment rotating ceramic and polymeric (MV020) membrane filters are proposed. Over 99% of the leached sludge particles are retained and can be recycled for bioleaching as leaching bacteria are still present. In the further step the sterile solution is passed to NF system. With NF99HF it is possible to remove all cations (Co^{2+}, Cu^{2+}, Fe^{3+}, Zn^{2+}) at retention ≥ 99% and Mo at retention > 97%. Concentrate is sent to the refining stage while the permeate stream is transferred to the next RO step (with RO90 membrane). There the Ge is concentrated in the retentate while Re passes to permeate. Both high tech elements can be further extracted from the corresponding streams by solvent extraction or adsorption.

5 Membrane technologies in obtaining lithium from brines

According to some estimates, nowadays 2/3 of the worldwide produced lithium is extracted from brines. This technology evaporates normally half a million litres of brine per ton of lithium carbonate. The process is chemicals intensive, extremely slow, and delivers large volumes of waste [43]. Methods have been searched for to speed the extraction and mitigate its environmental impact, including recovering at least some part of the water in brine as pure water.

Brines are highly saline solutions, containing typically large amounts of Na^+, and lower concentrations of Li^+, K^+, Mg^{2+}, and Ca^{2+}. The equivalent anions generally are mainly Cl^- with minor amounts of SO_4^{2-}, HCO_3^- and borates. Lithium concentration is low (in the range 0,3 - 1,5 %), concentrations of the other metals are high, and the chemical properties of the presenting Na^+ and K^+ are similar to those of Li^+. Consequently efforts to directly precipitate Li^+ salts from brine lead also to precipitation of large amounts of Na^+ and K^+ salts [44]. In addition, presence of Mg in high concentrations is also detrimental, since it possesses greater affinity to lime as compared to lithium, leading to inefficiency in lime precipitation of Li and also hinders the ED separation of Li [9].

Consequently, it is essential to find process for efficient separation and recovery of lithium from brine sources. NF and ME are the membrane processes mainly used in this application.

NF and low pressure reverse osmosis (LPRO) have been studied for their ability to separate lithium from salt lake brines with an emphasis on Mg^{2+}/Li^+ separation [45]. The results pointed that NF90 membrane was more efficient for Li^+ separation from a diluted brine because of its higher hydraulic permeability, lower critical pressure, its high rejection of Mg^{2+} (approximately 100 %), low rejection of Li (only 15 %), its higher selectivity between monovalent ions (40 %) obtained at lower operating pressure (below 15 bar) and its lower roughness showing decreased predisposition to fouling. However, the further step aimed to separate from the obtained permeate Li^+ and Na^+ by using the NF90 was not successful and dialysis at zero pressure was used to ensure the separation. Other authors also pointed that NF is suitable process for separation of Li^+ and Mg^{2+} from brines [46, 47].

Membrane electrolysis combined with crystallization is proposed as a new technology for lithium carbonate production from lithium-rich brines [44, 48, 49]. In the first stage brine is introduced in a membrane electrolyzer where anodic and cathodic departments are separated by anion exchange membrane. Water reduction increases the pH of the catholyte, and there Mg^{2+} and Ca^{2+}, migrated due to the applied voltage, are removed as $Mg(OH)_2$ and $Ca(OH)_2$. In the second stage brine, from which Mg^{2+} and Ca^{2+} are removed, is introduced in the middle compartment of a three-compartment water electrolyzer. Anodic and cathodic compartments are separated from the middle compartment by anion-exchange (AEM) and cation-exchange (CEM) membranes correspondingly. Monovalent cations (left in the brine after the first stage) migrate from the middle compartment through a cation exchange membrane to the cathodic compartment where water electrolysis leads to alkalinisation. It is found that under the experimental conditions applied, the ionic migration rate across the CEM decreased in the order $Na^+ > K^+ > Li^+$. A side-crystallizer is attached to the cathodic compartment and Na^+ is recovered as $NaHCO_3$ by introduction of CO_2 in the system. At heating the bicarbonate solution, the bicarbonate is converted to carbonate solid samples. Na_2CO_3 with a purity of 99.5% of was obtained from real brine samples. Thus the solution is depleted in Na^+ ions and it is more suitable for Li_2CO_3 recovery in a successive stage. This solution is introduced (in the 3rd stage) into the middle of another three-compartment water electrolyzer, similar to the one applied in the 2nd stage. Since the water is deprived of Na^+ ions, mainly Li^+ ions pass to the cathodic compartment, where, due to the alkalization caused by the electrolysis and introduction of CO_2, Li_2CO_3 (with a purity of 93,8 wt. %) is precipitated in a side-crystallizer, attached to the cathodic compartment. The method proposed recovers fresh water as a by-product (around 90 % of the initial volume).

More on the advantages and challenges of the membrane-based technologies applied to the lithium recovery from brines till the middle of 2019 can be found in the work of Li and coauthors [50].

Studies development in that area hinted to the idea that an integrated membrane separation process could be a potent alternative to conventional Li recovery methods. An integrated membrane process combining NF and MD was studied for the enrichment of Li from simulated salt lake brine [9]. NF90 and NF270 NF membranes were used in experiments. It has been found that under optimum operating conditions, the Mg/Li molar ratio changed from 10 to 0,19 when NF90 was used, and from 10 to 2,1 at NF270 use. The achieved concentration of Li from brine was 77 and 56% for NF90 and NF270 membranes respectively. Following NF treatments, the separated Li could be further concentrated (by up to 80 %) by means of direct contact MD system. Park and co-authors [51] also confirmed the ability of the combination NF - MD to recover Li from low concentration lithium brine, as they stresses, at "one-tenth of capital cost, process time, and foot-print of the conventional process". The cost can be decreased further by using the waste heat from the industrial plants and solar energy.

Very recently a comprehensive technology for preparation of Li_2CO_3, has been proposed [52]. It includes electrochemical intercalation-deintercalation, nanofiltration, reverse osmosis, evaporation, and precipitation. In the beginning the electrochemical intercalation-deintercalation method is used to ensure maximum separation of magnesium and lithium, i.e. to obtain a low mass ratio Mg/Li. The Mg/Li ratio decreased from 58,5 in the brine to 0,93 in the produced lithium-containing anolyte. Further, multivalent ions (e.g., Mg^{2+}, Ca^{2+}, and SO_4^{2-}-) are removed from the obtained anolyte via the NF method. Then NF permeate is concentrated by RO. The next step uses evaporation to increase further the lithium concentration. Finally Li_2CO_3 is precipitated by Na_2CO_3 addition. By the proposed technology a direct recovery of lithium from the high Mg/Li brine to the produced Li_2CO_3 can come to 68,7%. When recycling is ensured for the most of the solutions in the system, the total recovery of lithium will be higher than 85%.

6 Membrane technologies for recovering reagents, metals and water from mining waste streams

Treatment of in-plant process effluents and wastewater streams are presented in this section.

Membrane processes have been applied for treating in-plant effluents in order to regenerate reagents and/or to separate valuable materials. An example is application of ED for recovery of HCl, zinc and iron contained in effluents from chloride hydrometallurgy [17]. The waste stream was with high concentration of hydrochloric acid and of metal anionic and cationic chloro-complexes. Initially selective membrane-based solvent extraction step was applied to separate in raffinate cationic iron from the stripping solution that contained the HCl together with anionic species of zinc. The stripping solution was passed to ED system where Zn was concentrated in concentrate and the latter was suitable for Zn electrowinning. HCl was recovered in diluate to be re-used in the leaching process.

Another example is recycling of H_2SO_4 from raffinate, generated during copper ore hydrometallurgical processing, by use of bipolar membrane electrodialysis (BMED) system [53]. The raffinate is highly acidic and contains Fe, Zn, Cu, Ni, Cr, Cd, As in high concentrations. The experiments showed that 85,9% of SO_4^{2-} that present in the raffinate could be recovered by the formation of H_2SO_4. The removal rates of other pollutants were, in %: iron - 99,3, zinc - 99,1, copper - 99,0, nickel 84,9%, chromium - 70,6, cadmium - 95,8%, and arsenic - 94,8.

In order to find a sustainable solution for fresh-water demand in mining sectors, MD was proposed to reclaim POX effluent [54]. Different operational conditions were studies and under the optimum ones (PTFE membrane with spacer, feed temperature - 60 ◦C, recirculation flow rate - 0,3 L/ min), the average distillate flux was 6,82 L/m^2 h and a permeate recovery rate was 33,91% at retention rates for metals > 95,7% and for the acid > 99,9%. The system was working 240 days without any deterioration of parameters, generating a permeate that can be used directly as recycled water in the plant. Since the temperature of the POX effluent is in the range 50 - 80 ◦C, the effluent can be introduced directly into MD system thus decreasing the energy demand for the effluent processing.

In general, RO is the major membrane process used by the developed countries to treat wastewater streams from mine sites, especially with the aim to achieve water quality meeting the legislation requirements permitting water discharge in natural water bodies. Most often the technology is applied for water polishing after other treatment processes and before discharge to the environment. For example Oceana Gold - Waihi (New Zeeland) applies RO since 2008 to remove pollutants, such as TDS, Se and As left after treating the wastewater by a conventional wastewater treatment plant using chemical precipitation and clarification [22]. The water is purified to a level of purity, far in excess of that required by regulators [55].

Many mines in Australia are using the RO technology as a post-treatment process for removing heavy metals and other toxic compounds from their wastewaters before water discharge to the environment [56-58]. However, membrane fouling appears as one of the biggest problems when RO is used in a harsh environment like as mining operations.

A study evaluated the performance of RO plant as a wastewater post-treatment process in mining operations in Victoria, Australia [56]. The data analysis points that the RO treatment significantly improves the quality of the final water before it is being discharged to surface waters. Considering average rejection efficiency for the entire evaluated period (01.01.2015 - 27.11.2018), the concentrations of antimony, arsenic, nickel, zinc and iron were reduced by 95 %, 66 %, 82 %, 48 % and 10 %, respectively in the RO permeate compared to the feed water. The turbidity and TDS decreased by 85 % and 96 %. However, the sporadic inefficiency of the pre-treatment system, led up to serious failures in RO plant, resulting in a non-compliance with local discharge licence in some days. The conclusion was that since RO membranes are very sensitive to fouling, availability of a reliable and extensive pre-treatment system is the most critical factor to guarantee good performance and high durability of membranes.

Legislative measures forced not only gold and copper mining companies but also coal-mining enterprises to search for solutions to minimize their saline wastewater. A study was carried out aimed at evaluating the performance of an integrated FO - RO system with three different actual coal mine waters from Australia, containing different concentrations of sulphates and silica that are usually related with scaling and fouling of membrane systems [59]. Studies have shown that the integrated system concentrated the mine water, recovering more than 80% of the mine water volume and producing treated water of dischargeable quality. It is found that the combination of FO with RO provided a better results than individual FO or RO. The FO unit performed as an effective pre-treatment system prior to RO and showed a potential to successfully replace conventional pre-treatment processes for RO.

7 Conclusions

Application of membrane-based processes in mining and mineral processing industry offers many potential benefits such as (a) Improved selective separation of valuable metals, (b) Water and reagents recovery for reuse in the production process, (c) Reduction of volumes requiring conventional treatments, such as lime neutralization and precipitation. This in its turn leads to decreased usage of reagents and reduced costs for disposal, (d) Release of wastewater aligned with stringent regulatory standards for water discharge to the environment and even production of water usable for industrial, agricultural, and domestic purposes, (e) Efficiently dealing with AMD and MIW.

All mentioned translates into smaller and more efficient plants with lower capital and operating costs, as well as decreased environmental negative impacts.

Flexible application of membrane based technologies, with relatively small footprint, compared to traditional technologies, can be ensured by nowadays developments in the area. While RO is still "classics" in the wastewater treatment, in in-process technology NF gains increasing attention, since RO and NF provide similar rejection performances for commodity metals and multi-valent ions and NF shows a higher flux at lower pressure, leading to lower capital investment, lower cost of operation and maintenance. MF and UF are considered as necessary and suitable pre-treatments to remove suspended solids prior NF and RO operations.

Among the barriers hindering the application of membrane-based processes in mining and mineral processing the following can be pointed out: (a) Still relatively high capital and operational costs, (b) Fouling and scaling of membranes, since the waters entering the membrane plant have a large amount of complex suspended and dissolved solids. Need of chemicals and pre-treatment to avoid the mentioned problems and to ensure feed solution with predictable quality, (c) Still some improvements in module design and process optimization are needed.

However, the developments of science an technology in the area of membranes and membrane technologies is going to mitigate these problems.

Hopefully, this paper will be useful in providing some information and basis for widening the application of membrane technologies in mining and mineral processing in order to render metals extraction more environmentally friendly and sustainable.

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On the relationship between gas emission from undermined coal-bearing stratum and the intensity of coal seam mining

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Abstract. A theoretical scheme of gas release from the coalbed under production by treatment workings has been developed. The sizes of zones of different intensity of gas release from the working thickness are set according to the characteristic points of muld shift of the earth's surface. Total amount of releasing gas is determined by the area of the developed space, over which there is an intensive movement of the mined coal. The formation of this area is associated with the development of cleaning operations within the boundaries of the excavation site and the speed of movement of the treatment face. During the development of the theoretical scheme, several assumptions were made, the validity of which was verified on the basis of experimental data obtained in the conditions of four mines at fifteen excavation sites. Coal seams with coals of grades G and A were worked out by them at a depth of 300-1195 m, the capacity of coal seams was 0.90-2.20 m, cleaning works were carried out at a depth of 300-1195 m, the length of the lavas was in the range of 74÷270 m. The monthly movement of the treatment faces and the amount of gas released during this period were taken into account for each excavation site. It is established that the relative gas release per unit area of the developed space remains a fairly constant value for some mining and geological conditions, if the total amount of gas is attributed to the area that determines the active movement of rocks over a moving treatment face. This allows you to use the previously obtained results of determining the categorical danger of mines by relative gas release per ton of coal production in terms of improving the forecast of gas release from the coalbed under production more efficiently.

1 Problem statement

In modern coal mines, the main source of gas emission is the undermined coal-bearing strata.

The relationship between the intensity of gas emission and the degree of was established several decades ago [1, 2]. The highest levels of gas emission are associated with sediments of the main roof [3] and the development of the underworked strata movement towards the earth's surface when removing waste rock. Methane emission into mine workings is possible only from the zone of underworked strata movement with a break in its continuity. In degassing wells, methane emission can also occur from lamination cavities at the contacts of rock layers with different strength properties [4].

In parallel with the influence of the underworked strata movement, the phenomenon of a decrease in the specific flow rate of methane into the stope was established with an increase in the intensity of mining of shallow coal seams [5].

The intensity of seam mining means the level of coal production and the corresponding movement of the mine face. For the safe mining of gas-bearing coal seams, it is necessary to know the mechanism of formation of methane release from the underworked coal-bearing strata. Until now, there are practically no scientific research works in which the intensity of coal seam mining (the level of coal production or the rate of mine face movement), the development of undermining and gas release from undermined sources are considered together. Research in this direction is highly relevant.

2 Purpose, idea and research methodology

The objective of the study is to develop a scheme for the influence of mine faces on the formation of zones of active movement of the undermined coal-bearing strata and the possible intensive emission of methane from them. Establish the factors that determine the gas emission in relation to its emission per unit area of the underworked area.

Idea. It is assumed that the amount of emitted gas depends on both the rate of movement of the mine face ($\upsilon_{оч}$), and the intensity of the movement of rocks above it and the degree of development of mining operations in the extraction area.

Methodology. It provides for the consideration of experimental data on methane emission in relation to the developed scheme of the influence of mine face on the formation of zones of active undermined coal-bearing strata movement and gas release from the undermined strata.

Results. The layout of the methane emission zones in the undermined coal-bearing strata was developed in accordance with the formation of a displacement trough on the earth's surface [3] and the degree of development of mining operations in the mining area (Fig. 1).

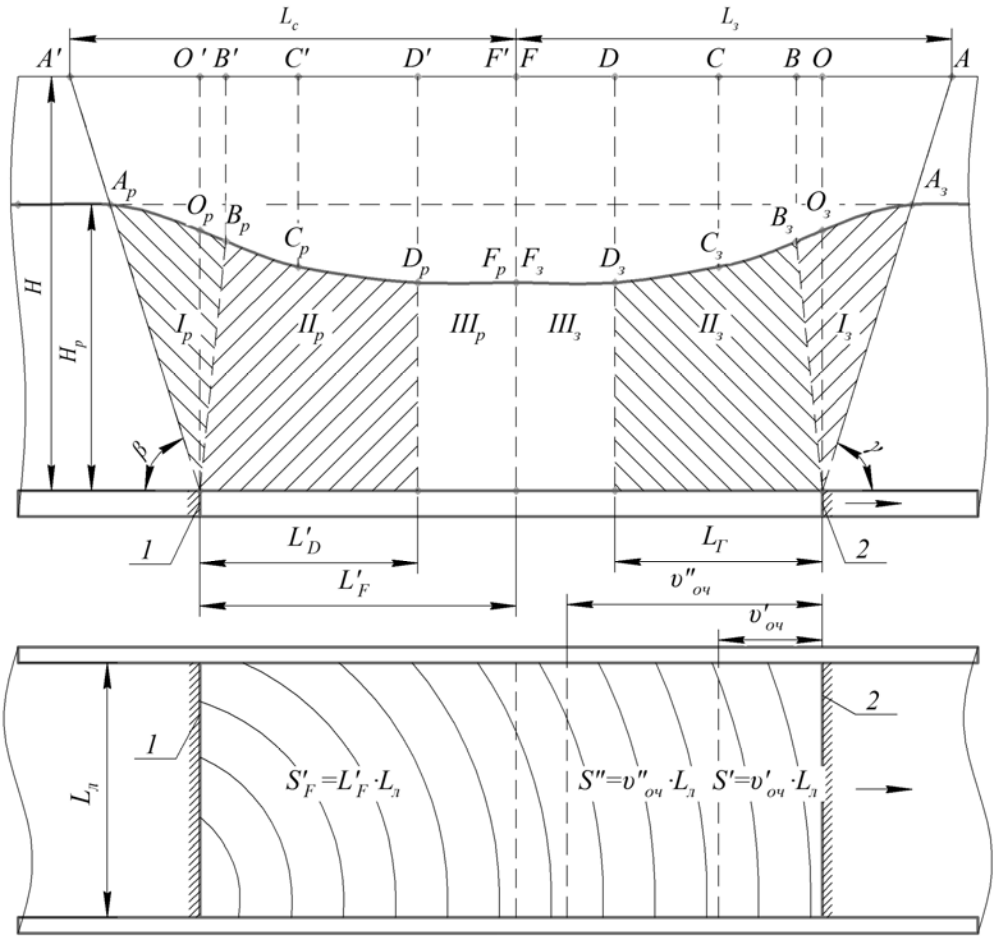

Fig. 1. Scheme of the location of gas emission zones in the undermined coal-bearing strata according to the formation of a displacement trough on the earth's surface (a) and the degree of development of cleaning work (b) in the excavation area: 1, 2 – respectively, the exposed surfaces of the seam of the cut mine and the clean face; 3 – earth surface; L_c, $L_д$ – respectively, stationary and dynamic semi-troughs; *A*, *O*, *B*, *C*, *D*, *F* and *A′*, *O′*, *B′*, *C′*, *D′*, *F′* – characteristic points of subsidence of the earth's surface of dynamic and stationary semi-troughs; A_p, B_p, C_p, D_p, F_p and $A_з$, $B_з$, $C_з$, $D_з$, $F_з$ – characteristic points of subsidence of a layer of undermined rocks at the edge (H_p) of a zone with a discontinuity, respectively above the open cut and the clean face; *H* – depth of cleaning works; $I_з$, $II_з$, $III_з$ and I_p, II_p, III_p – areas of possible gas enission, respectively, above the clean face and open pit; β, γ - boundary angles of influence of a working mine on the earth's surface; L'_D - the distance between the open pit and the clean face at which active gas emission occurs; L'_F - distance at which gas emission from the side of the cut furnace stops due to rock compaction; $L_Г$ - distance from the working face, at which active gas emission occurs from the undermined coal-bearing strata above the working face; $L_л$ – longwall length; S', S'' - the goaf, respectively, when moving the working face at a distance of $\upsilon'_{оч}$ and $\upsilon''_{оч}$; ⟶ - direction of the working face. movement.

3 Results

According to this scheme, a displacement trough is formed on the surface under the influence of cleaning works, which is divided into two semi-troughs. One of them, the stationary length L_c, is formed above the split mine (1). The second is a dynamic length $L_д$, it is formed as the clean face moves forward (2). These semi-troughs, according to the methods [3, 6, 7], can be divided into separate periods of their formation using characteristic points. Section $A'B'$ of the semi-trough of the earth's surface (the diagram shows a segment of straight line $A'B'$) corresponds to the initial period of the earth's surface displacement under the influence of a moving clean face. The most active earth's surface displacement occurs on the curve section $B_P\,D_P$, and at the point C_P the maximum subsidence rate is reached. At the point D_P, the end of the active stage occurs and the transition to damping of the processes of the earth's surface displacement occurs. At point F, the maximum subsidence is achieved and further advancement of the clean face has practically no effect on the processes of active movement of unmined rocks and the earth's surface.

Similarly, with different intensity, the undermined rocks move above the clean face in the coal-bearing strata. By analogy with the earth's surface, a subsidence semi-trough is formed in it with characteristic points $A_з$, $B_з$, $C_з$, $D_з$ and $F_з$. Insignificant gas emission from the rock stratum is possible from zone $I_з$, the dimensions of which are determined by the boundary angle and the position of the point $B_з$ in the undermined range. Point $B_з$ is located at a distance of H_p from the developed formation, which defines the boundary of the displacement zone of rocks with a break in their continuity. With the removal of the stope from the cut, H_p reaches a certain value, which remains constant as the extraction column is further worked out [8, 9, 10]. The most favorable conditions for intense gas emission appear in the zone ($II_з$) of active rock movement. The dimensions of this zone are determined by the section of the $B_з$ – $C_з$ – $D_з$ curve and the H_p parameter. Separate determination of gas emission from zones $I_з$ and $II_з$ experimentally in mine conditions is practically impossible due to the technical capabilities of modern measuring equipment. Based on the gas surveys in mine workings and measurements in degassing systems, it is possible to establish the total gas emission from zones $I_з$ and $II_з$, neglecting methane emission from zone $III_з$. The most accurate and accessible indicator characterizing the size of these zones is the area of the mined-out space $S_Г$. It can be determined by the product of the parameter $L_Г$ and the length of the $L_л$ longwall. The value of the parameter $L_Г$ is determined by the projections of points D and $D_з$. For coal mines of Donbass, the L_p parameter is approximately equal to 0,466 of the depth (H) of mining [3]. Based on the above scheme (Fig. 1), it follows that all the gas emission from the undermined strata (I_υ) when moving the clean face can be roughly attributed to the goaf area $S_Г = L_л \cdot L_Г$.

In production conditions, the value of the $L_Г$ parameter, as a rule, does not coincide with the monthly rate of movement of the clean face. If $\upsilon_{оч} < L_Г$, when determining the specific gas emission from the ratio, this indicator will be overestimated. Gas emission in fact refers to the goaf area of $L_л \cdot L_Г$, and it is referred, in some cases, to $S' = \upsilon'_{оч} \cdot L_л$.

It is extremely rare that the $\upsilon''_{оч}$values can exceed the $L_Г$ parameter, then $S'' = \upsilon''_{оч} \cdot L_л$ will exceed the $S_Г = L_л \cdot L_Г$ area and the specific gas emission per unit goaf area will be underestimated.

It can be assumed that, according to a similar scheme, gas emisiion occurs above the open cut from zones $I_з$ and $II_з$. Their sizes are also determined by the position of the characteristic points A_p, B_p, C_p, D_p and F_p in the underworked strata and the value of the H_p parameter.

When the clean face is removed from the open-cut mine at a distance of L'_D, zone II_p is largely degassed, since it was subjected to the most intense rock movement. Some gas emision is possible from the I_p zone, in which rock displacements were insignificant.

When the clean face is removed from the open-cut mine at a distance of L'_F, zones III_p and $III_з$ are more degassed. The rocks in these zones, before their compaction, successively went through all stages according to the intensity of their movement and, obviously, according to the activity of gas emission from underworked sources.

In the process of developing the scheme (Fig. 1), several assumptions were made that need to be verified and confirmed by experimental results. These include the assumption of the similarity of the gas emission processes from the undermined coal-bearing strata when the clean faces are removed from the split furnaces in the initial period of the excavation sections operation at a distance of L'_D (with the settlement of the main roof in zone II_p) and methane emission above the clean face, determined by the boundaries of zone $II_з$ and the goaf area $S_Г$, calculated using the parameter $L_Г$.

The analysis involved the results of the cleaning works development observations and gas emission at fifteen excavation areas of four mines. For these sites, in advance, considering the depth (H) of the cleaning works, the $L_Г$ parameter was determined [3]. For the conditions of the A.F. Zasyadko mine [11] (16th eastern longwall of the $m_3$seam) for a depth of H = 1195 m, the value of $L_Г$ is 547 m.

In the conditions of the 'Sukhodolskaya - Vostochnaya' mine, during the operation of the 12th bis and 24th eastern longwall of the $i_3$seam, the depths were 965 and 1016 m respectively, and they corresponded to $L_Г$ values of 450 and 474 m. For the D.F. Melnikov mine, the extraction area of the 1st northern longwall of the $\ell_6$seam was mined at a depth of 852 m, for which the parameter was 397 m. Mine in the name of the "Izvestia" newspaper mined an anthracite layer $\ell_2^в$at a depth of 300 m, and the calculated value of the $L_Г$ parameter was 140 m.

For each excavation site, monthly movements of the clean faces were pre-established and the amount of gas emission during this period was determined experimentally. After that, the movement of the clean faces ($L_{оч}$) was sequentially selected for a certain period (one or several months), starting from the moment of longwall operation in such a way that $L_{оч} \approx L_Г$. Then, for the selected values of $L_{оч}$, the goaf areas $S_Г = L_{оч} \cdot L_Г$ were found, which corresponded to gas emission when the clean faces moved to a distance of $L_{оч}$. We also took into account the period of longwall operation (t) when moving the faces to a distance of $L_{оч}$, the average gas emission per month and the specific methane emission $\frac{I_\upsilon}{S}$per m² of the goaf area when moving the clean faces at a distance of $L_{оч}$. This data is summarized in Table 1.

When the clean faces move in the initial period of exploitation of the extraction areas at a distance $L_{оч} \approx L_Г = L'_D$ (Fig. 1, Table 1), in most cases, the indicators of the amount of gas (I_υ), its average amount ($\bar{I}_1$) emitted in one month, as well as the specific gas emission from units of the goaf area $(\frac{I_\upsilon}{S_Г})$ were less in comparison with their subsequent values when moving the clean faces at a distance of $L_{оч}$. This is explained by the fact that intense gas emission from the undermined coal-bearing strata does not begin immediately after the introduction of the longwalls into exploitation, but occurs after the main roof has settled.

For example, in the conditions of the “Izvestia” mine, the sediment of the main roof occurred when removing clean face from cut workings at a distance of 80÷120 m [3]. At the same time, the peak values of methane emission when moving the clean faces on the L'_Dsection (Fig. 1, a), located closer to the open-cut working, were slightly higher than the gas emissions during their subsequent moves by the value of $L_Г$. The total amount of gas $I_v$emitted during the passage of the longwall sections $L_Г$ of the extraction pillars located far from the split furnaces, as a rule, exceeded this indicator during the operation of longwalls near the split workings.

Table 1. Information about the operating conditions of longwalls in zones of active rock movement and intense gas emission from undermined sources ($L_Г$).

Lawa	Face length, $L_л$, m	Estimated size of the gas emission zone, $L_Г$, m	Clean face movement, $L_{оч} \approx L_Г$, m	Goaf area, $S_Г = L_{оч} \cdot L_л$, m^2	Gas emission, I_v, mil. m^3	Longwall life, *t*, month.	Average gas emission per month, $\bar{I}_1$, mil. m^3	$\frac{I_v}{S_Г}$, m^3/m^2
1	2	3	4	5	6	7	8	9
A.F. Zasyadko mine [11]								
16th eastern	270	547	552*	149040	15,7	5	3,1	105,3
			540	145800	18,9	5	3,8	129,6
			541	146070	18,0	4	4,5	123,2
‘Sukhodolskaya - Vostochnaya’ mine								
12th bis eastern	240	450	448*	107520	14,3	16	0,9	133,0
			431	103440	20,5	20	1,0	198,2
24th eastern	240	474	455*	109200	15,7	7	2,2	143,8
			454	108960	24,8	11	2,3	227,6
			203	48720	16,0	9	1,8	328,4
D.F. Melnikov mine								
1st northern	220	397	408*	89760	2,8	12	0,2	31,2
			409	89980	2,7	9	0,3	30,0
			392	86240	5,3	30	0,2	61,5
			0	0	0,5	8	0,06	5,7
Newspaper "Izvestia" mine [12]								
1st western	185	140	143*	26455	0,9	4	0,2	34,0
			139	25715	1,3	5	0,3	50,6
	157		132	20724	1,7	4	0,4	62,4
	115		131	15065	1,8	6	0,3	119,5
	111		156	17316	0,4	4	0,1	23,1
1st bis western	74	140	113*	8362	0,2	4	0,05	23,9
	84		152	12768	0,5	3	0,2	39,2
	94		115	10810	0,4	8	0,05	37,0
2nd western	200	140	129*	25800	0,9	2	0,5	34,9
			107	21400	2,0	1	2,0	93,5
			143	28600	3,1	2	1,6	108,4
			86	17200	1,4	1	1,4	81,4
			133	26600	1,6	1	1,6	60,2
			139	27800	1,8	1	1,8	64,7
			127	25400	1,4	1	1,4	55,1
2nd bis western	185	140	123*	22755	1,4	4	0,4	61,5
			156	28860	3,1	10	0,3	107,4
3th western	215	140	141*	30315	1,6	2	0,8	52,8
			91	19565	1,4	1	1,4	71,6
			112	24080	1,6	1	1,6	64,4
			131	28165	1,6	1	1,6	56,8
			153	32895	2,9	2	1,5	80,2
			132	28380	1,4	1	1,4	49,3
4th western	210	140	194*	40740	0,7	2	0,4	17,2
			112	23520	3,3	2	1,7	140,3
			150	31500	2,2	2	1,1	69,8
			163	34230	2,0	2	1,0	58,4
			140	29400	1,5	1	1,5	51,0
			128	26880	2,1	1	2,1	78,4
			154	32340	1,5	1	1,5	46,4
			153	32130	1,2	1	1,2	37,3

* Note - removal of clean faces from cut workings at a distance of $L_{оч}$ in the period before the settlement of the main roof.

Such a ratio of indicators for gas emission in the areas $L_D^{'}$ and $L_Г$ indicates a different course of the processes of rock displacement and gas emission when clean faces are located in different parts of the extraction pillars.

We examined in more detail the cases when mining pillars in the areas $L_D^{'}$ and $L_Г$, when the indicators I_υ, $\bar{I}_1$ and $\frac{I_\upsilon}{S_Г}$ were quantitatively close to each other.

The D.F. Melnikov mine, during the operation of the 1st northern longwall of the $\ell_6$seam, the section of the pillar L_D'=$L_{оч}$= 408m near the split furnace was worked out for twelve months, and the subsequent section $L_Г$ = 409m after the settlement of the main roof - nine months (Table 1). During these periods, approximately the same amount of methane was emitted, respectively 2,8 and 2,7 mil m^3. In this case, with approximately the same areas of undermined stratum (89760 and 89980 m^2), practically the same amount of gas was emitted over different periods of time when a part of the extraction pillar was worked out on segments L_D' and $L_Г$. This indicates that the amount of methane emitted from the zone of active movement of underworked rocks depends on the time of degassing of the coal-bearing strata. The influence of the time factor on all indicators of gas emission I_υ, $\bar{I}_1$ и $\frac{I_\upsilon}{S_\Gamma}$)) is confirmed by the experimental results obtained during the refinement of the extraction pillar of the 1st northern longwall with a length of 392 m for thirty months. During this period, 5,3 mil m^3 of gas was released, because of which the $\frac{I_\upsilon}{S_\Gamma}$indicator also increased from 30,0 to 61,5 m^3/m^2 of methane (Table 1). The amount of methane emitted per month remained practically unchanged. After stopping the clean face (S_Γ=0), 0,5 mil m^3 of methane was emitted over eight months. The $\frac{I_\upsilon}{S_\Gamma}$ indicator must be determined according to the scheme (Fig. 1) from the $\frac{I_\upsilon}{L_\Gamma \cdot L_л} = \frac{0{,}5 \cdot 10^{-6}}{397 \cdot 220} = 5{,}7$$m^3/m^2$ ratio. After stopping the clean face, its movement is absent, which caused a decrease in the specific gas emission per unit of goaf area from 61,5 to 5,7 m^3/m^2. In this case, if the amount of emitted gas is related to the area corresponding to the monthly movement of the clean face (S_υ=0), then the $\frac{I_\upsilon}{S_\upsilon}$ indicator tends to infinity and it has no practical value. A similar mistake is made by the methodology of regulatory framework when determining the hazardousness of mines, when the amount of emitted gas is attributed to coal production per month. In its absence, the gas content of the mine seemingly tends to infinity. The absolute gas emission when the clean face is stopped depends on the the location of sources in the undermined coal-bearing strata, which are no longer associated with coal mining [13, 14].

On the site of the 8th western longwall of the $\ell_2^в$ seam of the "Izvestia" mine part of the extraction column L_D'=$L_{оч}$=151m was worked out for three months, and the next – $L_Г$ =131m for one month. During the exploitation of the mining area, 1,4 and 1,2 mil m^3 of methane was emitted in the corresponding periods. Indicators $\bar{I}_1$ and $\frac{I_\upsilon}{S_\Gamma}$ in the corresponding periods were equal to 0,5 and 1,2 million m3 and 43,1 and 42,6 m^3/m^2. In this case, with the same $\frac{I_\upsilon}{S_\Gamma}$ indicator, the average amount of gas emitted in one month significantly differed. Such a ratio of parameters in this case can be explained by the incomplete development of rock displacement processes at the initial stage of seam development at $L_{оч}$= 151m. After stopping the longwall, 0,5 mil m^3 of gas was emitted in two months. For this case, $\frac{I_\upsilon}{S_Г} = \frac{0{,}5 \cdot 10^{-6}}{140 \cdot 215} = 16{,}6$ m^3/m^2. This indicates a decrease in the specific gas emission per unit of goat area in the absence of coal mining for a certain period.

After stopping the 9th western longwall, 0,3 million m^3 of methane was emitted in four months, and the specific gas emission during this period was 8,6 m^3/m^2. This confirms the validity of the fact that when calculating the specific gas emission per unit of goaf area, the amount of emitted gas I_v must be related to the $S_Г$area that determines the active zone of rock displacement.

If the rate of clean face movement ($\upsilon_{оч}$) is approximately equal to the calculated value of the size of the zone of active displacement of rocks ($L_Г$) (Fig. 1), then it can be assumed that the values of specific methane emission per unit goaf area ($\frac{I_\upsilon}{S_\upsilon}$ and $\frac{I_\upsilon}{S_\Gamma}$) will slightly differ from each other. The closeness of the $\frac{I_\upsilon}{S_\upsilon}$ and $\frac{I_\upsilon}{S_Г}$parameters in this case also indirectly indicates the reliability of determining $L_Г$ by a calculation method.

Of the considered excavation areas, working out different seams, only in the conditions of the "Izvestia" mine for individual mining areas, in some cases, the speed of clean faces ($\upsilon_{оч}$) was close to the indicator $L_Г$ =140m. The $L_Г$ determination accuracy is about 20%. In this case, the $L_Г$ value is 140÷28m and should be in the range 112÷168m.

For six excavation areas, where there were cases of approximate equality $L_Г \approx \upsilon_{оч}$, we made samples according to the rate of clean faces movement in the indicated interval (112÷168m) and the corresponding amount of released gas ($I_{\upsilon_{оч}}$) and area ($S_{\upsilon_{оч}}$ and S_Γ) of worked-out spaces (Table 2). The graphs of the experimentally determined $\frac{I_{\upsilon_{оч}}}{S_Г}$ and $\frac{I_{\upsilon_{оч}}}{S_{\upsilon_{оч}}}$ values practically coincided with the bisector (1) of the coordinate grid (Fig. 2).

This is evidenced by the closeness of the regression coefficient to unity of the averaging straight line (2) and the high value of the correlation coefficient (r=0,97). The established facts indicate that in order to reliably determine the specific gas emission from a unit area of the goaf, it is necessary to take into account the zones of active movement of underworked rocks.

4 Conclusions

Conducted theoretical and experimental studies of gas emission from the undermined coal-bearing stratum by workings made it possible to draw the following conclusions:

- the developed theoretical scheme for the joint formation of zones of the undermined coal-bearing stratum active movement and intense gas emission made it possible, on the basis of experimental data, to establish a part of the goaf area, which determines the amount of methane emitted from the sources;

Table 2. Information on gas emission at the rates of clean faces ($\upsilon_{оч}$) is close to the size of the $L_Г$ zone of active movement of rocks in the conditions of the "Izvestia" mine.

Lawa	Face length, $L_л$, m	Speed of face movement, $\upsilon_{оч}$, m/month	Average methane amount in a seam, m^3/t.m.r.	Amount of emitted gas, I_υ, thousand. m^3	Goaf area, m^2		Gas emitted from 1m^2 of goaf, m^3/m^2		Observation date
					$S_{\upsilon_{оч}}$	$S_Г$	$\frac{I_\upsilon}{S_{\upsilon_{оч}}}$	$\frac{I_\upsilon}{S_Г}$	
1	2	3	4	5	6	7	8	9	10
2nd western	200	133	20,4	1589,2	26600	28000	59,7	56,8	III 1979
		139	18,6	1766,9	27800	28000	63,6	63,1	IV 1979
		127	15,8	1415,1	25400	28000	55,7	50,5	V 1979
		132	12,3	933,1	26400	28000	35,3	33,3	VI 1979
3th western	215	112	26,5	1607,0	24080	30100	66,7	53,4	XI 1979
		131	26,5	1584,7	28165	30100	56,3	52,6	XII 1979
		132	25,8	1391,0	28380	30100	49,0	46,2	IV 1980
		144	24,8	866,0	30960	30100	28,0	29,4	V 1980
		130	22,4	738,7	27950	30100	26,4	24,5	VI 1980
		134	20,2	915,1	28810	30100	31,8	30,4	VII 1980
		116	15,8	709,8	24940	30100	28,5	23,6	VIII 1980
4th western	210	123	28,1	738,7	25830	29400	28,6	25,1	XI 1980
		140	29,3	1481,8	29400	29400	50,4	50,4	VI 1981
		128	28,9	2129,3	26880	29400	79,2	72,4	VII 1981
		154	28,4	1473,1	32340	29400	45,6	50,1	VIII 1981
		153	27,1	1213,9	32130	29400	37,8	41,3	IX 1981
		128	24,4	589,2	26880	29400	21,9	20,0	X 1981
5th western	216	147	31,3	1330,3	31752	30240	41,9	44,0	VIII 1982
		149	31,0	334,8	32184	30240	10,4	7,5	IX 1982
7th western	230	118	34,8	1767,7	27140	32200	65,1	54,9	VIII 1983
		116	34,3	1412,6	26680	32200	52,9	43,9	IX 1983
8th western	215	131	35,0	1160,6	28165	30100	41,2	38,6	VIII 1984
		130	34,7	1032,4	27950	30100	37,0	34,3	IX 1984

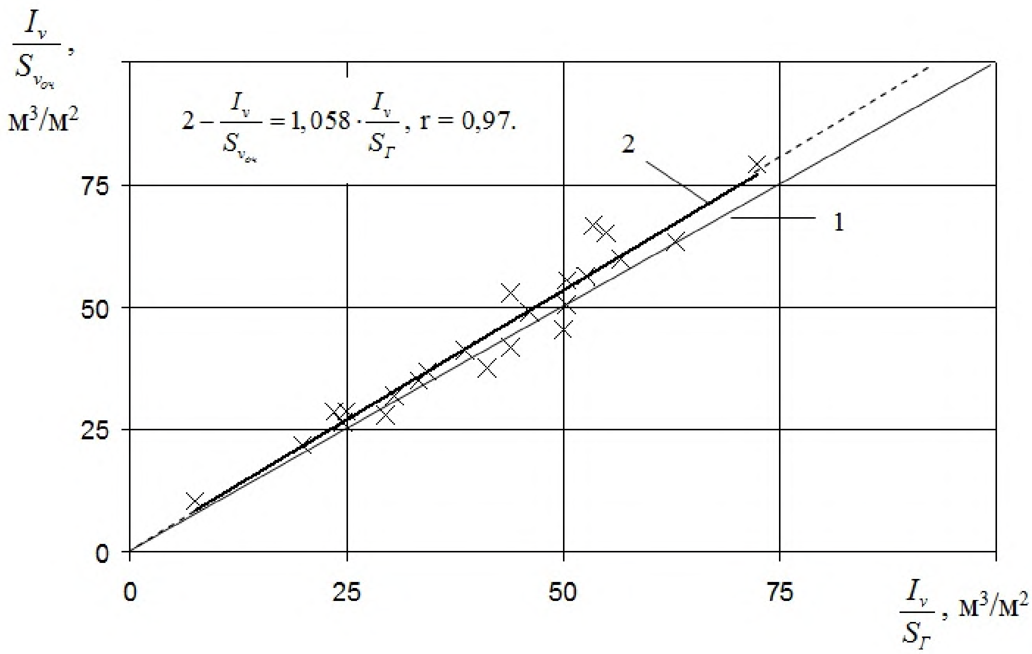

Fig. 2. Graph of the ratio of specific gas emissions per unit goaf, determined, respectively, by the monthly movement of the clean faces ($\frac{I_\upsilon}{S_{\upsilon_{оч}}}$) and the zone of active rock movement ($\frac{I_\upsilon}{S_Г}$) during mining of the $\ell_2^в$seam by the "Izvestia" mine: 1 – grid bisector; 2 – averaging straight line; × - experimental data; r – correlation coefficient.

- in the conditions of four mines at 15 excavation areas, the distinctive features of specific gas emission (per unit of goaf area) have been established, which are determined by the development of cleaning work and the speed of moving the clean face;

- the main factors that determine the specific gas emission are the area of the goaf, which affects the active stages of rock movement and the time period required for the formation of this goaf area;

- the obtained scientific conclusions make it possible to more effectively use the results of establishing the category of gas hazards in mines in terms of relative gas emission per ton of coal production in terms of improving the forecast of gas emission from the undermined coal-bearing stratum.

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Determination of the parameters of local reinforced zones under the protection means

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Abstract. In order to develop effective measures to ensure the operational condition of the development workings behind the face in the conditions of soft footwall rocks, the construction of local reinforced zones under the protection means has been proposed. The presence of such zones allows transferring the current load deep into the massif and creating a stable foundation under the protective structure. The results of researches concerning establishment of rational parameters of local reinforced zones with application of the method of finite elements, the method of experiment planning and the method of statistical processing of these results have been presented. The empirical dependence of the subsidence of the local reinforced footwall under the protection means on their load, deformation characteristics of the local reinforced zone and host rocks, width of protection means, strength of soft underlying rocks and geometric dimensions of the zone has been determined. The relative indicator of efficiency of local strengthening of a footwall which is used for determining of rational parameters of a locally reinforced zone has been offered.

1 Introduction

Recently, there has been a tendency in Ukraine to reduce coal consumption and switch to alternative energy sources. But coal will not lose its relevance because of its strategic importance to the state, as thermal power plants account for 31% of electricity generation. Nuclear generation has the largest share (55.6 %), but it is import-dependent due to the impossibility of having a closed nuclear fuel cycle within the country [1]. Therefore, the replacement of thermal energy with nuclear energy makes our country energy-dependent.

It is impossible to completely copy the models of European economies, as the level of development of industries, raw materials base, and export and import orientation in Ukraine differ significantly. It is unacceptable that a state that has its own coal resources exports it from Russia and Kazakhstan. In Kazakhstan coal still remains and will definitely remain the main source of energy in the near future, despite the fact that the country is a world leader in uranium mining [2], which has been increased several times over the past 15 years due to underground leaching [2, 3]. As a result, a considerable share of the country's export is accounted for uranium, coal and electricity. Therefore, the extraction and development of mineral resources is a strategically important task for Kazakhstan and Ukraine.

In Ukraine most of the resources are extracted with the underground method in conditions of high mining pressure. For ore deposits the main problem is efficient crushing of strong rocks [4] and ensuring the stability of workings and chambers at depths of 1115-1900 m [5-7], whereas in coal mines the situation is more complicated due to soft adjoining rocks, water content, disturbance of coal seams, and so on. The negative impact of these factors affects the general condition of the mine workings at depths of more than 300 m, especially preparatory ones, which are additionally exposed to actual works.

Coal mines have recently been using the development systems that provide the maintenance of workings behind the faces and construction of protection means on the boundary with the mined-out spaces [8-10]. However, in the case of soft footwall rocks, the protection means are mostly ineffective, as they act as dies [11-13], from which the rocks are extruded into the protected workings, and together with the contraction and subsidence of the means there happen significant displacement of the roof rocks areas around the working and the final section of face. In such conditions the question of providing proper rigidity of rocks under the protection means for maintenance of operational state of the protected workings is topical.

An effective measure in the conditions of soft footwall rocks is to construct the local reinforced zones in the rocks of the footwall under the protection means, the presence of which allows transferring the load into the massif and creating a steady foundation under the protective construction. In this direction, it is necessary to conduct comprehensive research to determine the rational parameters of such zones in specific conditions.

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2 Methods

The creation of local reinforced zones on the contour of a working is achieved to ensure its rigidity. This is evidenced by the results of research presented in [14-17]. The idea of making a local reinforced zone under the means of protection was first proposed in [18]. It is provided to place such a zone in soft rocks under the protection means to ensure their rigidity by making a holistic or consolidated construction (Fig. 1) using anchors [14, 19-23] or fastening mixtures [14, 20]. This design is able to withstand the loads coming from the protection means.

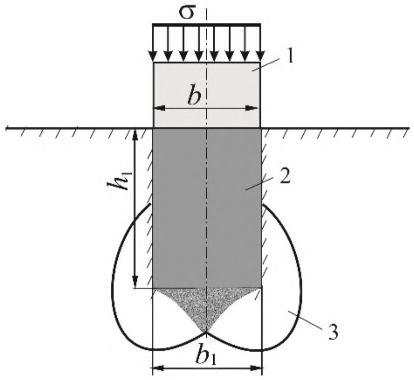

Fig. 1. Schemes of placement of protection means 1 over the local reinforced zones 2 with different shapes and deepening (1 - means of protection, 2 - local reinforced zone, 3 - area of boundary equilibrium, σ and b - respectively, the load on the protection means and its width, h_1 and b_1 - respectively, height and width of the local reinforced zone) [18].

Making under the protection means the local reinforced zone, in which the total deformation modulus is greater than the total deformation modulus of the footwall rocks, allows preparing in advance for the protective structure a rigid base that transfers load onto the massif. It increases the resistance of the footwall rocks, reduces the subsidence of the protective means according to the level of the footwall surface and reduces the displacement of the roof rocks. Since the part of the extrusion force from the foundation is directed deep into the footwall, it reduces the displacement of the footwall rocks in the working.

The efficiency of creation of such zones has been proved by the results of physical (Fig. 2) and numerical simulations (Fig. 3) [18], according to which it has been found that: laying a protective construction below the footwall surface reduces the displacement in the working and save its residual area by more than 82%; the average depth of the local reinforced zone in the range of 0.8≤d/b<2 can be considered effective; to determine rational parameters of the local reinforced zone under the protection means, it is sufficient to limit the parameters that determine the stress state of the underlying rocks, namely: strength and deformation characteristics of this zone under the protection means, its shape, depth and width, as well as the characteristics of the footwall rocks.

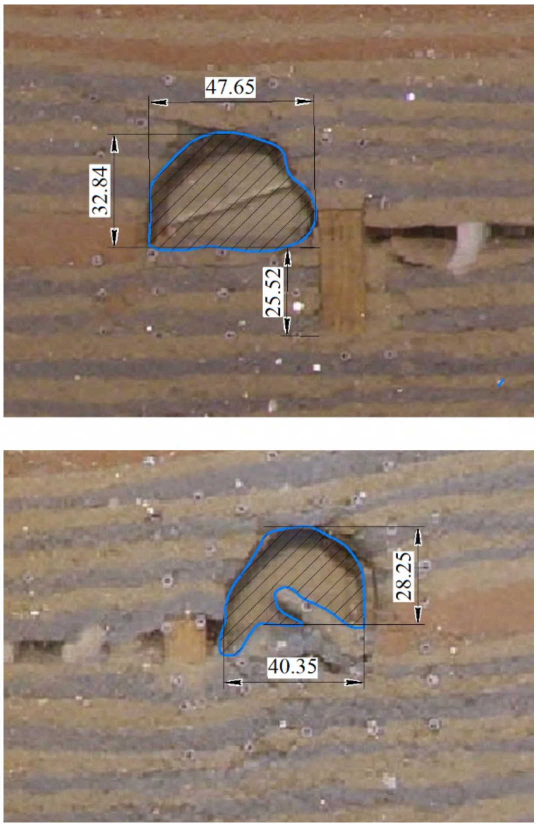

Fig. 2. General view of workings and protective constructions without deepening (a) and with deepening (b) in the model of equivalent materials at the end of measurements.

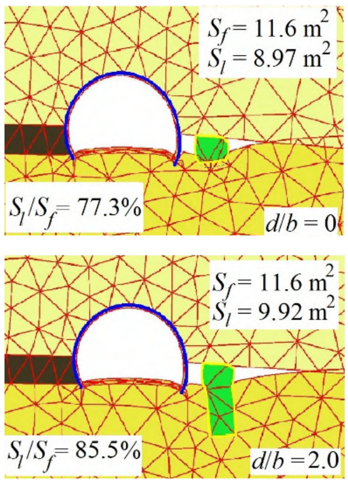

Fig. 3. General view of deformed grids of finite-element models at different relative size of depth of the protection means d/b (d - value of the depth, b - width of the protection means) to determine the relative residual cross section of the working S_k / S_n (S_n, S_k - the cross-sectional areas of the working respectively, before and after the model calculation) [18].

In the simulations it was assumed that the means of protection were under a steady load, and the strength of the local reinforced area was equal to the strength of the material of the protection means. Therefore, the means of protection and the area under it were considered as a holistic construction. Such simplification allows to establish the range of deepening of a construction and to establish the factors which need to be considered at determining parameters of local zones. However, according to the results of the research, it is not possible to determine rational parameters of the zone for certain protection conditions of a working. Therefore, there is a need for additional research that would be devoted to the development of methods for determining the parameters of local reinforced zones under the protection means for specific mining, geological and technical conditions.

3 Results and discussion

To determine rational parameters of local reinforced zones under the protection means, it is advisable to use the results of research as for determining the displacements of adjoining rocks around these means [24] and the effectiveness of laying these zones [18].

Local fixation of the partially destroyed massif and creation the blocks with greater strength than the surrounding rocks allows preserving the integrity of this massif and promotes self-wedging of the destroyed rock blocks in the process of movement [20]. As a criterion for determining the effectiveness of making a local reinforced zone under the protection means, the value of the change in subsidence of the protective construction relative to the surface of the underlying rocks has been proposed. This criterion can be shown by the coefficient k_o. Then

$$k_o = \frac{U_b}{U_b^*}, \tag{1}$$

where U_b, U_b^* - the amount of subsidence of the footwall surface under the protection means, respectively, without any measures and with the construction of a local zone, m.

The value of U_b depends on the magnitude of the load from the protective construction, its width, the strength of the soft layer of the footwall and their compressive properties, so it can be determined from the expression [24]

$$U_b = 0.835 m_v \sigma_o h_n, \tag{2}$$

where σ_o – are the stresses arising at the contact of the protection means and the underlying rocks because of the load, MPa; h_n – is the thickness of the direct footwall layer, m; m_v – is the coefficient of relative compressibility of rocks, MPa^{-1}, which is determined by the expression [25]

$$m_v = \left(1 - \frac{2\mu_n^2}{1-\mu_n}\right) \Big/ E_n, \tag{3}$$

where E_n- is the modulus of the total deformation of the direct footwall layer, MPa; μ_n- is a coefficient of relative transverse deformation of this layer.

This expression has been obtained according to the results of numerical simulation. It has a coefficient of determination R^2=0.9, and correlation - r =0.949, which indicates a strong correlation. In addition, $t > t_{\text{critical value}}$ (75.3>1.96) and $F > F_{\text{critical value}}$ (1883.9>2.62), so the relationship can be considered reliable; the correlation and determination coefficients are statistically significant, and the regression equation is statistically reliable.

According to the results of simulations [18], we can assume that the value of U_b^* depends on the shape of the local zone, its depth and width, as well as the strength and deformation characteristics of this zone and the underlying rocks. Peculiarities of the affect of bearing pressure on the underlying rocks depend on many factors, which include the structure and physical and mechanical properties of interlayer rocks, the angle of a seam inclination, the peculiarities of the development system, the roof control method, and the speed of a face displacement [26]. Let's limit to the parameters that must be changed in the model to establish the functional dependence: the magnitude of the load, the rigidity of the protective construction, its weight, width and height, as well as an indicator that characterizes the compressibility of the footwall rocks.

In general, the dependence of the amount of subsidence of the footwall surface under the protection means, in the presence of a local reinforced zone, from the influencing factors, may be determined by the expression

$$U_b = f(\sigma_o; b; h_1; b_1; \mu_1; E_n; E_1; \mu_n; h_n), \tag{4}$$

where b- is the width of the protection means, m; b_1, h_1– are, respectively, the width and the depth of the local reinforced zone, m; μ_1– is the coefficient of transverse deformations of the local reinforced zone, units; E_1- is the modulus of total deformation of the reinforced massif in the local zone, MPa.

In dimensionless form, the dependence (4) has the expression

$$\frac{U_b^*}{h_n} = f\left(\sigma_o m_v; \frac{b_1}{b}; \frac{b_1}{h_1}; \mu_1; \frac{E_1}{E_n}\right), \tag{5}$$

and includes nine factors. To quantify it, we use the plan of V. M. Mordashev [27] experiment with eight options for each factor, which has the form shown in table 1.

Table 1. Initial data for the construction of numerical models when determining the parameters of local reinforced zones

№ experiment	Value of indicators								
	σ_o, MPa	**b, m**	**μ_n, un.**	**E_n, MPa**	**h_n, m**	**b_1/b, un.**	**h_1, m**	**μ_1, un.**	**E_1/E_n, un.**
1	4	1	0.1	100	1	1	0.25	0.1	1.5
2	4	1.5	0.15	200	4	1.2	3	0.4	10
3	4	2	0.2	400	5	1.3	4	0.45	1.1
4	4	2.5	0.25	600	6	1.4	5	0.15	2
5	4	3	0.3	800	7	1.5	0.5	0.2	3
6	4	4	0.35	1000	8	1.05	1	0.25	5

№ experiment	Value of indicators								
	σ_o, MPa	b, m	μ_n, un.	E_n, MPa	h_n, m	b_1/b, un.	h_1, m	μ_1, un.	E_1/E_n, un.
7	4	5	0.4	1500	2	1.1	1.5	0.3	6
8	4	6	0.45	150	3	1.15	2	0.35	8
9	8	1	0.15	150	2	1.05	0.5	0.15	1.1
10	8	1.5	0.1	600	8	1.1	4	0.35	3
11	8	2	0.3	1500	3	1.4	3	0.25	1.5
12	8	2.5	0.45	200	7	1.3	1.5	0.1	5
13	8	3	0.2	1000	6	1.15	0.25	0.3	10
14	8	4	0.4	800	4	1	2	0.45	2
15	8	5	0.35	400	1	1.2	5	0.2	8
16	8	6	0.25	100	5	1.5	1	0.4	6
17	10	1	0.2	200	3	1.1	1	0.2	2
18	10	1.5	0.3	100	6	1.05	1.5	0.45	8
19	10	2	0.1	800	2	1.15	5	0.4	5
20	10	2.5	0.35	150	4	1.5	4	0.3	1.5
21	10	3	0.15	400	8	1.4	2	0.1	6
22	10	4	0.25	1500	7	1.2	0.25	0.35	1.1
23	10	5	0.45	1000	5	1	3	0.15	3
24	10	6	0.4	600	1	1.3	0.5	0.25	10
25	15	1	0.25	400	4	1.15	1.5	0.25	3
26	15	1.5	0.45	800	1	1.4	1	0.3	1.1
27	15	2	0.35	100	7	1.1	2	0.15	10
28	15	2.5	0.1	1000	3	1.2	0.5	0.45	6
29	15	3	0.4	200	5	1.05	5	0.35	1.5
30	15	4	0.2	600	2	1.5	3	0.1	8
31	15	5	0.3	150	8	1.3	0.25	0.4	2
32	15	6	0.15	1500	6	1	4	0.2	5
33	20	1	0.3	600	5	1.2	2	0.3	5
34	20	1.5	0.2	150	7	1	5	0.25	6
35	20	2	0.15	1000	1	1.5	1.5	0.35	2
36	20	2.5	0.4	100	8	1.15	3	0.2	1.1
37	20	3	0.1	1500	4	1.3	1	0.15	8
38	20	4	0.45	400	6	1.1	0.5	0.4	1
39	20	5	0.25	800	3	1.05	4	0.1	10
40	20	6	0.35	200	2	1.4	0.25	0.45	3
41	25	1	0.35	800	6	1.3	3	0.35	6
42	25	1.5	0.4	400	3	1.5	0.25	0.15	5
43	25	2	0.25	200	8	1	0.5	0.3	8
44	25	2.5	0.15	1500	1	1.05	2	0.4	3
45	25	3	0.45	100	2	1.2	4	0.25	2
46	25	4	0.1	150	5	1.4	1.5	0.2	10
47	25	5	0.2	600	7	1.15	1	0.45	1
48	25	6	0.3	1000	4	1.1	5	0.1	1.1
49	30	1	0.4	1000	7	1.4	4	0.4	8
50	30	1.5	0.35	1500	5	1.15	0.5	0.1	2
51	30	2	0.45	600	4	1.05	0.25	0.2	6
52	30	2.5	0.3	400	2	1	1	0.35	10
53	30	3	0.25	150	1	1.1	3	0.45	5
54	30	4	0.15	100	3	1.3	5	0.3	3
55	30	5	0.1	200	6	1.5	2	0.25	1.1
56	30	6	0.2	800	8	1.2	1.5	0.15	1
57	38	1	0.45	1500	8	1.5	5	0.45	10
58	38	1.5	0.25	1000	2	1.3	2	0.2	1
59	38	2	0.4	150	6	1.2	1	0.1	3
60	38	2.5	0.15	800	5	1.1	0.25	0.25	8
61	38	3	0.35	600	3	1	1.5	0.4	1.1
62	38	4	0.3	200	1	1.15	4	0.15	6
63	38	5	0.2	100	4	1.24	0.5	0.35	5
64	38	6	0.1	400	7	1.05	3	0.3	2

To establish the correlation dependence based on the expression (5), the numerical modeling by the finite element method has been performed [28]. The problem has been solved in a flat design, as the protective construction and the massif under it are elongated in plan and the stresses are distributed in a single plane. There have been constructed the geometric models of a unit thickness, which consist of the layers of direct and main

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footwall rocks with a local reinforced zone, on which evenly distributed load has been applied locally, simulating the affect of the protective means on the underlying layers (Fig. 4).

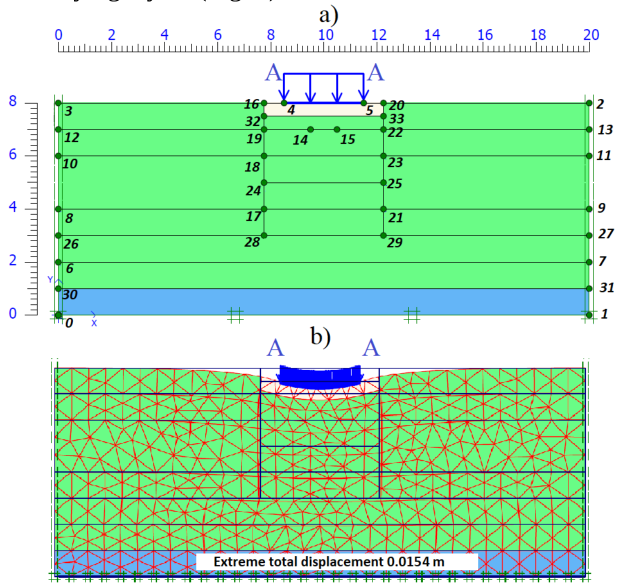

Fig. 4. Numerical model in the data entry window (a) and a finite element grid (b).

To realize the nonlinear nature of deformation of the massif, the elastic-plastic Mohr-Coulomb model has been used. According to the initial data (Table 1), 64 models have been built, during the testing of which the maximum pressing values of the footwall rocks U_b^* under the loading have been obtained. The general view of one of the models by the stages of its development is shown in Figure 5.

Processing of simulation results allowed to establish coefficients of empirical dependence of displacement U_b^* on the main affecting factors, which has the form

$$U_b^* = 0.835\sigma_o m_v h_n \left(\frac{b^2}{h_1 b_1}\right)^{0.163} \left(\frac{E_n}{E_1}\right)^{0.372} \qquad (6)$$

(R^2=0.896; t>$t_{\text{critical value}}$ (23.1>2.0); F>$F_{\text{critical value}}$ (51.7>2.06)), by which it is possible to determine the amount of subsidence of the protection means, under which the local reinforced zone is located.

Thus, from expressions (1), (2) and (6) it is possible to determine a relative indicator of efficiency of local strengthening of the footwall rocks by the formula

$$k_o = \left(\frac{h_1 b_1}{b^2}\right)^{0.163} \left(\frac{E_1}{E_n}\right)^{0.372}, \text{ (when } b_1 \geq b \text{ and } E_1 > E_n\text{)}, \quad (7)$$

which shows how much the subsidence of the protection means reduces relative to the surface of the underlying rocks when they are strengthened. It should be noted that in some cases, this figure may be less than 1. That is, with the wrong parameters of the local reinforced zone, the effect of its presence may be negative.

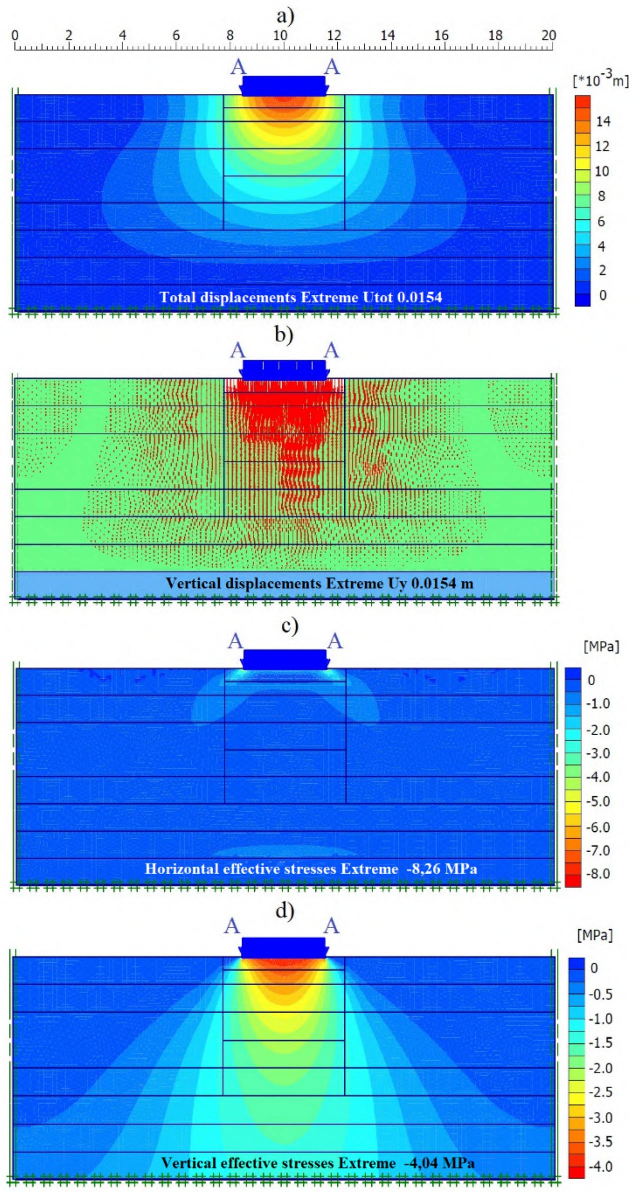

Fig. 5. General view of the numerical model for the study of deformation processes in the underlying rocks with a local reinforced zone (a– finite element grid, b, c, d– results of calculation, respectively, of vertical and horizontal stresses in the underlying rocks).

From expression (7) it follows that the parameters of the local reinforced zone under the protection means to ensure its stability are determined according to the assumption

$$\left(\frac{h_1 b_1}{b^2}\right)^{0.163} \left(\frac{E_1}{E_n}\right)^{0.372} > 1, \qquad (8)$$

according to which it is possible to take the appropriate size of this zone in relation to the width of the protection means and determine the required modulus of the total deformation of the zone in relation to the modulus of deformation of the soft layer of surrounding rocks. The left part of the assumption shows how much the subsidence of the protection means has been decreased with local strengthening of the footwall under it. In the assumption, the width of the local reinforced zone must be equal to or greater than the width of the protection means, and the deformation modulus of the local reinforced zone must exceed the deformation modulus of the soft layer of the footwall rock. Fulfillment of the condition shows the effective ratio of parameters of the local reinforced zone, the means of protection and a weak layer of footwall rocks, which increases the resistance of footwall rocks, reduces subsidence of the protection means relative to the level of the footwall surface, and reduces displacement of the roof and the protected footwall behind the face.

4 Conclusions

As a result of modeling the following conclusions have been made:
- the empirical dependence of the subsidence of the footwall surface under the protection means, below which the local reinforced zone is located, on the main influencing factors such as: load from the means of protection, deformation characteristics of this zone and host rocks, width of the protection means, strength of soft underlying rocks, and geometric dimensions of the local reinforced zone, has been established;
- the relative indicator of efficiency of local strengthening of footwall rocks which is used for determination of rational parameters of the given zone and considers its geometrical sizes, width of protection means, deformation and strength characteristics of a zone and host rocks, has been identified.

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Moisture as assessment criterion for coal rank and coal layers hazardous characteristics manifestation

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Abstract. For the time being, moisture effect to the useful quality of coals has been researched comprehensively in detail. Herewith, there are a lot of unsolved problems related to the safety working out of coal layers. Presence of different forms of moisture in fossil coals essentially influences the coal layers hazardous characteristics manifestation during the mining activities. The Article deals with the results of analyses of more than thousand samples of the Donets Basin coals from different deposits, to research the relationship of total moisture and organic matter components in the coal carbonizations during the metamorphic processes. The researches have allowed separation of 3 stages for the fossil coal conversions. It is noted that at the initial stage, the carbon content is about 80%, moisture proportion in carbonization is rather high—0.36; but it decreases abruptly down to 0.12, in case of the carbon content increasing up to 86.5%. And the proportion of components (hydrogen, oxygen, nitrogen, and sulphur) total increases essentially up to 0.88. At the next stage, at 86.5÷91.5%, the components proportion in carbonization changes insignificantly. At the final stage of coal metamorphic conversions, 4-time growth of moisture proportion takes place in carbonization. It is found that moisture proportion in any form to be found in the coals shall be considered as a rank index, which is necessary to determine the coal layers hazardous characteristics.

1 Introduction

Moisture is one of the most important quality indicators of coals. The significant content of moisture has an adverse effect to heating-performance and processing characteristics of coal; it reduces its calorific value and thermal resistance; its grinding, screening, and dressing becomes more difficult; it increases its carbonizing time and other coal processes, and makes its transportation (as ballast) more expensive [1].

To determine the above properties, the total coal moisture content (W) dried out to the constant weight at 105÷110°C shall be found. At the above temperatures, no pyrogenetic and hydrate moisture is removed and takes part in the total moisture content.

For the time being, the moisture influence to the coal useful properties has been researched comprehensively in detail. Herewith, there are a lot of unsolved problems related to the safety working out of coal layers.

Presence of different forms of moisture in fossil coals essentially influences the coal layers hazardous characteristics manifestation during the mining activities.

The significant role of moisture has been found in the gasdynamic events [2] and endogenous fires [3] occurrence, presence of dust-forming capability [4] and explosive properties of the coal dust [5]. These and several other negative manifestations of the coal layers hazardous characteristics are connected with changing the composition and properties of coals during their metamorphic conversions.

Generically, the metamorphism implies the various geological processes, which influence changes in the structure, mineral and chemical composition of coals [1]. Different forms of moisture content in the coals are connected with their metamorphic conversions as well. Determination of moisture content of each form and assessment of their influence to the coal layers tendency to manifest their hazardous properties is related to the mining problems, which are not solved yet [3]. Decreasing of accident risk and rate of injuries in the coal mines strongly depends on their solving and regulatory environment improvement. At its core, the moisture content relates to the metamorphic coal conversion indicators. Its content and forms of presence largely determine the elemental composition of coals and their properties [2-5]

The role of moisture in changing the composition and properties of coals during their metamorphic conversions has no proper reflection in the current Ukrainian regulations [6-9].

It's known that bed moisture in coals decreases as far as the metamorphism intensity increases; however, in

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passing to the anthracites, it increases again [4, 10]. These works used different interpretation of the coal rank definition. In the work [10], one of the main definitions of metamorphism has been kept: increasing the carbon content in the organic matter almost up to 100%, and reducing the total content of other main components down to zero. Keeping these provisions, 10 stages of metamorphism has been established based on the coke yield dry mineral matter free. Based on the analysis of multiple samples, average composition of the Donets Basin coals has been determined in the different coal ranks. The following has been taken under consideration: the content variation of carbon (C_0), hydrogen (H_0), nitrogen (N_0), sulphur (S_0), and oxygen (O_0).

In the work [4], the metamorphism intensity has been assessed by the coal ranks. The ranks as per industrial classifications define their useful quality, and do not reflect any alterations in the coal compositions and properties immediately. The useful quality of coals shall be established per totality of several classification indicators: the content of volatile agents (V^{daf}), coal plastometric index (y), semi coking resin yield ($T_{SK}{}^{daf}$), and free upheaving indicator (SI) [11]. Finally, they indirectly define the coke capacity that is one of the main tasks of industrial classifications. Coal humidity (W) has been considered as an additional criterion of the dust-forming capability [4], which has no direct relation to the metamorphic conversions. The content of volatile agents and coal rank are only indirect characteristics for variation of coal compositions and properties. In the case under consideration, they are assumed to be the key indicators of metamorphism intensity. By nature, V^{daf} and coal ranks are derivatives of component compositions of the initial substance organic and mineral parts during the geological processes. The moisture is an integral component of the fossil coals; its content suffers significant variations in parallel with the other constituents [10, 12]. For this reason, the moisture content in any form may serve as a criterion for the real hazard of coal layers during mining activities. This circumstance has been fully ignored in the regulations [6-9], when estimating the coal ranks.

In all the cases, the bed moisture (W) is considered as an independent indicator, which is not included in the organic matter composition, and independent of the other components content [1, 10, 13, 14]. The yield of pyrogenetic and hydrate moisture shall be included in the composition of volatile substances [10]. These forms of moisture content are not considered in the volatile substances yield, when determining V^{daf} indicator [1, 5, 13-15]. In both cases, the different forms of moisture content have immediate relation to the coal metamorphic conversions; and their indicators may determine the coal layers hazardous characteristics by many aspects.

One of causes of the normative documentation defects in a part of ensuring the safety conditions for mining operations is the proven insufficient previous study of the fossil coal moisture influencing their metamorphic conversion intensity.

Due to this, researches connected with the moisture study as an indicator of the coal metamorphic conversions are important today. The regulatory environment improvement largely depends on their results; it will help to reduce accident risks and rate of injuries in the coal mines.

2 Research procedure

Carbonization is one of the component parts of fossil coal metamorphic conversion processes. By definition [16, 17], it consists in the carbon (C_0) content increasing and hydrogen (H_0) and oxygen (O_0) reducing in the organic matter. In addition to C_0, H_0, and O_0, variation of the nitrogen (N_0) and sulphur (S_0) [10] content takes place in the organic matter during the metamorphic processes.

As rule, the total content of C_0, H_0, O_0, N_0, and S_0 is at least 99% of the whole organic matter. For this reason, the carbonization indicator values (C_n^{Σ}) in all the coal ranks shall be determined by the ratio:

$$C_n^{\Sigma} = \frac{C_0}{H_0 + O_0 + N_0 + S_0} \tag{1}$$

Consideration of such an aggregate of components helps to determine C_n^{Σ} more correctly.

The work procedure is actually based on the functional dependence of the totality of considered organic matter components on the carbon content [18, 19]. This provision is confirmed by the experimental data concerning variation of the components (H_0, O_0, N_0, S_0) totality depending on the carbon content in organic matter (Fig. 1, Curve 2). The information concerning variation of the components H_0, O_0, $N_{0,}$ and S_0 totality depending on C_0 content as per [10] is shown in Table 1.

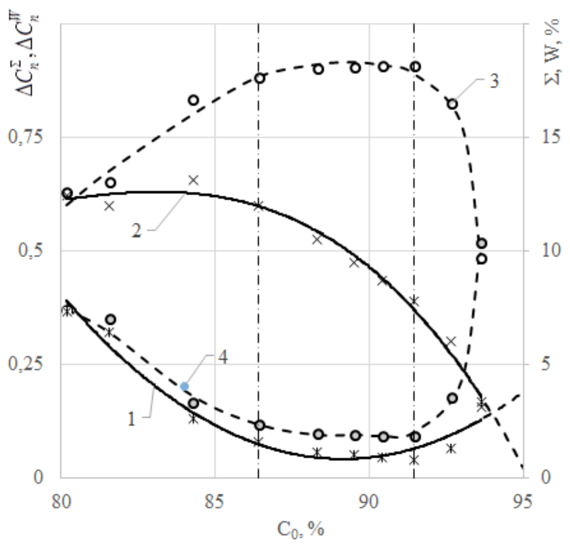

Fig. 1. Dependence of moisture variation (W) and total (Σ) of other components in the coal organic matter as per [10] and determination results of their part in coal carbonization Σ(H_0, O_0, N_0, S'_0) on the carbon content (C_0):
1, 2 – history curves of moisture and organic matter elements total, respectively; 3, 4 – history curves of part of organic matter elements total and moisture, respectively.
I, II, III – carbon content variation ranges, respectively 80÷86.5; 86.5÷91.5%; and more than 91.5%.

Table 1. Information concerning content in the moisture samples (W), and organic matter components as per [10], and results of determination of their part in the coal carbonization.

Indicators	**Content in moisture samples, and organic matter components, and carbonization parameters at content of C_0, %**									
	80.19	81.57	84.29	86.43	88.33	89.53	90.43	91.46	92.67	93.65
W, %	7.34	6.44	2.59	1.59	1.15	0.99	0.88	0.78	1.29	3.32
$\Sigma(H_0, O_0, N_0, S_0)$, %	12.47	11.99	13.12	11.98	10.52	9.48	8.69	7.76	6.04	3.03
$W^a + \Sigma(H_0, O_0, N_0, S_0)$, %	19.81	18.43	15.71	13.57	11.67	10.47	9.57	8.54	7.33	6.35
C_n^W	10.93	12.67	32.54	54.36	76.81	90.43	102.76	117.26	71.84	28.21
C_n^Σ	6.43	6.80	6.42	7.21	8.40	9.44	10.41	11.79	15.34	30.91
C_n	4.05	4.43	5.37	6.37	7.57	8.55	9.45	10.71	12.64	14.75
$(C_n^W)^{-1}$	0.092	0.079	0.031	0.018	0.013	0.011	0.010	0.009	0.014	0.035
$(C_n^\Sigma)^{-1}$	0.156	0.147	0.156	0.139	0.119	0.106	0.096	0.085	0.065	0.032
$(C_n)^{-1}$	0.247	0.226	0.186	0.157	0.132	0.117	0.106	0.093	0.079	0.068
ΔC_n^W	0.37	0.35	0.16	0.12	0.10	0.09	0.09	0.09	0.18	0.52
ΔC_n^Σ	0.63	0.65	0.84	0.88	0.90	0.91	0.91	0.91	0.82	0.48

At the same place, the data on bed moisture in the coal samples, which correspond to the total moisture (W) at the considered coal rank (C_0 content), are shown.

Dependence diagram of W on C_0 changes ambiguously (Fig. 1, Curve 1). During increasing the carbon content up to 86.5%, the moisture content in coal samples is reduced rather intensively by non-linear dependence from 7.34 down to 1.59%. In the carbon content increasing interval of 80÷86.5%, reducing of W content takes place less intensively in linear fashion from 1.59 down to 0.78%. Then, in the carbon variation range of 86.5÷91.5%, the moisture content growth starts from 0.78 up to 3.32%.

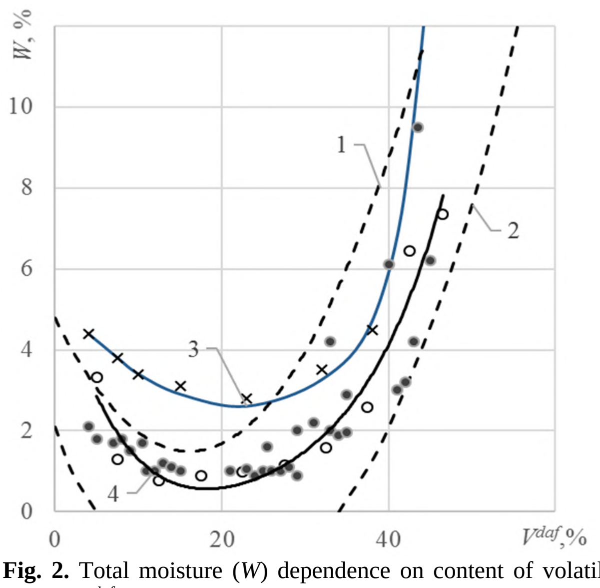

Fig. 2. Total moisture (W) dependence on content of volatile agents (V^{daf}) as per data processing [19].

1, 2 are upper and lower limits of moisture content variation in coals [5], respectively; 3, 4 are history curves of averaged moisture values as per [4] and [10], respectively

Such a variation of bed moisture is confirmed by the statistical data [5, 12-14] processing results [19] (Fig. 2). Curve 4 of the averaged data as per [10] is within limits between curves 1, 2 of potential individual variation values W for coals of different coal-bearing basins. It witnesses about the initial data [10] reliability, which have been received from the average results of analyses of more than thousand samples of the Donets Basin coals.

3 Discussion

Organic matter conversions under elevated temperatures and pressure are complex by nature. The vector direction of organic substance composition variation in case of the metamorphism intensification from lignites to bituminous coals, and then to anthracites is characterized by the carbon content increasing approximately from 70 up to 97-98%, and by the respective reducing of other components totality. For a certain coal layer, content of each main component of organic matter—C_o, H_o, N_o, S_o, O_o, and W – shall be determined by their initial ratio and fluids removal conditions during the metamorphic processes. The combined total of decreasing components (H_o, N_o, S_o, O_o, W) content shall be controlled by the carbon C_o content. Dependence of the main components (H_o, N_o, S_o, O_o) total on carbon content is characterized by the functional dependence by nature.

When C_o is increasing, individual reduction of the main components content is not so unambiguous. As rule, their links are subjected to non-linear dependences; and in some cases, there are abnormal deviations of some main components from the averaging curves. It evidences about differences between metamorphic conversion intensities of the certain coal layer and averaged indicators. Consequently, the elemental composition and properties of such coal layers will differ from the averaged indicators. These individual differences depend on the content of each component in organic matter. In the course of metamorphism, the oxygen content is reduced monotonously from 20-30% almost down to zero. During increasing the carbon content approximately from 70 up to 87-88%, the hydrogen content is unchanged and within the range of 4-6%. Its abrupt decreasing down to proportions of percent takes place in case of further growth of the carbon content. Reduction of the nitrogen takes place, when the carbon content is more than 95%. The sulphur percentage is almost unchanged in all the coal ranks. For separate coal layers, the total sulphur content may be less than one percent. There are cases of its maximum content up to 10%. The elemental individual content of each component of organic matter characterizes some region of the coal layer metamorphic conversion. Combinations of C_o, H_o, N_o, S_o, O_o, and W relations form the individual properties of coal layers, which are manifested during the mining operations. Work out experience of the separate coal layers and accumulated modern statistical material allow using the analysis results of coal laboratory samples with definition of C_o, H_o, N_o, S_o, and O_o. In majority of cases, the modern methodology of moisture determination is related with its drying up to the coal sample constant weight. For this reason, it is not always possible to designate W indicator as dry ash-free organic matter in combination with C_o, H_o, N_o, S_o, and O_o. The majority of organic matter components are intercorrelated between themselves. They include moisture content as well. W indicator depends on the carbon content, and its non-linear link with the oxygen content is established as well. It evidences that in the first factor block, which determine the coals ignitability, as minimum, it is necessary to consider the elemental relation between C_o, H_o, N_o, S_o, and O_o. Content of each of these components individually characterizes one of the aspects of coal layers metamorphic conversion processes. Variation of their relation indicates appearance of the different coal properties in comparison with the previous coal rank.

Based on its unilateral quantitative variation tendency, the carbon is a key indicator of the metamorphic processes intensity. The other components (H_o, N_o, S_o, O_o, W) supplement their characteristics. The most intensive variation takes place in the oxygen and moisture elemental content. The hydrogen content is decreasing essentially in the final metamorphic stages. Minimum variations are observed in the nitrogen and sulphur content. Rank order of the components—H_o, N_o, S_o, O_o, W—based on their part in the carbonization (C_o growth) in the different metamorphic stages influences the chemical activity of coals, including their liability to spontaneous ignition. The most ignitable coals are those, which have the leading places of oxygen, moisture, and sulphur in the rank order by the carbonization indicator.

Using the initial data (Table 1) on relation of the carbon C_0 variation and total of other components (H_0, O_0, N_0, S_0) of organic matter, by equation (1), the carbonation indicators C_n^{Σ} numerical values have been determined in the different coal ranks.

The indicators C_n^W (Table 1), which correspond to the carbonization intensity (C_0 increase) at the moisture (W) reduction in samples, have been considered by the equation:

$$C_n^W = \frac{C_0}{W} \tag{2}$$

The indicators C_n (Table 1), which characterize the general carbonization at decreasing the total of all the components (H_0, O_0, N_0, S_0) of organic matter and bed moisture (W), have been determined based on the dependency:

$$C_n = \frac{C_0}{H_0 + O_0 + N_0 + S_0 + W} \tag{3}$$

The carbonization indicators C_n, C_n^{Σ}, and C_n^W are interrelated between themselves by the relation:

$$\frac{1}{C_n} = \frac{1}{C_n^{\Sigma}} + \frac{1}{C_n^W} \tag{4}$$

Values of the indicators $\frac{1}{C_n}, \frac{1}{C_n^{\Sigma}}$, and $\frac{1}{C_n^W}$, which correspond to the define metamorphic conversion stage (C_0 content) are shown in Table 1.

Having taken $\frac{1}{C_n}$ value to be one, for each stage of the coal conversion, parts of ΔC_n^W and ΔC_n^{Σ} in the general carbonization have been found for moisture and total of other components:

$$\Delta C_n^W = \frac{\frac{1}{C_n^W}}{\frac{1}{C_n}} = \frac{C_n}{C_n^W} \tag{5}$$

$$\Delta C_n^{\Sigma} = \frac{\frac{1}{C_n^{\Sigma}}}{\frac{1}{C_n}} = \frac{C_n}{C_n^{\Sigma}} \tag{6}$$

The numerical values of indicators ΔC_n^W and ΔC_n^{Σ} evidence about continuous variation of the relation of parts of organic matter components totality (H_0, O_0, N_0, S_0) and moisture (W) in the different stages of coal conversion (Table 1, Fig. 1). It evidences that in these stages, the coal layers hazardous characteristics will be manifested differently based on the relation between part of moisture and other components.

At the initial stage of the fossil coal conversion ($C_0 \approx 80\%$), the part of moisture in carbonization is high enough ($\Delta C_n^W \approx 0.36$). It decreases abruptly down to 0.12 (Fig. 1 Stage I) at the carbon content increasing approximately up to 86.5%. The part of other components (H_0, O_0, N_0, S_0) increases essentially up to 0.88. At the following stage (II), the parts of components in carbonization change to a small extent, at C_0 content variation in the range of 86.5÷91.5%. At the final stage (III) of coal metamorphic conversions ($C_0 > 91.5\%$), the abrupt growth of moisture part (up to 0.52) in carbonization takes place. The analogous decreasing the organic matter components part is down to 0.48 (Table 1, Fig. 1).

Ambiguous change regularities of components of elemental compound of organic mass and various shares of their participation in carbonization are revealed. This allows to establish distinctive signs of separate stages of metamorphic transformations of coal. To reliably predict the dangerous properties of coal seams during mining operations, it is necessary to establish the peculiarities of the processes at individual stages of metamorphic transformations of coal. Each stage of metamorphic transformations of coal must be characterized by at least the following indicators: the percentage of carbon in the organic mass; moisture content; elemental composition of organic matter (hydrogen, nitrogen, oxygen, sulfur); the share of organic matter and moisture components in the carbonization of coal; the direction of change in the percentage of each component of organic matter and moisture with increasing carbonization; the direction of change of an individual share of participation in carbonization of components of organic weight and moisture. Given the actual differences in the elemental composition of the organic mass and moisture content, the prediction of the hazardous properties of each coal seams must be carried out according to the adjusted initial data. The share of participation in the carbonization of coal can be affected by changes in any component of organic matter and moisture. Oxygen, hydrogen, sulfur and moisture play a special role in the manifestation of the dangerous properties of coal seams. The possibility of clarifying the characteristic stages of metamorphic transformations is represented, for the most part, by the results of technical and elemental analyzes of coal. If necessary, in addition to them, it is possible to use data on the petrographic composition of coal. These features of changes in the composition and structure of coal during metamorphic transformations under the influence of moisture are not considered in regulations when determining the hazardous properties of coal seams. These variation particularities in the coals structure and composition during their metamorphism under influence of moisture are not considered in the regulations upon the coal layers hazardous properties determination.

Conclusions

The conducted researches allow making the conclusions important for the legal environment improvement:

1. The different forms of moisture in fossil coals significantly determine the coal layers hazardous properties: the gasdynamic events, liability to spontaneous ignition and dust-forming capability, coal dust explosibility.
2. Metamorphic conversion intensity during establishing the coal layers hazardous characteristics shall be determined by the useful quality indicators (content of volatile agents, coal plastometric index, semi coking resin yield, free upheaving indicator), which cannot directly characterize changing the elemental composition and properties of fossil coals.
3. Metamorphic conversions intensity is characterized by increasing the carbon content and decreasing the other components in organic and mineral parts composing the fossil coals.
4. Method to found the bed moisture part in coal carbonization has been developed.
5. Study of relationship between the general moisture part in carbonization and that of total of other components of the organic matter evidences not only about the elemental composition conversion, but about the coal inner structure as well.

Content of any form of moisture in the coals shall be considered as the rank index necessary to establish the coal layers hazardous characteristics.

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Rock pressure relief is the basic alternative for sustainable underground mining

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Abstract. Retreat longwall mining is the most productive system for underground extraction of tabulated deposits. However, the steady growth of the mining depth dramatically increased the ground pressure in chain pillars protecting the longwall entries. Therefore, several coal industries have tried to shift to pillarless mining and practiced maintenance of the head or tail entry behind the longwall in the stress relief zones using the backfill bodies in the thin coal seams. We modernized the pillarless variant of the retreat longwall system introducing the third roadway, which is driven in the consolidated goaf behind the moving longwall in a stress relief zone. We used a computer code FLAC3D to simulate stress redistribution during pillarless extraction of adjacent panels that assisted to determine optimal parameters of mining layout. This modernized technology provides for sustainable mining due to enhancement of transport, ventilation, safety conditions, and a comfortable environment because of the stability of the underground roadways, which serve the high productive longwalls.

1 Introduction

Shallow reserves of energy resources have depleted since the middle of the twentieth century. The depth of mining has increased steadily that was followed by the intensifying of the ground pressure. For example, the average depth of the underground coalmines in Europe exceeded 700 m. Several mines in Ukraine and China extract the coal at the depth of 1000 m and even more, which increased severe ground pressure manifestations such as gas, coal, and rock bursts, and spontaneous coal combustion. Also, the growing ground pressure augmented the problem of the underground roadway maintenance deteriorating its stability radically [1]. The worst of all is that the aforementioned problems have worsened sharply and unexpectedly.

The reason lies in a nonlinear response of underground roadways to the ground pressure raise [2]. Specialists in geomechanics use a simple but reliable empirical indicator that is a ratio k of the vertical stress component of ground pressure σ_v to unconfined compression strength (UCS) σ_c:

$$k = \sigma_v/\sigma_c \qquad (1)$$

If $k>0.33$ then the stability of an underground roadway fails dramatically since the convergence of the roof to floor and between sides of the roadway increases abruptly. Furthermore, the rate of convergence increment develops as the k exceeds 0.33.

The underground roadways present the main part of the underground mine fixed assets. Therefore, their deterioration dramatically inflates the total cost of extracted mineral resources. Meantime, world coal extraction has steadily grown because the demand for minerals and coal particularly raises.

Therefore, the task of maintaining the underground roadways' stability at the great depth has become a challenge.

The purpose of this presentation is to develop a prospective longwall technology using the maintenance of the roadways in the stress relief (SR) zones. In the second paragraph, we outlined the methods for the investigation of ground pressure redistribution during the pillarless panel extraction. Analysis of the traditional chain pillars system and substantiation of a new system using the third extra roadway has been described in the third paragraph. Then we investigated ground pressure redistribution during pillarless panels' expansion that helped to determine optimal parameters of the novel mining layout. Finally, the advantages of the new system have been discussed and the main conclusions outlined.

2 Methods

We used methods of computer simulation to investigate stress distribution and ground deformation around underground workings. The finite element algorithm (FEA) and finite difference methods are the most powerful and popular techniques, which are employed to solve complex problems when the stress-strain state of the rock mass should be investigated regarding nonlinear behaviour of the rocks and especially processes of their damage [3]. FEA successfully has been used during simulation of hydro-fracturing of the rock mass by SC-

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CO_2 mixture [4], fluid dynamic simulation [5], induced microseismicity by hydro-fracking [6], modelling of fracturing processes in discontinuous, porous rock masses [7].

The finite difference methods (FDM) are even more sophisticated for the simulation of geomechanical processes [8]. Alghalandis used FDM to improve discrete fracture network engineering [9], Bouzeran et al. simulated ground support performance in highly fractured and bulked rock masses [10], Bai et al. conducted numerical investigations of gateroad system failure induced by hard roofs in a longwall top coal caving face [11]. That is why we employed FLAC3D commercial code to simulate underground roadways behaviour in deep coalmines [12].

FLAC3D uses the explicit calculation cycling that propagates perturbation from an unbalanced force damping equations of motion that simulates dissipation of kinetic energy, Also, Cundall and Strack proposed an approach [13], when the calculation of motion (Newton second law) was solved ahead of the constitutive equation describing the stress-strain relation, including nonlinear behaviour of the rock. This imitated the real physics because the velocity of a disturbance wave is always limited in solid and liquid. This approach has provided success in preventing numerical instability and reproducing a realistic path of loading during simulation of nonlinear behaviour of the rock mass.

We also used physical modelling of irreversible ground movement to investigate the redistribution of ground pressure during consequent extraction of coal seams with longwall faces. Synthetic material that simulated a rock mass was a mixture of fine sand with plaster and mica.

Actual measurements of ground movement and deformation provided final and the most reliable data for confirming the results of computer simulation and physical modelling.

3 Chain pillar technology and its alternative

The longwall technology is the most popular in underground mining of tabulated deposits because of its exceptional economic efficiency. The majority of the coal reserves are extracted by retreat longwalls because the advanced longwall movement envisages driving the entries behind the moving face. In other words, the advanced longwall face moves blindly, which exposes it to the risk of impact with an unforeseen geologic fault.

A chain pillar system has been successfully used in US and Australia coalmines during the longwalls retreating since the middle of the last century to mine coal at a shallow and average depth (Fig.1). Longwall panel is outlined with at least two head entries 1 and 2 and tail entries 3 and 4. The head and tail entries are periodically connected with crosscuts 5. Longwall face 6 moves in Fig. 1 to the right as indicated by empty arrow and remains behind itself an empty waste area or goaf 7.

To provide safety, longwall 6 is ventilated by fresh air stream indicated by solid arrows. Mixture of air and methane/carbon oxide is removed through tail entry 4 as is indicated by intermitted arrows.

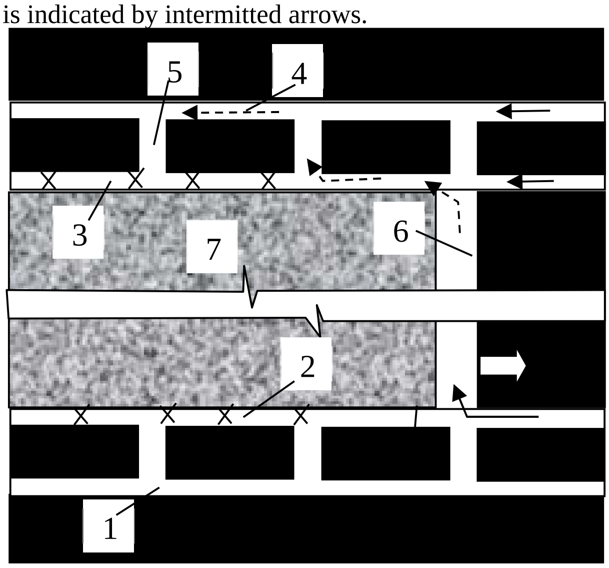

Fig. 1. Layout of the chain pillar system during the first longwall retreat: 1, 2 – head entries; 3, 4 – tail entries; 5 – crosscuts; 6 – longwall face that moves in direction indicated by the empty arrow; 7 – goaf; solid arrows indicate the stream of fresh air whereas intermitted arrows show the movement of the air and methane mixture; crosses specify uncontrolled parts of entries

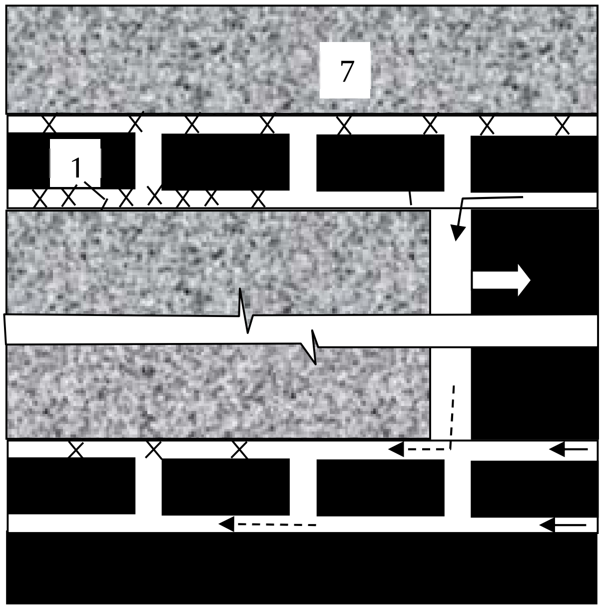

Fig. 2. Layout of the chain pillar system during the next adjacent panel extraction; numerals and arrows indicate the same positions as in Fig. 1

The ground pressure destroys head entry 2 and the crosses indicate an uncontrolled part of tail entry 3 behind the longwall. The next adjacent panels are extracted reusing head entry 1 as a tail entry (Fig. 2).

The content of the dangerous coal methane or carbon dioxide increases coherently with the growth of the depth that raises the probability of rock and coal bursts. That is why practitioners prefer to use Y-shape ventilation system, which provides moving both fresh air and a mixture of air and methane in the same direction as is indicated in Fig. 1. Opposite to the face advance, codirected movement of the air and contaminated gases pushes the dangerous gases out of longwall face and drifts them to the depth of the goaf promoting safety. This system envisages maintenance of the head entry behind the moving longwall where intensive ground pressure causes extensive damage to the roadway. The chain pillars are remained behind the longwall to eliminate this negative effect of the ground pressure.

The idea of the chain pillar technology was based on reusing the head entry 1, which is extreme relatively the goaf boundary. This entry is used again during mining the next adjacent panel (Fig. 2). The head entry, which was close to the goaf boundary, is destroyed after the extraction of coal in the previous panel. However, the extreme head entry ought to be saved and reused as a tail entry for the next panel.

All entries in the chain pillar system are maintained in abutment zones, which concentrate ground pressure and deteriorate the entries. Therefore the more depth of mining the more intensive the abutment pressure is. This situation demands to increase the width of the chain pillars but enlarging the pillars' dimension does not help essentially because of the high overall level of the ground pressure. For example, the index *k* of the roadway stability increases up to 0.5>0.33 at the depth of 800 m and UCS of 40 MPa.

That is why a relevant area of the chain-pillar system implementation is limited by 450-500 m. In other words, the steady growth of the mining depth dramatically increased the ground pressure and excessively wide chain pillars become unacceptable. Therefore, several coal industries, for example, Chinese and Ukrainian have tried to shift to pillarless mining [15] and practiced maintenance of the head or tail entry behind the longwall [14].

US regulations forbid driving of a single underground roadway due to certain ventilation risks. However, European and Asian countries allow such driving. This circumstance made it possible to get rid of the chain pillars and apply Y-shaped ventilation system. In order to do this, the head goaf-side entry 2 was retained behind the longwall face using a roadside backfill body [16], [17], or an artificial wall [14] (Fig. 3).

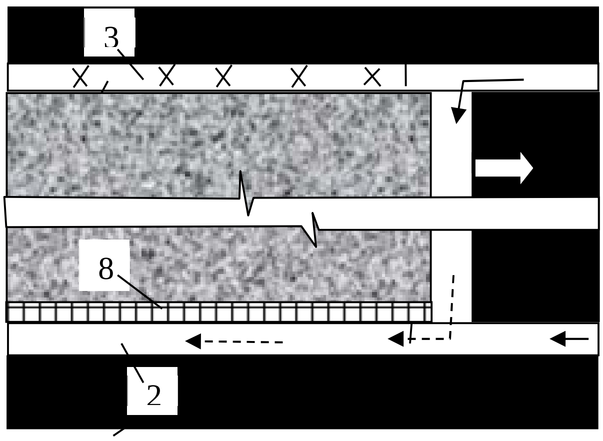

Fig. 3. Mining design with the artificial wall 8

Designers conceive to maintain the head entry with the cement backfill body, which should save stability and integrity during its reusing in the course of the next panel extraction as is shown in Fig. 4.

Reusing the head entry during pillarless mining is a very attractive idea because it saves labour, materials, and energy. However, as far as we know, a successful experience of reusing the head entry, which was driven before the longwall extraction and retained behind this longwall has not been published. Furthermore, several authors emphasize that even retaining and maintenance of an entry behind the advancing (not retreating) longwall is not an easy task at a great depth [16], [19], [18]. That is why the artificial wall technology has been enhanced by a roof cutting to relieve stress at the goaf side [20], [21].

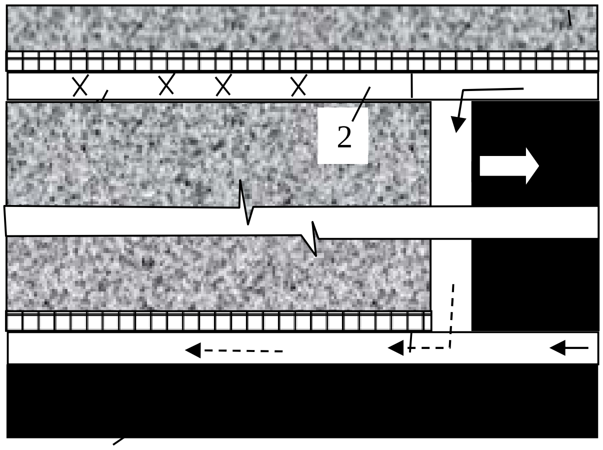

Fig. 4. Mining of an adjacent panel reusing head entry 2

Feng and Wang [22] described an original innovative technology of SR. The entry was planned to be driven under the goaf edge employing split-level longwall panel layout. However, such a system is relevant for the thick coal seams having the height, which exceeds more than two heights of the gateways.

4 Investigation of ground pressure evolution during pillarless mining

SR formation around the roadways has a long history and tradition. We consider the most popular technologies, which have proven their efficiency in the mining practice. Analysing any SR technology we should keep in mind that the relief from the high level of stress is inextricably linked up with a yielding. To get certain unloading from the ground pressure we should be ready to provide some deformation, which will reduce the area of a roadway section.

Zhan et al. [14] investigated a retained goaf-side tail entry, which has been maintained by means of building the artificial wall along the goaf side when the longwall face advanced. The roof of the roadway was reinforced by rock bolts and long 5-metre cables having a total bearing capacity of more than 400 kN/m^2. Despite this, the roof of the entry subsided to 500 mm whereas the floor heaved up to 1700 mm, which deteriorated the roadway section unacceptably when the longwall face had moved a considerable distance. Therefore, the entry has been repaired to a large extent.

The integrity of the artificial wall was checked, and the cracks and fissures on the wall surface were filled to

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prevent water and gas in the goaf area from flowing into the roadway space during maintenance.

The floor was dinted to recover the working space for the following operations. This made it possible to remove the squeezed part of the coal side of the roadway. As a result, initially installed rock bolts and cable bolts were exposed due to the widening of the entry. The extra ends of the bolts and cable were cut off, and the retained portion inside the surrounding rock was prestressed again.

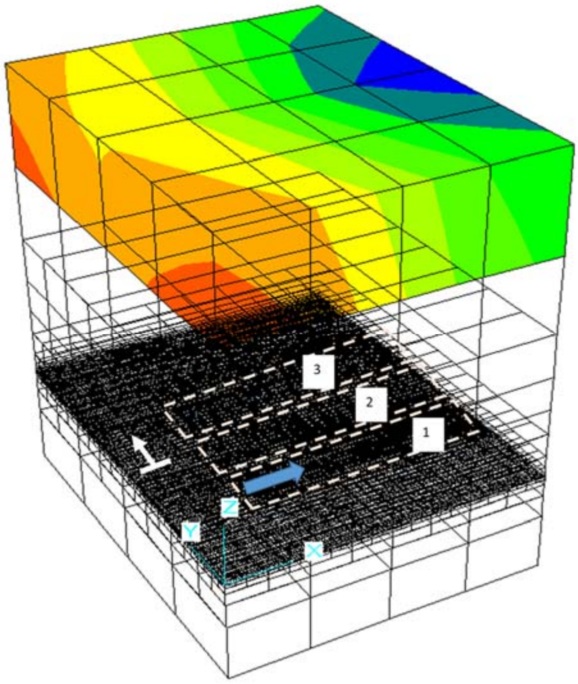

Fig. 5. Layout of the model; numbers indicate the sequence of panels extraction.

According to [14] the roadway section has been recovered and satisfied the requirements of the adjacent panel excavation. However, there was no information concerning the experience of this important part of mining. Pillarless extraction of a panel adjacent to a previously formed goaf causes an extensive ground pressure intensification there, which inevitably will worsen ground control and maintenance of the roadway. To investigate this process, we have carried out a computer simulation of the ground pressure redistribution during adjacent panels' extraction.

Fig. 5 demonstrates the layout of three panels extraction without abandoning inter-panel pillars. The vertical dimension of the model was 1500 m and a flat 1.5-meter coal seam was at the depth of 1100 m. The dimension of the model along the strike (axis X) was 1024 m and alongside with the dip (axis Y) 1240 m. The direction of the panel retreat is indicated by the fat arrow. Every panel had a width of 256 m and located relatively model boundaries at 256 m. The step of the longwall retreat was 10 m that was moving at the rate of 250 m per month.

We used Mohr-Colomb law as the constitutive model of the rock mass. We also accounted for the process of softening due to the rock damaging involving elements of Hoek-Broun empirical rules. The cohesion of the rock dropped down to 1.0-0.5 MPa when dilation strain reached up to 0.004.

The thickness and mechanical properties of the rocks are presented in Table 1, and Fig. 6 shows the vertical movement of the rock mass after extraction of the first panel. Geologic and geomechanical conditions describe those, which were at a typical deep coal mine 'Pocrovs'ke' in Ukraine.

Table 1. Properties of the rock layers in the model

Rock	**Thickness, m**	**Bulk modulus, GPa**	**Shear modulus, GPa**	**Cohesion, MPa**	**Angle of friction, degree**	**Tension limit, MPa**	**Dilation, degree**
Rock	Cover & Base	14.0	8.4	9.0	35	7.0	10
Sandstone, roof	20.0	24.0	14.4	12.0	28	9.0	9
Shale, immediate roof	10.0	14.0	8.4	7.0	28	5.0	10
Coal	1.5	14.0	8.4	7.0	28	4.0	11
Shale, immediate floor	10.0	14.0	8.4	9.0	28	5.0	10
Shale, floor	20.0	14.0	8.4	12.0	35	9.0	10

Elastic recovery of the floor was 40 cm, which is close to 34 cm registered in situ using levelling at the depth of 915 m. This simulation has been conducted in 'set large' displacement mode, which envisages recalculation of the node coordinates according to current increment of the displacements.

Fig. 7 demonstrates the distribution of the vertical stress component around the goaf of the first panel. Average vertical stress in the goaf does not exceed 8 MPa that 3.36 times less than geostatic level, which was 27 MPa.

Furthermore, the stress diminished down to 3 MPa in the immediate vicinity of the goaf border 1 that is nine times less than the geostatic level.

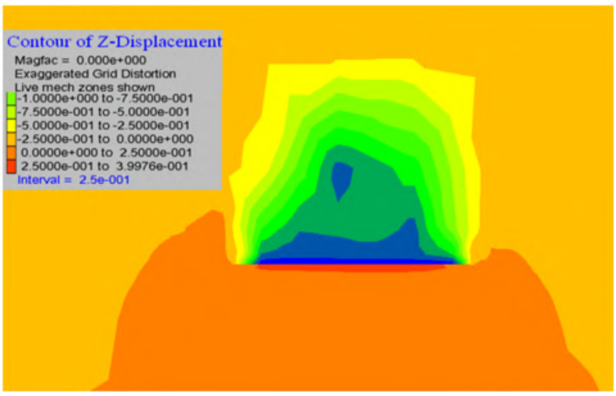

Fig. 6. Contour of the vertical displacement after the first panel extraction.

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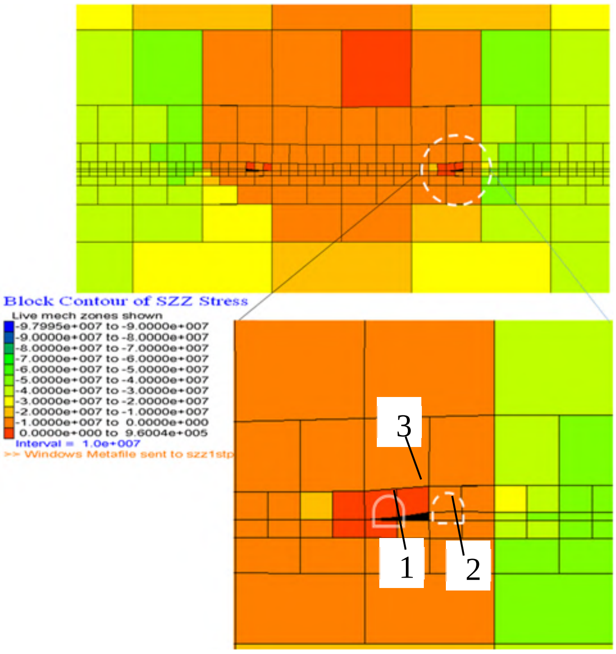

Fig. 7. Distribution of the vertical component of the ground pressure after the first-panel mining.

Position 2 in Fig. 7 indicates the edge of the coal seam that is adjacent to the goaf boundary 3. This area was essentially relieved of the ground pressure reducing it down to 10 MPa. Therefore, miners drive the roadways in the aforementioned area that got traditional characteristics as ‘skin-to-skin’ driving.

Roadway 1 is in a highly favourable position because of an extremely low surrounding stress. Such roadways have been driven in the goaves of Ukrainian coalmines since 1960th. SR zones attracted practitioners to place the roadways in the goaves (Fig. 8). The stability of these gateways was excellent for a long period while the goaf boundary was fixed. However, the roadway state has worsened as an adjacent to the boundary panel was mined. Therefore, we should examine the case when the adjacent panel will be extracted.

Fig. 8. An example of good stability of a roadway driven in compacted and consolidated goaf.

Fig. 9 demonstrates that pillarless extraction of the adjacent panel reduced SR in the goaf of the previous panel. For example, ground pressure in the goaf after extraction of panel 2 was approximately 12 MPa. However, pillarless extraction of the third panel essentially increased the stress in the goaf of the second panel. The vertical stress in goaf 2 increased up to 22 MPa that raised k-index up to 0.55>0.33 (Fig. 9), which has worsened the ground pressure background regarding the roadway stability.

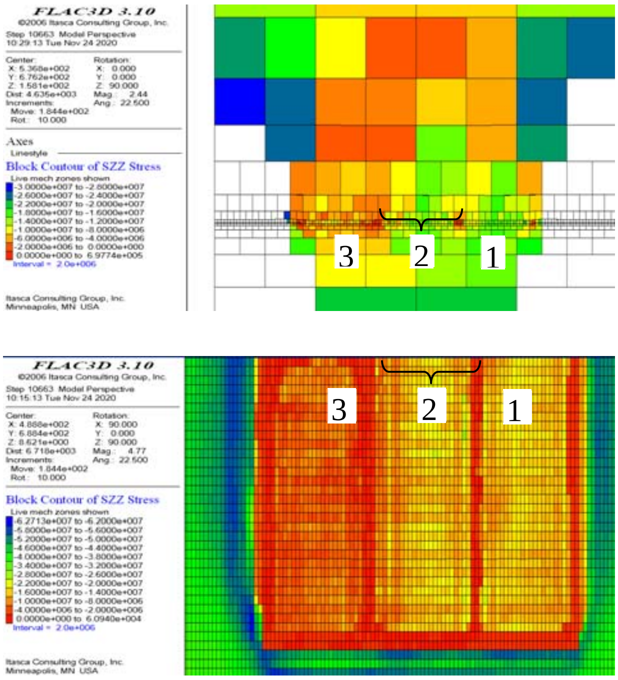

Fig. 9. Stress distribution after extraction of all three panels: vertical section (top); plan view (bottom).

Fig. 10 demonstrates as the k-index evolved during the expansion of mining. Stages from 0 to 2 correspond to the extraction of the current panel whereas stages from 2 to 5 describe the situation when the next (adjacent) panel was extracted.

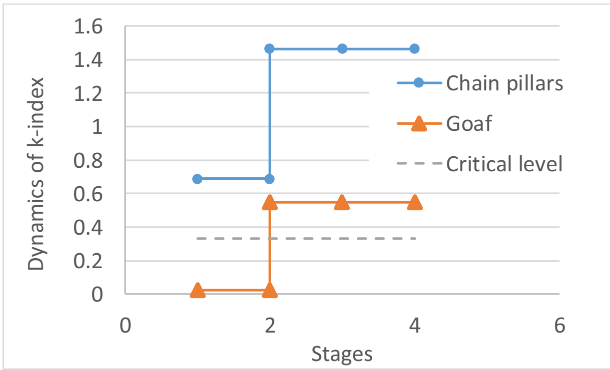

Fig. 10. Evolution of k-index during the extraction of the panels.

The driving and maintenance of the roadway in a goaf is much more favourable than the maintenance of the entries by the chain coal pillars because the ground pressure is less by 30 times behind the current panel and by 2.66 times less after the adjacent panel mining. However, despite this advantage, the roadway in the goaf will suffer because the k-index exceeded the critical level of 0.33.

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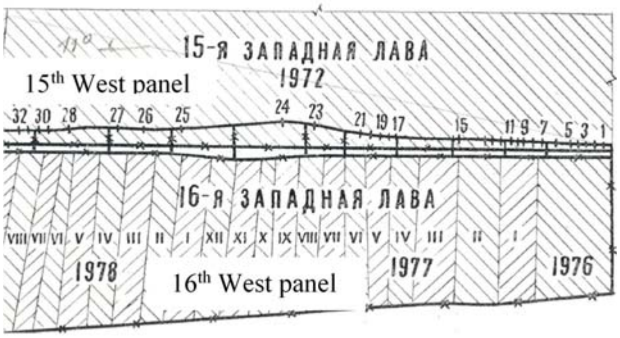

Fig. 11. Mining layout with the third entry drove in a goaf of l_4 coal seam.

The results of the computer simulation have been proven by an experiment in situ (Fig. 11). West panel #16 extracted the flat 1.6-meter coal seam l_4 at the depth of 720 m (the coal mine named after Abakumov, Donetsk, Ukraine) [23]. Weak mudstone having UCS of 20-30 MPa and thickness of 10 m represented the immediate roof whereas medium-strength sandstone deposited in the main roof. Shale with UCS of 30-40 MPa bedded in the immediate floor.

The third entry was driven in 1975 through the goaf of the 15th West panel, which was extracted in 1972. The convergence of the roof and floor in the experimental entry has been periodically measured at the stations indicated by numbers from 1 to 32. Panel #16 was extracted by a longwall with the rate of 30-40 m/month. Roman numbers on the layout in Fig. 11 indicate the month advances.

We selected the monitoring stations from 17th to 20th for demonstration of the third entry reaction to the West longwall #16 retreating. These stations were sufficiently far from the start-up room and reflect a typical periodic roof caving during longwalling.

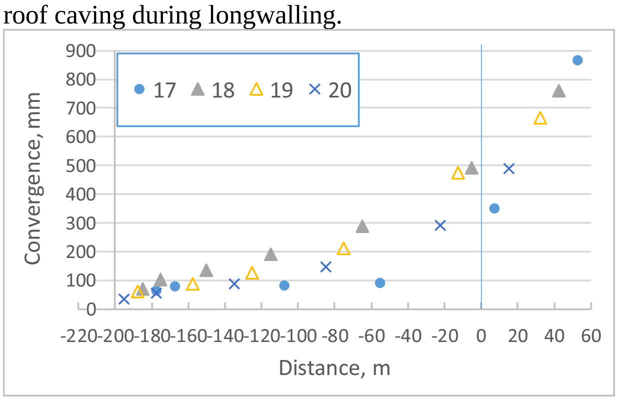

Fig. 12. Results of the convergence monitoring in the third entry.

The negative distance in Fig. 12 points to the position of the monitoring stations before the approaching longwall (outby) whereas positive values of the distance indicate that the longwall passed by the station and moves away from it. The third entry has not been maintained behind the longwall (inby) but there was a possibility to continue the monitoring inby it some period. Fig. 12 shows there was not a subsiding tendency. Furthermore, the convergence had approached up to 0.8 m and steadily continued to grow.

Therefore, additional means are necessary to protect the roadway in the goaf from the negative influence of the adjacent panel mining. The most technological means is the backfill body [24], [25] (Fig. 13).

Roadway 9 is driven behind the longwall. The face of roadway 9 lags to prevent the negative impact of the ground subsidence behind the moving longwall. Distance D should protect the roadway stability and secure that it will be driven in a completely consolidated goaf.

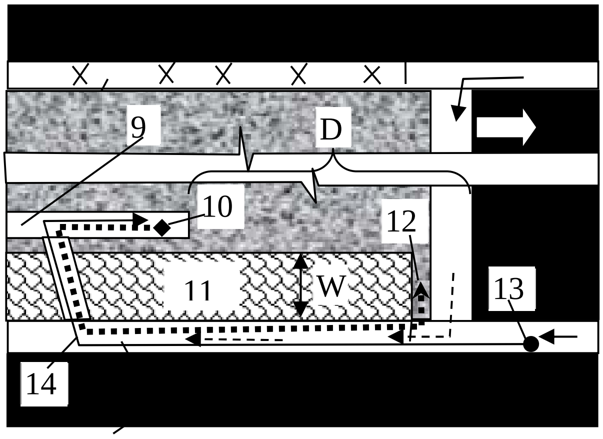

Fig. 13. Mining layout during driving of the roadway 9 in the goaf of the first (previous) panel; 10 – conveyor chain for transportation of the waste rock for the filing of the back body 11; 12 – pneumatic discharge of the crashed waste rock; 13, 14 – local fan and flexible tube for the roadway face ventilation; D – lag distance of the roadway 9 from the longwall.

The waste rock from the driving of roadway 9 is removed by conveyor chain 10, ground by crusher, and packed to the backfill body 11 with pneumatic machine 12. The building of body 11 from the waste rock is viable economically and friendly ecologically. Width *W* of the backfill body 11 is proportional to the section area of roadway 9 and diminishes as the coal seam height increases. For example, W≈25 m when the net roadway section is 20 m^2 and the height of the coal seam is 1.5 m.

Fan 13 ventilates roadway 9 with fresh air, which is collected in front of the longwall face.

Lag *D* of the roadway face depends on the rate of the longwall retreating. For the depth of 1100 m and the rate 300 m/month *D*=245 m (Fig. 14). Such a distance guarantees a perfect stability of the roadway 9 because it will be driven in the consolidated goaf out of active subsidence of the undermined strata.

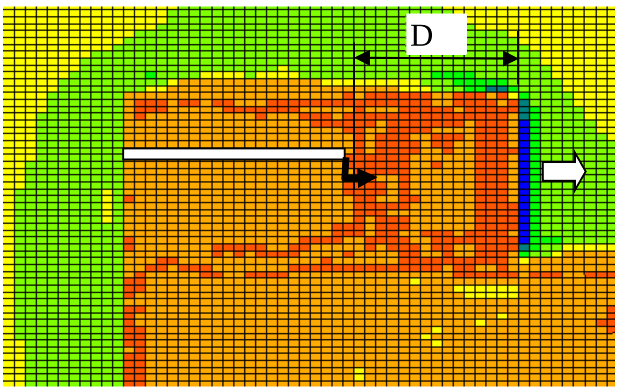

Fig. 14. Distribution of the ground pressure in the goaf behind the moving longwall face.

Fig. 15 shows layout of the mining works during the adjacent panel extraction.

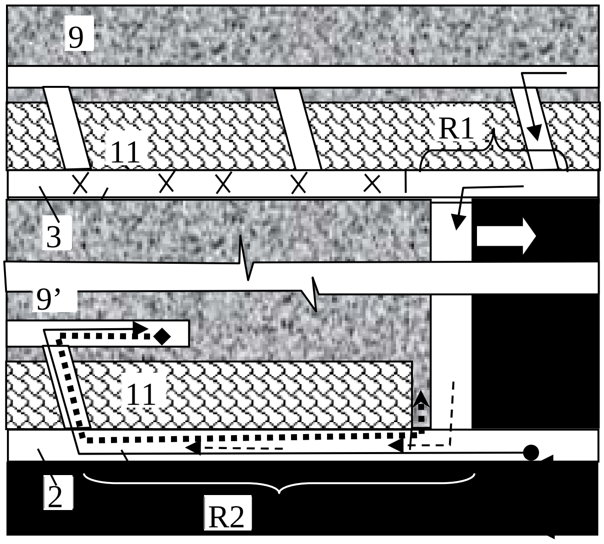

Fig. 15. Mining layout during adjacent panel extraction

This layout has an essential advantage over the chain pillar system. There is no need to maintain entries 2 and 3 through the whole length. It will be sufficient to retain entry 3 between the moving longwall face and the forward crosscut (interval R1), and entry 2 between the longwall and the closest rear crosscut (interval R2). General main service for mining operations will be provided by the roadway 9 and 9': entry 9 will provide the longwall for fresh air and transportation of the coal whereas entry 9' will remove the mixture of air and methane. This is the best variant #1 from the technical point of view and safety consideration.

There is another option #2 when the fresh air stream moving along the longwall reverses its direction, namely goes from the bottom to the top. In this situation, entries 9 and 9' swop their functions but entry 3 must be maintained behind (inby) the longwall, namely from the face to the closest rear crosscut that is not so easy task. Both roadways 9 and 9' will be in a stable state due to protection of the backfill bodies 11 that was demonstrated on the physical model (Fig. 16).

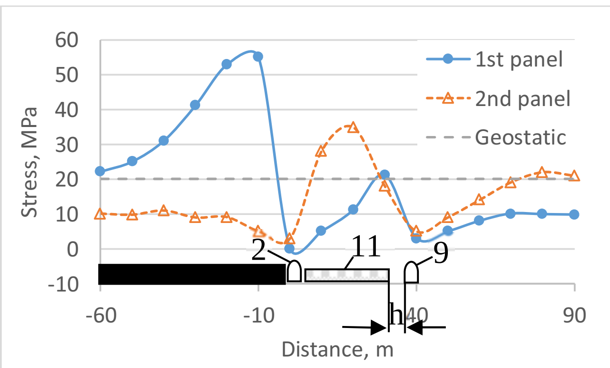

Fig. 16. Stress distribution after 1st and 2nd panel extraction.

The backfill body 11 creates local SR zones at the edges. These zones conserve SR that minimizes the ground pressure activation after the second (adjacent) panel extraction. That is why roadway 9 should be driven in the goaf immediately at the backfill body edge or at the distance h=5-6 m from it.

Mining practice has demonstrated that it is impossible to provide the ideal stability of entries 2 and 3 at the great depth of mining [26]. However, this is realistic to provide minimum means for retaining their intervals R1 and R2 if to use the arch shape of the entries and support them by a combination of yield frames, rock bolts, and cables. Then the dinting of the floor will be sufficient because the self-supporting effect will stabilize the roof [27].

An economic assessment has demonstrated that extra cost of the third roadway driven in the goaf does not exceed 10% of the total profit from the increase of the coal output due to enhancement of transport, ventilation, safety conditions, and comfortable environment because of stability of the underground roadways serving the high productive longwalls.

5 Conclusion

Retreat longwall mining using the chain pillars has become popular in underground mining since the 1960th. However, the steady growth of the mining depth dramatically increased the ground pressure and excessively wide chain pillars become unacceptable. Therefore, several coal industries have tried to shift to pillarless mining and practiced maintaining the head or tail entry behind the longwall in the stress relief zones using the backfill bodies in the thin coal seams.

The mining experience has demonstrated so far that it is not easy to retain entries behind the longwall with the backfill bodies. We modernized the pillarless system introducing the third roadway, which is driven in the consolidated goaf behind the moving longwall and used as a tail entry.

The waste rock from the driving is ground and discharged by pneumatic equipment into the goaf. The backfill body is erected from the waste at hand material immediately behind the longwall face. This backfill support protects the roadway from the ground pressure activation during adjacent panel extraction and reusing of the roadway as a head entry.

The extra cost of the third roadway driven in the goaf does not exceed 10% of the total profit from the increase of the coal output owing to Y-shape ventilation system exploding. New technology provides for sustainable mining due to enhancement of transport, ventilation, safety conditions, and a comfortable environment because of the sufficient stability of the underground roadways, which serve the high productive longwalls.

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Innovative mining technologies with complex geomechanical characteristics

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Abstract. The article presents innovative technologies for the extraction of minerals from underground mines with complex geological, mining, and technical and geomechanical characteristics. The need to develop such mining technologies is discussed and the conditions under which they should be applied are presented. Principal variants of extraction technologies such as Raisebor technology, Raisebor technology in combination with the drilling and blasting method and the continuous development system using Alimak or KOV - 25 monorail complex are shown in the article.

The need to develop new technologies

The development of the technologies for mineral processing leads to significant improvement of technical, technological and economic indicators of the overall production. It is possible to process low-grade ores, develop deposits with more complex geomechanical characteristics and achieve a positive economic result. This situation in the mining industry is also helped by the gradual but continuous increase of the prices of the end products produced over the last 15-20 years.

Hence, reassessment of the reserves and adjustments in the commercially useful components in the extracted raw materials are necessary.

Thus, an increase in the amount of reserves is achieved, both in existing mines and in newly created ones. In addition, a certain extension of the operational time of existing mines is also achieved by re-categorizing reserves. Conditions are also being created for the development of new mineral deposits considered to be not very promising (with non-minable contents of useful components).

All this sets up preconditions for creating opportunities for the development of deposits with complex geological, morphological, mining, technical and geomechanical characteristics during the operation of underground mines.

As it is well-known, in the underground mining of complex-structured deposits the classical systems of development are the sublevel stoping method of mining and the square-set stoping-and-filling method of mining with Alimak technology and subsequent mass drawing and caving.

The variants of the sublevel stoping method of mining of deposits with low strength indicators are characterised in two directions: with light portable mechanisation or with mobile mechanisation and front recovery of the ore. In order to do this, a network of opening access roads and inclined development workings for the mining equipment is created. [1] The recovery ratio is 0.9 and the contamination factor is 15 to 20%.

The application of the square-set stoping-and-filling method is universal for this type of deposits and it is characterised by low economic efficiency due to the external production processes such as the support and the filling of the mined-out area. The variants are supports with ¾ wooden frames and wooden lining of the stope or roof bolting with a metal net combined with shotcrete. A high recovery ratio of 0,95 to 0,98 and minimum contamination factor from 3 to 5% are typical for these variants. The Alimak technology is also applicable in complex-structured deposits with shrinkage of the ore. The variant of this technology with open chambers (continuous system) for ore bodies with high dip is not applicable and the caving method of mining of the bedding rocks is used.

In the variants with sublevel caving and the Alimak Technology certain deformations of the surfaces of deposits are admissible which requires additional resources for the reclamation of the damaged lands. The Raisebor technology is used for the extraction of uranium in Canada (Cameco Corporation) [2]. Similar systems have been also described for the development of complex-structured rich iron deposits. [3]

It is important to define correctly the parameters of blasting works, taking into consideration the strain and stress condition of the rock mass when applying these systems for development. [4]

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Conditions for the applicability of innovative ore mining technologies in deposits with complex geomechanical characteristics

Innovative technologies for the extraction of minerals are increasingly used in the mining practice for the development of deposits with complex morphology, complex geomechanical characteristics and high value of the mineral resources. The adjusting and reworking of existing development systems and extraction technologies to specific conditions is aimed at finding a solution to a particular problem in a given deposit and not at creating conventional technologies for mass application.

These innovative technologies should be applied in the development of new deposits with complex geological, mining, technical and geomechanical characteristics (ore bodies with complex morphology, ill-defined boundaries, weak ore and host rock strengths, high temperature, etc.), and high value of the extracted raw material.

The objective of developing innovative mining technologies for deposits with complex mining, technical and geomechanical characteristics is to find out a new solution for optimizing yield results. This new engineering solution must be different from the conventional methods of extraction, whereby we will have a positive economic effect (as opposed to classical methods of extraction) from the development of a given deposit.

Raisebor technology

The Raisebor technology consists of extracting vertical layers (rises) from the ore body in a specific order, with the mined out spaces being filled. [5, 6] The primary chambers are filled with a paste-hardening fill to achieve sufficient camera strength to open a secondary chamber next to the filled rock mass without leaving pillars [7]. The secondary chambers can be filled both with a paste-hardening fill and a rock-fill from a sterile mass obtained during the driving of the mining workings.

The purpose of developing a Raisebor technology is to provide a productive mining technology applied in complex morphological and geomechanical conditions. Thus, the loss and impoverishment indicators of the raw materials extracted (without pillar recovery) are reduced. [8].

On the other hand, the technology is designed in such a way so that during the whole stage of operation, the ore extraction is carried out without the presence of people in the mining areas. This ensures safety at work due to the absence of people in the mining areas, as well as the reduction of additional processes for the maintenance of mining areas, ventilation, etc.

Raisebor technology makes it possible to mine ore bodies with complex morphology and ill-defined boundaries. Ore bodies with an average thickness of 0.7 - 2.5 m and an angle of inclination from 90° - to 60° can be mined out. This mining method can be applied to bodies with complex morphology both for the overall development of an underground mine and for its individual sections.

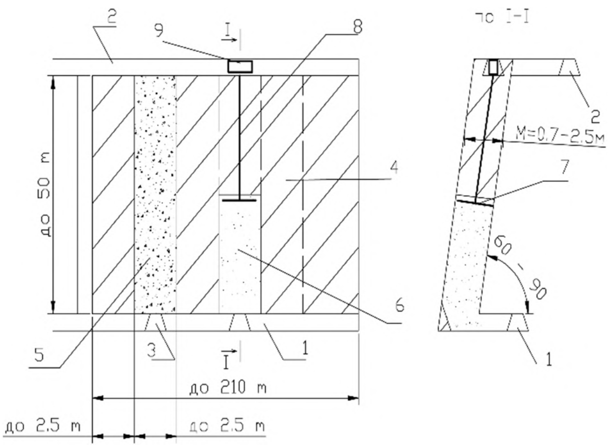

Fig. 1. Raisebor technology for mining of mineral resources
Legend: 1 – haulage level; 2 – air drift; 3 – loading cut-off entries; 4 – ore body; 5 – paste-hardening fill; 6 – fines, extracted ore; 7 – cutting head; 8 – borehole; 9 – Raisebor machine.

The technology offers several options for mining-out:

A - Using stationary mechanization:

- **Standard** – a pilot hole, which expands from the bottom up, is drilled. This method is characterized by a maximum diameter of the side cutting of up to 6 m and a maximum depth of 1000 m;
- **Descending extension** - a pilot hole from top to bottom is drilled, with subsequent top to bottom extension (descending). In this method, the diameter of the working is up to 1.5 m and the depth reached is up to 30 m;
- **Ascending extension** - a pilot hole from bottom to top is drilled, with simultaneous side cutting to the full diameter of the extraction working. Rises of up to 2.5 m in diameter and up to 150 m in depth can be driven by this method.

B - Using mobile mechanization:

- **Ascending driving** - this method is intended for driving a compensation rise in mining systems in sub-level workings, sub-level caving and block caving systems.

The machine operates in workings with 4.5 m x 4.5 m dimensions. This method allows a rise of up to 1.2 m in diameter and up to 200 m in length to be driven.

- **Descending driving**- the method is characterized by a top-down rise with a maximum diameter of 0.75 m and a length of up to 60 m.

The drilling angle varies from 90° to 60° in all directions.

Knowing the capabilities of Raisebor mechanization provides the opportunity to use it as a mining mechanization - to develop an innovative technology for underground extraction of minerals, which strictly meets the specific requirements and characteristics of a given deposit.

It is important to note that the application of the Raisebor technology needs to be well-ensured from a

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geomechanical point of view. The geomechanical dimensioning will give the maximum open surfaces that can be naturally sustained. Hence, the specific dimensions of the mining blocks and their parameters should be determined, as well as the specific mechanization and method of driving the extraction workings.

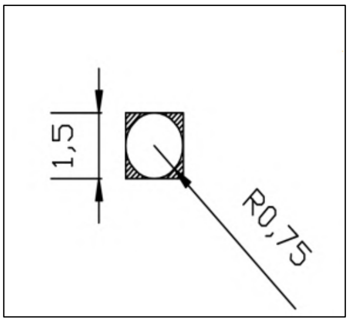

Fig. 2a. Raisebor technology for different diameters of the bit – R = 0,75 m

$$S_1 = a^2 = 2{,}25\ m^2;\quad S_2 = \pi R^2 = 1{,}77\ m^2;\quad S_1 - S_2 = 0{,}48\ m^2;\quad S_1/S_2 = 0{,}78 \tag{1}$$

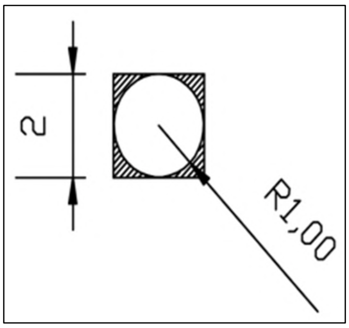

Fig. 2b. Raisebor technology for different diameters of the bit – R = 1,00 m

$$S_1 = a^2 = 4{,}00\ m^2;\quad S_2 = \pi R^2 = 3{,}14\ m^2;\quad S_1 - S_2 = 0{,}86\ m^2;\quad S_1/S_2 = 0{,}78 \tag{2}$$

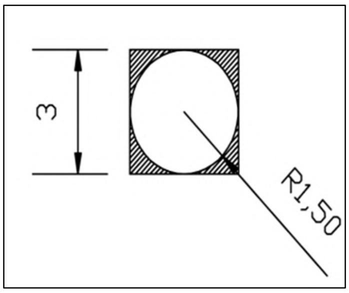

Fig. 2c. Raisebor technology for different diameters of the bit – R = 1,50 m

Optimisation of the losses and contamination when using the Raisebor technology

In order to ensure maximum recovery of the reserves using the Raisebor technology, different cases are considered for including the cutting head in ore bodies with thickness from 1.5 to 5 m (Fig. 2a, 2b, 2c, 2d, 2e).

$$S_1 = a^2 = 9{,}00\ m^2;\quad S_2 = \pi R^2 = 7{,}07\ m^2;\quad S_1 - S_2 = 1{,}93\ m^2;\quad S_1/S_2 = 0{,}78 \tag{3}$$

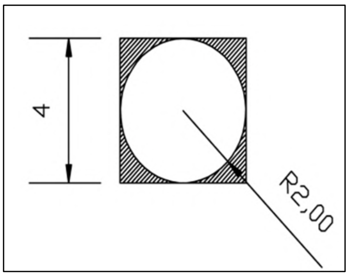

Fig. 2d. Raisebor technology for different diameters of the bit – R = 2,00 m

$$S_1 = a^2 = 16{,}00\ m^2;\quad S_2 = \pi R^2 = 1{,}77\ m^2;\quad S_1 - S_2 = 0{,}48\ m^2;\quad S_1/S_2 = 0{,}78 \tag{4}$$

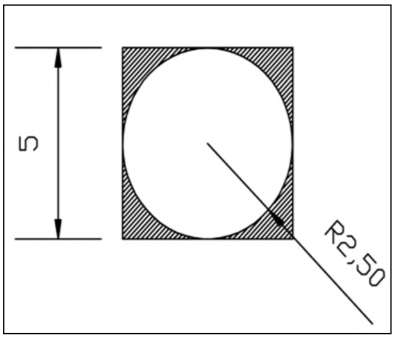

Fig. 2e. Raisebor technology for different diameters of the bit – R = 2,50 m

$$S_1 = a^2 = 25{,}00\ m^2;\quad S_2 = \pi R^2 = 19{,}62\ m^2;\quad S_1 - S_2 = 5{,}38\ m^2;\quad S_1/S_2 = 0{,}78 \tag{5}$$

The area ratios in the variant shown in Figure 2, S_2/S_1 for the five cases (a, b, c, d and e), show a mineral loss of 22% (the recovery ratio in this case is 0,78) or the contamination here is in the framework of the primary.

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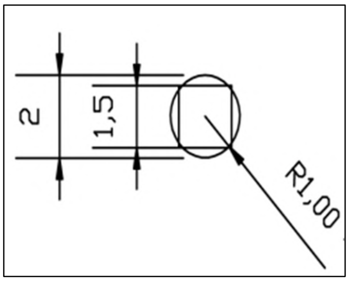

Fig. 3a. Raisebor technology with overlap of the contour

$$S_1 = a^2 = 2{,}25\ m^2;\quad S_2 = \pi R^2 = 3{,}14\ m^2;\quad S_2/S_1 = 1{,}39\quad S_1/S_2 = 0{,}72 \tag{6}$$

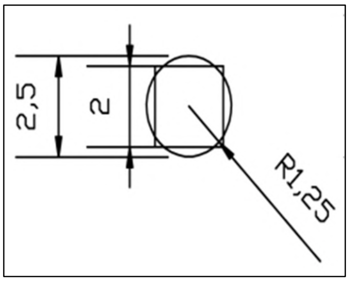

Fig. 3b. Raisebor technology with overlap of the contour

$$S_1 = a^2 = 4{,}00\ m^2;\quad S_2 = \pi R^2 = 4{,}91\ m^2;\quad S_2/S_1 = 1{,}23\quad S_1/S_2 = 0{,}82 \tag{7}$$

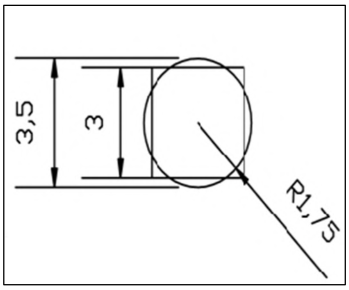

Fig. 3c. Raisebor technology with overlap of the contour

Table 1. Ratio diameter/thickness.

No	**Ratio diameter of recovery/thickness of the ore body**	**R_o %**	**Z %**
1	2,0/1,5 = 1,33	39	28
2	2,5/2,0 = 1,25	23	18
3	3,5/3,0 = 1,17	7	6
4	4,7/4,0 = 1,18	8	8
5	6,0/5,0 = 1,20	13	12

In order to reduce the losses, Figure 3 shows variants with an increased area of the cutting head relative to the ore body.

On Figure 3a with an ore body thickness of 1,5 m the diameter of the cutting head of the Raisebor machine is set to 2 m. In this configuration, the S_2/S_1 ratio = 1,39 or 39% contamination and S_1/S_2 = 0,72 or 28% losses.

When the thickness of the ore body is 2,0 m and the diameter of the cutting head of the Raisebor machine is 2.5 m, the ratios are S_2/S_1=1,23 and contamination of 23% and S_1/S_2=0,82 and contamination of 18%.

$$S_1 = a^2 = 9{,}00\ m^2;\quad S_2 = \pi R^2 = 9{,}62\ m^2;\quad S_2/S_1 = 1{,}07\quad S_1/S_2 = 0{,}94 \tag{8}$$

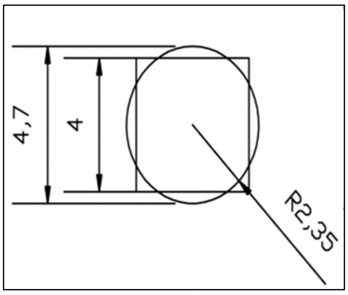

Fig. 3d. Raisebor technology with overlap of the contour

$$S_1 = a^2 = 16{,}00\ m^2;\quad S_2 = \pi R^2 = 17{,}34\ m^2;\quad S_2/S_1 = 1{,}08\quad S_1/S_2 = 0{,}92 \tag{9}$$

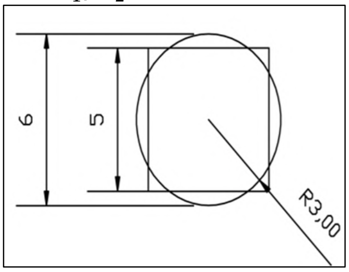

Fig. 3e. Raisebor technology with overlap of the contour

$$S_1 = a^2 = 25{,}00\ m^2;\quad S_2 = \pi R^2 = 28{,}26\ m^2;\quad S_2/S_1 = 1{,}13\quad S_1/S_2 = 0{,}88 \tag{10}$$

On Figure 3c with an ore body thickness of 3 m, the diameter of the cutting head of the Raisebor machine is set to 3,5 m. In this configuration, the S_2/S_1 ratio = 1,07 or 7% contamination and S_1/S_2 = 0,94 or 6% losses.

For an ore body thickness of 4.0 m and a diameter of the cutting head of the Raisebor machine of 4,7 m, the S_2/S_1 ratio = 1,18 or 8% contamination and S_1/S_2 = 0,92 or 8% losses.

When the thickness of the ore body is 5 m and the diameter of the cutting head of the Raisebor machine is 6 m, the S_2/S_1 ratio = 1,20 or 13% contamination and S_1/S_2 = 0,88 or 12% losses.

In order to reduce the damage from losses and contamination, it is recommended to observe the ratio S_2/S_1 from Figure 3c, which will determine the selection of the diameter of the cutting head of the Raisebor machine.

Raisebor technology using VCR method

This method for mining out the mineral reserves combines the drilling and blasting works (VCR method) with the Raisebor technology. [9, 10] Here again, we have the extraction of vertical levels (rises) from the ore body in a certain order, with the mined-out spaces being filled. This method is characterized by mining out the primary chambers by applying drilling and blasting works. It is important to note that the complete drawing of the extracted ore from each layer takes place after its complete blasting. Until the blasting of the last section (VCR method), part of the ore remains in the layer (rise), thus ensuring its safety without the need for its further support. After drawing the ores off from the primary chambers, they are filled with a paste-hardening fill to achieve sufficient strength of the chamber in order to open a secondary chamber next to the filled-in rock mass without leaving behind pillars.

The secondary chambers are mined out using the Raisebor technology and after their removal, they can be filled with both a paste hardening fill and a rock fill of sterile mass.

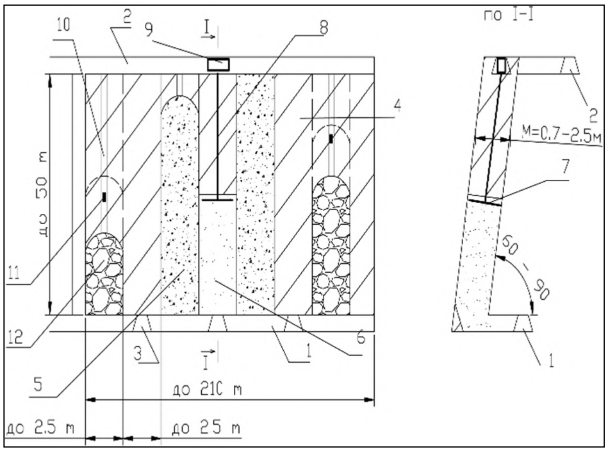

Fig. 4. Raisebor technology using the VCR method for extraction of mineral resources
Legend: 1 – haulage level; 2 – air drift; 3 – loading cut-off entries; 4 – ore body; 5 – paste-hardening fill; 6 – fines, extracted ore; 7 – cutting head; 8 – borehole; 9 – Raisebor machine; 10 – central borehole; 11 – VCR method; 12 – blasted ore.

The Raisebor technology using the VCR method emphasizes again on security, since during both production stages (VCR method and Raisebor technology) the processes are carried out without the presence of workers in the mining areas.

The geomechanical dimensioning will give the maximum open surfaces that can be naturally supported as well as the dimensions of the primary and secondary chambers. From here, the specific sizes of the mining blocks and their parameters should be determined, as well as the order for removing the reserves.

Continuous system for ore shrinkage and use of Alimak or KOV-25 monorail

This is a classic variant of the continuous system for ore shrinkage, but the specifics is that it has been redesigned for the purpose of applying a productive technique, elimination of the manual labour, removal of people from the mining areas, and its application in rocks with low strength indicators.

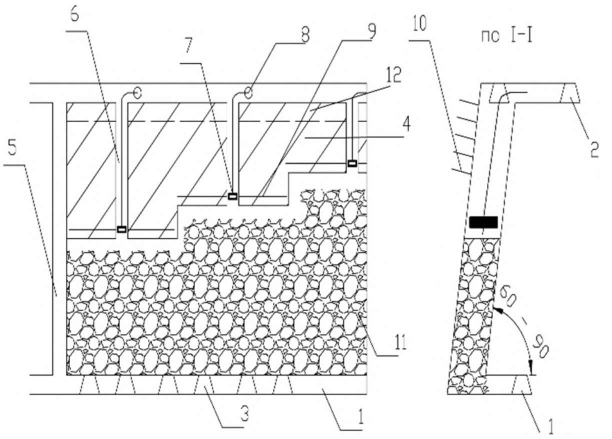

Fig. 5. Continuous system for ore shrinkage and use of Alimak or KOV-25 monorail complex
Legend: 1 – haulage level; 2 – air drift; 3 – loading cut-off entries; 4 – ore body; 5 – stope rise; 6 – cut rise; 7 – KOV-25 monorail complex; 8 – a winch for hoses of the monorail complex; 9 – drilling boreholes; 10 – rock bolts; 11 – retained ore; 12 – sheet pillar.

In the continuous system with ore shrinkage and use of Alimak or KOV-25 monorail complex, the mining operations are performed by cut rises with horizontally positioned blast holes (horizontal layers are blasted). The use of monorail ore mining complexes significantly increases labour productivity - hydraulic mechanization is applied. Through this configuration of the block and the extraction of the cut rises, the work safety is ensured, with the workers being in pre-fixed workings. Therefore, greater safety at work is achieved and the cost of ancillary processes is also reduced.

Another important point that should be noted in this technology is its application in the development of deposits with weak ores and host rocks. In the variant presented, the retained ore is used to support the host rocks. By the time the ore is completely blasted from the block, the amount of ore that has been drawn off must be just enough to absorb the blasted ore from the next blast layer. After the blasting is completed, the ore is drawn off in parallel with the filling of the store. The fill in this case may be dry rock fill with material; obtained from preparatory activities. Thus, we have constant support, eliminating the risk of unwanted movements in the rock mass.

Conclusion

These innovative mining technologies aim at developing deposits with complex geological, mining technical and geomechanical characteristics. The aim is to provide sufficient labour safety, increased productivity, reduced loss rates and impoverishment during the mining process.

The presented innovative production technologies meet these requirements.

The advantages of implementing and using them in a particular mining company can significantly improve the processes for the following reasons:

1. The developed innovative technology for mining of mineral resources (shrinkage method of mining, filling and setting of rib pillars – Alimak technology) allows for recovery of reserves without pillars and with minimal losses and contamination during the mining process.
2. With the application of the VCR - Raisebor technology for mining of mineral resources when developing complex-structured and geothermal deposits, we achieve a high level of system safety.
3. It is important to take into account the specifics of the deposit itself and the characteristics of the ore bodies, and based on this to select the number and type of mechanization, as well as the order of mining.
4. When mining with the Raisebor technology, it is not necessary for the obtained ore fines (the extracted ore) to undergo coarse crushing - it is possible to eliminate additional processes and ensure direct feeding of the ore to the mineral processing plant for further processing. This leads to a significant reduction in production costs.
5. When applying the VCR-Raisebor technology for mining there is a considerable positive effect because the obtained rock mass from the development stages is used for filling in the secondary chambers. Thus, the haulage of the mining mass (ore and sterile body) is facilitated and the volumes of the waste dumps for sterile rock mass are considerably reduced.
6. By developing innovative technologies for mining, in particular VCR - Raisebor technology, we create an opportunity for safe and secure development of deposits with complex conditions and characteristics, previously considered to be economically not viable.

Geomechanical models should also be developed in order to identify open surfaces that can naturally be supported. Thus, the specific parameters of the selected extraction technology such as height of levels, presence of sub-levels, dimensions of blasted layers, etc. could be determined.

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Source term model of radioactive liquid spills for actual decision support systems

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Abstract. Spills of liquid radioactive material are reviewed as potential event that can be associated with release into the atmosphere. Existing approaches to radiological impact assessment for onsite as well as offsite of facility are presented. The example of using the actual Java version of the European RODOS system as prototype of the decision support system shows the general implementation of the analysis and preparation of initial data in order to model the radiological impact on the public, personnel and environment. Given the specifics of the occurrence of emergency scenarios of this type, features of atmospheric models application, description of the source term model, software integration features, ventilation task solving, completeness and format of the initial data required for radiological consequence modelling.

1 Introduction

Today, more and more often in order to model the radiological impact on the public, personnel and environment, decision support systems (DSS) for responding to nuclear and radiological accidents in real time are used (RODOS, ARGOS, HPAC, NARAC, etc. [1-6]). In addition to the primary tasks of the software, they are also applied in frame of emergency preparedness and planning, quantitative and qualitative analysis of possible scenarios taking into account the evolution and phenomenological stages of the events. This is primarily due to the wide range of data assessment tools both in terms of design capacity and in terms of simplicity of input and analysis of results. However, at present, a significant challenge for users of these DSS is to prepare a correct and complete package of initial data, in particular, source term data for each of the emergency scenarios under consideration. A large number of works are devoted to the development of separate special tools for creating information communication between source term assessment codes and radiological impact assessment systems. For instance developers of RASCAL have been overcome the obstacle related to fast source term assessments and simplified atmospheric modelling calculation that is fully justified by emergency response goals. However, the wide variety of potential emergency processes at nuclear power plants does not allow to create unified tool for preparing source term data that would cover all possible state of the affected facility.

An important area of nuclear power plant (NPP) safety analysis is the analysis of emergency scenarios associated with the spill of radioactive liquids [2]. In this paper, on the example of the use of JRODOS DSS, the basic requirements for the initial data in order to model the radiological impact in accidents are formed.

Worldwide there have been more than 30 significant accidents with spills of liquid radioactive materials at nuclear fuel cycle facilities for the last 60 years according to work [3]. Among there is the accident at research reactors, nuclear power plants, nuclear complexes, uranium facilities, pilot plants and chemical plants, etc.

Many special computer codes and methods are currently developed to assess, with sufficient accuracy, parameters of releases for various accidents at nuclear fuel cycle facilities (e.g. MELCOR computer code manual, US NRC for NPP). But, according to study [2, 3], these codes have some disadvantages and often require a large amount of input data, calculation time.

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2 Analysis of previous publications

In the world practice of liquid radioactive material (LRM) - related events analysis assessments of the radionuclides distribution in the liquid-vapor system are based on the results of research (model and experimental data) in the context of normal operation, summarized in the standards and guidelines and standards of the US NRC such as NUREG-0016 [4], NUREG-0017 [5] on calculation of releases of radioactive materials in gaseous and liquid effluents. American National Standards ANSI/ANS-18.1-1999 [6] ANSI/ANS-18.1-2016 [7] have information on radioactive source term for normal operation of light water reactors. Among the latest studies in the direction of investigation on the intensity of evaporation from open surfaces of liquids [8-11] can be considered. Detailed description of the models integrated in actual decision support system JRODOS can be found in [12-14]. Studies on thermodynamic calculations ventilation and air conditioning, experimental data of heat and mass transfer during evaporation of the liquid with a free surface, thermodynamic properties of water and steam are collected in [5-20]. Information on existing toolkit for ventilation task solving, atmospheric dispersion modelling and dose projection such as ANSYS, Solid Works, OpenFOAM, MACCS, RASCAL, HOTSPOT is concentrated in [21-28]. The report [31] is focused on the results of the AVESOME project on source term uncertainties in decision support system context.

The publications [32-37] provide an information on existing procedures and format for data exchanging covering USIE platform, decision support systems and adjacent software.

The aim of the work is to complete the all stages of radiological consequences analysis for the group of events related to radioactive material spills using developed source term model taking into account requirement from side of actual decision support systems. It can be achieved due to solving of the next tasks:

• to give the definition of LRMs and describe the area of their application;

• to present proposed source term model;

• to put the light on integration of the developed model in context of actual approaches to ventilation task solving, atmospheric dispersion modelling and dose projection;

• to overview the uncertainties associated with source term modelling taking into account nowadays decision support systems and international projects conducting;

• to provide recommendation in selection of suitable atmospheric dispersion model on example of JRODOS system;

• to describe actual exchanging data format to approach the link between the stages of modelling.

3 The research results

3.1 Radioactive liquids

LRM are liquid solutions, which include impurities of radioactive elements (possibly bound in high-molecular complexes). The isotopic composition of LRM is determined primarily by the source of radioactive impurities. The main sources of LRM at nuclear power plants and nuclear complexes are as follows:

• primary coolant that is discharged for operational reasons;

• water that is used to back flush filters and ion exchangers;

• floor drains that collect water that has leaked from the active liquid systems and fluids from the decontamination of the plant and fuel flasks;

• leaks of secondary coolant;

• laundries and changing room showers;

• and chemistry laboratories.

LRM can be located: both under containment of NPP units and beyond (for example, in an auxiliary building). At Ukrainian power units, temperatures of the LRM can reach 320ºC (under pressure), fluctuations in the range from 40 to 100ºC are possible in pipelines and tanks, depending on the ways of discharge of radioactive effluents. Accidents involving LRM spills are characterized by intense heat transfer due to the evaporation of the liquid - the formation of vapor-aerosol forms, which are subsequently localized on the materials of treatment or localization systems - for example, on drops of a sprinkler system or on gas-aerosol filters of ventilation equipment. In case of disability of localizing systems, significant emissions of radionuclides can be considered due to the leakage from the emergency rooms.

The isotopic composition and activity of the LRM at the NPP varies greatly. E.g., the primary coolant and the water of NPP spent fuel pool holding with light water reactors makes a collection of fragments of forced separation ^{235}U and ^{238}U, isotopes of corrosion metals, neutron activation products, etc. Within an auxiliary building, radioactive media can be maintained for a long time and include only long-lived radionuclides (^{60}Co, ^{134}Cs, ^{137}Cs, ^{54}Mn etc.) in the isotope composition. A similar case is observed in research reactors. Heavy water, which is used as a moderator on liquid reactors, also has high activity due to the presence of tritium in it.

World nuclear complexes produce and process radioactive materials (e.g. NPP fuel, isotopic mixtures, industrial and medical sources). At nuclear complexes, as well as at nuclear power plants, reactor installations of different capacity are used. Nuclear complexes, chemical plants and research centers also work with the LRM. A distinctive feature of these enterprises in comparison with the NPP, in terms of the characteristics of the LRM used, is the large range of radioactive solutions involved in the technological processes of the enterprise.

At nuclear power plants and nuclear complexes, LRM are mainly aqueous solutions of decay products of nuclear fuel according to International Atomic Energy Agency (IAEA) safety standards and FSUE's materials [7]. Pilot plants and chemical plants may contain a full range of isotopes and solvents. LRM can be found on the site for processing the radioactive liquids.

Issue is a significant problem for radiotherapy medical hospitals. The problem is to analyze the emergency situations related to the special reservoir systems in the underground rooms of hospital (DTS systems – Decay Tank Systems containing ^{99m}Tc, ^{131}I, ^{18}F, shown in Fig. 1).

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Fig. 1. DTS (Decay Tank Systems).

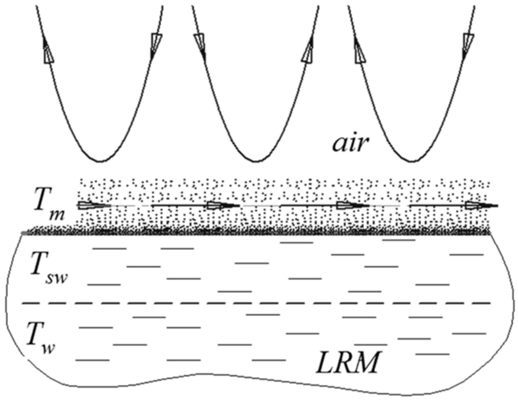

Fig. 2. The temperature layers near the surface of LRM.

3.2 Source term model

The proposed approach is based on the theory of non-stationary heat and mass transfer in surface evaporation of liquid heated below the boiling temperature.

The physical model includes: active liquid medium, steam-aerosol radioactive mixture (SARM), air of forced ventilation, airborne filters, and the floor of emergency area. The key aspects of the model are evaporation of liquid material, its removal with exhaust ventilation and partial trapping on airborne filters. It is considered that SARM is released to the environment after filters.

The model is developed to assess the radiation consequences in an accident with spill of LRM and describes the spread of radioactive material by two consecutive ways: releases within the emergency area and further transfer of SARM into the atmosphere. In this paper, we focus on the relationship of these pathways and study the process of evaporation as special one for accident with spill of LRM (Fig. 2).

To solve the problem of unsteady LRM evaporation, four balance differential equations were written to relate the main parameters of LRM and air space of area over time.

$$\begin{cases} \dfrac{dm_w}{dt} = -\beta_{sw}\left(p_{sw} - p_m\right)S - G_d \\ \dfrac{dm_a}{dt} = \beta_{sw}\left(p_{sw} - p_m\right)S - G_V \cdot \dfrac{m_a}{V} \\ \dfrac{dm_q}{dt} = G_V \dfrac{m_a}{V}\left(1-\psi\right) \\ \dfrac{dT_w}{dt} = -\dfrac{r_w\beta_{sw}\left(p_{sw} - p_m\right)S + kF\left(T_w - T_f\right)}{c_p m_w} \end{cases} \tag{1}$$

where m_a – current mass of SARM in air of the area, *kg*;

G_d – flowrate of LRM through the drainage channel (it also includes the volume of LRM leakage from the area), *kg/s*;

V–air volume in the area, m^3;

G_V – flowrate of involved air of forced ventilation (this parameter includes SARM leakage through the gaps or clearances in walls of the emergency area) m^3/s;

ψ – coefficient of filtration (efficiency of filtration);

m_q –mass of released SARM into the atmosphere, *kg*.

Functions $\beta_{sw}(T_{sw})$, $p_{sw}(T_{sw})$, $p_m(T_m)$, $r_w(T_w)$ and $c_p(T_w)$ are polynomials. They are compiled according to [8-12].

In model, the performance of forced ventilation unit is determined by the flowrate of involved air. After the exhaust ventilation pipe, SARM partially settles on filters. This phenomenon accounts for the coefficient of filtration. It determines the relative amount of SARM that is deposited on the filter material. SARM further passes through the ventilation stack into the atmosphere.

Another method to confine LRM is to drain the spilled liquid by drainage pumps or by gravity. This process is characterized by the flowrate of LRM through the drainage channel.

The partial removal of radioactive substances from the liquid by evaporation depends on physicochemical properties of radioactive impurities and the solvent.

This system of nonlinear differential equations includes polynomial functions. Using the Mathcad sphere for solving the system of equations provides the desired functions in matrix form (the values of the functions at particular moments of accident).

Average activity concentration of the radionuclide in the area air A_{air} (Bq/m^3) is given by the formula

$$A_{air} = \frac{A_w}{V} H \cdot m_a \tag{2}$$

The ultimate objective of the model is to determine the dynamics of LRM evaporation, SARM activity in the air space and the integral release of radioactive substances into the atmosphere. The mass fraction of a radionuclide in the release relative to its original content in radioactive liquid is commonly used in practice:

$$q = \frac{A_w}{m_0} H \cdot m_q \cdot 100\% \tag{3}$$

where m_0 –initial mass of LRM, *kg*

This value is used as an input parameter for the assessment of doses to the public from atmospheric release.

3.3 Ventilation task solving

Using such products as ANSYS software [13], OpenFOAM [14], SolidWorks [15] additionally studies the impact of forced ventilation system on the velocity of the underlying layer supply air. The velocity values found

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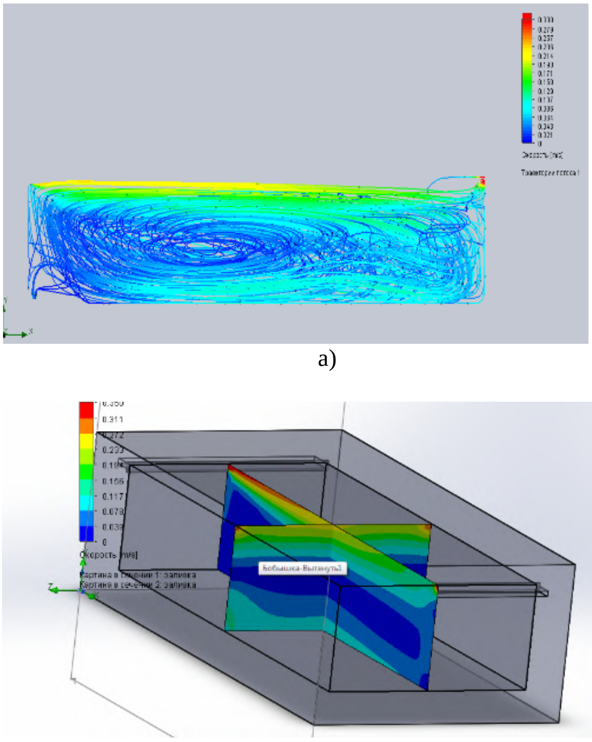
are used to clarify the surface temperature of the liquid according to [8-12]. The results of the impact analysis revealed that the speed the incoming flow has a significant effect on the evaporation intensity, as the consequence - on the ejection. Therefore, one of the prerequisites for the preparation of initial data and boundary conditions for the model is a preliminary ventilation solution tasks within the established technological parameters.

Using the SolidWorks software, the influence of the ventilation system flow on the velocity of the underlying inlet air layer was investigated (Fig. 3-5).

3.4 Integration in atmospheric dispersion and dose projection tools

Based on the results of the mathematical model with a view to further determination of radiological impact on the workers, public and the environment the environment can be used analytical methods and software tools (Table 1).

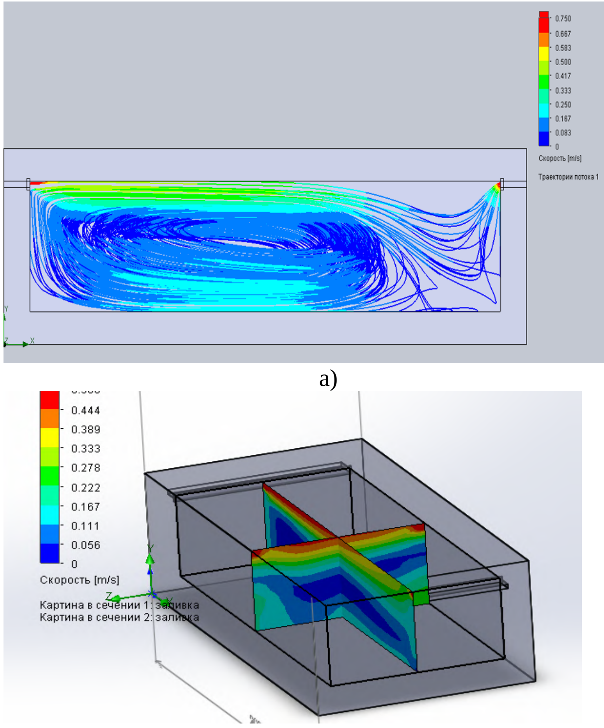


a)

b)

Fig. 3. Air flow fields SolidWorks simulation (G_V=0,75 m^3/s): flow trajectories (a), velocity fields (b).

Real-time On-line Decision Support System for off-site emergency management (RODOS) provides consistent and comprehensive information on radiological situation development, the extent and the benefits and drawbacks of emergency actions and countermeasures, and methodological support for taking decisions on emergency response strategies. Main users of the system are those responsible at local, regional, national and international levels for off-site emergency management.



a)

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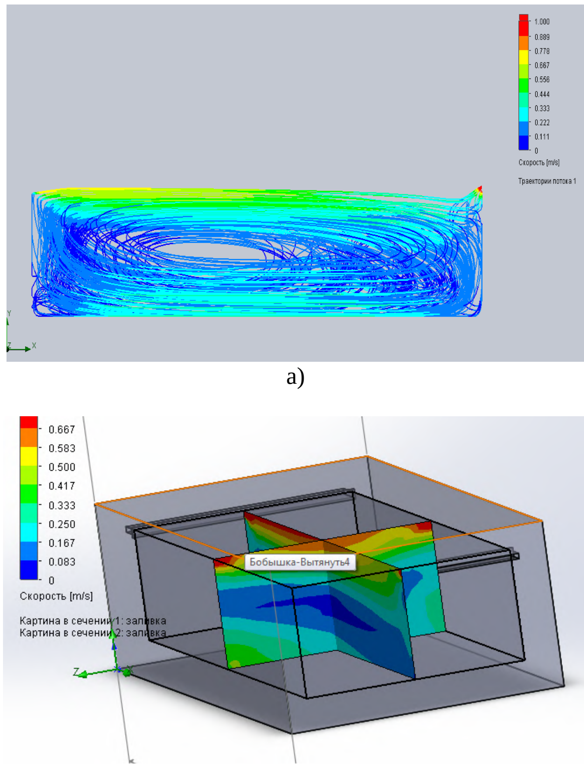
Fig. 4. Air flow fields SolidWorks simulation (G_V=1,5 m^3/s): flow trajectories (a), velocity fields (b).



a)

b)

Fig. 5. Air flow fields SolidWorks simulation (G_V=1,5 m^3/s): flow trajectories (a), velocity fields (b).

RODOS has the most diverse collection of dispersion models, with one of each type of dispersion model incorporated into the code: Lagrangian (RIMPUFF, DIPCOT and LASAT), Eulerian (MATCH). Additional decision aiding components can facilitate the ranking and selection of alternative options using decision analysis procedures. Thus, RODOS system allows real-time operation for offsite emergency management as well as applications for exercise, preparedness, and planning.

Table 1. Font styles for a reference.

Model outputs	**Workers exposure**	
	internal	external
Array of air concentrations in emergency room Av(t)	• Analytical base and methods (NRC, ICRP, UNSCEAR [16]); • Dose conversion factors FGR-11/13, EPA [16]	• Analytic base (NRC, EPA, ICRP) + dose from skin exposure (α and β); • MICROSHIELD, ISOCSR (+ dose from equipment and spill domain) [16]
	Public exposure and environmental contamination	
Array of time-integrated activity released into the atmosphere (source term) Q(t)	• RODOS: RIMPUFF atmospheric dispersion model with 10-min. time step + FDMT [17]; • ARGOS: complex terrain ADM, dose projection module (any other DSS); sophisticated models for short range (CFD-, LES-modeling); • simplified Gaussian models HOTSPOT [18], RASCAL (INTERRAS) [19]; NRC MACCS code (probabilistic analysis tool) [20]; • GENII, RESRAD, PAVAN, ARCON 96, XOQDOQ (RAMP codes family)	

RODOS is user-friendly and has an intuitive graphical user interface. The integration of GIS functionalities enables graphical representation of results. JRODOS features and tools allow the adaptation of the system to national conditions and user preferences.

In 2013 in the frame of European Commission project INSC U3.02/08 (UK/RA/08) Java-based Decision Support System JRODOS was installed in SNRIU's Information and Emergency Centre (IEC). At the Rivne NPP, the RODOS system was implemented in 2012. The RODOS system was installed at the central post of the automated radiation monitoring system (ASRM). ASRM equipped with powerful meteorological complexes that is very important for the use of RODOS. Data in special formats from four ASRM meteorological complexes, from radiation monitoring points and mobile laboratories are transmitted to RODOS via software that ensure interface of ASRM with RODOS. On October 8-10, 2013, the training course “Program system JRODOS – new multiplatform version of the European DSS for the off-site nuclear emergency management – RODOS” was held in Kyiv. Experts from SNRIU, SE NNEGC “Energoatom”, State Emergency Service of Ukraine, Ukrainian Hydrometeorological Center, State Enterprise “State Scientific and Technical Center for Nuclear and Radiation Safety”, Khmelnytskyi NPP, Rivne NPP, Zaporizhzhia NPP were invited to participate in the training.

On October 11, 2013, testing was carried out on the RODOS software system, which was already installed at the IEC of the SNRIU. The testing was performed with participation of technical experts of the Karlsruhe Institute of Technology (KIT). The testing addressed, inter alia, issues of connection of the RODOS to the ASRM system and the system of operational weather forecasting for the Rivne NPP. At the Rivne NPP, RODOS uses global meteorological data covering the entire globe and predicts the movement of air masses in case of radiological accident, "dirty" bombs and other nuclear emergency scenario. Due to the cooperation with the Ukrainian Center for Environmental and Water Projects, which at one time developed the hydrological model of the river Stir for the RODOS system, and reprogrammed the RODOS system into the JAVA programming language (this version is currently used by European and Asian users), Rivne NPP installed software which allows to independently calculate the weather forecast for almost any territory of the Earth. The calculations are based on input from the US National Oceanic and Atmospheric Administration.

Today, RODOS system is operated by SNRIU's IEC, UHMC, State Emergency Service of Ukraine, Khmelnytskyi NPP, Rivne NPP, Zaporizhzhia NPP, South Ukraine NPP and State Agency of Ukraine on Exclusion Zone Management.

Since 2017 all Ukrainian JRodos users are supported by numerical weather prediction provided by Ukrainian Hydrometeorological Center (UHMC) and The Institute of Mathematical Machines and Systems Problems of the Ukraine National Academy of Science (IMMSP NASU). SNRIU's IEC has access to 96-hour NetCDF files WRF result and DMI-files covering the whole territory of Ukraine in real time (Fig. 6-7). Since 2019, more precise NWP are available separately for southern and northern parts of Ukraine.

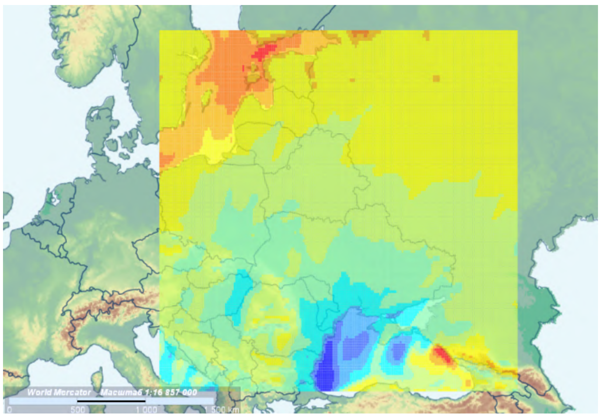


Fig. 6. NetCDF file – the whole territory of Ukraine and neighboring countries: duration of prognosis – 96 hrs, step of updating – 6 hrs, spatial resolution – 0.15°.

JRodos-DataSupplier as an application to JRODOS system is installed in SNRIU’s IEC for an automatic receipt of fresh numerical weather predictions for all the territory of Ukraine, parts of adjacent countries and for some territories around Ukrainian NPPs and Chornobyl Exclusion Zone. SSTC NRS experts have an access to sftp-server with numerical weather predictions data. Some additional weather information or extended numerical weather data can be required from Ukrainian Hydro-meteorological Center (UHMC).

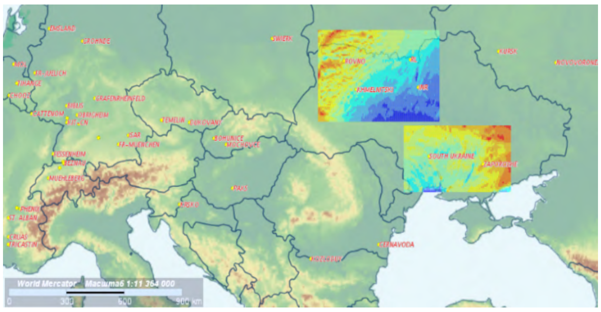


Fig. 7. NetCDF files covered Rivne NPP, Khmelnytskyi NPP, Chornobyl NPP and South Ukraine NPP, Zaporizhzia NPP: duration of prognosis – 96 hrs, step of updating – 6 hrs, spatial resolution – 0.05°.

HIRLAM files for MATCH model has the spatial limitation as for NetCDF files.

The system includes a number of atmospheric models that make it possible to simulate the motion of a radioactive cloud and atmospheric diffusion at different scales relative to the source term (Table 2). In [2], it was determined that the total amount of activity released during accidents involving the spill of liquid radioactive media is insignificant compared to severe accidents at nuclear power plants and leads to significant contamination of nearby areas in the path of radioactive cloud propagation. In the Table 2 shows the models of atmospheric transport by priority in order to solve the problem of estimating the radiation impact on the population for events with the spill of radioactive liquids.

Atmospheric dispersion modelling provides a lot of requirements be taken into ac-count in source term modeling for event associated with LRM. E.g., local scale model chains of DSS JRODOS allow to use several ways to fill in input parameters window. Most of them are used to bind to the initial activity (the number fission products) of the NPP reactor core. However, for cases where source term is undetermined by de-fault user library, such as wildfire in the contaminated forest, unintentional melting sources of ionizing radiation, emissions of pharmaceuticals and etc., it is possible to enter initial parameters at some number of time intervals (e.g., in the versions of DSS JRODOS 2017, 2019 - up to 128 time steps).

It is important to notice in most cases territory affected due to LRM spills are cordoned in near range scale. So scaling effects related to it (e.g. building wake effect shown in Fig. 8) should be considered in atmospheric dispersion modelling.

Moreover, selected time step of source term should be harmonized with both spatial resolution of modelling and time resolution of numerical weather data. Given the resolution of numerical meteorological data for the model RIMPUFF, a minimum results time step that correlates with local sensitivity JRODOS atmospheric dispersion models and meteorological pre-processor is 10 minutes. Such step allows to provide an accurate calculation in near and middle range up to 21 hours. In the case of input of stationary meteorological fields (manually) time step of the input data the source term needs additional adjustments in accordance with the minimal time step of meteorological data.

Practice of sensitivity analysis of such primary ones atmospheric propagation results as the integral radionuclide concentration in the ground layer to the general JRODOS initial data package in [21, 22], shows that the main problem in modelling is uncertainty in the source term. Such data include power, chronological parameters, speed, temperature, geometric height, radionuclide composition and physic-chemical forms of emission over time. For import source data from the outside or export to a file, the JRODOS system uses xml-formats.

3.5 Uncertainties issue

The practice of sensitivity analysis of such primary results of atmospheric propagation as integral concentration of radionuclide in the surface layer of air to the general package of initial data of JRODOS system shows that the main problem in modeling is uncertainty in initial data on source term. Such data include power, chronological parameters, velocity, temperature, geometric height, radionuclide composition and physicochemical forms of emission over time. To import source data from outside or export to a file, the RODOS system uses XML-formats.

Table 2. JRODOS atmospheric dispersion models.

№	Name	Type	Calculation distance, km	Resolution in the results tree (minimal), м	Meteorological data format	Remark
1	RIMPUFF (RIsø Mesoscale PUFF model)	mesoscale Lagrangian puff model	<800	50x50	user-defined / NWP data NetCDF	takes into account the initial parameters of the atmospheric dispersion; marked by stable calculation
2	LASAT (LAgrange Simulation of Aerosol Transport)	Lagrangian particle model	<800	50x50	user-defined / NWP data NetCDF	approved methodic approach of doses assessment is used
3	DIPCOT (DIsPersion over COmplex Terrain)	Lagrangian particle model	<800	50x50	user-defined / NWP data NetCDF	takes into account the complex terrain, however, does not take into account the initial parameters of atmospheric dispersion
4	MATCH (Mesoscale Atmospheric Transport and Chemistry)	Eulerian mesoscale model	not limited	~38000x 52000	binary format GRIB (HIRLAM)	used for transboubdary tasks

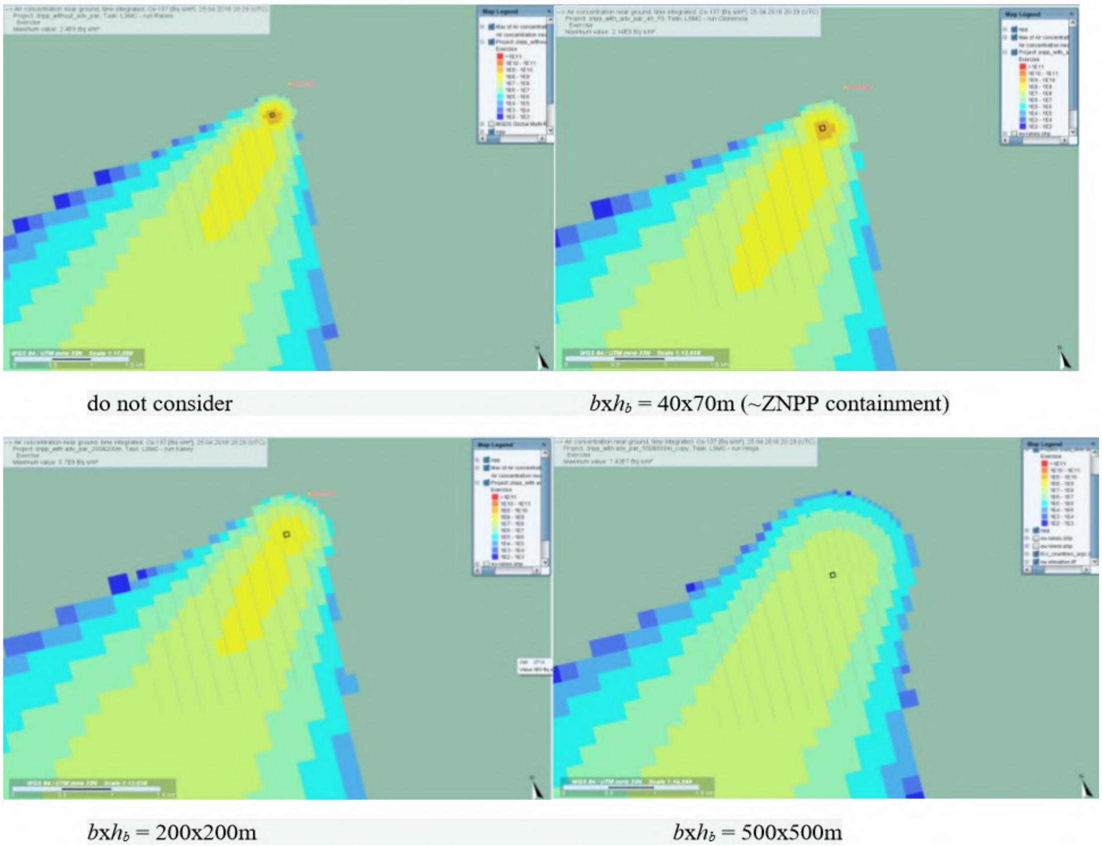


Fig. 8. NetCDF files covered Rivne NPP, Khmelnytskyi NPP, Chornobyl NPP and South Ukraine NPP, Zaporizhzia NPP: duration of prognosis – 96 hrs, step of updating – 6 hrs, spatial resolution – 0.05°.

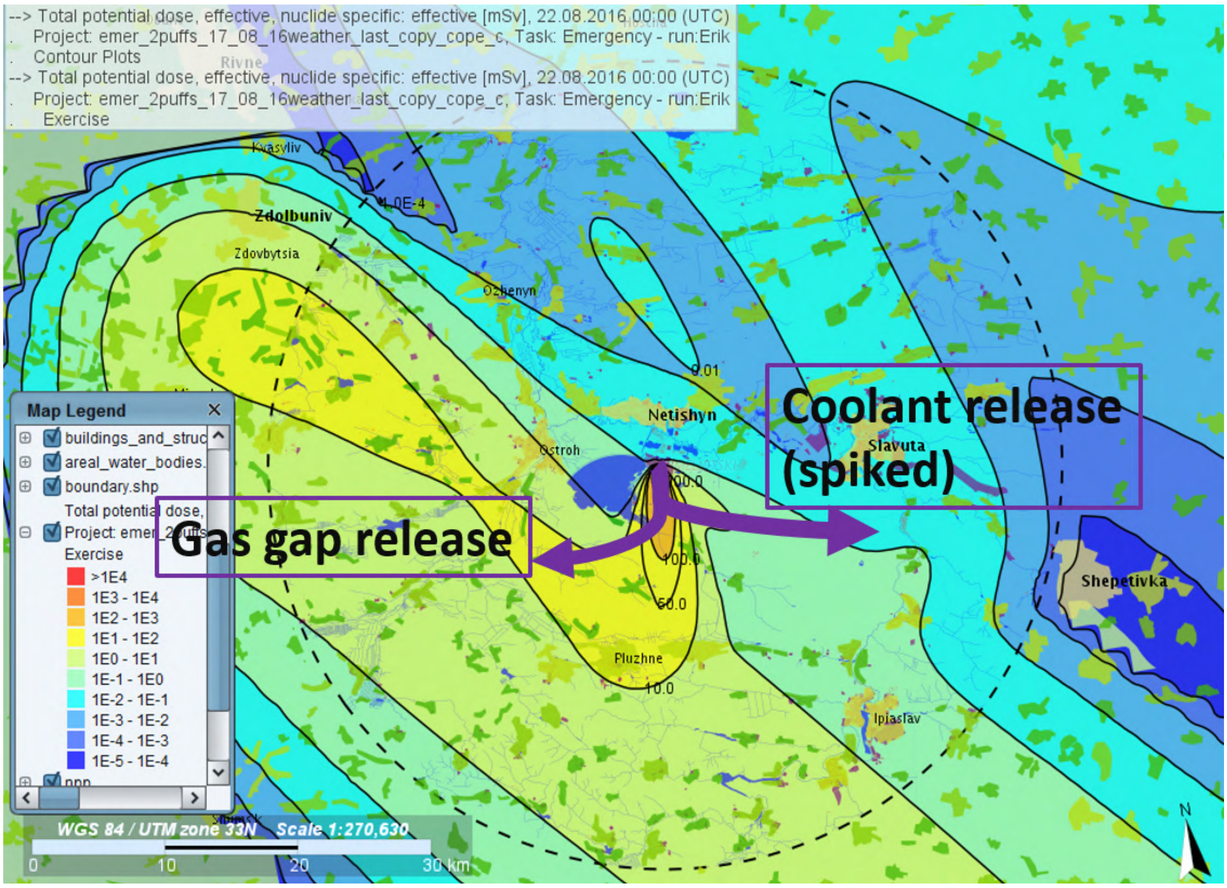


Fig. 9. Effective dose patterns from coolant and gas gap puffs (45-min difference between 2 release stages), mSv.

The main task of modeling the emission source is to obtain a set of arrays of output parameters depending on the time variable using separate analytical and / or numerical means. However, a preliminary analysis of existing industry and industry-wide computer tools [2, 3] showed that modern modeling tools in this direction have a number of significant shortcomings that do not allow it to be used for quantification of emission sources in spills of liquid radioactive.

In frame of FASTNET project experience of more than 20 countries was analyzed. The main output of the project is an investigation in the area of qualitative characteristic of source term – resolution in time. Taking into account spatial and temporal resolution of numerical weather predictions used in Europe countries, FASTNET group recommend the use of 15-min intervals in source term.

Fig. 9 shows a case of unstable meteorological conditions within 30-km surveillance zone of Khmelnytskyi NPP in summer 2016. This is an experience of SSTC NRS JRODOS calculation on NWP-data of July 11, 2016 (1-hr, 0.15º resolution). Source term was modelled for reactor core accident according to with consequent phenomenological steps coolant (spiked) release, gas gap release, and start of early in-vessel phase.

Practice of regular calculations demonstrates significant uncertainties in conjunction «source term – NWP-data». Under unstable meteorological condition with complex patterns of integrated concentrations, using of more than 15-min. source term intervals can lead to crusual impact on radiological consequences results.

JRODOS users can operate pre-estimated source terms data. Source term library filling can be specified by requirements to source term files taking into account meteorology data resolution. Uncertainties of the source term on the prediction of atmospheric dispersion of released radioactivity involve both the amounts of radionuclides released and the temporal evolution of the release.

In AVESOME project [23], a methodology is developed which can handle both a few-member source-term ensemble and a large ensemble spanning all possible releases. The AVESOME methodology will work well with the Rapid Source Term Prediction (RASTEP) system, which provides a set of possible source terms with associated probabilities based on pre-calculated source terms. The methods, which are being developed in AVESOME, allows for efficient real-time calculations by making use of scaling properties in the equations governing the release and the atmospheric dispersion of radionuclides. Accordingly, the computer-resource demanding calculations should be carried out at the high-performance computing (HPC) facilities available e.g. at national meteorological services, whereas less demanding post-processing should be carried out at the computer hosting the DSS.

A protocol is suggested for interactive communication between the DSS and the HPC facility enabling the requests from the DSS user for long-range atmospheric dispersion model calculations. It is based on an existing operational protocol extended with the capability of simultaneous handling of a number of source-term descriptions, including a full source-term ensemble.

3.6 Data exchange

IRIX is a technical standard developed by the IAEA in cooperation with experts from Member States and the European Commission (EC). The standard is designed to enable the development of interoperable systems and solutions for exchanging emergency information and data between organizations at both national and international level during a nuclear or radiological incident or emergency. A principal concept in the IRIX Format is the IRIX report. Any information exchanged in the IRIX Format must be packaged as the IRIX report according to [24-26].

The IRIX report represents a message containing emergency related information and data, and/or requests for such information or data, sent from one organization to one or more other organizations. The IRIX report encompasses information such as basic information about the event (date and time of event, location, etc.), information about the status of the nuclear facility or radiation source involved, information about any releases of radioactive material to the environment, information on protective actions taken or planned to protect the public, and radiological monitoring data. The report covers information that is of immediate use to authorities for taking decisions on protective actions for the public, but also more detailed information and data that can be used for improving the assessment of the emergency situation and the subsequent decision making. The IRIX report structure supports the key categories of information to be exchanged internationally under the terms of the Convention on Early Notification of a Nuclear Accident. The use of the IRIX Format is, however, not limited to this application.

IRIX is an open format based on the Extensible Markup Language (XML), which makes it both machine- and human-readable. It should be used to exchange radiological information between IAEA and RANET teams, or between any other two (or more) assisting parties, during a nuclear or radiological emergency. The IAEA has developed the IRIX format as the recommended standard to exchange information among emergency response organizations at national and international levels during a nuclear or radiological emergency. The standard covers the data content, the data format (XML), and the system interface specification. Data can include status information about a nuclear installation, information about any radioactive releases to the environment, information on protective actions taken or planned by affected countries, and environmental radiation monitoring data. Regarding to [26-28], the system interface specification (or web-service specification) enables organizations to interconnect their emergency information systems to automate their information exchange in an emergency.

4 Conclusions

In the paper general context of radioactive liquids events in modelling area is presented. For the first time source term model for radioactive liquids spills taking into account technological premises and adjacent environmental has been proposed and developed. This model, unlike other models, takes into account the parameters of the radioactive liquid composition and the design conditions of their storage.

Possible ways of software integration of the developed mathematical model into atmospheric dispersion modelling and dose projection toolkit, taking into account the requirements of the adjacent radiological impact assessment tool and the specificity of liquid radioactive accident spill, is proposed. It solve the problem of complex radiological estimation for events including LRM. The developed model can be applied as useful tool of source term preparation in the case of LRM spill in advance as a well as in real time with a reasonable degree of conservatism. It allows to provide an adequate assessment of the radiological consequences for the set of initial conditions of accidents with spills of LRM in areas with forced ventilation.

IRIX format has been considered as an effective data exchange tool to perform the initial data or radiological consequences results in modelling area.

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Environmentally-efficient approaches to oil and gas producing sites

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Abstract. We have offered the investigations aimed at the design of eco-efficient technologies during oil and gas producing sites life cycle. The authors have conducted the analysis of conditions causing environmentally hazardous situations at oil and gas producing sites. We have established the necessity of quick maintenance of operation during emergencies that makes it possible to reduce material costs and environmental pollution. The increase of environmental safety in the process of winding up oil and gas wells emergencies that took place as a result of catching drilling string or some other pipe is crucial. We have analyzed different ways and various structural designs of the devices for pipe unscrewing from caught strings. We have established the ways of negative environmental impact reduction in the winding up emergencies at operating as well at stack oil and gas rigs. The recommendations regarding the structural design of the device are given. The device design is patented and the prototype model of the device is designed and manufactured. The device functions as the transformer of clockwise drilling string rotation into anticlockwise rotation of fishing tools. We have highlighted the positive effects after the implementation of the given device. We have noted the importance of innovative technologies design as well as the importance of forming adequate response skills during emergencies when wellsites are being constructed. The technical solutions and recommendations we have introduced make it possible to prevent negative environmental impact and reduce resource flows at different stages of wellsite life cycle.

1 Introduction

The activities of oil and gas producing sites affect the environment, especially during some emergencies. The complexity of the issue lies in the fact that those oil and gas producing sites may be located close to protected or recreational areas [1]. Alongside with this negative effects may last for a long time and be dangerous to the environment [2], which calls for the search of innovative technical solutions, as well as alternative energy sources development. [3, 2] When industrial objects function in their normal mode it has a set of consequences: sickness rate increase, disturbance of natural environment functioning, resource capacity influence. There is also the economic constituent of the given issue [4, 5]

2 Analysis of previous publications

The environment within the boundaries of oil and gas producing sites is intensively affected. Saksonov M.N. and others point out the environmental changes in the process of man-caused impact of oil and gas extraction [6] The most dangerous are the emergency situations that are the most unpredictable ones in terms of economic and environmental consequences [7, 8].

There is a set of conceptual approaches for maintaining environmentally safe production process at oil and gas producing sites [9, 10, 11]. The important measures that make it possible to prevent environmental pollution and to cut the material costs – are modernizing equipment [2, 12, 13]. Environmental aspect of modernizing equipment includes cutting expenditure resources during equipment manufacturing as well as during man-caused operations with the use of this equipment.

The investigations aimed at the increase of equipment operation responding for emergency drillstring jamming (e.g. pumping compressor, casing) in the wells are topical, because the removal of emergency situations demands unscrewing the pipes from the jammed part of the string, which is accompanied by economic losses, namely material and power ones. The removal time is also influences economic losses and environmental safety. If the wellsite is abandoned or put out of commission it is also necessary to unscrew the pipes. This calls for the necessity to develop environmentally efficient methods of prompt emergencies removal.

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3 The research results

3.1 The triggering events of environmentally hazardous situations at oil and gas producing sites

Emergencies that take place at oil and gas complex, namely at wellsite are the cause of a set of environmental issues. These issues that are typical to oil and gas complex have been investigated in academic papers [14, 15, 16, 17].

Technological processes of oil and gas extraction are characterized by multicomponent structure of working environment (drilling fluids, extracted fluids and other technological fluids), that may contain toxic components and be flammable. These factors when summed up, pose a certain threat for the staff and contiguous territories with their inhabitants. One of the high risk-bearing factors is also the high level of technological equipment wearing. The processes that take place in this equipment cause its intensive degradation in long-term operation conditions and at presence of aggressive media that in their turn increase the environmental risks during oil and gas extraction. Equipment wearing is a serious risk factor that makes it difficult to solve environmental issues at oil and gas extraction complex.

In oil and gas extraction industry apart from specified and accounted pollution sources there may emerge unpredictable emergency conditions resulting in substantial costs of resources for primary operation conditions restoration, environmental pollution is noted and hazard to staff's health arises [18, 19, 20]. Different stages of oil and gas industry life cycle fig. 1 affect the environmental impact of different levels of intensity and damage [21]. Thus, we my single out specified emissions, caused by provided technological processes. Environmental hazards estimation if the impacts alike at are described at different stages in academic papers [22, 23, 24, 25]. The most important stage of environmental impact estimation is monitoring of different environments [26, 27, 28].

Modern geophysical investigation methods make it possible to collect information about equipment condition and wellsite geological profile which helps to evade significant environmentally hazardous consequences with occurrence of environmentally hazardous substances [29, 30]. The combination of methods for environmental monitoring and equipment condition makes it possible to reduce the risk of environmentally hazardous cases. But emergency conditions that may occur during operating conditions should be removed within the shortest possible time. Thus, taking into account all the factors mentioned, the aim of this article is to develop the effective tool for unscrewing pipes within a wellsite with increased operation reliability and enhanced technological possibilities. The main idea of innovative tool development is to reduce time costs for removing emergency conditions that makes it possible to increase environmental safety level of the wellsite construction process and oil and gas extraction.

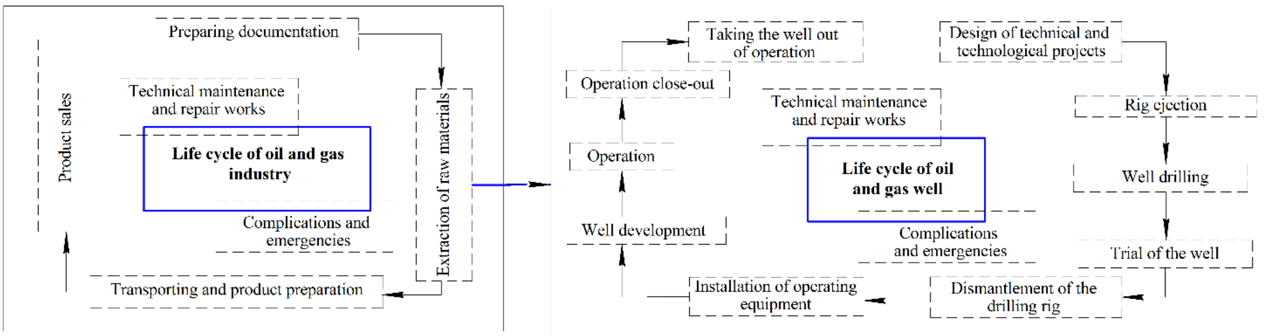

Fig. 1. The chart of life cycle of oil and gas well in the system of oil and gas extraction industry [21].

3.2 The analysis of equipment constructions used for unscrewing pipes in the wellsite

As we have already noted above, in emergency conditions it is crucial to select the technology that will make it possible to eliminate faults promptly and efficiently. Taking this into account we have analyzed the existing devices for unscrewing pipes in the wellsite.

We are aware about the device for unscrewing pipes in the wellsite [31], consisting of a case, upper (master) and lower (driven) pipes with pipeline thread for joining it to drilling strings and fishing tools respectively. This device also has an anchor knot (anchor) with fixing elements in the shape of elastic chambers and reverse gear in the shape of bevel gearbox. The master device also has the device for anchor knot actuation, consisting of throttling nut, screwed at the lower end of upper (master) shaft. The device sets the anchor knot going by means of feeding flushing liquid into fishing string, which at the cost of change of pressure in the throttling screw restores required pressure in the anchor knot and penetrates elastic chambers, broadening them for contact with the internal part of casing string.

The essential limitation in the use of this device is the low reliability of device fixture by flushing liquid pressure and also the use of elastic chambers as fixture elements as they may be corrupted when the device is lowered into the wellsite.

The next device for unscrewing pipes in the wellsite

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[32] is the one that has hollow cylindrical case with the pipe thread placed at its lower part. The hollow shaft with the screw is located at the upper part to be joined to the fishing string. The anchor knot (anchor) is also present with fixing telescopic parts and reversing gear in the shape of pull chain interacting with the rim, placed at the inner surface of hollow cylindrical case of the device. The driven device also has the mechanism for anchor knot activation which consists of throttling screw, placed at the lower end of hollow shaft. The device sets the anchor knot going by means of feeding flushing fluid into fishing strings that at the cost of change of pressure in the throttling screw causes pressure in the anchor knot case on fixture elements.

Among the drawbacks of this device are the following:

• reversing gear low performance index, that makes it impossible to create sufficient moment of force, necessary for screwing fishing instruments with further pipes unscrewing. It happens due to sufficient pull chain dragging against outer cylindrical case surface of anchor knot;

• technological complexity of the design of separate elements of the device, namely, the rim on the inner case surface.

There is also the device for unscrewing pipes in the wellsite [33] that has hollow cylindrical case with the left reducing coupling located at the lower part with the right coupling device located at the upper part of the device. The anchor knot with fixture elements is also present, the reversing gear in the shape of planet gear, consisting of master hollow shaft-gear and planet carrier placed so that it is possible to interact with shaft-gear and the rimmed surface, performed on inner cylindrical surface of the device’s case. The shaft-gear device is placed at the roller bearing with the ability to rotate towards the case of the device and with the presence of anchor knot activation device.

The peculiarity of this device is the fact that the anchor knot fixture elements are designed in the shape of slips that have the ability by moving along pyramidal facets of the case of the device radially to interact by their working hard-alloy surface with the inner wall of the casing string, ensuring reliable fixture of the device.

Among the drawbacks of this device are the following:

• the use of slips in the anchor knot, placed at bearing slides such as “dovetail” significantly complicates the device configuration and decreases its operation reliability. It is caused by the penetration of abrasive particles that are abundant in the wellbore of that direction, which may result in jamming and, respectively – device nonoperation;

• the use of the wedge mechanism in the anchor knot significantly limits the range of radial slips advancement which does not ensure the possibility to use the driven device in casing strings of different diameter without the replacement of fixture elements.

In order to unscrew the stuck (jammed) drilling string two basic methods are used [34, 35]. The first one – is the use of the string with double-sided screw, the second one presupposes the use of a special device that turns clock-wise rotation of the given drilling string into anti-clockwise rotation of the fishing tool (taper tap, collar socket, tubing catch, etc.) connected to the jammed part of the string.

The first method, the one that is using pipes with anti-clockwise screw has the following drawbacks:

• the necessity to purchase or lease that kind of a string if it is operating at a different wellsite, or manufacturing the needed amount of them, which causes additional expenses;

• transportation expenses of a big number of pipes;

• the replacement of the existing string of pipes with that one with anticlockwise screw is a labor-consuming process;

• environmental pollution with exhaustion gases and petroleum products during transportation and double replacement of pipe strings;

• time-consuming preparatory works, associated with the expansion of storage space and storage of a big amount of pipes and increase of expenses, that has a negative effect on the environment.

Taking into account all the above-mentioned the given academic paper is mostly concentrated on the second method – the use of a special device for turning clock-wise rotation of the given drilling string into anti-clockwise rotation of the fishing tool. In our case it is obvious that the above-mentioned drawbacks are neutralized by using of anti-clockwise pipes.

3.3 The design of innovative device construction for unscrewing pipes in the wellsite

The purpose of design of a new efficient device is to create a device construction for unscrewing pipes in the wellsite with high performance output and improved technological possibilities, achieved at the expense of addition of anchor knot fixture elements of a specific shape to working surfaces, placing those fixture elements with the possibility of rotation towards the axe that are parallel to the axes of the device, and also the design of the device for anchor knot activation in the shape of spacious cam gear [36].

The given aim is achieved by the presence of a hollow cylindrical case in our device with the left pipe reducer placed at its lower part and the right pipe reducer placed at the upper part of the device. The anchor knot with fixture elements, reversing gear in the shape of planetary gear consisting of master hollow shaft-gear and carrier gear with satellites are also present.

The external working cylindrical surface of fixture elements is obtained by the motion of the generant in part of the Archimedean spiral and enabling fixture elements to rotate around the axes parallel to the axis of the device in order to change the external diameter of the device. It ensures bigger interaction area with internal surface of a casing string, which prevents its contact damages that may be the source of its further destruction. Besides that the offered construction of fixture elements makes it possible to use the designed device in casing strings of different diameters without the replacement of the very fixture elements.

The device for pipes unscrewing contains hollow cylindrical case 1 (fig. 2) that has geared surface 2 on its

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inner cylindrical surface and with left pipe adapter at its lower part 3.

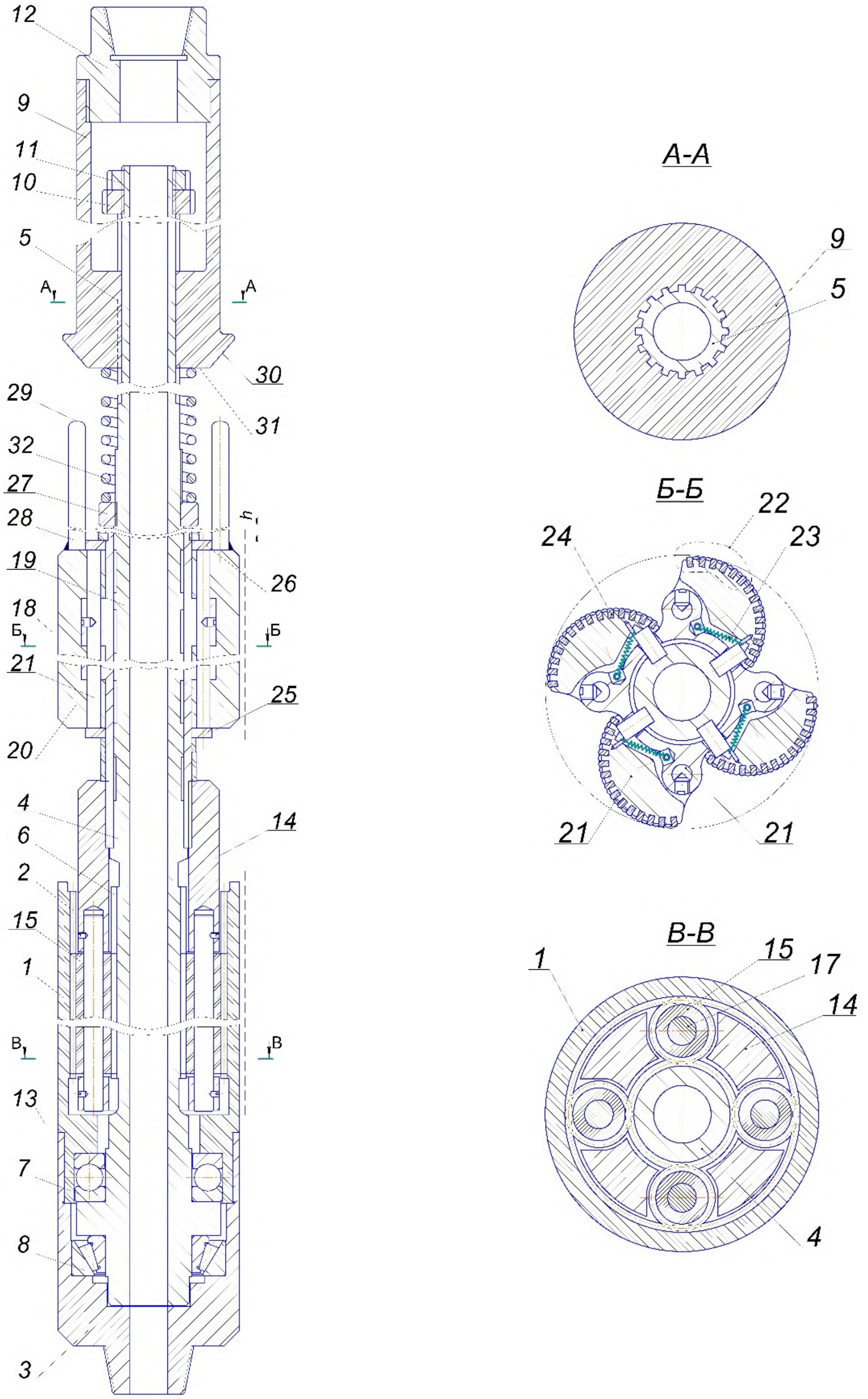

Fig. 2. The scheme of the device for unscrewing the captured column of pipes.

Inside the case 1 the hollow shaft-gear 4 is installed the upper end of which is designed in the shape of splined surface 5, closer to the lower end of shaft-gear 4 there is geared surface 6. The shaft-gear 4 is placed with the ability of rotation towards the case 1 of the device. With this purpose the rolling bearings 7 and 8 are placed at the lower part between them. On the upper part of the shaft-gear 4 on splined surface 5 the spacing sleeve 9 is placed and it is able to perform limited axial movements towards shaft-gear 4. The limitation of this movement is ensured by screw 10, screwed at the geared end of shaft-gear 4 and fixed from unscrewing by locking nut 11. At the upper part of spacing sleeve 9 the right pipe adapter 12 is fixed with the help of screwed joint, adjoining it axis.

The device also has the reversing gear 13 in the shape of planetary gear, consisting of master hollow shaft-gear

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4, carrier gear 14 with satellites 15 placed with the possibility of interaction with external geared surface 6 of shaft-gear 4 and internal geared surface 2, designed in the cylindrical hollow case 1 of the device. The satellites 15 are placed at the respectful hollows 16 of the carrier gear 14 on the axes 17.

The offered design of the device for pipes unscrewing also contains anchor knot 18 consisting of cylindrical case 19, immovably (e.g. by screw connection) fixed at the upper part of carrier gear 14 and placed with the possibility of rotation at shaft-gear 4. The anchor knot 18 also has fixture elements 20 (ranging in number from 3 to 12) placed with the possibility of rotation around axes 21, placed in case 19 parallel to shaft-gear 4 axis. The external working cylindrical surface 22 of fixture elements 20 is designed by the motion of the generant in part of the Archimedean spiral. Fixture elements 20 are manufactured from solid material like steel, processed by relevant thermochemical methods (cementing, boration, chromizing, etc.) and thermal (hardening+low dismissal) of treating. The working surface 22 is carved or armed by hard-alloyed insertion pieces 23. The anchor knot 18 also has extension springs 24 (according to the number of fixture elements 20), the force of them being directed at rotation of fixture elements 20 towards O-O axis of the device.

Apart from that the anchor knot 18 is provided by two spacers 25 and 26, placed at case 19 in order to fix axes 17 axially.

The anchor knot 18 is placed at shaft-gear 4 with the possibility of relative rotation and limited axial movement by the magnitude h that can be altered by adjustor nut 27, screwed at screwed surface, performed at shaft-gear 4 under splined surface 5.

The anchor knot drive of the patented device consists of abutting carrier gears 28, immovably fixed at upper end faces of fixture elements 20 and designed in the shape of cylindrical shafts with spheric endings 29. The lower part of spacing sleeve 9 consists of two surfaces: cutaway conus 30 and flat end surface 31. The drive also contains the spring 32, placed between upper flat end surface of adjustor nut 27 and flat end surface 31 of spacing sleeve 9.

The sizes and mutual location of cutaway conus 30 and spheric endings 29 of carrier gears 28 ensure their interaction during the movement of spacing sleeve 9 (along splined surface 5 of shaft-gear 4) in the direction of spring 32 contraction.

Before the device installation it is necessary to conduct well logging that will make it possible to clearly define the place where the device should be installed [29, 30, 37, 38] on the part of the pipe that is not damaged.

The device operates the following way. The offered device (fig. 2, 3) altogether with fishing tools: taper tap, drill pipe spear etc., attached to the lower pipe adapter 3, is lowered altogether with fishing string of right drilling pipes with the help of right upper pipe adapter 12.

Fig. 3. Laboratory experimental model of a device for unscrewing a captured column of pipes.

This process is continued in the cased wellsite up to the lineup of the fishing tool with the upper end of the stuck string stern. Further lowering sets the upper pipe adapter 12 going altogether with spacing sleeve 9 along the splined surface 5 of shaft-gear 4, pressing string 32 by that. Conic surface 30 of spacing sleeve 9 starts interacting with spheric endings 29 of abutting carrier gears 28 resulting in the action of charge away from the O-O axis of the device. As carrier gears 28 are immovably fixed at the upper faceplate of fixture elements 20, the latter ones, resisting extension strings 24, turn around their axes 21 towards case 19 of anchor knot 18, moving to contact external cylindrical surfaces 22 of fixture elements 20 with external wall of casing string.

Mutual axial location between spheric endings 29 of abutting carrier gears 28 and conic surface 30 of spacing sleeve 9 is adjusted by screw 10, screwed at screwed end of shaft-gear 4 and fixed from unscrewing by locking nut 11.

Spacers 25 and 26 are placed at the external cylindrical case surface 19 from the side of fixture elements edges 20 and mitigate axial movement 21. Besides, spacers 25 and 26 do not let abrasive particles get into junction: the case holes 19 – axis 21 – fixture elements holes 20, preventing jamming and device incapacitation.

The anchor knot is fixed in the casing pipe by drilling string weight indicator.

Working surfaces 21 link with casing pipe wall. The reliability of this link is ensured by the design of fixture elements working surface by the motion of the generant in part of the Archimedean spiral and thread cutting fixture elements 20 on working surface 21 or reinforcement those surfaces by hard-alloyed insertion pieces 23. The link of fixture elements 20 with the external surface of casing pipe wall prevents anchor knot 18 from rotation in cased borehole.

The rotation is initiated by drilling string. As the anchor knot does not let carrier gear 14 rotate towards the O-O axis of the device, planetary gear 13 is turned into common spindle reversing gear. Drilling string rotation through upper right pipe adapter 12, spacing sleeve 9, through splined surface 5 drags over to shaft-gear 4 and further through satellites 15, placed in the hollows 16 at axes 17 onto case 1 of the device. The latter, having the possibility of rotation towards shaft-gear 4 at rolling bearings 7 and 8 sets anticlockwise (reverse) rotation of the lower left pipe adapter 3 with the fishing tool.

After fishing tool is screwed into the emergency pipe body the unscrewing of the weakest thread in emergency drilling string is begun.

Axial movements that appear during fishing tool cutting-in and pipes unscrewing is ensured by axial movement (sliding) of satellites 15 along geared surfaces 2 and 6 respectively in case 1 of the device and at shaft-gear 4 at the expense of spacing gap h between upper part of anchor knot 18 and lower edged surface of adjustor nut 27. Depending on fishing tool schedule and unscrewed pipes thread this spacing gap is adjusted by means of according tightening adjustor nut 27.

After the weakest screwed joint assembly is unscrewed which is noted by drilling string weight indicator, the rotation of the fishing string is stopped and it starts being lifted. The impact of spring 32, placed between adjustor nut 27 and flat end surface 31 of spacing sleeve 9, sets the spacing sleeve 9 going towards shaft-gear 4. Alongside with that as a result of upward axial movement of conic surface 30, the thrust force on spheric endings 29 of carrier gears 28 is reduced – fixture elements 20 under the impact of springs 24 reset, unlocking the device from casing string. The device with the unscrewed pipe or several pipes is lifted from the wellbore.

4 Conclusions

1. It is often the case with oil and gas production industry when emergency situations associated with catching (wedging up) drilling string or pumping-compressor pipes. And the number of these occasion call for the pipes unscrewing from the caught pipe.

2. The most popular way of unscrewing pipes from the caught pipe is the use of pipes with anticlockwise screw. This way is labor-consuming, power-consuming and causes environmental pollution.

3. The use of the way mentioned in clause 2 of the conclusion causes extra pollution to the environment by transportation means delivering and taking away big amounts of tools with anticlockwise screw and sustainable operation of drilling rig engines when the available pipes with clockwise screw are replaced by the ones with anticlockwise screw, and when the operation is completed, the reverse replacement takes place. The total length of pipes with anticlockwise screw is equal to the length of the wellbore and may comprise from 1000 m up to 6000 m and more.

4. The offered construction of the device that functions as a transformer of rotation direction is lowered into the wellbore with the aid of existing pipes with clockwise screw after which there is no necessity to use pipes with anticlockwise screw. It reduces the time of preparatory works needed to remove the emergency and respectively the environmental impact is shortened.

5. The cost of the offered device is next lower order than with the use of pipes with anticlockwise screw.

6. In addition, in order to prevent environmentally hazardous situations oil and gas production sites should employ highly qualified and certified staff. This approach will reduce the impact of human factor as the reason of emergency situations by forming adequate response skills during emergencies when wellbores are being constructed. [39, 40, 41]. Specialists should be trained with the use of modern educational technologies that will make it possible to imitate real life conditions and get practical experience of proper response to incidents in the workplace [42].

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Quantitative method for determining the solution error of the inverse problem in the electrometry of oil and gas wells

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Abstract. Determining the quantitative degree of connection between logging error and the corresponding error of oil and gas wells electrometry inverse problem solving is considered. A quantitative method to determine the magnitude of the error of solving the inverse problem depending on the magnitude of the logging error for a given model of a single layer or section as a whole is described. Examples of determining the error of the inverse problem for real well materials, taking into account the actual measurement error, are given. A method for determining the characteristics of the spatial resolution of electrometry methods is described. Examples of its use for low-frequency induction logging equipment are given. The proposed methods allow to determine the areas of equivalent solutions and the areas of existence of stable / unstable solutions of the inverse electrometry problem.

1 Introduction

The geoelectric parameters definition problem of the section helps to answer two questions [1]:

- Where is the useful fluid?
- How many are there?

Determining these geoelectric parameters requires solving an inverse mathematical problem that links the data of direct measurement of some apparent conductivity (AC) or apparent resistivity (AR) values around the well space with unknown values of these parameters of the model of the studied section. The main method of solving such problems is numerical. But almost any numerical solution involves error. So the final result of solving such a problem will not be a numeric value (or a vector in vector space), but some area of possible values. However, all elements in this area will have the same opportunity to be the solution of the problem. This means that they are equivalent. The size of the area of equivalent solutions that accord the same initial conditions determines the spatial resolution of the solution. In general, it allows us to identify areas of sustainable solutions. And accordingly, identify areas where there are no stable solutions.

2 Analysis of previous publications

There are many reasons for the problem of defining the boundaries of productive intervals in vertical and inclined vertical oil and gas wells. One of the main reasons is the insufficient (for many of the conditions inherent in the Dnipro-Donetsk depth) vertical resolution of geophysical well research (GWR) complexes used in practice. The use unfocused laterolog tools (BKZ), where most sondes are not symmetrical is one of the factors of such a problem. To illustrate it we can cite the well-known problem of determining the position of water-oil contact, the solution of which is devoted to many studies.

The error in determining the boundaries of productive intervals leads to an error in determining the daily flow rate of useful fluid (due to inaccurate determination of perforation) and, accordingly, is a factor in the error of the initial conditions of further technical operation of the well as an anthropogenic loading on the environment.

The work is part of a study of the possibilities of improving the efficiency of solving inverse problems of well electrometry [2-4].

In general, many program-methodological and analytical methods have been developed to analyze the impact of violation of technical requirements for the exploitation of wells on the ecosystems of hydrocarbon production areas [5-13].

The problem of the impact of the oil and gas wells exploitations on the ecological state of the geosphere is more than topical [14-17].

Applied tasks even include the study of the effects of hydrocarbon extraction on the development of regional tourism. This is more than relevant because the Carpathian region is potentially oil and gas and is one of the centers of tourism in Ukraine [18-23].

The environmental impact of oil and gas well operation is also similar to the environmental impact of fuel combustion in boilers [24-27].

In addition, the inevitable use of radioactive methods together with electrometric methods in GWR requires solving the problem of the impact of such methods on different components of the geosphere [28-31].

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The combination of all these approaches makes it possible to use already developed decision support systems [32-40].

It should also be noted that to increase the efficiency of numerical calculation in recent decades has become widely used method of physical simplification. This method is widely used in solving modeling problems of engineering problems and is to simplify the equations of mathematical physics by introducing simplifications that take into account the physical content of processes [41-51].

3 The solution error of the inverse problem and the spatial resolution of the inverse problem

3.1 Error solving the inverse problem

The main error that occurs in the problems of electrometry is a significant measurement error (sometimes the allowable error is an error of 20-40%).

In addition, there may be other possibilities of error. The occurrence of an error in solving the inverse problem can be due, for example, to the following reasons:

1) its mathematical description is inaccurate, in particular inadequately or inaccurately described the model itself or its parameters, etc .;

2) the used method of solving is not accurate;

3) arithmetic operations and outputting data is rounded.

Errors that correspond these reasons are called:

1) irreversible error;

2) the error of the method;

3) computational error.

For the future, the main thing will not be the nature of the error and the fact of its existence. From this point of view, we will investigate the relationship between the magnitude of the error in the initial conditions and the magnitude of the error in solving the inverse problem and consider a method for studying the areas of equivalent solutions.

3.2 Three-layer model

As a geoelectric model of the medium we will consider a three-layer model (Fig. 1).

This model consists of a well (specific resistivity (SR) of mud – ρ_W), invaded zone (or «zone»; SR of zone – ρ_Z) and uninvaded zone (or «layer»; SR of layer – ρ_B).

This model is simplified, but adequately describes the most relevant reservoirs inherent in the conditions of the Dnipro-Donetsk depth (including complex, thin-layer and anisotropic reservoirs, residual oil saturation collectors, abnormally low resistance reservoirs, faulty collectors, etc.).

To determine the values of the reservoir parameters, we consider the following depending on the type of fluid saturation (Table 1).

For simplicity, we will assume from the beginning that the layer has infinite thickness. The case of studying layers of finite thickness requires consideration of the so-called boundary effects [2-3].

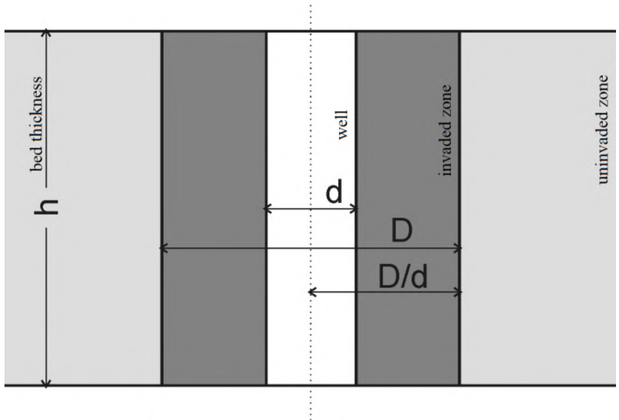


Fig. 1. Three-layer formation model

Table 1. Typical parameters of the layers.

Saturation type	ρ_B, Ohm·m	ρ_Z, Ohm·m	D/d
water-saturated	4,5	20	5
oil-saturated	8,5	30	4
gas-saturated	50	30	5

3.3 Array induction tool

Our geoelectric model is described by several unknown parameters (for the three-layer infinite model – three). To find them, we need to have at least three known values of measured conductivity or resistance in front of each layer.

Existing and widely used induction logging equipment in the world provides such an opportunity. Such equipment consists of four (seven) probes of low-frequency induction logging (IL) – 4IK (7IK). The lengths of the sondes are 0.5, 0.85, 1.26, 2.05 meters (for the 7IK three more sondes of lengths 0.15, 0.25, 0.35 meters are added).

The given methods of research of connection of data of direct measurement with unknown values of parameters of model of the investigated layers are applied without restriction of generality and for other multiprobe systems of electrometry. Such equipment consists of BKZ, lateral logging tool (BK) and low-frequency induction logging tool (AIK) and gives us for each layer (measuring point) even 9 measured values that are not linearly dependent. These are six values measured by the BKZ complex, one value measured by the BK, two values (active and reactive) measured by the AIK.

4 Solution of the inverse problem in the presence of an error

4.1 The magnitude of the equipment error

The simplest way that can be chosen to study the effect of error in the boundary conditions of the inverse problem on its final result is to find the range of possible solutions that correspond to the range of possible values of the boundary conditions. That is the purpose of the study will not be the cause of the error, but how its magnitude affects the error magnitude of solving the inverse problem.

Before that, let us recall two definitions. A correctly posed (well-difined) problem is a problem that satisfies the following three requirements:

– the problem has a solution (requirement of existence);

– the existing solution is unique (requirement of unity);

– the existing and unique solution continuously depends on the input data (continuity condition).

Unstable problem is a problem for which a small error in the initial data can lead to a much larger error in the solution.

Let us now investigate the mapping of the range of admissible values of each measurement vector into the space of the vectors of the geoelectric section model, using the values of the errors that correspond to what is really possible.

One of the possible ways to determine the magnitude of the error is:

– for BKZ (not more than) in % ($\tilde{\rho}$– AR):

$$\varepsilon_{BKZ} = \pm\left(2{,}5 + 0{,}004\left(\frac{5000}{\tilde{\rho}} - 1\right)\right);$$

– for IL (not more than) in mSm/m ($\tilde{\sigma}$ – AC):

$$\varepsilon_{IL} = 0{,}03\tilde{\sigma} \pm 1;$$

– for BK (not more than) 5%.

4.2 Algorithm for establishing areas of equivalent solutions

We will demonstrate "the simplest way" on an example of logging by a 4IK complex in two wells.

The error will be set in two ways:

– the measurement of each probe has an error within a given interval, i.e. is not a number but a confidence interval:

$$\left(1 - \frac{\varepsilon}{100}\right)\tilde{\rho} < \tilde{\rho} < \left(1 + \frac{\varepsilon}{100}\right)\tilde{\rho};$$

– the resistance of the mud is determined with some error, i.e. ρ_W can take any value from the range:

$$(1-\delta)\rho_W < \rho_W < (1+\delta)\rho_W.$$

The second type was chosen to study the stability of the solution from well parameters. Consider the solution of the inverse problem for the already mentioned wells: Vatynska (Fig. 2) and Eganska (Fig. 3).

The error values were set as follows: ε = 10% (Fig. 2.a, 3.a), ε = 20% (Fig. 2.b, 3.b).

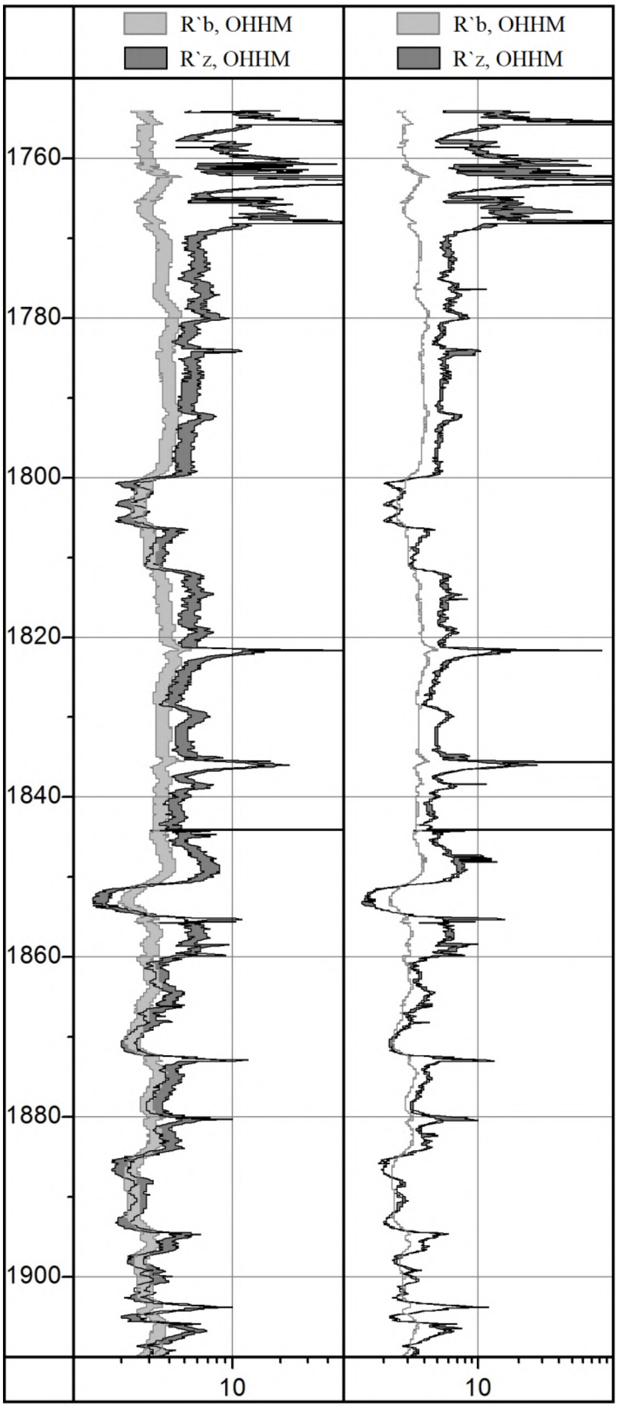
4.3 The inverse problem solving method without error in the initial conditions

The effectiveness of the inverse problem solving method is determined:

– by the choice of method for determining the measurement data of the sondes for the selected parameters of the environment;

– by choosing the parameter "proximity" of the calculated probe readings and real;

– by the method of selecting model parameters for the selected parameter "proximity".



a b

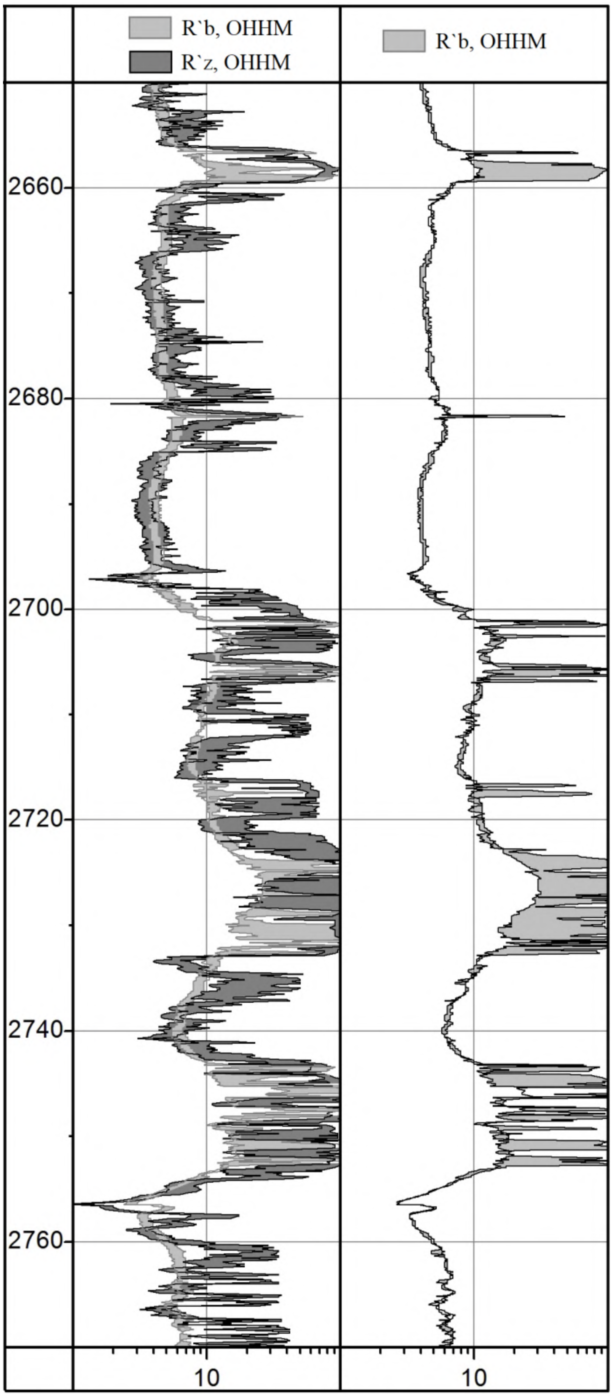
Fig. 2. Well «Vatynska» (ρ_W=1.6 Ohm · m). The result of solving the inverse problem

These questions can be paraphrased accordingly as:

– choice of the method of solving the direct problem (finite differences, finite elements, integral currents, semi-analytical solution, etc.);

– the type of functional that will be minimized when solving the inverse problem (previously this item looked like "choosing the visually closest palette");

– method of iterative process of solving the inverse problem.



a b

Fig. 3. Well «Eganska» (ρ_W= 0.34 Ohm · m). The result of solving the inverse problem

We will not consider the first and third issues, assuming that they are resolved.

As a criterion for the proximity of the found solution with the desired true value, we can consider the minimization of the functional:

$$F(\rho_1^T, \dots, \rho_n^T) = \frac{1}{n}\sqrt{\sum_{i=1}^{n}\left(\frac{\rho_i^T - \rho_i^P}{\rho_i^T}\right)^2},$$

where is n – the number of equipment sondes; ρ_i^T– calculated values of AR for the model under consideration; ρ_i^P – actually obtained values of AR.

There are also some variations of the functional record, which will be minimized in the process of solving the inverse problem. For example, in the form:

$$F(\rho_1^T, \dots, \rho_n^T) = \frac{1}{n}\sqrt{\sum_{i=1}^{n}\left(\frac{\rho_i^T - \rho_i^P}{\delta_i \rho_i^T}\right)^2},$$

where δ_i – the relative error of the i probe.

Or:

$$F(\rho_1^T, \dots, \rho_n^T) = \frac{1}{n}\sqrt{\sum_{i=1}^{n}\left(\frac{\rho_i^T - \rho_i^P}{\delta_i \rho_i^T + \chi_i}\right)^2}, \qquad (1)$$

where χ_i – the absolute error of the i probe.

We will consider the functionality of the form:

$$F(\rho_1^T, \dots, \rho_n^T) = \sqrt{\sum_{i=1}^{n} K_i\left(\frac{\rho_i^T - \rho_i^P}{\rho_i^T}\right)^2}, \qquad (2)$$

where K_i – weight coefficients of each sonde of the complex, which can be changed by the interpreter.

Several studies have been devoted to the choice of different values of weights.

It is clear that the change in weights will significantly affect the size of the area of equivalent solutions, because it can reduce the impact of sondes that have a larger measurement error and increase the impact of sondes that have a smaller measurement error, for example.

Further research will be devoted to this issue. In this study, without loss of generality, we will assume that:

$$\forall i: K_i = 1. \qquad (3)$$

4.4 Examples of the inverse problem solving taking into account the error in the initial conditions

To demonstrate the method, we take the real well material and assume that the result is obtained with an error (Fig. 2.a, Fig.3.a – ε = 20%; Fig. 2.b, Fig. 3.b – δ = 0.2). For such values of possible initial intervals we will solve the inverse problem (we will define ρ_B,ρ_Z that are designated as R`b, R`z in Fig. 2,3).

Note that in Fig. 3.b shows the results only for the AR of layer, because the intervals of possible values of the zone are frankly chaotic and do not carry any information, resembling a random number generator and therefore not given. This chaotic nature is evidence of a typical example of an unstable solution, when for each specific value of the measurement data we have a specific solution value, but a small change in the measurement data corresponds to a large (orders of magnitude larger) change in the solution value of the inverse problem. This is also an example the way of how a solution can satisfy a condition of continuity but not be stable.

Based on the results obtained, the following conclusions were made.

For a well filled with clay drilling mud (Fig. 2):

– the inverse problem of the 4IL complex within the values of the model parameters is stable relatively to the measurement error (the range of possible values of the model parameters is almost proportional to the range of possible measurement values (Fig. 2.a));

– the inverse problem for the 4IL complex within the values of the model parameters up to 10 mSm/m is stable relatively to the change of ρ_W (the range of possible values of model parameters is almost proportional to the range of possible drilling fluid values (Fig. 2.b));

– the inverse problem for the 4IL complex within the values the model parameters more than 10 mSm/m satisfies the condition of continuity, but is not relatively to the change of ρ_W (the range of possible values of model parameters is much larger than the range of possible ρ_W values (Fig. 2.b));

– values of R`z are more "sensitive" to change of parameters of a well, than values of R`b.

For a well filled with saline drilling mud (Fig. 3):

– the inverse problem of the 4IL complex within the values of the model parameters up to 10 mSm/m is stable relatively to the measurement error (the range of possible values of the model parameters is almost proportional to range of possible measurement values (Fig. 3.a));

– the inverse problem of the 4IL complex within the values of model parameters more than 10 mSm/m satisfies the condition of continuity, but is not stable relatively to measurement error (the range of possible values of model parameters is much larger than the range of possible values of measurements (Fig. 3.a);

– the inverse problem of the 4IL complex is not stable relatively to the change of ρ_W (the range of possible values of one of the parameters of the model (namely R`z) is much larger than the interval of possible values of ρ_W;

– the parameter R`b has both a stable region of definition (up to 10 mSm/m) and an unstable region of definition (more than 10 mSm/m), as can be seen in Fig. 3.b.

There are many similar examples of wells and complexes, but the main one is the fact that, in principle, there are areas of unstable solutions in wells.

That is, by setting specific values of the AR, we will, of course, get a specific value of the solution, but it may be unstable. It is clear that such a solution cannot be used while GWR.

Alternatively, in further interpretation, it will lead to erroneous conclusions regarding the determination of well performance characteristics.

So, we come to the conclusion that it is not enough to have a way to solve the inverse problem on its own. We also need to have a method that will allow to determine the areas of stability of the solutions of the inverse problem for each section model and each electrometry complex.

5 Spatial resolution characteristics of solving the inverse problem

Consider the space of the parameters $\mathbf{P}$ of the studied objects $\mathbf{p}$ and the space $\mathbf{G}$ of possible values $\mathbf{g}$ of measurement by the well-logging complex. In order for the problem to have a solution, we will require that the number of independent measurements be greater or equal to the number of required parameters of the model. There is a unique mapping: $\mathbf{P} \rightarrow \mathbf{G}$ (we will denote the corresponding mapping function G). Consider the features of the inverse mapping (we will denote the corresponding function G^{-1}), which in the case of mapping one element will be considered unambiguous. If the mapping object is not one element $\mathbf{g}$, but an area $\mathbf{g} + \Delta\mathbf{g}$ where $\Delta\mathbf{g}$ takes any values within the allowable error, then the image of such a mapping will also be some. Consider the following mapping:

$$\mathbf{p} + \Delta\mathbf{p} = G^{-1}(\mathbf{g} + \Delta\mathbf{g}). \quad (4)$$

Note that since the inverse problem is nonlinear, the value depends on both the model itself and the measurement error: $\Delta\mathbf{p} = \Delta\mathbf{p}(\mathbf{p}, \Delta\mathbf{g})$. The measurement error also generally depends on the model of the environment: $\Delta\mathbf{g} = \Delta\mathbf{g}(\mathbf{p})$.

Such a complex dependence does not allow to introduce a general simple concept and definition of the spatial resolution of the equipment not only for the whole range of parameters of all possible current models of sections, but even for a set of several separate models and requires the study of quantitative dependence (4) for each model.

Accordingly, we can talk about the characteristics of the spatial resolution of specific equipment only for a specific model of the section: even with a slight change in the parameters of the model, the characteristics can change significantly. This is exactly what we observed in the previous section.

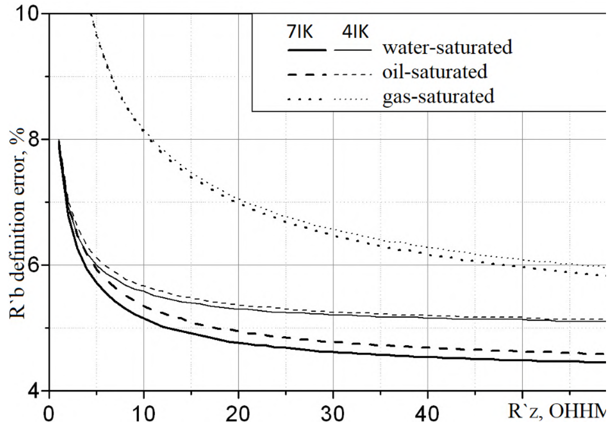


Fig. 4. Dependence of the error in determining the ρ_B on the ρ_Z

Therefore, the analysis of such characteristics should be performed for a separately selected model.

For each such selected model we will perform the following steps:

1. Set its parameters – determine the vector of model parameters $\mathbf{p}$ (we will use table 1).

2. Solve a direct problem for $\mathbf{p}$ – determining the vector of measurements $\mathbf{g} = G(\mathbf{p})$.

3. Solve the inverse problem for a definite $\mathbf{g}$ – finding an element such that:

$$\mathbf{p}` = G^{-1}(\mathbf{g}) = G^{-1}(G(\mathbf{p})).$$

4. Compare $\mathbf{p}`$ and $\mathbf{p}$ – determine the accuracy of solving the inverse problem.

If it does $\mathbf{p}`$ not differ from $\mathbf{p}$ (within the allowable, arbitrarily small, predetermined error), we will assume that:

$$\mathbf{p}` \equiv \mathbf{p}. \tag{5}$$

Execution (5) will mean that the obtained characteristic of the spatial resolution is correct and does not depend on the method of solving the inverse problem.

5. Solving the inverse problem for the area $\mathbf{g} + \Delta\mathbf{g}$ – finding the set of possible models $\mathbf{p}+\Delta\mathbf{p}$ that correspond $\mathbf{g} + \Delta\mathbf{g}$ (determination of the error $\Delta\mathbf{p}$ depending on the given value of the error $\Delta\mathbf{g}$).

6 Results

We will demonstrate this connection between the registration error and the error of possible determination of the required parameters.

The error will be set separately for each sonde. To qualitatively explain the expected results, it is enough to use the approximate Doll`s theory and record the AC measured by each sonde, ignoring the signal from the well in the form:

$$\sigma^i = \frac{g_Z^i}{\rho_Z} + \frac{g_B^i}{\rho_B}, \tag{6}$$

where σ^i – the apparent conductivity of the ith probe; g_Z^i, g_B^i – geometric factors of the invaded zone and the layer.

It is obvious that the relative accuracy of determining the SR of the layer and the invaded zone is
related to the relationship between the first and second terms in (6).

Yes, when:

$$\frac{g_Z^i}{\rho_Z} << \frac{g_B^i}{\rho_B}, \tag{7}$$

the parameters of the invaded zone are determined with a much larger error at than the parameters of the layer at $\rho_Z = const$.

In addition, condition (7) is fulfilled particularly strictly with increasing penetration, when, in addition, condition (6) is amplified even more. The error in determining the parameters of the near zone is improving with decreasing penetration, because the condition significantly weakens condition (7). But, among other things, this is confirmed by direct numerical simulation of the spatial resolution characteristics.

Thus, Fig. 4 shows the dependence of the accuracy of determining the SR of the layer from the SR of the zone, Fig. 5 – the dependence of the accuracy of determining the SR of the layer on the diameter of the zone, Fig. 6 – the dependence of the accuracy of determining the SR of the zone on the diameter of the last one.

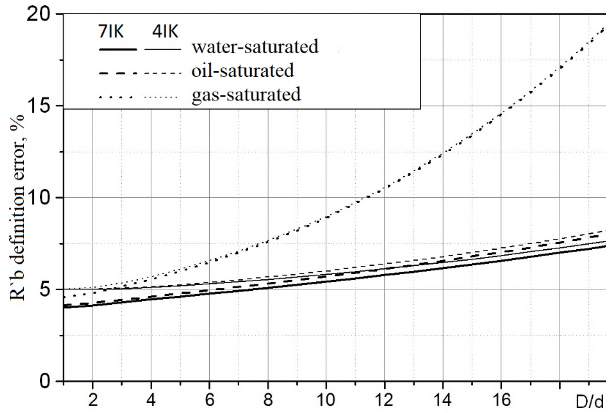


Fig. 5. Dependence of the error in determining the ρ_Z on the diameter of the zone

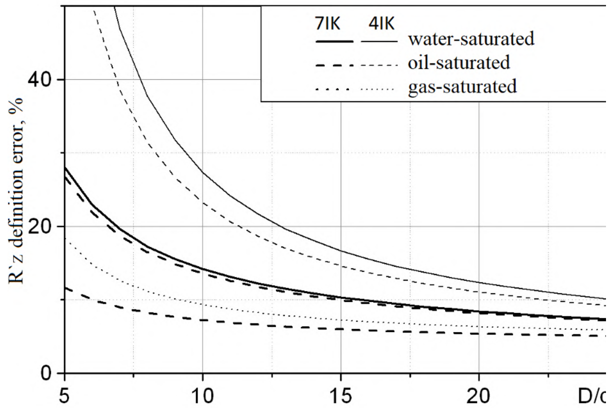


Fig. 6. Dependence of the error in determining the ρ_Z on the diameter of the zone

7 Conclusions

These results lead to the following conclusions:

– Before the practical application of any method of solving the inverse problem, it is advisable to explore the areas of stability of its solutions, which will allow them to be used in the future without losing useful information.

– In order to be able to effectively further work with the obtained results, it is also advisable to explore the areas of equivalent models that correspond to the real error of logging and its geophysical conditions.

– The given method of research of spatial resolution of the solution of the inverse problem of electrometry of oil and gas wells allows to investigate effectively areas of stability of its decisions and areas of equivalent models corresponding to a real error of logging and its geophysical conditions.

The question of why use (2) is more adequate than use (1) will be covered later.

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The essence and mechanisms of environmental competence formation in students of natural science departments

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Abstract. A comparative analysis of the ecological (environmental) educational component of the training in students of Natural Science Departments (Chemistry, Biology, Earth Sciences, Ecology) and future teachers of natural sciences has been carried out. The general and professional competences, program results of training, and applicants training educational programs on the example of several Ukrainian universities are analyzed. It is revealed that the formation of environmental competence is carried out by acquiring environmental education by means of interactive technologies, forms, and methods of organizing the educational process. The positive influence of students' involvement in research, environmental, ecological, and naturalistic work in extracurricular time on the formation of their environmental competence has been confirmed. The role of educational and industrial practices in the process of students' professional training and the formation of their environmental competence is emphasized.

1 Introduction

The strategy of the state ecological policy of Ukraine for the period till 2030 provides the following: introduction of the ecosystem approach in branch policy; integrated environmental management and implementation of international standards; taking into account the environmental component during economic activity; implementation of international environmental initiatives in Ukraine [2].

The document emphasizes the importance of maintaining air quality, reducing greenhouse gas emissions; protecting natural waters, forests, lands and soils; developing a national biosafety system; preserving the biological and landscape diversity, etc.

Ukraine has developed a national system of continuous sustainable development goals, which should become the foundation for overcoming imbalances in the economic, social, educational and environmental spheres; thus, it will contribute to the quality of life of present and future generations in harmony with the environment, as well as it will guarantee socio-economic and environmental stability, including a decent level of education and public health.

An important task today is the formation of ecological competence, environmental culture and environmental worldview of all segments of the population. In our opinion, the issue of formation of ecological competence of specialists of water quality analysis, forestry, agriculture, mining industry is especially urgent; nevertheless, specialists in Chemistry, Biology, Geography, Ecology; as well as teachers of natural sciences should also be covered, for the state of the environment will largely depend on the level of their ecological competence.

2 Literature review

The Second United Nations Conference on the Environment (Rio de Janeiro, 1992) declared the Agenda for the XXI Century program document, which for the first time set out the basic provisions for sustainable development. This is a kind of model of socio-economic development, in which the vital needs of the current generation are met in such a way that future generations are not affected by the depletion of natural resources and environmental degradation [3].

"Environment for Europe" congress took place in Kyiv in 2003, during which the member states of the United Nations Economic Commission for Europe (UNECE) have adopted the "Declaration on Education for Sustainable Development". It declared that education is one of the tools that ensure environmental protection and sustainable development of society. The world community has begun to talk more and more about the role of education in the transition of humanity to the principles of sustainable development. The UNECE Ministers of the Environment invited countries to include the concept of sustainable development in education

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systems at all levels (preschool, secondary, higher); as well as in non-formal and out-of-school (extracurricular) education.

At the Eighth Conference of EEC Ministers of the Environment "Environment for Europe" (Batumi, 2016) it was stated that by 2030 it is necessary to achieve that all students acquire the knowledge and skills necessary for sustainable development, which will substantially enhance the relevant competence [4].

In general, in the European educational space, competence is defined as a dynamic combination of knowledge, skills, abilities, ways of thinking, personal qualities, attitudes and values, which determines a person's ability to successfully carry out professional and / or educational activities. Competences underlie the qualifications of graduates of higher education institutions (HEIs) [7; 28].

European researchers attach great importance to environmental competence. For example, Roczen proposed environmental competence model, which includes cognitive and motivational components. Thus, author examined the structure between different forms of environmental knowledge as well as connection with nature and ecological behavior [15]. Researcher identified the connection between human beings and nature as the motivational source of an individual's ecological behavior. This model conceptualizes environmental competence as the interlayer between connection with nature and ecological behavior promoting environmental knowledge. Therefore, the motivational source for ecological behavior is the connection with nature [15; 16].

Frick and colleagues (2004) consider cognitive component the most important one. They distinguish three forms of environmental knowledge: 1) knowledge as a system (knowledge about nature and about environmental problems), 2) action-related knowledge (knowledge about ecological behaviors), and 3) knowledge about corresponding behavioral effectiveness [5]. Scientist claims that ecological behavior is induced by intellectual abilities [26]. However, whereas motivational dispositions strongly impact on ecological behavior [15; 16].

According to Kumar and Rani, environmental education of teachers has a great importance [8], for it is an interdisciplinary subject. It can solve multiple environmental problems, which are faced by the humanity nowadays (global warming, pollution, greenhouse effect, ozone depletion etc.). The research results revealed that out of 600 trainees, 26.00% of teachers showed low level of environmental competencies; 45.33% of applicants possessed moderate level of corresponding competencies. Since teachers play key role in the environmental education, he/she is expected to possess substantial environmental knowledge, environmental awareness, positive environmental attitude and environmental competencies in order to achieve the objectives of environmental education. Therefore, teacher training institutions should take the accountability to organize orientation programs, refresher courses, seminars and workshops on environmental problems and their solution, conferences, which imply great increase in the teachers' qualification [8].

According to Ponomarenko et al., the work on students' environmental competence formation consists of three main stages: 1) environmental orientation formation; 2) environmental professional competence formation (duty, ability, and willingness to make practical decisions following environmental safety); 3) environmental responsibility formation (integral value that allows a person to live in harmony with nature, other people and himself) [12].

The concept of ecological competence of students is the subject of scientific research of many Ukrainian scientists. The issue of formation of ecological competence of university students of biological specialties was researched by Tytarenko [29]. Theoretical and practical issues of environmental training of college students, technical schools are revealed in the works of Hurenkova et al [9], Ridei [14], Rudyshyn [13], who devoted their works to analyzing and solving various issues of professional training of ecologists. The ecological competence of the future biology teacher is the subject of research of Melnychenko [10; 11], Homlya [6], Tsurul [27], [19] etc.

Most authors agree that ecological competence is a category related to environmental awareness, environmental education and culture, corresponding values and thinking. It is formed at the social and household level in different segments of the population and is a *key competence* of graduates of general secondary, specialized secondary, vocational and higher education.

Specialists in the sphere of ecological education and upbringing Pustovit et al. define the «*ecological competence*» as:

– the ability of the individual to make decisions and act with the least harm to the environment;

– ability to responsibly solve life situations, to subordinate the satisfaction of their needs to the principles of sustainable development;

– ability to apply environmental knowledge and experience in professional and life situations, guided by the priority of environmental values and non-pragmatic motivation to interact with the environment;

– awareness of personal involvement in environmental problems solution and responsibility for the environmental consequences of their own professional and domestic activities [13, p. 8].

For students of Natural Science Departments and some technical, engineering and economic specialties, ecological competence is an integral part of *professional competence.*

In particular, Tytarenko considers the environmental competence of biology students as "the ability to apply environmental knowledge and experience in professional and real-life situations, guided by the priority of environmental values, namely: awareness of personal involvement in environmental issues, responsibility for environmental consequences of their professional and home activities." [29].

Shapran claims that the ecological competence of a future biology teacher is a component of professional competence. Its level is manifested through professional and domestic activities, when the acquired environmental knowledge, skills, values, experience are actualized in the ability to make decisions and perform adequate actions, aware of their consequences for the environment [19].

Lukianova and Hurenkova also consider the environmental competence of college graduates as a component of their professional competence; an integral characteristic of business and personal qualities, which seems to "reflect" the level of knowledge, skills, experience necessary for professional activity, as well as the social and moral position of an individual [9].

I. Barna et al. emphasize that during the training of 101 specialty "Ecology" bachelors each student will be able to become a professional, expert in ecology, provided mastery of special and general competencies specified in the standard, including: the ability to assess the impact of man-made factors on the environment; to identify the environmental risks; to use of ICT(s) for environmental research; to inform the public about the state of environmental safety, etc. [1].

Karpenko et al. notes that the formation of ecology competence of future environmental specialists is aimed at the conscious use of acquired knowledge in practice; formation of a system of values, human attitude to the environment. The same authors accordingly link the ecological competence of students with several aspects: 1) the formation of a system of knowledge about the environment; 2) gaining practical experience in using knowledge to solve environmental problems at the local and regional levels; c) forecasting appropriate behavior, activities in the professional sphere and life; d) the need to communicate with nature, the desire to take a personal part in its restoration and preservation [7, p. 10].

A similar opinion concerning the ecological-evolutionary worldview of an individual as a system of principles, views, knowledge, values, beliefs, practical actions that determine the understanding of the unity of social and natural environment is expressed by L. Rybalko, O. Topuzov, L. Velychko. The authors believe that the abovementioned worldview has three important components: intellectual (ecological and scientific-natural knowledge, competencies), emotional-value (caring for the environment, admiration for the beauty of nature), and activity (environmental, research, ecological-naturalistic work) [18, p. 3].

Summarizing the different scientific views and personal experience of training students of students of Natural Science Departments, we note that the formation of environmental competence is carried out during:

− realization of *ecological education* (ecologization of the content of professional disciplines, conducting environmentally friendly training and corresponding types of practice);

− organization of *extracurricular eco-directed work* (nature protection, naturalistic, research activity);

− use of *interactive technologies*, *innovative methods and forms of organization of the educational process* (trainings, projects, case studies, group work, information and communication technologies (ICTs), eco-oriented scientific selectives, etc.).

The aim of our article is to analyze the mechanisms of formation of ecological competence of bachelors of Natural Science Departments, including future chemists, biologists, ecologists, as well as teachers of natural science in the educational environment of the university.

2 Materials and methods

The material for the article was the curricula and educational programs for the training of specialists of the first (bachelor) level of higher education of three universities of Ukraine – Zhytomyr Ivan Franko State University, National Pedagogical Dragomanov University and Kherson State University. The following educational and professional bachelor programs were analyzed: specialty 091 "Biology", 101 "Ecology", 102 "Chemistry", 103 "Earth Sciences", 014.05 "Secondary education (Biology and Human Health)", 014.06 "Secondary education (Chemistry)", 014.07 "Secondary education (Geography)". Thus, the investigation was conducted from the point of view of the ecological (environmental) component of compulsory and variable educational components. Based on the analysis of the Standards of Higher Education, the program learning outcomes and competencies of the relevant specialties of various fields of knowledge on environmental orientation are highlighted.

While working with students of advanced training courses in the system of Institutes of Postgraduate Pedagogical Education of selected regions of Ukraine, namely Vinnytsia, Zhytomyr and Rivne, we conducted a survey of more than 200 teachers of natural sciences. With the help of questionnaires, the levels of formation of the main components of environmental competence in teachers were determined, the most effective forms and methods of their environmental work with students were identified.

During the implementation of Sorochynska Oksana's author's course "Training of future biology teacher for extracurricular ecological and naturalistic work with primary school students" a pedagogical experiment has been conducted for two years with the participation of about 400 students of the Faculty of Natural Sciences of Zhytomyr Ivan Franko State University.

3 Results and discussion

3.1 Higher Education standards and programs analysis

The importance of environmental knowledge, values, skills and corresponding competence at the professional level in the process of training of bachelors of natural sciences, biology and human health is recognized and supported at the state level in many countries, including Ukraine.

Thus, the Standard of Higher Education, specialty 091 "Biology" provides for the formation of two general (GC) and three special competencies (SC) of environmental orientation in students [21]:

GC01. Ability to realize his/her rights and acknowledge responsibilities as a member of society, as well as to accept and implement the values of civil society and the need for its sustainable development, the rule of law, human and civil rights and freedoms in Ukraine;

GC09. The ability to act socially responsibly and consciously in order to preserve the natural environment;

SC06. Awareness of the need to preserve biodiversity, protect the environment and conduct rational and effective environmental management;

SC09. Ability to analyze the results of the interaction of biological systems at different levels of the organization, their role in the biosphere and the possibility of their use in different sectors of the economy, including biotechnology, medicine and environmental protection;

SC10. Ability to demonstrate knowledge of mechanisms for maintaining homeostasis of biological systems.

In addition, obtaining the bachelor level qualification of specialty 091 "Biology" in the system of higher education involves the formation of 7 program learning outcomes that contribute to the sustainable development of society and understanding of the relationship between man and the environment, namely:

✓Understanding of the social and economic consequences of the introduction of the latest inventions and scientific research results in the field of biology within the professional activities;

✓Demonstration of skills needed to assess unpredictable biological problems and make informed choices;

✓Application of models, methods and data of physics, chemistry, ecology, mathematics in the process of learning and professional activity;

✓Adherence to the provisions of biological ethics, rules of bio-safety and bio-protection in the process of training and professional activities;

✓Ability to predict the effectiveness and consequences of environmental protection measures;

✓Application of methods for determining the structural and functional characteristics of biological systems at different levels of their organization in practice;

✓Ability to analyze data on diverse living organisms [21].

The standard of higher education of specialty *102 "Chemistry"* in addition to the general competence GC 01 provides for the formation of only one environmentally oriented program learning outcome: "Assess And Minimize Risks to the Environment While Carrying out Professional Activities" [24].

The standard of higher education of specialty *103 "Earth Sciences"* in addition to the general competence GC 01 (see 091 "Biology") provides for the formation of only three professional (special) competencies related to sustainable development, namely: 1) knowledge and understanding of theoretical foundations of "Earth Sciences" as a complex natural system; 2) the ability to apply basic knowledge of physics, chemistry, biology, ecology, mathematics, information technology, etc. in the study of the Earth and its geospheres; 3) the ability to monitor natural processes [25].

The standard of higher education in the specialty *101 "Ecology"* aims to develop such an integrated competence as the ability to solve complex specialized issues and practical problems in the field of ecology, environmental protection and sustainable use of nature. In the educational process the methods of environmental sciences are characterized by complexity and uncertainty of conditions" [22]. In addition to general competence, similar to the considered specialties, the standard provides for the formation of 13 special (professional) competencies and more than twenty program learning results in the field of ecology, environmental protection, environmental safety, environmental law, landscape management and biological diversity.

In the Draft Standard of Higher Education in the field of knowledge *01 Education / Pedagogy,* specialty 014 *"Secondary education* (by subject specializations)*"* in 2017 very few competencies and program learning outcomes aimed at forming the ecological competence of the future teachers [23].

Thus, for the specialty 014.05 "*Secondary education* (*Biology and human health*)" there is only one professional competence declared (ability to understand and implement the strategy of sustainable development of mankind in the process of teaching the students) and one program learning outcome (ability to understand and characterize the strategy of sustainable development, as well as to reveal the essence of the relationship between the natural environment and a human being).

For the specialty 014.06 "*Secondary education* (*Chemistry*)" - no (!) learning outcomes or other corresponding educational results are associated with sustainable development and formation of ecological worldview.

The training of geography teachers is the most nature-centric and environmentally-oriented. Moreover, for future geographers of the specialty 014.07 "*Secondary education (Geography)*" the formation of two subject competencies and five learning outcomes is provided. For example, a student must be able to:

✓describe the main mechanisms of functioning of natural and social territorial complexes, their individual components, as well as to classify the links, dependencies and interrelations between them; to know the causes, results and consequences of the processes occurring in/between them;

✓explain the changes that occur in the geographical environment under the influence of natural and anthropogenic factors; formulate the consequences and determinants in the context of the concept of sustainable development of mankind;

✓characterize natural landscapes and regions, explain their features and interconnections formed by geographical location and other geo factors;

✓understand global socio-geographical processes, be able to compile characteristics of the world's population, sectors and spheres of the world economy;

✓to characterize and evaluate natural conditions and resources, population and economy of Ukraine, its role and place in socio-geographical processes of the modern world [23].

After conducting the analysis of bachelor degree education programs (240 ECTS credits, 30 hours each) and curricula of various higher education institutions that train specialists in the above-mentioned specialties of natural and educational fields, we confirmed low and medium percentage of environmental educational components in their composition (Fig. 1).

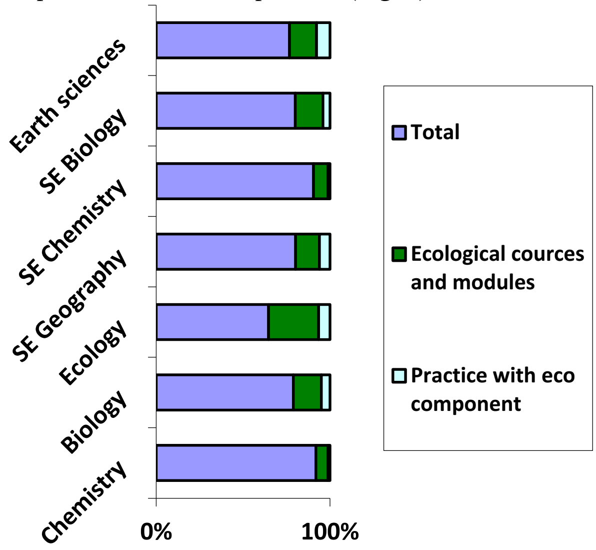

Fig. 1 Ecological **(**environmental) component of educational and professional programs (compulsory educational components), ECTS credits.

Thus, in the structure of the educational-professional program “Chemistry” at Zhytomyr Ivan Franko State University, the courses “General and Chemical Ecology” (3 credits), “Ecological Chemistry” (5 credits) are obligatory. In the curricula such courses as “Fundamentals of Chemical Technology” (6 credits), “Polymer Chemistry” (4 credits) contain separate topics aimed at developing the ecological worldview and competence of students. In addition, for several years in a row, among the selective educational components of the program students choose “Green Chemistry”, “Environmental Chemistry”, “Ecoanalytical Chemistry” courses.

In the educational-professional program “Biology” of the bachelor's level, the following subjects are obligatory for studying the discipline: “Bioethics and Biosafety” (4), “Ecology and Rational Use of Nature” (3). Some elements of ecological knowledge, including ideas about biodiversity, are given by the following courses: “Botany”, “Zoology” (12.5 credits), “Microbiology” (5), “Soil Science” (3), “Biogeography” (4), “Plant Physiology” (5 credits), etc. Among the selective educational components, which are traditionally chosen by the majority of biology students, there are many that have an ecological focus (“Ecology and Ethology of Fish”, “Systematics Of Chordates With The Basics of Ecology”, “Systematics of Higher Plants with the Basics of Ecology”, “Biomonitoring of Natural Waters”).

For applicants studying in the educational-professional program “Secondary Education (Geography)” at Zhytomyr Ivan Franko State University the following disciplines are obligatory to master: “Environmental Safety and Sustainable Development” (5 credits), “Landscape Ecology” (4 credits), and also many courses containing semantic modules of ecological direction, including “Geography of Soils With Bases of Soil Science” (4,5 credits), “Economic and Social Geography of Ukraine” (5), “Meteorology and Climatology” (5,5), “Landscape Science” (4.5); “Fundamentals of Social Geography” (4), “Methods of Extracurricular Work in Geography” (5.5), “Regional Economic and Social Geography” (4), “Geography of the World Economy” (4 credits). In addition, future teachers of geography often choose such selective educational components as: “Regional Ecology”, “Recreational Geography”, “Ecological Foundations Of Nature” and others.

In the process of training of students of the same specialty at the National Pedagogical Dragomanov University and Kherson State University, the curriculum also provides for more than 40 credits of normative disciplines, similar to the above-mentioned, which include content modules of environmental orientation. Selective disciplines are focused on the formation of ecological competence (“Anthropogenic Geomorphology”, “Ecological Hydrology”, “Management of Natural Resources” (3 credits each).

The Earth Science program at Kherson State University has significant potential for developing the environmental competencies of students. Thus, it includes compulsory educational components of the environmental professional competence and natural sciences, which contain environmentally oriented content of individual modules, namely: “Ecology” (3 credits), “Social Ecology” (3), “Life Safety and Environmental Safety” (3), “Environmental Monitoring” (3,5), “Modeling and Forecasting of the Environment” (3,5), “Organization of Ecological Management” (3), “Standardization of Anthropogenic Load on the Environment” (3), “Marine Geology and Geomorphology” (5), “General Geology” (3,5), “Meteorology and Climatology” (5), “Evolution of the Earth's Geospheres” (3), “General Hydrology and Oceanology” (4), “Landscape” (3), “ Geography of soils with the basics of soil science “(3,5). In addition, a significant part of the selective disciplines proposed for this specialty has an environmental focus: “Economics of Nature”, “Rational Use of Natural Resources”, “Recreational Geography”, “Environmental Marketing”, “Soil and Earth Protection” and others.

Formation of environmental competence of students of the educational program “*Secondary education (Chemistry)*” at National Pedagogical Dragomanov University is provided by a) normative disciplines: “Fundamentals of Chemical Safety” (6 credits), “Fundamentals of Production” (10), “Inorganic and Organic Toxicants” (6); b) disciplines of free choice of the student: “Environmental Chemistry” (6 credits) and “Modern Information Technologies in Ecological Chemistry” (4 credits).

In the educational training program for the specialty 014.05 *Secondary education (Biology and Human Health)* of the National Pedagogical Dragomanov University and Kherson State University, the formation of environmental competence of applicants is carried out during the study of normative disciplines “Ecology” and “Biogeography” (3 credits). Some components of ecological knowledge form the normative courses, namely: “Botany”, “Zoology” (11 credits), “Soil Science” (5), “Microbiology with the basics of virology” (4), “Plant Physiology” (5), “Evolutionary morphology” (3) and selective courses: “Plant Ecology”, “Animal Ecology”, “Dendrology”, “Mycology”, “Entomology” (3 credits each), “Animal Ethology”, “Ecological and valeological training for health activities”, “Biological systems” (4 credits each).

It is confirmed that the largest educational component of environmental orientation is the program “Ecology” for bachelors in all universities. So, at Zhytomyr Ivan Franko State University (ZIFSU) it includes 24 credits of educational and industrial practices, 3 credits of course works in various directions of ecology, 13 credits of educational courses containing modules of ecological direction, and also 94 credits for studying of various fundamental and applied ecological disciplines, among which there are: “Hydrology with the basics of hydroecology”, “Bioindication of environmental quality”, “General ecology”, “Environmental monitoring”, “Modeling and forecasting of the environment”, “Ecosafety and technoecology”, “Environmental legislation and environmental law”, “Economics of Nature Management”, “Landscape Ecology”, “Reserved Business”, “History of Ecology”, “General Ecology and Neo-Ecology”, “Organization of Management in Environmental Protection”, “Formal and Informal Environmental Education”, “Ecosystemology” and others. Among the elective educational components, students of ZIFSU mainly choose courses “Agroecology”, “Bioindication of Aquatic and Terrestrial Ecosystems”, “Ecological Tourism”, “Ecotoxicology”, “Ecophysiology of Animals”, “Ecological Biotechnologies” and others.

Students of ecological specialties at Kherson State University and National Pedagogical Dragomanov University have a very similar “core” of the educational program, which contains more than 90 credits of environmental disciplines. These include courses similar to the Zhytomyr Ivan Franko State University program, as well as educational components such as: “Standardization of Anthropogenic Pressure on the Environment”, “Environmental Impact Assessment”, “Urban Ecology”, “Environmental Inspection”, “Environmental Entrepreneurship”, “Environmental Marketing”, “Environmental Policy”, “Corporate Environmental and Social Responsibility”, “Countering Climate Change”, “Environmental Education and Science”, etc.

Thus, the environmental education component is best expressed in the training of future bachelors of ecology (more than 50% of credits for the study of required courses and practices), which is related to their professional qualifications. In the training of future biologists, bachelors of Earth Sciences (geologists, hydrologists, organizers of nature management, etc.), teachers of geography, biology, environmentally oriented disciplines (or individual modules) and practice account for about 24-33% of the workload. Educational training programs for chemists and future high school chemistry teachers have the lowest percentage of educational components aimed at the formation of environmental competence – less than 10% of ECTS credits.

3.2 Practical training as the means of forming students' ecological competence

An important component of students training is practice and internships. We believe that they play a leading role in shaping the environmental competence of future biologists, chemists, ecologists and teachers of natural sciences.

During productive practice in laboratories, which is mainly conducted in natural and artificial ecosystems, there is process of verification of the received theoretical ecological knowledge and its transition to practical one, as well as the formation of awareness of its efficiency and reliability. The internship provides students with the data on regional environmental problems in combination with the acquisition of experience of interaction with nature; formation of corresponding skills, which contributes to the emergence of a professionally sufficient level of environmental competence of chemists, biologists, ecologists. In addition, the environmental competence of future teachers of biology, basics of health, science, geography and chemistry is a necessary condition for the formation of appropriate personality traits in students [10; 11; 27].

Educational-professional training programs for students majoring in the specialties 102 “Chemistry” and 014.06 “Secondary education (Chemistry) provide practice in the basics of chemical production (3 credits), which must include analysis of environmental risks, environmental safety of a production, its impact on the environment.

Educational practices in zoology, botany, plant physiology and genetics (15 credits in total) at Zhytomyr Ivan Franko State University contribute to the formation of ecological competence of students majoring in 091 “Biology”. They are held mainly in the spring and summer, combining laboratory classes with excursions to natural biocenoses, reserves, sanctuaries, botanical gardens, zoos and more. Similar teaching practices are provided by the National Pedagogical Dragomanov University for future biology teachers in accordance to the training programs, namely: botany, zoology (9 credits), soil science (1.5 credits) and biogeography (1.5 credits).

For students majoring in 014.07 “Secondary Education (Geography)” educational program at Zhytomyr Ivan Franko State University provides 24 credits of practice, 6 of which are focused on internships in educational institutions, and others have a professional aim and significant potential for the formation of environmental competence, namely the following ones:

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geology with the basics of geomorphology; soil science and landscape science; economic and social geography of Ukraine; i meteorology, climatology and cartography.

At the National Pedagogical Dragomanov University a similar set of practices for future geographers is also significant (12 credits included), namely it includes: complex (economic-geographical and physical-geographical) and educational practice in meteorology and climatology; geology; hydrology; geomorphology; soil geography with basics of soil science; cartography with the basics of topography.

Training of students majoring in 101 "Ecology" provides 24 credits of practical training at Zhytomyr Ivan Franko State University (bachelor degree), which includes the following: general ecology (7.5), ecosystem (7.5), landscape ecology (3) and industrial practice (6). Training of ecologists at National Pedagogical Dragomanov University also has 24 credits of practical training, including industrial practice (9 credits) and four educational practices – general environmental (3), secondary environmental (6), environmental monitoring (3), technological (3 credits).

Educational (out-of-laboratory in-the-field) practices of biological, ecological, geographical directions can be considered one of the most effective forms of ecological education of students, for they ensure the formation of culture of nature, behavior in natural ecosystems, a responsible attitude to nature, including emotional perception and rethinking the origin of objects and phenomena of the environment.

We agree with the point of view of many researchers [6; 17] concerning usefulness of undergoing the training practice of future biologists, ecologists, teachers of natural sciences in close proximity to the objects of nature, e.g. visiting reserves national parks, forests etc. to undergo However, only some of higher education institutions have stationary practice-oriented bases in protected areas. Thus, National Pedagogical Dragomanov University has a combined training and health complex in the Kolochava village on the territory of the Synevyr National Nature Park (Fig. 2). Uzhgorod National University's eco-training facility is located nearby, as well as the rehabilitation center for brown bears. Lake Synevyr Park also contains numerous natural monuments of regional importance where Red Book species of flora and fauna can be found (Fig. 3-5).

This ecological facility of national importance possesses a number of advantages, which are of a great importance for its use an outdoors educational base, including picturesque terrain, natural protection against environmental disasters, the availability of corresponding infrastructure which ensures satisfaction of all needs of the students in order to carry out effectively study of the fauna and flora of Transcarpathia, as well as possibility to monitor organized tourism and conduct environmental work in the national park, participate in the activities of the rehabilitation center for brown bears, while conducting research during internships. All this contributes to the formation of future natural sciences teachers' environmental competence and nature-centric worldview.

Fig. 2. Educational and health complex of National Pedagogical Dragomanov University, located in Kolochava village.

Fig. 3. Synevyr lake, biology students of Zhytomyr Ivan Franko State University during field practice.

Absence of property that may serve as the base for scientific or industrial practice makes it mandatory for the organization to conclude agreements on cooperation with other institutions of higher education (if such facilities are in their official possession), national parks, reserves or other corresponding legal entities. Combining several courses and / or several practices of one course (for example, botanical and zoological; zoology of invertebrates and chordates, etc.) is highly recommended. Therefore, practice leaders will get the necessary aid to effectively organize transportation, supplies provision, students' accommodation in order to carry out comprehensive environmental projects and conduct research. Students of the Faculty of Natural Sciences have the opportunity to undergo training and internships in Polissia, Drevlia, Rivne, Kaniv Nature Reserves, Synevyr National Nature Park through cooperation agreements with Zhytomyr Ivan Franko State University, which results in possibility to organize excursions to Shatsky lakes (Fig. 6, 7).

Natural science students and future teachers of biology and geography at Kherson State University are partially trained in the Askania-Nova Biosphere Reserve.

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Fig. 4. Darvaika Mountain near Kolochava village, biology students of Zhytomyr Ivan Franko State University during zoology and botanic field practice.

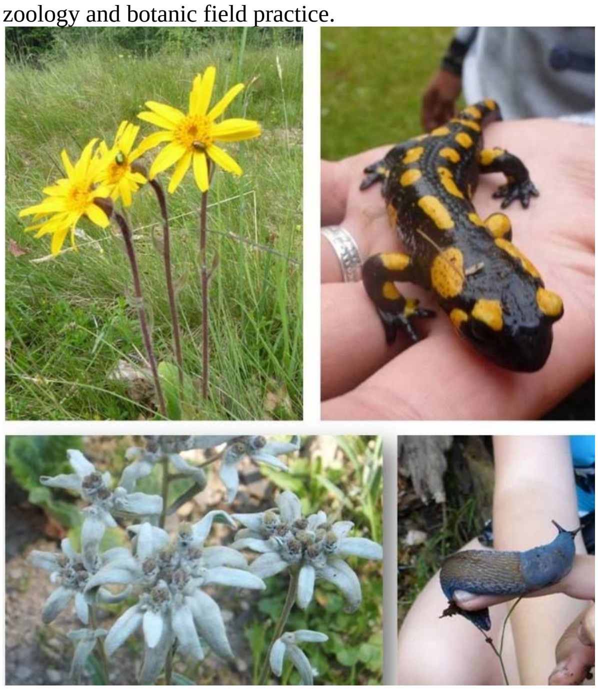

Fig. 5. Representatives of Transcarpathian Red Book flora and fauna species (students' photoreport).

Fig. 6. Shatsky national nature reserve, ecology students (environmentalists) biology students of Zhytomyr Ivan Franko State University during practice.

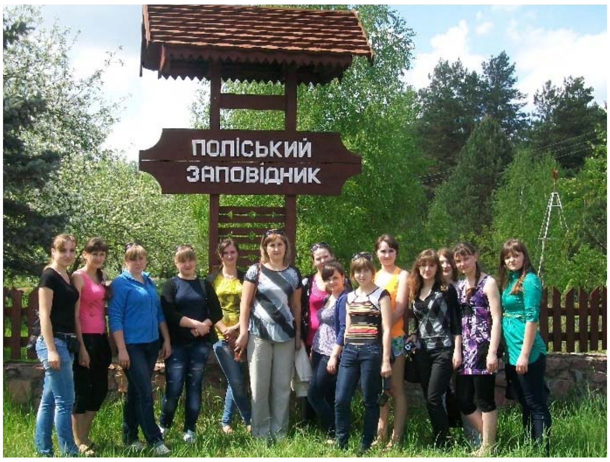

Fig. 7. Polissia Natural Reserve, biology students of Zhytomyr Ivan Franko State University during the practice.

3.3 Students' field (out-of-laboratory) ecological-natural and research activities

Involvement of students of natural specialties in the research, environmental and ecological-naturalistic work during extracurricular activities plays and important role in the formation of their environmental competence. Moreover, this is a characteristic feature of modern education in Europe [11]. In our opinion, ecological and naturalistic activity involves mastering environmental knowledge by students/pupils, as well as gaining experience in solving corresponding problems, which accustoms young people to the organization, implementation of practical environmental and research work, formation of ecological culture of personality, social experience, basic skills of horticulture, floriculture, forestry, etc.

Thus, students majoring in "Ecology" together with associate professor of ecology and geography department of Zhytomyr Ivan Franko State University Ivan Khomiak volunter to participate in the international project "Polissia – wildlife without borders". The aim of the project is to study and preserve the biodiversity of Polissia region as one of the largest natural landscapes in Europe. The project activities are implemented in such areas as: research and monitoring; expansion of existing and creation of new protected areas, improvement of their management; restoration of environments (unique wetlands); raising public awareness of the nature of Polissia; improving the welfare of the population of the territory in environmentally acceptable ways (https://wildpolesia.org/ukr/?fbclid=IwAR1o69KDRH3Zt2GJT9hlgRm9P7fXlGpjydSQQoAEoPD9Zzor09N90KHuCPI). In particular, volunteers supported the initiative of the Ukrainian Society for the Protection of Birds to create a biosphere reserve under the UNESCO program "Man and the Biosphere" in the border areas with the Republic of Belarus, Zhytomyr and Rivne regions. Students of ecological specialties successfully competed with each other during the "Bird Day" campaign in team-based challenges, as well as monitored the nests of black storks *Ciconia nigra* in the Polissia Nature Reserve together with scientists.

Students' participation in ecological forums, projects, and flashmobs proved to be quite effective ecologically oriented extracurricular work. For example, students of ecological specialties and the educators of the Faculty of Natural Sciences of ZIFSU joined the International Forum "Environmental Ambitions of Youth" (February 27, 2020, Kyiv, Verkhovna Rada).

Future chemists, ecologists, and biologists have repeatedly participated in the "Climate Collage" game, which was developed by Cedric Ringenbach in order to give young people a deep understanding of the relationships within the ecosystems and the impact of a human being on the environment. The game was first presented at the UN Climate Conference in Madrid in 2019 and since then it has been successfully used as an interactive method for the formation of environmental competence of young people.

They supported the international movement "Let's Do It, World", cleaning the historic part of the city of Zhytomyr, as well as participated in the "World Cleanup Day" flash mob (September 19, 2020) (Figs. 8-10).

Fig. 8. Students and educators of ZIFSU visiting "Ecological Ambitions of the Youth" forum in the building of Verkhovna Rada of Ukraine.

Fig. 9. "Ecological collage" game, faculty of natural sciences of ZIFSU.

The effectiveness of ecological and naturalistic work of young people is confirmed by research conducted in the framework of the introduction of university selective discipline "Methods of ecological and naturalistic activity in general schools and out-of-school educational facility" (National Pedagogical Dragomanov University, Olga Tsurul) [27] and the author's course "Training a future biology teacher for extracurricular environmental and naturalistic work with primary school students" (Zhytomyr Ivan Franko State University, Oksana Sorochynska) into the educational environment [20].

Fig. 10. Participants of «World Cleanup Day» campaign (Zhytomyr).

In particular, the program of the course "Training of future biology teachers for extracurricular ecological and naturalistic work with primary school students" provided for the introduction of traditional and innovative forms, methods of organizing ecological and naturalistic work into the educational process in order to improve the quality of formation of ecological competence of students, therefore an author's program, methodical recommendations and a manual "Ecological and naturalistic work at school" were developed and implemented. The author's program exploits such forms of work as a conference, development of an ecological project, ecological excursion and field hike, ecological expedition, ecological training, quest. Among the innovative methods used, there are the method of graphic and research works, business- and simulation games, dramatization games, case studies, interactive methods ("Fish Bowne", "Bloom's Cube", "Mental Map", "Brainstorming", etc.).

The experimental work lasted for 2 years and involved the ascertaining and forming stages of the experiment. At the initial stage, two groups of students were identified: control group (CG), which included 196 students, and experimental group (EG) with 198 participants.

To create a holistic picture of the formulated aim of the research, a survey was conducted, which allowed to identify a list of forms of ecological and naturalistic work. Prior to the implementation of the author's program, the level of students' awareness of the forms of such work was at a fairly low level. About half of the respondents mentioned forms of work that are theoretical in nature and have little effect on the formation of environmental competence (environmental exhibitions, holidays and competitions, writing essays, environmental campaigns, environmental-themed evenings and weeks, "What? Where? When?" intellectual club, CCS club, etc.). Only 19% of students noted the organization of environmental lectures and conferences, round tables; "blue" and "green" watch patrols, school forestry, ecological museums and theaters, ecological trails; performance of research and experimental works on school geographical and meteorological platforms, ecological laboratories research work; training and substantiating research projects.

However, in contrary to the students, teachers-practitioners from Zhytomyr, Vinnytsia and Rivne regions have given a particularly different statistical gradation of the effectiveness of applied forms of ecological-naturalistic work in the formation of ecological competence:

1) ecological excursions and expeditions (58,7%),
2) ecological campaigns (56,1%),
3) ecological trail experiments and observation (54,8%),
4) eco-trainings (53,5%),
5-6) empirical experience while working at the pet's corner or conducting a field research at the out-of-laboratory research site (по 49,6%),
7) eco-scientific projects (35,1%),
8) ecological contests (19,8%),
9) ecological exhibitions (17,2%),
10) eco-fashion contests (15,9%),
11) collecting eco-stuff, conducting eco-holidays, flashmobs etc. (8,9%) [10].

The results of our survey of teachers of natural sciences correlate with the research of other scientists [20]. According to the data collected, the most effective forms of environmental activities at school are the following: preparation and substantiation of environmental projects (over 50%), seminars and conferences (42.3%); business- and role-playing games (36.5%); organization of cooperative creative work and educational environmental activities related to certain international and state projects (32.7%); implementation of research and exploration work, excursions, ecological trails (26.9% each); conducting lessons on sustainable development and environmental issues (26%) [10].

However, teachers mostly introduce forms of theoretical work and to a lesser extent are engaged in research work, observations and experiments on the ecological trail, conducting ecological excursions and expeditions, practical work in wildlife and educational areas, training, which indicates an unfortunately low level of their empiric involvement (Fig. 11).

This fact can be explained and justified by the insufficient level of eco-oriented training during their studies at the universities, as well as lack of time, unwillingness to carry out the specified form of work, which result in general weakening of students' interest in learning.

The formation of students' environmental competence within the author's program was carried out on the basis of the developed model of preparation for ecological and naturalistic work. Identification of the level of environmental competence of students (initial, intermediate, high) was carried out according to 4 criteria (motivational-target, cognitive, practical, personal-reflexive), which correspond to its structure. The generalization of the results of the experiment was conducted using the method of score scales, which allowed to calculate the level of formation of environmental competence of students and the dynamics of change [20].

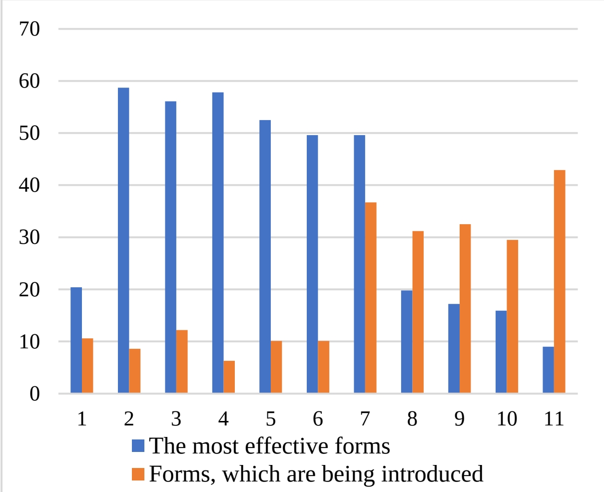

Fig. 11. Effective forms of environmental and naturalistic work that contribute to the formation of ecological competence of students (according to the results of a survey of teachers, %).

Comparative results of identification of levels of formation of environmental competence on motivational-target criterion of control and experimental groups are specified in fig. 12.

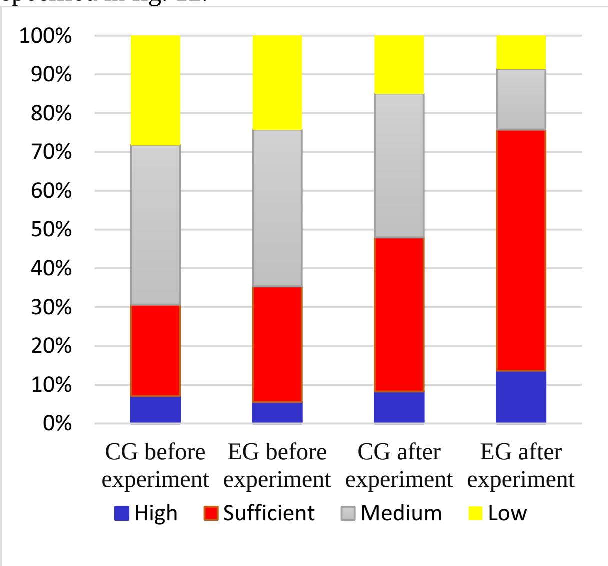

Fig. 12. Levels of formation of environmental competence of students on a value-motivational component according to results of experiment.

Cognitive component of the formation of environmental competence involved the gaining a set of knowledge (psychological-pedagogical, professional-environmental and naturalistic, methodological, organizational-methodological). Each of the knowledge groups contained a list of indicators for which the assessment was carried out.

The analysis of the results of the observational stage of the experiment showed a mostly low level of formation of students' ecological knowledge. Identifying the indicators of the cognitive component of the formation of environmental competence of students of control and experimental groups by cognitive criteria are shown in Fig. 13.

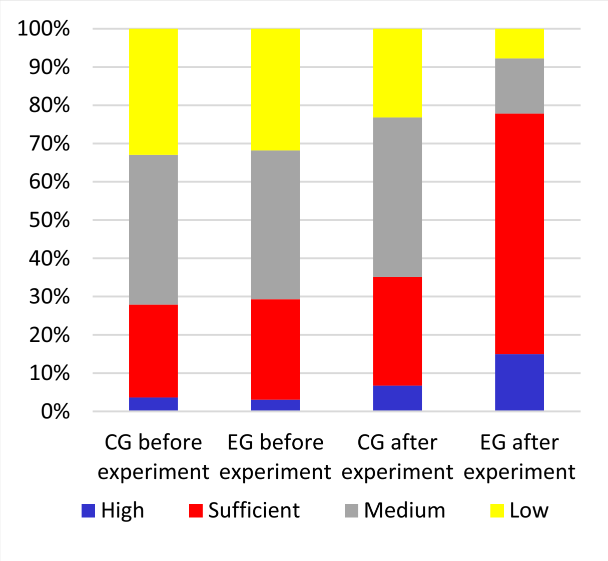

Fig. 13. Levels of formation of environmental competence of students on a cognitive component according to experimental results.

We observed significant changes in the results of cognitive component formation in the experimental group (EG) compared with the data of control group (CG). In particular, a high level of formation of environmental competence was shown by 14.66% of EG students, sufficient – 61.63%, medium – 14.15%, primary – 7.57%. In turn, the distribution of CG students' answers was as follows: high level – 6.73%, sufficient – 28.38%, medium — 41.72%, low – 23.16% (Fig. 13).

Practical (activity-based) component included such groups of skills as gnostic, designing, constructive, organizational, applied. Among the gnostic skills we singled out the following: the ability to conduct scientific research, monitor results of scientific activity, analyze scientific literature, etc. Designing skills are identified as the ability to: model forms and methods of ecological and naturalistic work; plan work and design the content of ecological and naturalistic work, etc. Constructive skills include the ability: to construct the content of ecological and naturalistic work, to introduce the most effective forms and methods; to have strategies for the formation of ecological competence, etc. Organizational skills are referred as the ability to carry out research activities; to manage the work of organizations of ecological and naturalistic orientation; to conduct ecological and naturalistic propaganda, and others. Practical (applied) skills are the application of methods of diagnosis of ecological and naturalistic abilities, organization of excursions, hikes, the ability to use ICTs, designing, modeling, etc. The level of ecological competence in the activity component was carried out on the basis of specially designed questionnaires, thus the reliability of the results was checked using the method of O. Smirnov, using Student's t-test. Indicators of the practical criterion after the introduction of the author's course differed significantly in the experimental group compared with the control (Fig. 14).

Personal-reflexive component of the formation of environmental competence of students involved the development of certain qualities and abilities (love of nature, erudition, diligence, perseverance, creativity, observation, environmental activity, etc.).

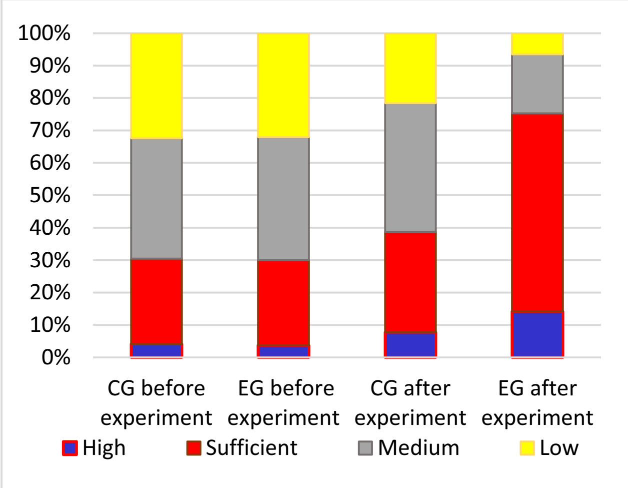

Fig. 14. Levels of formation of environmental competence of students on practical component according to the results of the experiment.

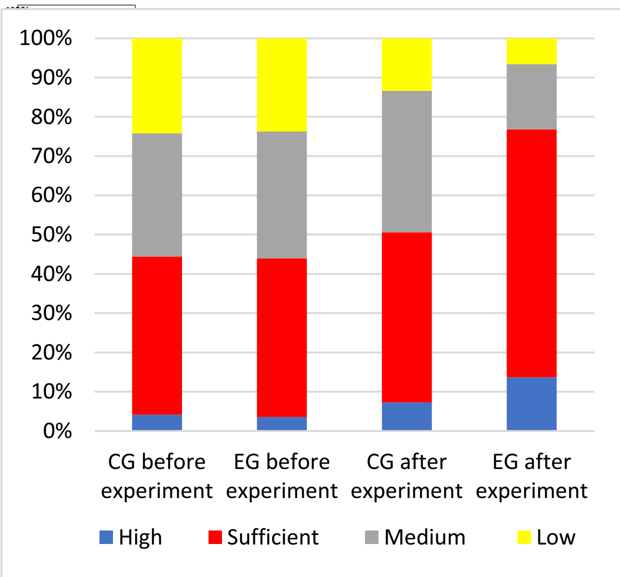

Fig. 15. Levels of formation of environmental competence of students on a personal-reflexive component according to results of experiment.

Analysis of the results of the formation of ecological competence in process of introduction of the author's program "Training of future biology teachers for extracurricular environmental and naturalistic work with primary school students" showed the effectiveness of its implementation in the educational process. After the formative stage of the experiment, the levels of environmental competence of students in the experimental groups were distributed as follows: high – 15.03% of students; sufficient – 62.01% of respondents; medium – 16.66% of participants; low – 7.31%. In the control group the indicators are: high level – 7.51%, sufficient – 35.60%, medium – 38.63%, low – 18.27%.

Thus, the generalized results of formation of environmental competence of students in experimental groups by results of ascertaining and forming stages of experiment show positive dynamics on all indicators and components (table 1, fig. 16) that testifies to efficiency of the introduced author's program.

Table 1. Dynamics of levels of environmental competence of students according to the results of the experiment.

Level of formation of environmental competence	**Control Groups (CG)**			**Experimental Groups (EG)**		
	Initial stage of the experiment, ,%	Final stage of the experiment, %	Dynamics, %	Initial stage of the experiment, %.	Final stage of the experiment, %	Dynamics, %
High	4,5	7,5	3,0	3,9	14,0	10,1
Sufficient	27,9	35,6	7,7	30,4	62,0	31,6
Medium	35,9	38,6	2,7	37,5	16,7	-20,8
Low	28,6	18,3	-10,3	28,2	7,3	-20,8

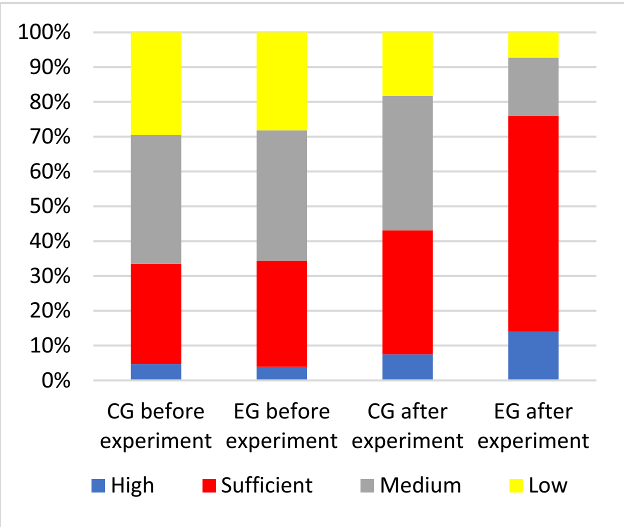

Fig. 16. Dynamics of levels of environmental competence of students according to the results of ascertaining and forming stages of experiment.

4 Conclusions

Thus, our research indicates that the need to implement the concept of sustainable development highlights the issues of formation of ecological (environmental) competence in students of natural sciences within the educational environment of the universities. In turn, the formation of environmental competence is carried out by acquiring environmental education through interactive technologies, innovative forms and methods of organizing the educational process, as well as during eco-oriented extracurricular activities.

An analysis of the ecological education component of training of students of natural sciences confirmed the fact that its best manifestation is found in the content of education of future bachelors of ecology (over 50% of credits are directed to mastering the required courses and undergoing corresponding types of practice). In the process of training of future biologists, specialists in the field of Earth sciences, including teachers of geography and biology environmentally oriented disciplines (or individual modules) and practice account for about 24-33% of the entire workload. Educational training programs for chemists and future chemistry teachers have the lowest percentage of educational components aimed at the formation of environmental competence (less than 10% of ECTS credits), which significantly affects the level of formation of their ecological environmentally-oriented competence.

It is proved that the leading role in the formation of environmental competence of students of natural specialties is played by interactive practice-oriented forms and methods of teaching, as well as training and production practices, which is an essential component of their professional training.

The positive impact on the level of environmental competence development of students of natural specialties produces their involvement in research work, as well as active participation in environmental and ecological-naturalistic activities in extracurricular time, which is evidenced by the generalized results of the ascertaining and formative stages of our experiment.

The following fields are considered the most perspective for our further research: development and implementation of innovative technologies of extracurricular ecological and naturalistic work of students; finding theoretical and practical solution to the problem of integrating knowledge from different disciplines in the process of environmental education; analysis and implementation of foreign experience in the formation of environmental competence of youth; involvement of students of natural specialties in the activities eco-oriented associations for children and youth.

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Predicting anomaly conditions of energy equipment using neural networks

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Abstract. In modern conditions for complex thermal power facilities, the issue of developing methods for predicting equipment failures is especially relevant. Methods based on the intellectualization of diagnostic systems and allowing to obtain predictive models based on the use of both current data received in real time from measuring equipment and retrospective information are considered promising. Intellectualization of the system in terms of the ability to learn allows to quickly adjust the parameters of forecasting models under changing conditions of equipment operation, to determine new deadlines for scheduled repairs and minimize equipment downtime. A limitation of the use of methods is the incompleteness of failure statistics, ie when equipment failures are rare or non-existent. Such diagnostics of energy equipment, especially thermal power facilities, contributes to a more environmentally friendly production.

1 Introduction

Modern technical facilities, including thermal power facilities, are complex systems built of different components – mechanical, electrical, electronic, etc., combined with the tasks of control of a particular process. Distinctive features of functioning of objects of heat power engineering are work in the conditions of irregular dynamic loadings applied practically to all elements of its design [1-3]. These loads can occur both due to internal factors and as a result of the influence of other equipment operating nearby [4].

At present, a large number of complex thermal power plants (nuclear and chemical reactors, turbines, powerful boilers, various furnaces for smelting metal, etc.) are equipped with automated control systems for technological parameters [5-7]. The controlled parameters, in addition to information about the flow of technological processes, also contains information about the current state of the equipment, the appearance and development of various faults [8-10]. Analysis of changes in these parameters, performed after accidents, unscheduled equipment stops, usually shows that there were signs of malfunctions that caused the accident or stop, long before the incident [11-13]. Thus, there is a fundamental possibility to identify abnormal conditions (faults) before they caused the accident and, thus, to prevent the accident or significantly reduce its consequences. Such cases are known to any operator who controls the technological processes of complex thermal power facilities (CTPF), but they are rare, exceptional due to limited human capabilities in the rapid processing of large amounts of information and lack of prior analysis of processes in case of failure. Automated systems for collecting and processing information significantly expand both the operator's ability to identify faults and allow to automate the process of their detection, ie diagnosis [14,15]. For this purpose it is necessary to have a technique and corresponding diagnostic algorithms which use the information from sensors of technological control [16]. Such techniques and algorithms can significantly increase the effectiveness of CTPF diagnosis.

One of the important tasks of diagnostics of power equipment is to minimize the impact of power equipment on the ecological state of the environment. In this case, it is necessary to solve the following tasks:

- research and minimization of the negative impact on the environment at all stages of production, transmission and consumption of different types of energy [17-22];
- implementation of activities for the conduct of environmental studies, including the assessment of the impact on the environment [23-25];
- utilization / neutralization of energy equipment waste after completion of operation [26-30];
- participation in programs for the development of renewable energy sources, taking into account the application of the world practice of using market mechanisms for their support on the basis of "green" tariffs [31-34];
- formation of environmental requirements for the development of modern power equipment [35];
- analysis of developments and implementation of techniques, standards, criteria, requirements in the

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field of environmental protection, environmental safety and rational use of natural resources [36-41];

- development of educational programs in the field of environmental safety in the production, transmission and consumption of electricity etc [42-46].

Thus, the diagnostics of power equipment should become one of the mandatory steps in improving the environmental friendliness of enterprises in the fuel and energy complex.

2 Anomaly detection based on neural networks

The method of detecting anomalies based on neural networks includes two stages: 1) the neural network learns to recognize classes of normal behavior in a training sample; 2) each instance of the instance comes as an input signal to the neural network. A neural network-based system can recognize one or more classes of normal behavior.

Replicative neural networks are used to find anomalies by recognizing only one class [47]. Deep Learning neural network technology has also been used successfully to solve this problem [48].

Various methods can be used to search for anomalies [49-51], the advantages and disadvantages are presented in the Table 1.

Machine Learning is a class of methods of artificial intelligence, which is characterized by indirect problem solving, and learning in the process of applying solutions to many similar problems [52]. In the process of constructing such methods can be used mathematical statistics, numerical methods, optimization methods, data mining, probability theory, graph theory.

Using machine learning possible the study of patterns in the data, which are then used to detect abnormal behavior. Machine learning tasks are usually divided into the following categories depending on the availability of a training “signal” or “feedback” available to the training system.:

– learning with a teacher using “reaction-stimulus” examples;

- partial training with a teacher;
- active learning;
- reinforced training;

– learning without a teacher, suitable for tasks in which objects are described in detail and it is necessary to establish internal relationships between objects.

Next, deep neural networks will be considered as methods used to detect anomalies.

Table 1. Advantages and disadvantages of anomaly detection methods.

Method	Advantages	Disadvantages
Statistical analysis [52-55]	Lack of requirement for a priori information on signs of anomalies, which makes it possible to detect zero-day vulnerabilities against which protective mechanisms have not yet been developed	The difficulty of determining the threshold for optimal detection of anomalies, the impossibility of identifying anomalies as a result of malicious actions similar to normal actions or work and the requirement of statistical distributions in the absence of all elements of the process
Machine learning [56]	Improved system based on prior knowledge	High computational costs, as well as the complexity of adaptation to the subject area
Artificial neural networks [57]	Resistance to inaccurate input, as well as independence from the availability of information about the dependencies of the examples of input data	Complex and long training of neural networks, as well as demanding on the size of the training sample
Genetic algorithms [58]	Works well in solving large-scale optimization problems. Uses two decision mechanisms: deterministic and probabilistic. Uses multiple search space points	The complexity of the selection rules for selecting the best solutions
Hybrid methods [59-62]	The most flexible, as it allows to reduce the impact from the disadvantages of one method taking advantage of another	

The advantage of deep neural networks is the automatic selection of these important features. An inverse error propagation algorithm based on the gradient descent method is used to train neural networks [63]. In a deep neural network with several hidden layers, an error is calculated that is transmitted from one layer to another. In the first stage, the value of the error at the output of the neural network is calculated, for which the correct values are known. Then the error at the input to the output layer of the network is calculated, which will be used as an error at the output of the hidden layer. Therefore, the calculation continues until the error on the input layer is known. However, this algorithm is often not effective when the training sample is large, because it takes a long time to process all its elements. In practice, the method of stochastic gradient descent or its modification is most often used to train neural networks [64,65].

However, the error back propagation algorithm is not sufficient for effective deep learning due to the problem of the vanishing gradient [66]. This problem is solved by the architecture of the neural network with long short-term memory (LSTM) [67,68]. Such networks contain special types of nodes that allow to remember values for a long time. The LSTM network unit contains a special neuron that is used as a memory element (Fig.1).

The output of a neuron is connected to its own input with a single weight. As a result, the value in the neuron is rewritten at each stage and thus stored. Neuron control is performed by three valves: input, output and forgetting valve. When the inlet valve is open, the value at the inlet is written to the memory cell. If the inlet valve is closed, the inlet signals do not affect the contents of the cell. An open outlet valve allows to read values from a cell. When the value is no longer needed, it can be erased with the forget-me-not valve. Valves are connected to other nodes of a neural network which in the course of training define when it is necessary to open or close this or that valve.

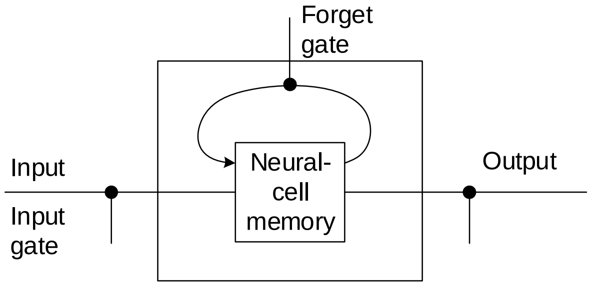

Fig. 1. LSTM network block diagram [67].

Through these networks cells LTSM can determine the importance of the events that occurred thousands of discrete time steps back and remember these events. Recurring networks previously used could remember the event for no longer than ten time steps [69].

The choice of neural network architecture is based on several factors. First, the sensors generate highly correlated multidimensional time series. In addition, these time series are aperiodic and synchronous (aligned in time), with fast (long-term) and slow (short-term) subprocesses. Under these conditions, conventional neural networks of direct propagation usually show poor results. An accurate data-driven predictive model can be developed using a neural network with LSTM cells [70].

Since not all time series can be predicted [71], it is possible to use an additional method of finding anomalies – autocoder, which allows to apply training without a teacher during using the method of reverse error propagation. A synchronous architecture was chosen for the autocoder, among the advantages of which is the possibility of using the streaming mode of data processing and a relatively smaller number of neural network parameters compared to other architectures.

3 Neural network architecture for anomaly prediction

3.1 The process of detecting anomalies

The process of detecting anomalies consists of the following stages:

1. Calculate the estimate of the anomaly of some observations or subsequences of a given time series using the detection method.

2. The obtained estimates are used to calculate estimates of anomalies of test time series. This application is performed in different ways, for example: (1) the average value of all anomaly indicators, (2) the average value of the upper anomaly estimate, (3) the average value of the logarithm of the anomaly estimates, (4) the anomaly estimates exceed the threshold, etc.

Test time series with the assessment anomaly that exceeds a threshold, denoted as abnormal.

The block diagram of failure forecasting is developed (Fig. 2) and the algorithm of detection of anomalies which consists of two parts is offered: forecasting and detection.

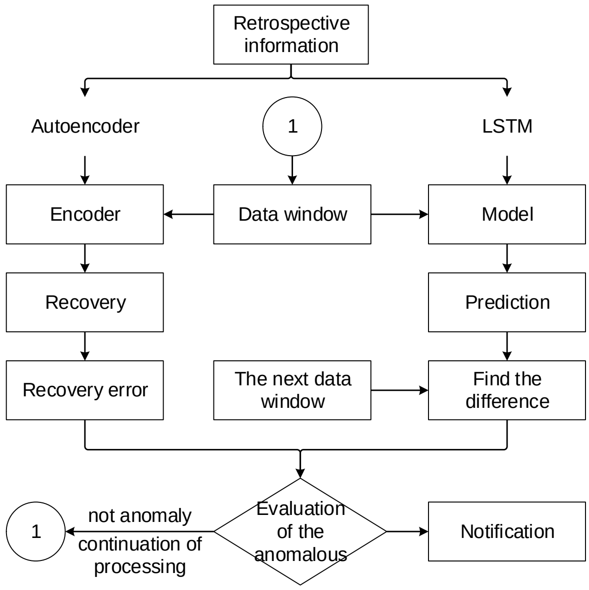

Fig. 2. Block diagram of the neural network for predicting anomalies.

First, all time series (collected at different points in time statistical material on the values of any parameters of the studied process) are divided into sequence levels of length w, namely $X(i) = x(j), x(j+1), \dots, x(j+w-1)$, where i – the sequence number, $j = w(i-1)+1$ – the number of the first countdown in the sequence. At the prediction stage, the values for the next sequence $X(i+1)$ are selected using the data of already performed measurements $X(1), X(2), \dots, X(i)$.

All data points in the presented data set have the same time grid and have significantly different absolute values. To reduce these variations and combine different dimensions, the normalization transformation is applied to each dimension separately:

$$x_i^{*(j)} = \frac{x_i^{(j)} - \bar{x}_i}{\sigma_i}$$

where $i = \overline{1, n}$; $\bar{x}_i$ and σ_i – mean and standard deviation for each measurement.

The detection stage is based on the search for time points, where the root mean square error between the measured values of $X(i+1)$ and the predicted $X'(i+1)$ becomes greater than the pre-calculated threshold.

To detect anomalies, a recurrent neural network with a long-term memory architecture and an autoencoder were chosen, which allows to apply training without a teacher during using the method of error back propagation. A synchronous architecture was chosen for the autoencoder, among the advantages of which is the possibility of using the streaming mode of data processing and a relatively smaller number of neural network parameters compared to other architectures.

Finding neural network parameters is an iterative task. Most often, developers select the optimal values of the structural parameters of the network and the size of the training sample, based on personal experience and repeated trials and errors. Therefore, the structural parameters of the network and the size of the training sample may not be optimal in terms of some function of the approximation error.

Several main rules for neuronal isolation have been presented, for example, the number of hidden neurons should be less than twice the size of the input layer [72,73]. Several statistical methods have also been developed, some of which are presented in Table 2. Although such methods are proposed, they are difficult to implement using commercial software packages. Typically, these recommendations are applicable to the specific cases of a particular network topology.

Table 2. Review of methods for selecting the number of hidden neurons [74].

Method	Number of hidden neurons
Li et al. method [75]	$N_h = (\sqrt{1+8n} - 1)/2$
Tamura and Tateishi method [76]	$N_h = N - 1$
Fujita method [77]	$N_h = K \log\|P_c Z\|/\log S$
Zhang et al. Method [78]	$N_h = 2^n/n + 1$
Jinchuan and Xinzhe method [79]	$N_h = (N_{in} + \sqrt{N_p})/L$
Xu and Chen method [80]	$N_h = C_f (N/d \log N)^{0.5}$
Shibata and Ikeda method [81]	$N_h = \sqrt{N_i N_o}$
Hunter et al. Method [82]	$N_h = 2^n - 1$
Sheela and Deepa method [83]	$N_h = (4n^2 + 3)/(n^2 - 8)$

The amount of training set is also a parameter that optimizes the quality of neural network model.

The greater the amount of training set, the greater the amount of memory required to store it, time spent on training the neural network and gather information about the object. A training sample with a small amount of data is not informative enough to characterize the behavior of an object with acceptable quality. This leads to the fact that the network is often unable to predict the behavior of the object outside the examples of the training sample.

Insufficient number of neurons in the hidden layer will not allow to fully approximate the behavior of the object, and the prediction error will be large. But the more complex the neural network, the more time it takes to learn and work on the task. The predictive power of the network may also decrease due to the effect of retraining. The neural network will show insignificant or insignificant details in the studied dependence, such as noise, the output vector will change significantly with small deviations of the input vector and the neural network will not be able to generalize – prediction of the output vector with input data not included in the training sample.

Based on the above information, the decision to make a variation of the neural network training parameters:

- training periods are 1, 4 or 12 months;
- number of hidden layers – 2 or 4;
- the number of hidden neurons in the first layer – 8, 15, 20, 24, 30, 45, 60, 90;
- the number of hidden neurons is halved in each subsequent layer.

3.3. Neural network training

A total dataset (retrospective data) of 15,120,000 measurements over 35 months from more than 107 sensors [83] has the following values:

- date in the format – day/month/year;
- time in the format – hour: minute: second;
- densor ID;
- sensor_measure temperature value.

Sensors generate highly correlated multidimensional time series, which are aperiodic and synchronous (aligned in time), have multiscale processes, fast (long-term) and slow (short-term) subprocesses.

Each created model is evaluated on the basis of a graphical overview of the model trend. Models are evaluated using the following hierarchical criteria:

- suitability of the model on educational data;
- suitability of the model on the data for monitoring the normal state;
- detection of anomalies.

To be considered reliable, the model must meet all of the above criteria. The evaluation criteria are hierarchical, as each model must meet the previous criteria before evaluating the next criterion.

Table 3. Evaluation criteria forecasting models.

Model criteria	Suitability of the model during the training period or monitoring of normal condition	Detection of anomalies
Very bad ($0 < R^2 \leq 0.2$)	Models with a constant very significant deviation from the measured values or with a clearly inconsistent forecast	Unable to detect anomalies model is not reliable
Bad ($0.2 < R^2 \leq 0.4$)	The models follow the measured trend to some extent, but are characterized by constant significant deviations and periodic very significant deviations from the measured values	Unable to detect anomalies, the model follows the trend measured in the same or a higher level
Satisfactory ($0.4 < R^2 \leq 0.6$)	Models can record the dynamics of the process, but are characterized by constant slight deviations and periodic significant or very significant deviations	Insignificant indicators of anomalies, the model follows the measured trend
Good ($0.6 < R^2 \leq 0.85$)	Most of the time, the models have an accurate forecast with frequent minor deviations	Indicators leading to a more detailed analysis
Very good ($0.85 < R^2 \leq 1.0$)	The models follow the measured trend and have only a few slight deviations from the measured values	Clear indication of anomalies

Validation and verification of the used neural network models was performed. The criteria for evaluating forecasting models during network training based on the coefficient of determination are given (Table 3).

In Table 3, the coefficient of determination R^2 of the model of the dependence of the predicted values on the measured values is determined by the formula:

$$R^2 = 1 - \frac{\sum_i (y_i - f_i)^2}{\sum_i (y_i - \bar{y})^2},$$

where y – predicted values, f_i – current values, $\bar{y}$ – average value.

Determination coefficients R^2 together with scattering graphs provide a fairly simple tool for estimating model prediction. However, it should be emphasized that R^2 is a relative indicator of the adequacy of the model (test and training samples are representative, the network structure is not redundant) and should not be used only as an indicator of efficiency.

Since in most cases the result of errors depends on the shape of forecasting errors are more commonly used performance based on the likelihood of true or false prediction. Assume that for each set of test data, the predicted probability of success $f(x_i)$ is compared with a fixed threshold *C*. If the probability is greater than *C*, it was assumed that the model successfully predicts; otherwise it was believed that the prediction is unsuccessful. The result of this procedure of comparing the true and predicted values of the dependent variable for *n* observations in the test data set can be presented in the form of a contingency table (table 4).

A simple indicator of the effectiveness of the model is accuracy, the proportion of correct predictions in the entire data set of testing:

$$ACC_C = \frac{TP_C + TN_C}{n}.$$

Metrics such as precision and completeness are also used to evaluate the model algorithm. Precision within a class is the proportion of objects that actually belong to this class relative to all objects that the system has assigned to this class:

$$Precision_C = \frac{TP_C}{TP_C + FP_C} = \frac{TP_C}{P_C}$$

Recall of the system – a lot classifier found objects belonging to the class with respect to all objects of this class in the test sample:

$$Recall_C = \frac{TP_C}{TP_C + FN_C} = \frac{TP_C}{S_C}$$

The resulting accuracy of the classifier is calculated as the arithmetic mean of its accuracy for all classes. The same with completeness. Technically, this approach is called macro-averaging.

The average harmonic value of precision and completeness determines the F-score:

$$F_c = 2 \cdot \frac{Precision_C \cdot Recall_C}{Precision_C + Recall_C}$$

This formula gives the same weight of accuracy and completeness, so the F-score will fall equally with decreasing precision and recall.

Table 4. Contingency table.

	True class: Positive	True class: negative	Measures
$f(x) > C$, predicted class: positive	TP_C	FP_C	P_C
$f(x) \le C$, predicted class: negative	FN_C	TN_C	N_C
Measures	S	F	n

As a result, it was found that the performance of models with a training period of 12 months differs the most (Fig. 3). In the figure, the dotted lines are divided into three periods: training, normal operation and detection of anomalies.

Table 5 and Figure 4 present the results of the calculation of precision, recall, F-score and efficiency of the 2C8 model.

Table 5. Contingency table for model 2C8.

	0	1	Accuracy	Macro avg	Weighted avg
Precision	0.98	0.84	0.97	0.91	0.97
Recall	0.98	0.86	0.97	0.92	0.97
F-score	0.98	0.85	0.97	0.91	0.97
Support	1604	196	0.97	1800	1800

As a result, it is established that in order to diagnose the condition of the service station it is necessary to substantiate and build a model that provides detection of an anomaly with a minimum number of false alarms during operation in the normal state.

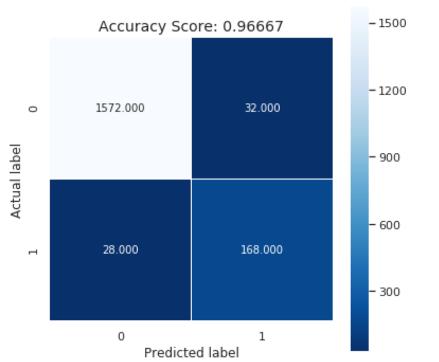

Fig. 4. Graphical representation of the contingency table for the 2C8 model.

4 Model testing results

It is accepted that during using models, they must be rated “good” or “very good” to be considered accurate enough for use in the diagnostic process (Table 3).

It is shown that 13 of the 96 created models meet the established criteria. Model 2C8 with a training period of 12 months, 30 automatically selected independent variables, 4 hidden layers and 90 hidden neurons showed very good results and was chosen as a reference model (Fig. 5). This made it possible to predict the anomalous state of the service station with a coefficient of determination of 0.965 based on the measurement of the surface temperature of thermal power equipment, which can be used as an indicator of the technical condition.

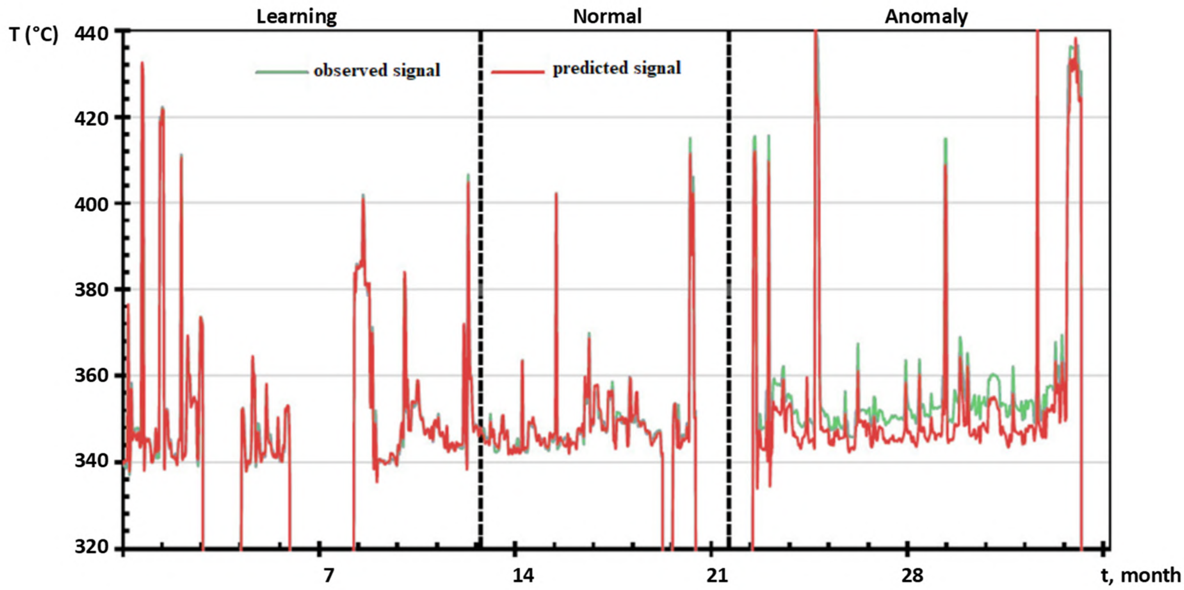

Fig. 5. The results of direct measurements (according to kaggle.com) and the predicted surface temperature of the boiler based on the reference model 2C8 for 35 months. Dotted lines indicate three periods: training, normal operation, detection of anomalies.

According to the results of testing the diagnostic system, it was found that models with a training period of one month show similar behavior to each other, regardless of other learning parameters. These models are characterized by satisfactory adaptation to these exercises. It is shown that the training period of one month is too short for the network to learn about the full features of the process.

It is shown that models with a training period of 4 months have better forecasting characteristics. Models 1B5–1B7 and 2B5–2B8 with 30 hidden neurons in the first hidden layer have relatively better overall R^2 values at all stages of training, monitoring and detection of abnormalities. These models are the group with the best performance, as they account for 7 out of 13 reliable models.

The accuracy of the models increases with the addition of two hidden layers. The set of variations among these models and the influence of the number of hidden neurons on the efficiency of the model are analyzed.

5 Conclusions

The structure of the neural network was developed on the basis of stacking algorithms of the recurrent neural network with the architecture of long short-term memory and autoencoder as part of the technical diagnostic system of the service station, which allowed to predict equipment failures in a small number of anomaly precedents. The use of the neural network in diagnostic systems increases the reliability of predicting anomaly conditions by 9%.

Models of neural networks are implemented and tested. Model 2C8 with a training period of 12 months, 30 automatically selected independent variables, 4 hidden layers and 90 hidden neurons showed very good results and was selected as a reference model. This made it possible to predict the anomalous condition of the service station with a coefficient of determination of 0.965 based on the measurement of the surface temperature of complex thermal power facilities, which can be used as an indicator of the technical condition.

According to the results of research, it is established that models of neural networks with a training period of 4 months have relatively better characteristics, while the number of hidden layers and neurons is recommended to be determined experimentally.

Such approach to diagnostics of energy equipment can make energy industries more ecological, because concentrations of different pollutants in exhaust gases of thermal power facilities can use as information parameter of the process. So, continuous diagnostics on the bases of exhaust gases analysis can reduce the concentration of pollutants which throw out into the atmosphere.

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Ecological changes in geological media and Siverskyi Donets River basin under the condition of goal mines flooding

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Abstract. Complex economic, geological-technological state of coal mines and impact of the armed conflict factors (the breakdown of energy supply, objects of critical infrastructure, etc.) accelerated closure of coal mines by the method of "wet preservation" in particular. In most developed EU countries decommissioning of coal mines, which have great depth (up to 1,0-1,5 km) and areas of minefields, occurs according to the post-mining (PM) research and production complex, which is based on the scientific and technological activities regarding prevention of dangerous changes in the geological environment (GE) - subsidence of ground surface, lands flooding, emission of explosive and toxic gases as well as reduction of outflows of polluted water into the local river basins (RB) and the soil aquifer. Additionally, PM suggests some mining works turning into the hydraulic-filtration system of mine water retention at a depth of 250-350 m with a purpose of preventing pollution flow into the freshwater aquifers and river network, preserving regional aquitards, degassing of mountain surface. In general, the PM activities complex aims at maintaining the balance and protective potential of the GE as mineral and landscape basis of the biosphere, elimination of dangerous changes in ecological parameters of the hydrographical network. It is shown that new models of subsoil and water use, geological prospecting structure, scientific basis for permissible changes in GE and RB are required together with closure of "old" mining works (MW) and opening of new ones, improvement of the environment monitoring based on GIS technologies and Earth remote sensing.

1 Introduction

Market restructuring of the mining and industrial complex (MIC) of Ukraine has led to a significant increase of requirements to technic-economic and ecological-social parameters of the subsoil use. Critical acceleration (with the start of the armed conflict in 2014) of closure and liquidation of mines of Donbas mostly through "wet preservation" (auto-rehabilitation flooding) conditioned poor consideration of the object-territorial and regional changes in ecological parameters of the natural-technogenic geosystems (NTGS) "coal mining region - geological environment" under the current social-economic and geopolitical conditions [1-15].

From our point of view, during the period of restructuring of the leading coal mining sectors (CMS - Donbas, Lviv-Volyn coal basin, West Donbas, Dnipro brown coal basin) experience of EU countries (Great Britain, Germany, France, Poland, etc.) in creating a legal basis and substantiating the NGTS new state ecological safety parameters as a result of abnormal changes in ecological parameters of its leading element - technogenic-geological system (TGS) "mining complex - geological environment" has not been taken into consideration. It was mainly connected with uncontrolled flooding of most mines at insufficient consideration of the new ecological state of the geological environment (GE) as a result of restructuring its accumulated long-term changes within the boundaries of various NGTS of Donbas [1-6, 9-14, 16-21, 23-25, 35].

Under these circumstances, substantiation and implementation of post-mining principles and technologies relate to significant difficulties as a result of gaps in ecology legislation as well as a big complex of accumulated and newly created irreversible and dangerous changes in the ecological state of the subsoil.

Taking the above-mentioned into consideration, we can conclude that further functioning of the coal mining of Donbas on the controlled and non-controlled territories is possible based on accelerated post-mining activities implementation to the subsoil use on separate areas with sufficient power of mine pumping at further mining of coal fields.

2 Analysis of previous publications

The mining industry is dynamic, with some resources being mined for centuries until reserves are depleted or

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technical and market conditions change, as has been the case in the former communist countries after 1990.

In almost all known cases, the cessation of exploitation of mineral resources has led to a number of serious problems [36-49]. The problems are similar in all mining regions [44-60], and the research in this paper points out these facts.

Research experience of the Institute of Telecommunications and Global Information Space of the NAS of Ukraine shows that use of the GIS can facilitate a significant increase of reliability of estimates of the ecological-technogenic conditions of the NTGS "waste polygon-environmental constituents" on the condition of reduction of the geological environment defensive ability as a consequence of the mines and pits flooding [5, 19-34].

The main factors which define the ecological state of the Donbas coal mining sectors are:

- geomechanical and hydrogeofiltrational imbalance of the rock mass as a result of conducting mining works with the exemption of large volumes of mineral raw materials, formation of a significant amount of polluted underground water flow into the local river network (up to 800 million m^3 per year) and greenhouse gas (up to 6 bln m^3 per year), destruction of regional aquitards and development of non-watertight areas of technogenic fissuring;
- formation of mining and recycling waste;
- destruction of hydrogeological and hydrological conditions of the territory.

All the other factors (development of hazardous geological processes, pollution of the surface atmosphere, soil, loss of biodiversity, etc.) in most cases derive from these three factors [1-9, 17, 18].

3 The research results

The biggest ecological-technogenic, social-economical and technogenic threats to the population occur when coal mining enterprises closure is ecologically imbalanced due to the accelerated flooding of coal minings, level rise and pollution of local underground and surface sources of drinking and economic water supply beyond the claim mine concessions, additional deformation of the land surface, increasing upward migration of polluted mineralized water and explosive and toxic gases (methane, radon, hydrogen sulfide, etc.), which is connected with the depletion of regional waterproof (low permeable) layers [13, 17, 18, 25]. At that, soil pollution surface centres can get in the zone of active water exchange (industrial and domestic waste polygons), surface flow and groundwater, which can actively move to the rivers and expand the area of water ecological risk.

In practice, it can result in disabling surface and underground drinking water supply systems, flooding and destruction of housing and industrial objects and communication (including ecologically dangerous objects such as oil and gas pipelines, chemical enterprises, etc.), complicated conditions of agricultural activities. Uncontrolled development of these processes, which are mostly irreversible in the coal mining sectors of Ukraine, including the additional impact of the armed conflict complicating factors on the East, global climate change and so on can lead to an ecological disaster, consequences of which will be extremely long-term and regional (borderless).

At that, the analysis of long-term changes in the ecological parameters of various NGTS in Donbas allows concluding the leading impact under current conditions of the anthropization of the geological environment and the Siverskyi Donets river basin as a regional drain of the underground flow technogenic reformation.

The main factors of technogenic changes in ecological parameters of the GE and river basins (RB) in the Donbas region under the conditions of postmining are:

- chemical pollution of landscapes;
- significant lowering of the underground water level, undermining of surface water bodies (up to 600 cases with different level of the surface flow interception);
- highly mineralized aggressive mine water flow in the river system;
- accelerating exogenic geological processes (landslides, karst, flooding), development of the original ground subsidence and complicating the engineering-geological state of housing and industrial objects;
- decrease in engineering-seismic resistance of rock mass influenced by increase in mobility of rocks in the areas of their undermining by mining works, development of hydromechanical impulses, etc.;
- formation of a large amount of waste pits, which are also a source of water resources, ground and surface air pollution.

The most dynamic changes in ecological parameters of the geological environment and river basins in Donbas are connected with inflows of underground water into the coal minings, the overall flow level of which into the river network at a maximum development of mining works was 25,0 m^3/sec (1990). At a regional amount of natural water resources equal to about 12,0 m^3/sec, it indicated active drainage of surface water sources and hydraulic interconnection between mines [58-60]. At an average salinity of mine water equal to about 3,6 g/dm^3, it conditions the outwash of salts mainly into the Siverskyi Donets river basin at a level of 2,7 mln tons per year, which significantly activates pollution of the transboundary river flow in the Don (at the territory of Russian Federation) and Azov sea basin.

In the context of the armed conflict surface water objects, first of all, those of the Siverskyi Donets river basin, which is the major source of drinking and economic water supply (40-80% of local water consumption) have a significant threat of dangerous deterioration of the geological state.

Evaluation of the ecological state of the reserve sources of drinking and economic water supply of Donetsk and Luhansk regions population, on the controlled and non-controlled by the Ukrainian government territories, is extremely important, as it is conditioned by the active use of pollution vulnerable local dug wells, boreholes and reservoirs by the local population beyond the central water supply system.

The authors created an indicative scheme of carrying out express research in the given region, which allowed evaluating the most vulnerable section critical for the health and ecological safety.

An important component is defining the role of emerging technologies, use of contact, remote methods of monitoring and geoinformation technologies (GIS) in particular.

Based on the geodata integrated into GIS, authors built models of surface water pollution dynamics in the Siverskyi Donets river basin.

To build models of pollution space distribution and evaluation of surface water quality authors used geostatic methods that allowed receiving interpolation area of pollution level values and building relevant maps of surface water quality change probability in the whole basin and the territory overall.

Activation of technogenic changes in, first of all, the surface flow of Donbas, is influenced by undermining of 129 rivers and beams and 26 reservoirs (> 683 cases) caused by mining works as well as by continuous subsidence of the original surface on the territory up to 8000 sq.km in the area of impact of which there are up to 1000 different industrial and potentially dangerous objects (Fig. 1) [1, 13, 25].

A significant complication of the mines closure process creates up to 250 earlier flooded mines, hydraulically connected with the active ones. According to the current evaluation, total mining works exceed 2,3 km^3 and contain up to 1,6 km^3 of water which can significantly accelerate regional activation of flooding of cities and villages territories, migration of pollution into the surface and underground intakes and the river network, as well as increase threat of emergency water breakthrough into the active.

Additional above-mentioned evaluations allow concluding that transformation of water-ecological parameters of natural-technogenic geosystems (NTGS) “mining complex - underground and surface hydrosphere” in the context of current auto rehabilitation flooding of mines in Donbas has considerable complexity and uncertainty during the implementation of post-mining activities. It is mostly conditioned by the fact that areas of the underground water level rise 5-10 times and more exceed areas of mining works, thus forming dynamic reformation of levels and chemical composition of underground water and its flow into the hydrographical network.

In our view, under the current conditions of social-economical and ecological-technogenic restructuring of subsoil use in Donbas, the biggest water-ecological threats to health and safety of a large number of people in the region (more than 50%) occur when mining enterprises are closed without a sufficient complex of protective and ecological-stabilizing activities. Taking into consideration a spatial-temporal structure of factors of the changes in ecological parameters of GE and the surface flow of Donbas, we have substantiated a scale of ecological impact of the coal industry zone post-mining initial phase on the state of life-supporting components of the environment (lithosphere, hydrosphere, etc.).

The authors’ evaluations showed that in the biggest by area and depth of mining works region of Donbas ecologically critical consequences of the auto rehabilitation flooding of mines (so-called “wet preservation”) are connected with the absence of a pumping-hydraulic system which should keep the underground water level on the ecologically optimal depth lower than the regionally permeable crust of weathering coal rocks (from the experience of the EU countries - 250-350 m.). The given approach excludes active lateral spreading of polluted and mineralized mine water and its flow into the overlying freshwater aquifers and surface streams.

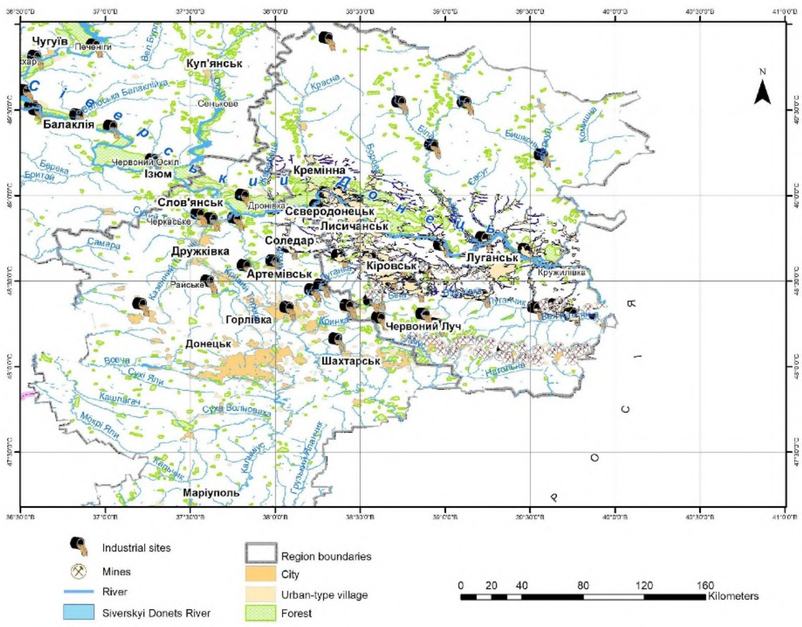
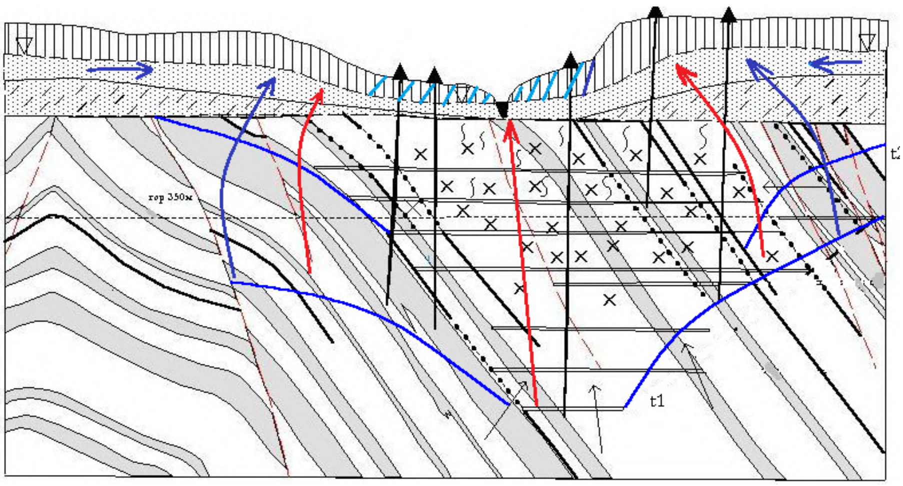


Fig. 1. Map of technogenic pressure on the Siverskyi Donets River Basin.

The experience shows that at that, underground water level rise beyond the claim mine concession, additional surface subsidence, increasing migration of polluted mineralized water to underground and surface sources of water supply and explosive and toxic gases to housing and industrial buildings also occur in the most MW, which is mostly connected with tectonic and technogenic depletion of waterproof layers. The Fig. 2 shows the fundamental scheme of formation of underground and surface water flows interaction during the coal mine flooding in Donbas.

Taking into consideration the above-mentioned characteristics of interaction between the underground and surface water flows during the flooding of a coal mine in Donbas we have developed the "Scheme of the technogenic-geological system "mining complex - geological environment" transition into the post-mining phase", is presented in Fig. 3.

The above-mentioned values show that disturbance of the balanced geomechanical state of the subsoil, level and hydrochemical mode of underground and surface water and deformation of the earth's surface in the context of auto rehabilitation flooding of mines ("wet preservation") are the main factors of development of potentially water-ecological threats and risks of emergencies of water-ecological nature.



top-down unsaturated filtration area (aeration area)
area of groundwater spreading
low permeable rocks of the ground aquifer sole
level of the ground aquifer
area of the regional water permeable fissuring development in the casing part of coal rocks
coal seams
mined coal seams
sandstone
siltstone
tectonic depletion
surface mine facilities
underground mining works
areas of technogenic fissuring
level of deep aquifers underground water during the mine flooding at different periods of time
mineralized underground water flow directions
underground water flow directions during the mine flooding (radial and lateral flows)
riverbed (regional drain of underground water)
sectors of flooding and active subsidence of surface

Fig. 2. Fundamental scheme of formation of underground and surface water flows interaction during the coal mine flooding in Donbas.

In general, results of the analysis of changes in the water-ecological state of developed ("old") mining regions of Donbas considering critical technical-economical parameters of the natural resource potential achieved by them before the transition into the post-mining phase allow concluding possibility of partial realisation od correspondent activities on improvement of water-ecological safety of vital activities.

Mainly it is connected with the irreversible disturbance of balanced natural interaction between the underground and surface components of the Donbas region hydrosphere as a result of exemption of large volumes of the coal mass followed by ruining regional aquitards and river valleys, subsidence of large areas of the earth's surface, geochemical pollution of surface and underground water-collecting landscapes, the collapse of host and casing rocks.

In that regard, in our opinion comparison of renewal levels of geological environment ecological-protecting functions (mostly ground and rocks of the aeration area) and surface hydrosphere (sediment) of the Chernobyl Exclusion Zone and the zone of the flooding of Donbas Central region mines are illustrative, is presented in Table 1.

Table 1. Comparison of changes in the ecological status of the geological medium of the Exclusion zones and the unconditional (obligatory) resettlement of the Chornobyl NPP and the impact area of the massive closure of mines in the Donbas (Influences levels: red – critical, yellow – dangerous, green – background).

Types of changes in the ecological condition of the geological medium	Technogenic influence factors	
	Chornobyl NPP emergency area	**The area of impact of a large-scale closure of the Donbas mines**
Landscape and geochemical pollution	Auto-rehabilitating cleanup (up to 90% by 2035)	Irreversible changes
Lithospheric - equilibrium	No changes	Destructive changes
Hydrological	Short-term radionuclide pollution	Sustainable pollution
Hydrogeological	Low concentrations of radionuclides	Pollution and depletion of groundwater resources
Gas-geochemical	Short-term contamination of the atmosphere with radionuclides	Increasing pollution of surface air pollution
Engineering-geological	Almost no changes in engineering-geological conditions	Destructive changes
Seismic-engineering-geological	Relatively stable condition	Reduction of engineering and geological stability

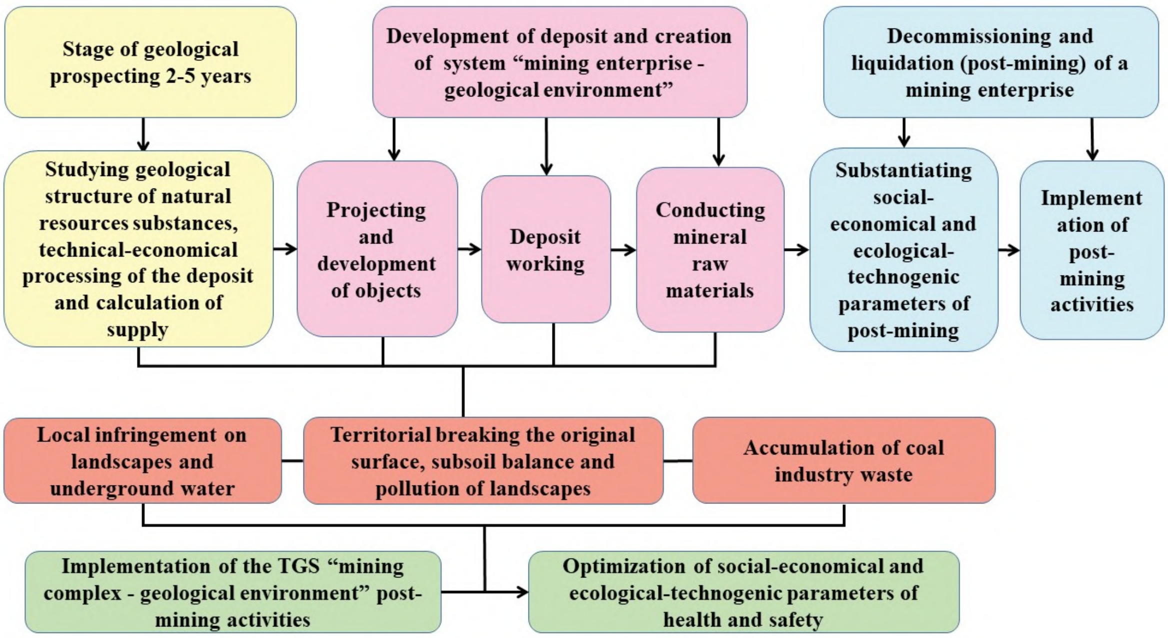


Fig. 3. Structural scheme of formation of the post-mining methodical base in the context of ecologically stable development of mineral raw materials deposits.

Based on the data given in table 1 ecological state of the geological environment as a part of an NTGS is a crucial parameter of the natural resource potential renewal and formation of water-ecological factors of health and safety.

4 Conclusions

Based on the above-given evaluations a complex of ecological-technogenic and social-economical post-mining activities in the most MS in Donbas can be partial, taking into consideration irreversibility of most changes in ecological parameters of a geological environment and surface hydrosphere, which have occurred or are at a stage of active development. At that, a large number of ecological functions of a geological environment (landscape-chemical, water-ecological, engineering-geological, etc.) are lost in almost all developed CMS at the post-mining stage due to complex violations of the subsoil balance during exemption of large volumes of copper rock raw materials and creation of “lack of mass” in the upper zone of the lithosphere.

Thus, the main task of the post-mining separate activities implementation focused on the improvement of health and safety of the local population in the mining sectors of Donbas can be the following:

- improvement of forecasting the changes in main life-supporting components of the environment (ground, hydrosphere, subsoil, etc.);
- proactive development of a compensatory model of a stable social-economical and ecological-technogenic development of mining sectors in Donbas taking into account the restructuring mining complexes experience in the EU countries (Germany, Great Britain, etc.);
- improvement of the monitoring structure based on the broadening the complex of evaluating parameters, implementation om mathematical models of TGS in the mining sectors, use of the GIS and ERS technologies (interferometry, spectrometry and so on);
- scientific basis for permissible changes in the ecological parameters of the environment components and long-term health and safety;
- provision of long-term exploitation of the critical infrastructure objects (energy, water and heating supply complexes, transport network, etc.);
- increase in consumption of fresh underground water resources as a protected from technogenic pollution resource of drinking and economic water supply;
- definition of farmland sectors which are geochemically safe for receiving agricultural commodities.

In general, the stage of creating basis and developing the post-mining policy in the CMS in Donbas for the economics and a large number of people is a strategic scientific-technological and social-economical task, taking into account the leading role of a coal-raw component in contributing to the GDP and providing resource and energy safety of the country.

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Detection of intervals / layers in sections of the wells with anomalous areas of drilling mud filtrate contamination according to the well logging (with negative test results of horizons)

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Abstract. The zone of infiltration of the drilling fluid filtrate into the reservoir rock creates significant difficulties for the study by logging methods and during further testing of the formation. Due to the penetration of filtrate, significant contamination of the near-wellbore zone occurs. The porosity and filtration characteristics of reservoir rocks are changing. There is a possibility of blockage by filtrate in the invaded zone of oil or gas flow from the formation to the well. As a result of the studies carried out using well logging data, it was found that the presence and distribution of a mud cake on the borehole wall opposite the reservoir is an important factor influencing the process of filtration of the drilling fluid into the layers. On the examples of the Yablunivske oil and gas and Kolomatske gas fields of the Dnieper-Donets basin, it is shown that the absence of a mud cake on the borehole walls leads to the formation of maximum, anomalous zones of filtrate invasion. The determining of the diameter of the invaded zone was carried out according to the data of electrical logging methods. In addition, the diameter of the invaded zone was calculated as a solution direct task equation for the case of direct filtration without blocking by the mud cake. Comparison of the results of determining the diameter of the invaded zone by two methods made it possible to draw certain conclusions. An important conclusion is that even partial absence of mud cake on the reservoir wall in the well leads to horizontal and vertical filtration of the drilling fluid from the well into the formation. As a result, the invaded zone may be so deep, that the gas flow rate is absent even at high values of porosity, permeability and gas saturation.

1 Introduction

The process of drilling an oil and gas well inevitably causes the environmental contamination. Including geological. In addition to creating a hole in the wellbore in the permeable layers, a zone of invasion of the drilling fluid filtrate is formed. This filtrate is actually an aqueous solution of inorganic and organic compounds, significantly changing the geological environment around the well. The changes concern the porosity and permeability of reservoir rocks; there is a swelling of clay minerals, the well space is clogged with solid particles and colloids.

2 Theory and Methods

The main methods that allow to study the well outer space during and after drilling –the well logging. Actually, only with the help of the results of geophysical research it is possible to really estimate the size (diameter) of the invasion zone of infiltration of the filtrate into the porous layer. The principles of estimating the size of the filtrate invasion zone and its electrical characteristics were developed in the 50s of the last century [1]. Along with the development of sounding technology for electric logging systems of different sizes (BKZ), the interpretation of the logging data was proposed [1-3]. The wellbore space was considered as a 2-or 3-z medium. In the presence of filtrate penetration, it was considered that this invasion (penetration) zone (ZP) has different electrical characteristics than the formation and the well itself. The relative diameter of the invasion (penetration)zone Dzp/Cal was determined using the so-called 3-layer palettes BKZ. The most famous scientists, whose work was the basis for the interpretation of BKZ data, include the work of H.G. Doll, V.M. Dakhnov, S.G. Komarov, L.M. Alpin. Currently, the determination of the diameter of the invasion zone and its specific electrical resistivity is performed based on the results of studies of wells with multi-probe gradient probes, lateral logging, induction logging [4-7]. Thanks to the data of electrologging, researchers have the opportunity to assess and analyze the degree of filtration and the processes that occur during the formation of the invasion zone [8-10]. Here, geophysical methods are used as a tool to determine the parameters of the filtrate invasion zone in field research and interpretation of reservoir test results, features of primary reservoir opening, planning of optimal methods and perforation technologies [11-12].

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Calculations of the size of the invasion zone by solving the direct filtration task [13-18] indicate a wide range of approaches to take into account various factors that affect filtration processes in the gradient space around the well. Therefore, considerable attention should be paid to statistical modeling of the invasion zone based on the use of a priori information, which can be obtained from geophysical and other studies in drilled wells [19].

The total volume of permeable liquid leachate depends on the duration of time from the start of filtration, repression of pressure on the reservoir, the viscosity of the filtrate and formation fluid (and other rheological properties), the permeability of the reservoir [20, 21] and the thickness of the mud cake [18, 22, 23].

The volume of filtrate that penetrated into the formation can be divided into two components. The first stage of penetration is the rapid absorption of the filtrate by the formation (instantaneous filtration). The second stage is the filtration of the washing liquid through the mud cake. However, even the inhibition of filtration into the formation by increasing the mud cake does not always contribute to the formation of small penetration zones. There are many examples of this, when under all the positive conditions regarding the reservoir characteristics of the formations, the presence of mud cake, the tests did not receive significant inflows of fluids into the wells [17, 24-26]. In addition, the technological parameters of drilling significantly influence the test result. According to the data [15-16], many wells drilled in Ukraine did not produce during development. These include the well № 100 - Kiltsivska Square, № 1 - Bitlyanska in the Dnieper-Donets Basin and several wells in the western region with very low reservoir pressures, namely: № 1 - Hutsulivska, № 3 - Kolomyia, № 6 - St. Bohorodchanska. All of them were drilled with excessive excess density of the drilling mud, respectively, huge invasion zones were formed. Only after changes in the drilling regulations by reducing the density of the flushing fluid from the standard used 1.20 to 1.10-1.20 g/cm^3 was obtained a conditional gas inflow.

Static and dynamic studies of the filtration properties of the washing liquid are used to estimate the filtration rates. To date, there is no universal model for calculating the parameters of the invasion zone, including its diameter.

If we do not take into account the influence of mud cake, then the first approximation, the depth of the penetration zone can be calculated by the following equation [16]:

$$L = \frac{\Delta p \cdot \sqrt{K}}{a \cdot \tau_0}, \qquad (1)$$

where L is the radius of the invasion zone, m; Δp - real repression of pressure on the formation, Pa; K - permeability coefficient of the rock, m^2 [20, 21]; a–is the coefficient that can be taken [16] equal to (155-180) $\cdot$ 10^{-4}; τ_0 –maximum / limit shear stress, Pa.

Thus, under normal conditions (Δp = 2 · 106 Pa; K = 10 · 10-15 m^2; a = 160 · 10-4; τ_0= 10 Pa), the calculated value of penetration of the filtrate into the formation (in the absence of mud cake) is equal to 1.25 m. This is a fairly significant value, which may already be the cause (or explanation) of the absence of inflow into the well of formation fluid or gas during testing.

Consider real examples of the absence of positive test results in comparison with the parameters of the layers and the invasion zone.

Well 14-Yablunivska (Fig.1). Testing of productive strata determined by the well-logging data was carried out according to the classical bottom-up scheme. In the interval of perforation by the corpus perforator PKOT-73 after 3 times aeration of salt water the inflow in the well was not obtained. Although the reservoir parameters of the reservoir (interval 5070-5071.6 m) are much higher than the limit: porosity 10%, permeability coefficient 41.2 mD (by the well-logging), gas saturation – 83%. The authors of the first report (1984) on the petroleum reserves calculation of Yablunivske field note that chalk was used as a weight addition during drilling; as a result, a large invasion zone with significantly deteriorated filtration properties was probably formed. This is the main explanation for the absence of fluid inflow from this reservoir. According to our calculations, the relative diameter Dzp/Cal here is 18.5, and the absolute value of Dzp = 3.7 m.

Layers were also tested above the section in this well. In the range of 4921.6-5049.0 m (perforation by PKS-80) at the first lowering of the water level received a small inflow of gas with a flow rate of 1.5 thousand m^3/d. Only after 3 times of aeration the formation began to work with a gas flow rate of 49.2 thousand m^3/d. on an 8-mm fitting. The weighted average parameters of reservoirs in the test interval: total layer thickness 48.7 m, porosity 11%, permeability coefficient 132.6 mD, gas saturation 84%. According to our calculations, the relative diameter Dzp/Cal here is 7.9, and the absolute value of Dzp = 1.5 m.

In the third interval 4876.8-4911.8 of perforation by the corpus perforator PKS-89 after replacement of salt water with fresh water a significant inflow of gas was immediately obtained - 284.8 thousand m^3/d. on an 8-mm fitting. The reservoir properties of the formations are as follows: total layer thickness 10.5 m, porosity 14.7%, permeability coefficient 211 mD, gas saturation 85%. The relative diameter Dzp/Cal here is equal to 5.1, and the absolute value of Dzp = 1.1 m. The given example of test results of terrigenous section layers of the Tournaisian stage in one well of Yablunivske oil and gas field testifies to the importance of taking into account not only the main reservoir parameters of formations (porosity, effective thickness and gas saturation), but also the permeability coefficient (penetration) [27, 28]. Inflow call technologies should be adjusted to take into account the size of the filtrate invasion zone with appropriate measures, including re-perforation.

In Fig. 1 shows the curve of the calculated values of the invasion zone depth (Lzp) according to the model (1) [16] of filtration into the formation in the case the absence of mud cake. The presence of mud cake makes significant adjustments to the size of the invasion zone.

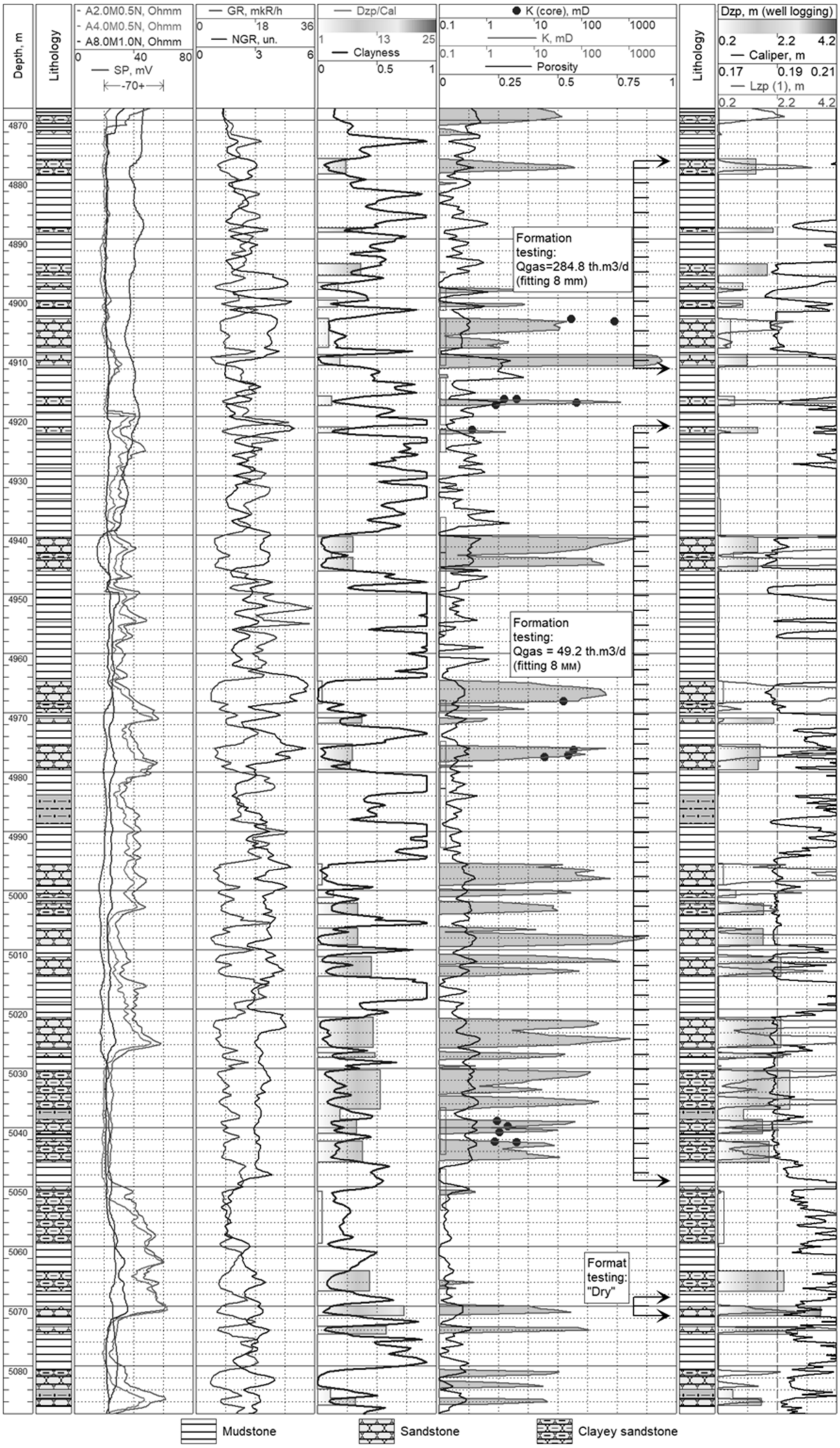

Fig. 1. Section of 14-Yablunivska well with the given test results and calculated values of the relative invasion zone according to well-logging data interpretation.

The tendency is clearly visible: where is the mud cake (the diameter of the well is less than the diameter of the bit), the (in the main) the actual value of the diameter of the invasion zone is smaller than calculated without taking into account the effect of reducing the filtration through the mud cake. In the lower part of the section (Fig. 1), where the largest values of Dzp are observed, there is no mud cake at all. Due to the possible structural inhomogeneity of the rocks of the lower part of the Tournaisian stage, zones with increasing diameter were formed during drilling, in the absence of mud cake formation. As a result, there are large areas of filtrate penetration and negative results during the testing of formations (Fig. 2).

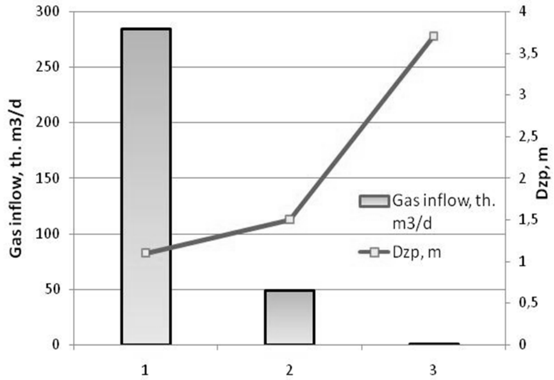

Fig.2. The ratio of the diameter of the invasion zone (according to well-logging data interpretation) and the obtained gas flow rate opposite the reservoirs of 14-Yablunivska well.

Similar negative test results due to the presence of a large zone of filtrate penetration in the sections of the wells, where there are gas-saturated reservoirs, were obtained in the significant number of Dnieper-Donets basin oil and gas fields. In Fig.3 shows a tablet of log diagrams with the results of interpretation and test data of layers and perforation intervals of 31-Kolomatska well. It should be noted that the productive terrigenous strata of the Serpukhovian stage at the Kolomatske gas condensate field lie at considerable depths, more than 4500 m. 31-Kolomatska well show that a number of productive objects with porosity values higher than the critical 6.5 - 10.5% are distinguished in the section. Gas saturation coefficient - in the range of 61 - 78%.

During the testing of formations in the section interval 5486 - 5512 m inflow was not received. Perforation was performed using modern equipment OWEN 3 3/8 "with a frequency of 18 holes / m. According to the well-logging data, all layers of sandstone in this interval are productive (Fig. 3). Above in section according to the results of a joint test of two perforated intervals 5464 - 5475 m and 5440-5452 m received a conditional gas flow of 191.4 thousand m^3/d on a 7-mm fitting. The equipment and conditions of perforation here were similar.

Pays attention to the fact that in the lower test interval 5486 - 5512 m with negative results on the caliper curve there is almost no mud cake; the diameter of the well is larger than the diameter of the bit opposite the reservoirs. At the same time, in front of sandstones in the two upper perforation intervals 5464 - 5475 m and 5440-5452 m there is a mud cake everywhere (see curve Caliper in Fig. 3). Calculations of the values of the relative diameter of the invasion zone Dzp/Cal according to the electrical methods of well-logging using the GeoPoisk system [29] showed the following. In the test interval 5486 - 5512 m, the values of Dzp/Cal in the reservoirs vary from 6.4 to 11.1.

In the upper intervals, where a significant gas flow is obtained, the values of Dzp/Cal are generally at a minimum level of 2.0. Such values are observed in front of reservoir layers with porosity values greater than the limit values. Only in the range of 5470.5-5474.6 in the calculations obtained the value of the relative diameter of the invasion zone of 6.2. We calculated the point values depth of the invasion zone of the filtrate *L* by formula (1) [16]. These results correspond to the possible values of filter penetration in the absence of mud cake. In the lower interval in the negative test results in the actual absence of mud cake, the calculated values of the relative diameter Dzp/Cal according to electrologging correlate well with the curve *L (Lzp)*. That is, the fact of the presence of a large zone of filtrate penetration led to the absence of gas inflow to the well according to the test results (int. 5486 - 5512 m).

To verify the statement about the identity of reservoir rocks by their capacitive and productive properties in the intervals with different test results, statistical analysis was performed using Student's t-test. For this purpose, two multidimensional sample sets with the conditional names "gas" and "dry" were formed - according to the test results. Selection of parameter values was performed with a step of 0.5 m from log diagrams.

Table.1 gives a clear picture of the statistical characteristics (mean and standard deviation) of the main geophysical parameters and coefficients of clayness, porosity and gas saturation of the two objects (samples).

According to the table data, the limit value of the Student's t-test is equal to 1.99 by the value of the confidence interval $\alpha = 0.05$. As you can see, only the mean (average) values of the diameter of the well, the intervals of the section have significant differences. Here, the value of the t-test 4.7 is significantly greater than the limit value of 1.99 (see Table 1) That is, the absence of mud cake (increasing the diameter on the Caliper curve) led to the formation of a large invasion zone in the sandstone interval with negative test results. Thus, there is reason to believe that the results of the preliminary conclusion about the presence of a gas-saturated reservoir within the test interval 5486 - 5512 m are statistically confirmed. And the test results in this interval should be considered unproven.

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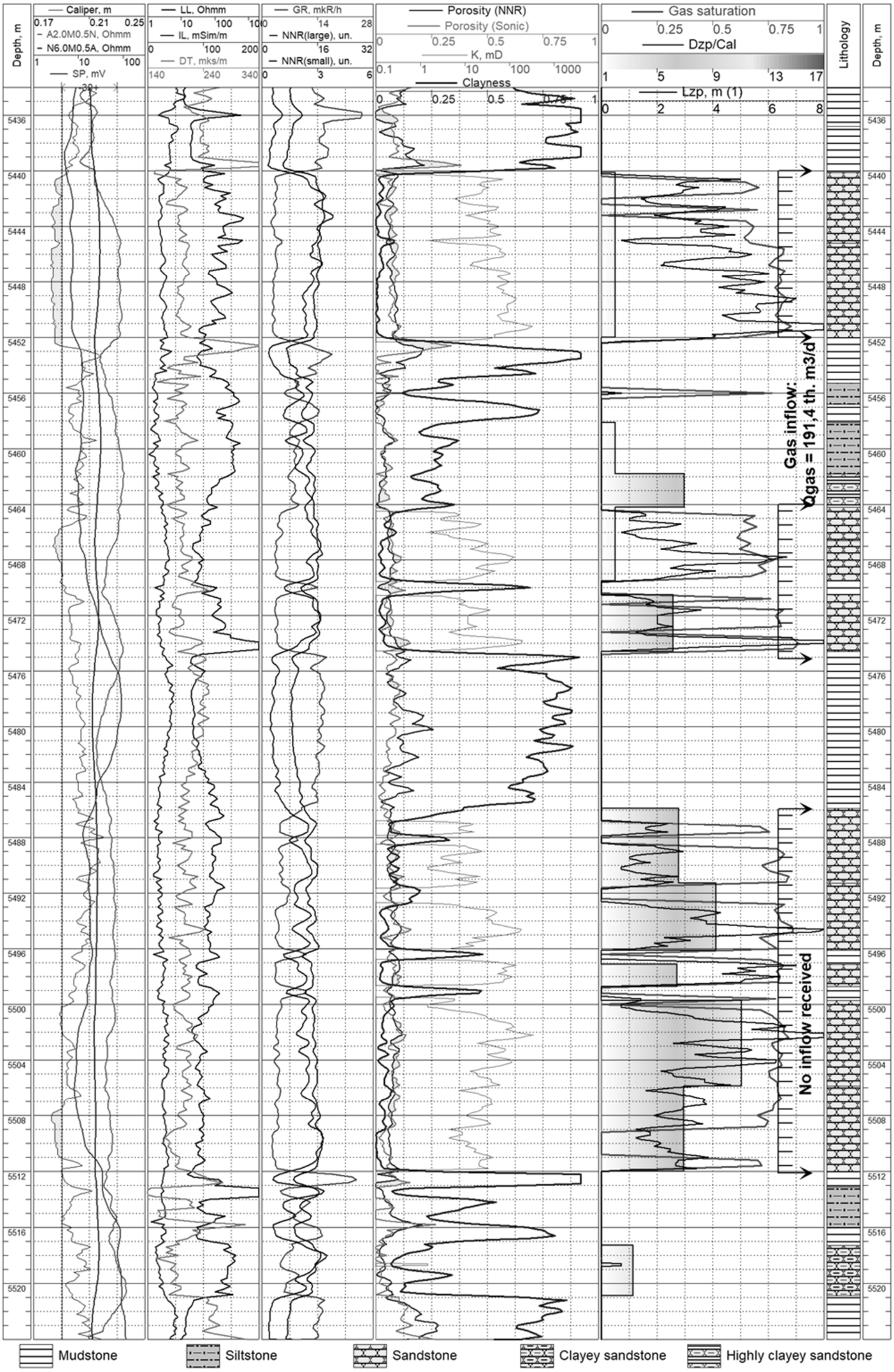

Fig. 3. Section of 31-Kolomatska well with test results and calculated values of the relative penetration zone depth according to well-logging data interpretation.

Table 1. Statistical characteristics of the distributions of petrophysical characteristics of sandstones for two test intervals: int. 5440 - 5475 (conditional gas inflow), int. 5486 - 5512 (inflow not received). Well 31-Kolomatska.

Result of formation testing	N	DT, mks/m	Caliper, m	GR, mks/m	Clay	Resistivity, ohm·m	Porosity	Gas saturation
Means								
Gas inflow	45	201.1	**0.196**	3.71	0.063	105.0	0.072	0.629
Dry	44	205.0	**0.207**	3.91	0.069	90.2	0.083	0.678
Standard deviations								
Gas inflow	45	11.5	0.010	1.15	0.053	59.2	0.017	0.283
Dry	44	14.6	0.013	0.68	0.026	13.7	0.021	0.275
Calculated t-test values (cut off value 1.99)								
t-test values	44+ 45	1.39	**4.70**	1.02	0.68	1.64	2.74	0.82

3 Conclusions

The process of drilling mud penetration into the reservoirs and the formation of the invasion zone can be divided into three main stages. In the first stage, when drilling near the bottom of the well in the area of the most active circulation of the flushing fluid, there is an area of high pressure with a large pressure drop not only in the radial direction, but also along the axis of the well. In the second stage, an important factor in the formation of the invasion zone is the formation of a mud cake on the wall of the well, which significantly impedes the water exchange processes between the well and the layers [30]. In the initial moments of time there is a squeezing of formation water and oil / gas phase from the bottom hole, which has a spatial character. In the third stage, after the drilling tool leaves the reservoir, the displacement process is mainly due to the excess of the constant hydrodynamic pressure in the well above the reservoir pressure and is mainly radial [30].

Our research using the methods of mathematical statistics proved that for terrigenous reservoir rocks with a granular type of porosity on the examples of several oil and gas condensate and gas condensate fields the following was established.

1. Negative test results of formations (with the recommended oil and gas potential according to the well-logging data) in the perforation intervals are caused by the presence of anomalous zones of penetration of the flushing fluid filtrate [24, 31]. Among other factors of different nature, the depth of the invasion (penetration) zone (Dzp) is largely controlled by the presence and size of the mud cake. The presence of a mud cake leads to "containment" or "inhibition" of the filtration of the liquid into the formation, resulting in the formation of small invasion zones. It is recommended to compare the calculated values of the penetration depth of the filtrate *L (Lzp)* in the absence of mud cake (1) with the values of the diameter of the penetration zone Dzp according to the electrical methods of well-logging. Similar in size, the large areas of the filtrate invasion by two calculations are evidence of a problematic situation and a high probability of no fluid inflow from the formation during the test. The use of calculations in two ways significantly increases the reliability of the conclusions about the flow of the invasion zone on the test results.

2. It is proved that the presence of a mud cake along the entire thickness of the productive layer significantly affects the formation of small zones of penetration of the filtrate and contributes to obtaining reliable test results within the perforation interval. If the mud cake is only partially formed within the formation crossing by the well, then there is a high probability that the filtrate penetration can occur not only in the radial but also in the vertical directions in the formation, which can cause large diameters of the invasion zone Dzp.

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Differences in the generation of industrial waste from economic activities in Ukraine and the EU and the prospects for the integrated use of mineral raw materials

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Abstract. The paper presents the comparative analysis of the amount of waste generated in Ukraine and European countries (except for radioactive waste) based on the official EU and Ukrainian statistical data. The data on waste generation are compiled according to the following classification: by economic activity and household, waste category, grades of hazard, and regions. In Ukraine, 352.3 million tons of waste was generated in 2018. By 2018, almost 13 billion tons of waste had been accumulated at the managed dump-sites, including about 12 million tons of hazardous and over 200 million tons of household waste. In the European Union, 2.6 billion tons of waste was generated in 2018. Over 70% of it was generated by 10 countries: Germany, France, England, Poland, Romania, Italy, Sweden, the Netherlands, Spain and Finland. By economic activity, the largest amounts of waste in Ukraine are generated by the mineral extraction and processing industry, the smallest – from water treatment and construction. In the EU countries, these values are somewhat different. For example, in Germany and France, the largest amounts of waste are generated from construction and manufacturing, the smallest – from agriculture, forestry and fishery. By waste category, the waste generated both in the EU countries and in Ukraine is mineral and solid waste. In Ukraine, the largest amounts of waste are produced and accumulated in the Dnipropetrovsk, Donetsk and Zaporizhzhia regions which accommodate large enterprises for extraction and mineral processing of iron and manganese ores, titanium-zirconium placers, coal, dolomite, and metallurgical limestone, as well as metallurgical and ferroalloy plants.

1 Introduction

Rapid global economic growth at the end of the last millennium led to excessive use of non-renewable natural resources and increase of human impact on the environment. The amount of generated waste became one of the challenges facing humanity in the nearest future.

In accordance with the national waste management programmes, the European Union and Ukraine make inventories of the waste generated both by economic sectors and households. The waste inventories reflect the socio-economic differences and different approaches to treatment and identification of waste types. The list of waste used in Ukraine does not fully correspond to that in EU. In 2014–2017, Ukraine took initial important steps to change the situation through commitment of compliance with the EU Directives as a part of the Association Agreement with the EU and adopting the National Waste Management Strategy until 2030.

Waste statistics play an important role in understanding and monitoring respective changes in the production/consumption processes towards more sustainable solutions.

The data used in the article were taken from the Eurostat and Ukrstat databases for 2018.

The amount of waste generation in different countries varies depending on the economic activity and society's production and consumption patterns. The largest amount of waste is generated in countries with developed mining and metallurgical industries. At the same time some countries with high level of household consumption demonstrate significant generation of household and construction/deconstruction waste. Although the three biggest economies – Germany, the United Kingdom and France – have the highest generation of waste in absolute figures, no direct link between economic production and waste generation is observed for all EU countries. For example, in smaller economies like Bulgarian and Romanian, the waste generation in mining and metallurgical industries is amongst the highest.

Limited natural resources, environmental impact of rapidly growing amounts of waste require urgent measures aimed at waste reduction.

Waste management is a key environmental concern both in Europe and Ukraine. The situation in Ukraine has already proven to be critical in many cities and regions due to a lack of proper waste management infrastructure

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and adequate government policy, business approach and public response.

2 Results and discussion

According to the State Statistics Service of Ukraine (Ukrstat), over 300 million tons of waste have been generated annually from 2014 to 2018, including 0.6 - 0.7 million tons of hazardous waste and over 10-11 million tons of household waste. By 2018, almost 13 billion tons of waste have been accumulated at the managed dump-sites in Ukraine, including about 12 million tons of hazardous and over 200 million tons of household waste (the data for the temporarily occupied Crimea and some territories of Donetsk and Luhansk regions are not included) (Table 1) [1].

Table 1. Waste generation and accumulation at the managed dump-sites in Ukraine, mln. tons.

Year	Total waste generation	Hazardous waste	Household waste	Total waste accumulation at managed dump-sites	Hazardous waste	Household waste
2014	354.803	0.7	10.748	12115.241	11.951	166.112
2015	312.267	0.6	11.492	12281.353	11.996	170.306
2016	295.870	0.6	11.563	12451.659	12.102	174.514
2017	366.054	0.605	11.271	12442.169	12.198	201.145
2018	352.334	0.627	10.000	12972.428	12.217	227.435

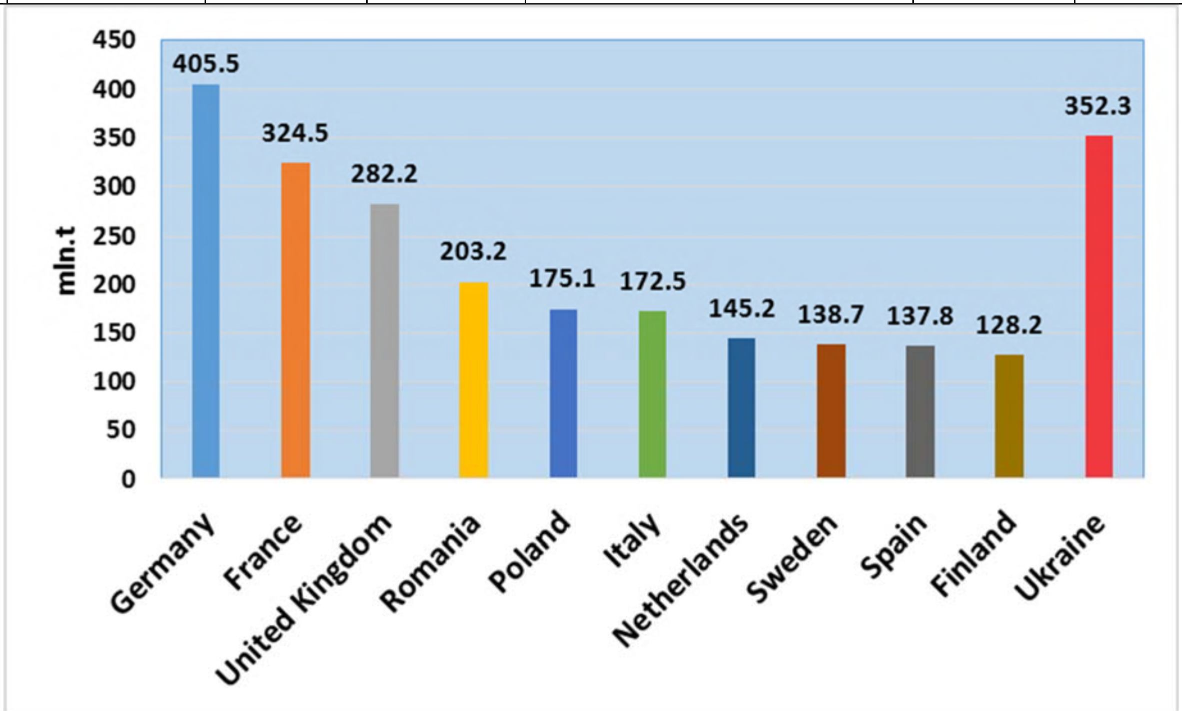

Fig. 1. Waste generated by some EU countries and Ukraine.

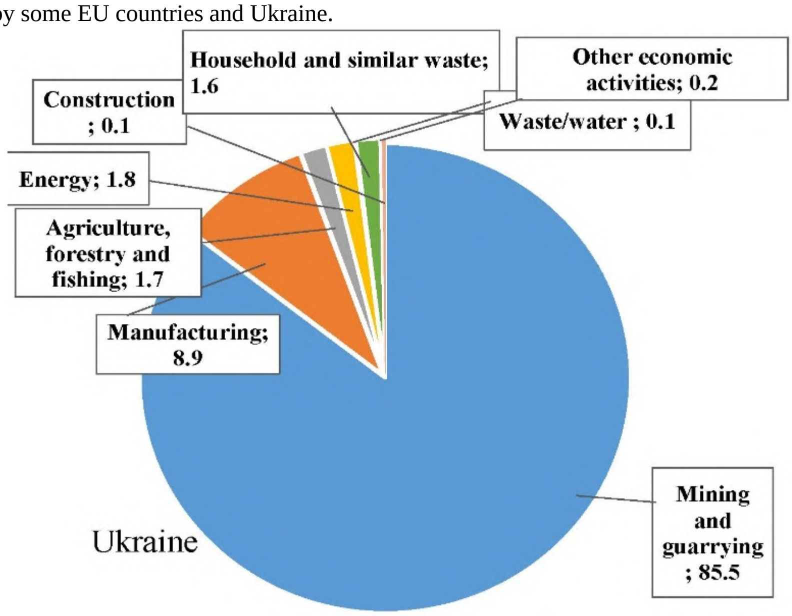

Fig. 2. Waste generation by activity in Ukraine, mln. tons.

According to Eurostat data, 2.6 billion tons of waste was generated in the EU (EC-28) in 2018 (Fig. 1). More than 70% of it was generated by 10 countries: Germany, France, United Kingdom, Romania, Poland, Italy, the Netherlands, Sweden, Spain, and Finland [2].

As can be seen in the chart, the amount of waste generated by some European countries in 2018 in million tons was as follows: Germany - over 400, France - over 300, UK – about 280, Romania - about 200, Poland and Italy - more than 170, Netherlands, Spain and Sweden - about 140, Finland - more than 120. In Ukraine, the amount of waste generated was over 350, which is less than in Germany and more than in France and the United Kingdom.

According to Eurostat data, in 2018 the following amounts of waste (mln. tons) were generated by each of the following European countries: Turkey – 90, Greece, Belgium, Austria and Serbia – from 40 to 70, Czechia, Estonia and Denmark - over 20, Hungary, Ireland, Portugal – from 14 to 18, Luxembourg, Slovakia, Norway – from 12 to 14. From 1 to 6 million tons were generated by other EU countries.

The State Statistics Service of Ukraine keeps records of waste generation and accumulation at the managed dump-sites in accordance with the National Waste Classifier. Waste is classified according to different parameters (by economic activity, waste categories, hazard classes, required disposal operations, and households). The same inventory strategy is used in the European Union.

Based on the State Statistics Service data [3], the chart in Fig. 2 presents waste generation by economic activity in Ukraine.

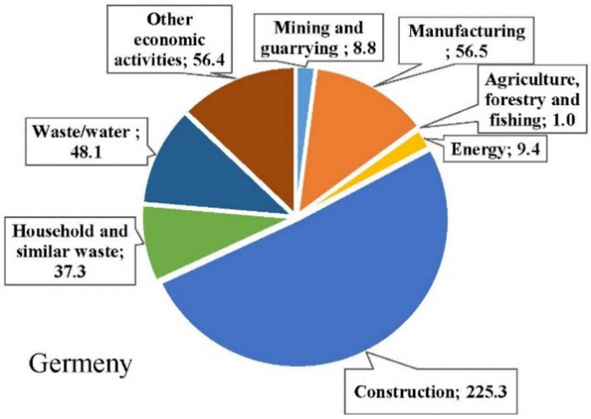

Fig. 3. Waste generation by economic activity in Germany, mln. tons.

The largest volumes of waste in Ukraine (million tons) are generated by quarrying and mining – 301.4 (74.3%), and manufacturing – 31.5 (17.5%), the later includes metallurgical and chemical enterprises, food industry etc. Household waste amounts to 5.5 million tons (1.1%). For comparison, in Germany and France, the largest volumes of waste are generated by construction industry – 225.3 million tons (55.6%) and 240.2 million tons (70.2%), and the manufacturing industry – 56.5 million tons (13.9%) and 22.4 million tons (6.6%) respectively. The household garbage volume is 37.3 million tons (9.2%) in Germany and 29.7 million tons (8.7%) in France (Figs. 3, 4) [2].

According to the State Statistics Service of Ukraine [1], the main sources of waste generation and accumulation in Ukraine are the following economic sectors (Table 2). Thus, the largest amount of waste in Ukraine is generated by quarrying and mining operations – over 300 million tons. It makes on average 74.3% of the total waste. At that, 80% is the waste from metal ore extraction (iron, manganese, titanium-zirconium). According to the National Waste Classifier, metal ore mining and quarrying waste in Ukraine include slurry and tailings, waste from pelletes and flux production (dust, powder, etc.), red mug from alumina production, and non-ferrous metal ore processing waste.

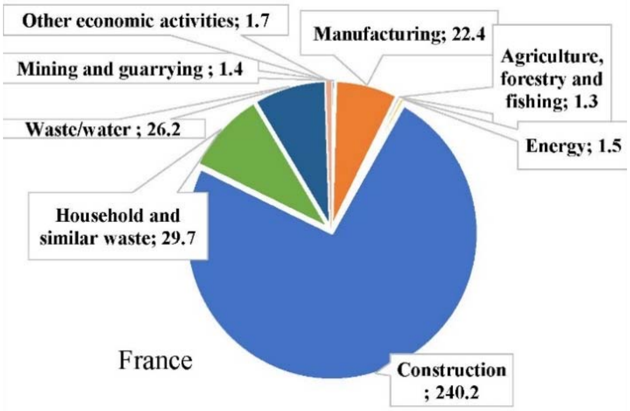

Fig. 4. Waste generation by economic activity in Germany, mln. tons.

Table 2. Dynamics of waste generation by economic activity in Ukraine, mln. tons.

Economy sectors	**2014**	**2015**	**2016**	**2017**	**2018**
Total	*355.00*	*312.27*	*295.87*	*366.05*	*352.33*
Type of economic activity	*348.69*	*306.21*	*289.52*	*360.20*	*346.79*
Agriculture, hunting, and provision of related services	8.4	8.7	8.7	6.2	6.0
Mining (Total)	297.2	252.1	237.3	313.6	301.3
Mining of metal ores	*281.5*	*238.1*	*222.5*	*293.7*	*282.5*
Mining of hard coal, lignin and peat	*13.0*	*12.1*	*10.5*	*12.9*	*10.8*
Mining of other ores	*2.7*	*1.9*	*4.3*	*7.0*	*8.0*
Manufacturing industry (Total)	29.50	25.60	28.20	29.60	28.80
Iron and steel production	23.4	20.7	22.3	22.0	21.8
Chemical industry	1.1	0.7	0.8	1.2	1.2
Food industry	5.8	5.1	5.7	6.8	6.2
Other branches of mining industry	4.5	4.5	5.3	2.2	2.3
Production and distribution of energy, gas and steam, and air conditioning	6.0	6.6	7.5	6.2	6.3
Other types of economic activities	*5.0*	*2.2*	*1.8*	*2.0*	*1.6*
Households	*6.3*	*6.0*	*6.3*	*5.9*	*5.5*

The group of waste from hard coal, lignin and peat mining includes substandard coal, slurry and tailings from concentrating mills. Other group of waste generated by Ukrainian enterprises comprises waste from mining of granite, limestone, chalk, dolomite, refractory clay, building stone and others.

On average, the manufacturing industry generates 17.5% of waste, over 69.2% of which come from the metallurgical industry (blast-furnace, steelmaking and ferroalloy slags and slurries, etc.).

The structure of metal-containing waste generated by the mining and metallurgical industries and accumulated at the managed dump-sites is shown in Fig. 5 and 6 [4, 5].

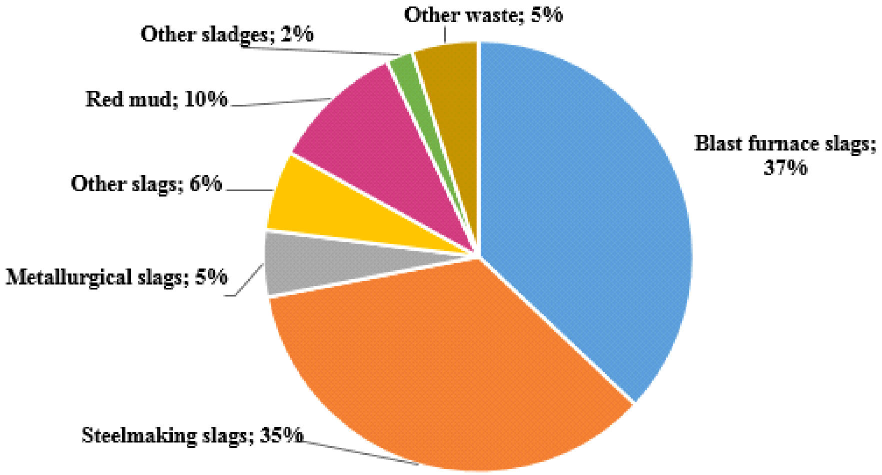

Fig. 5. Structure of waste generated from major metals production, %.

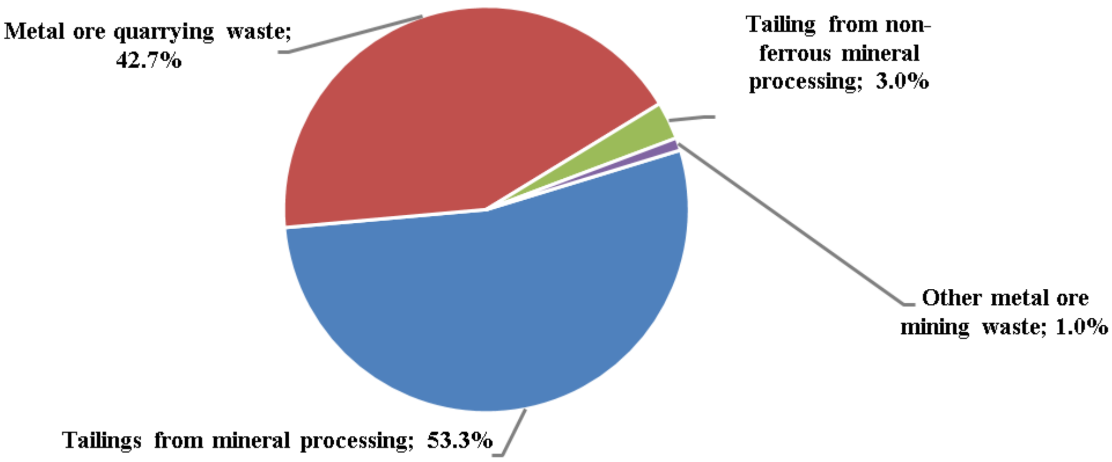

Fig. 6. Waste generated by metal ore quarrying and mining, %.

Fig. 7. Waste from iron ore quarrying.

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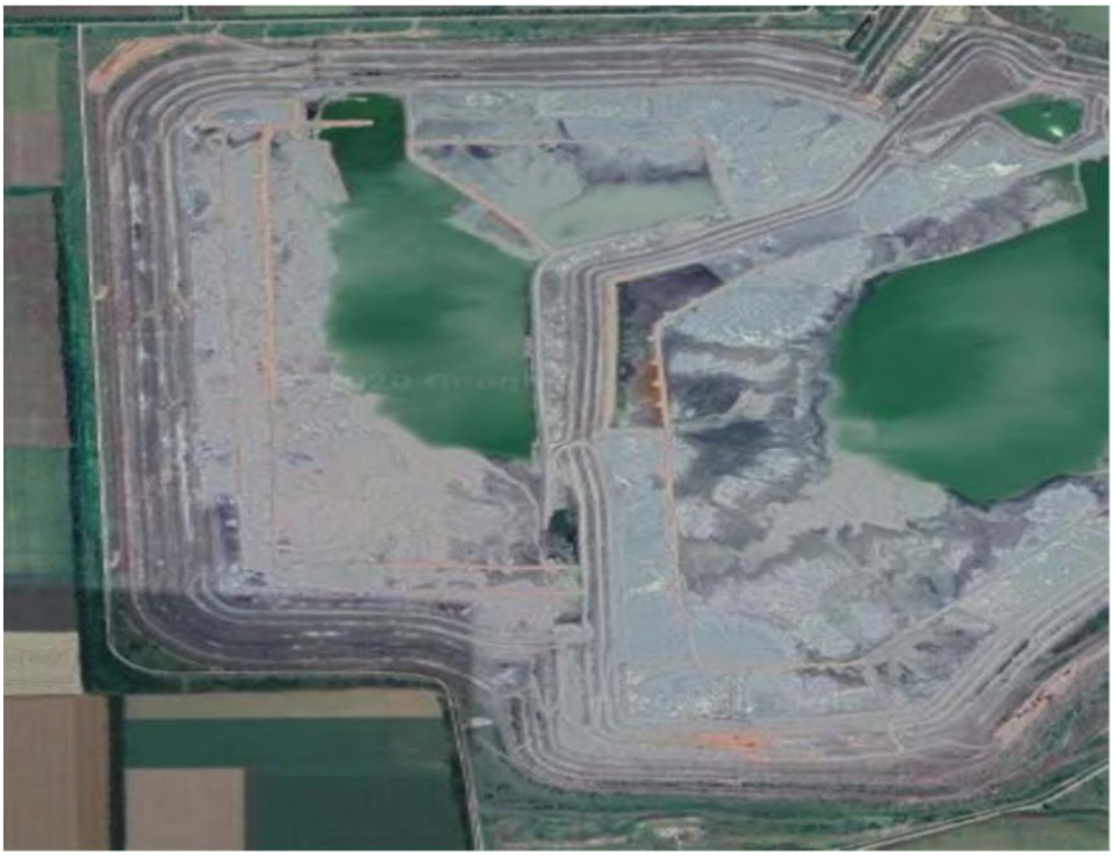

Fig. 8. Managed dump-sites with iron tailings.

Fig. 9. Waste from mineral processing of Irshansk Mining and Processing Plant.

The predominant part of the waste (78%) from major metals production is metallurgical and ferroalloy slags. Metallurgical sludge is the dust captured by air purifying equipment using liquid filters. It is stored in sludge collectors. After settling, the water is discharged into the surface water bodies, while the solids, if not reused, are accumulated at the managed dump-sites. Red mugs are generated at two enterprises – Mykolaiv alumina refinery and Zaporizhzhia alumina processing plants which produce alumina from bauxite. As can be seen from the chart (Fig. 6), the red mug makes 10% of the total waste from the major metal production.

One of the ways to reduce the amount of waste at the stage of extraction and processing of the metal ores in Ukraine is the integrated use of the mineral resources and the utilization of enrichment waste.

The chart shows that 96% of the waste generated by quarrying and mining is the metal ore waste and tailings from mineral processing (Fig. 7, 8).

The annual generation of iron tailings is over 130 mln. tons. Recycling of the tailings through ferrous concentrate and construction sand production will allow to decrease considerably the amount of the stored waste.

The problem of metal ore quarrying and mining in Ukraine is that host rock is not used. For example, in case of selective extraction and separate storage, talcum, garnet, muscovite and quartz concentrates can be produced from talc-, garnet- and muscovite-shales, respectively. Clays can be used for production of expanded clay and ceramics. The host rock can also be used for production of building sand and natural pigments (ferrous oxide, ocher, seladonite etc.). Mineralogy and chemical composition of some host rocks have been studied and described in detail in [7-12, 14, 15].

Clay, sands and limestone-shells from the overburden can be attributed to the resource potential of the manganese ore production waste in Ukraine, which can be selectively extracted and subsequently used in the national economy. In addition, more than 400 million tons of manganese-containing sludge have been accumulated in sludge storage facilities, with a mass fraction of Mn 10.5 - 17.5%. By sludge processing applying different schemes, it is possible to obtain manganese concentrate with a mass fraction of Mn from 35-41% (high-gradient magnetic separation with flotation) to 50% (magnetic-chemical technology) with an extraction of Mn 65-68% and 64%, respectively.

The enrichment waste prevails in the total amount of wastes from extraction and enrichment of heavy mineral titanium-zirconium sands. The overburden from the development of titanium-zirconium placer deposits in Ukraine (clay, loam, sand) is acceptable to be used for reclamation works.

Ore minerals in the technogenic sands of the Malyshevskyi deposit (the Volnogorsk MMC) are represented by zircon, rutile, leucoxen and ilmenite. Mostly they are concentrated in the fraction – 0.16 + 0.06 mm. Disten, sillimanite, staurolite and tourmaline have relatively significant contents.

Studies of the material composition of the waste from the Irshansk group of deposits have revealed that 60 wt.% of sands are represented by 0.5-0.125 mm grains; 5-15 wt.% is the metallic fraction, 85-95 wt.% – the non-metallic one. The ore minerals are mainly ilmenite, rutile, ilmenorutil and zircon. The presence of zircon as the main mineral carrier of zirconium is confirmed by the mass fraction of the latter in the waste (0.05 - 0.5 wt.%). We consider that these technogenic sands can be used to produce titanium and zirconium as well as quartz sand (Fig. 9).

Eurostat and the State Statistics Committee of Ukraine keep records of waste generation by material as well. Subdivision of wastes by material based on EU and Ukrainian data (2016) is presented in Table 3 [2, 3].

Table 3. Waste generation by waste category in Ukraine and EU countries.

Country	Total volume in a country, mln. tons	%	Mineral and solid waste, mln. tons	%	Chemical and medical waste, mln. tons	%	Animal and plant waste, mln. tons	%	Sludges, mln. tons	%	Reprocessing of waste, mln. tons	%	Equipment, mln. tons	%
Total EU, million tonnes	**2454.72**	**100.0**	**1796.6**	**73.19**	**54.15**	**2.21**	**95.28**	**3.88**	**20.71**	**0.84**	**246.13**	**10.03**	**17.83**	**0.73**
Germany	400.07	16.30	261.39	65.33	8.92	2.23	15.62	3.91	1.49	0.37	39.38	9.84	2.43	0.61
France	323.47	13.18	261.76	80.92	4.96	1.53	11.81	3.65	1.21	0.37	34.90	10.79	2.44	0.75
England	277.26	11.29	141.64	51.09	4.80	1.73	10.29	3.71	4.17	1.50	43.11	15.55	3.80	1.37
Poland	182.01	7.41	122.71	67.42	2.99	1.64	3.19	1.75	0.66	0.36	13.56	7.45	0.70	0.39
Romania	177.56	7.23	163.36	92.00	0.95	0.54	0.86	0.49	0.20	0.11	5.82	3.28	0.13	0.08
Italy	164.00	6.68	65.46	39.91	14.29	8.71	7.85	4.79	6.08	3.70	28.10	17.14	3.03	1.85
Sweden	141.62	5.77	101.83	71.90	1.29	0.91	2.38	1.68	0.40	0.28	6.31	4.45	0.85	0.60
Netherlands	141.02	5.75	104.04	73.77	2.40	1.70	15.20	10.78	0.66	0.47	8.39	5.95	0.54	0.39
Spain	128.96	5.25	67.03	51.98	2.66	2.06	9.14	7.08	1.46	1.13	12.56	9.74	1.21	0.93
Amount	1935.97	78.87	1289.21		43.26		76.35		16.32		192.14		15.13	
Other countries	518.75	21.13	507.39	26.81	10.89	97.79	18.93	96.12	4.39	99.16	53.99	89.97	2.70	99.27
Ukraine	**295.87**		**226.20**	**76.4**	**1.44**	**0.49**	**13.89**	**4.69**	**3.90**	**1.32**	**…**		**…**	

As indicated in table 3, over 2 billion tons of waste is generated annually in EU countries. The total volume of waste generated in all 28 EU countries in 2018 was 2.6 billion tons. Mineral and solid waste constitutes the largest part of the total waste generated in all countries – from 39.9% in Italy to 80.9% in France. In Ukraine, they constitute 76.4% of the total waste generated.

In the EU countries, various amounts of waste are generated from waste recycling – from 6% in Netherlands to 16% in the United Kingdom. In Ukraine, the amount of waste from waste recycling is only 0.07%.

Fig. 10 shows waste accumulation at managed dump-sites in different regions in Ukraine [3].

The chart shows the amount of waste accumulated at managed dump-sites in different regions in Ukraine. Based on this amount the regions were divided into 3 groups. The first includes areas accommodating hundreds of millions of tons of waste. The second – tens of millions of tons. The third – less than 10 million tons.

Having the well-developed industry Dnipropetrovsk region accommodates the largest volumes of waste. The plants extract and enrich iron, manganese, titanium-zirconium ores and coal. There are also metallurgical and ferroalloy plants.

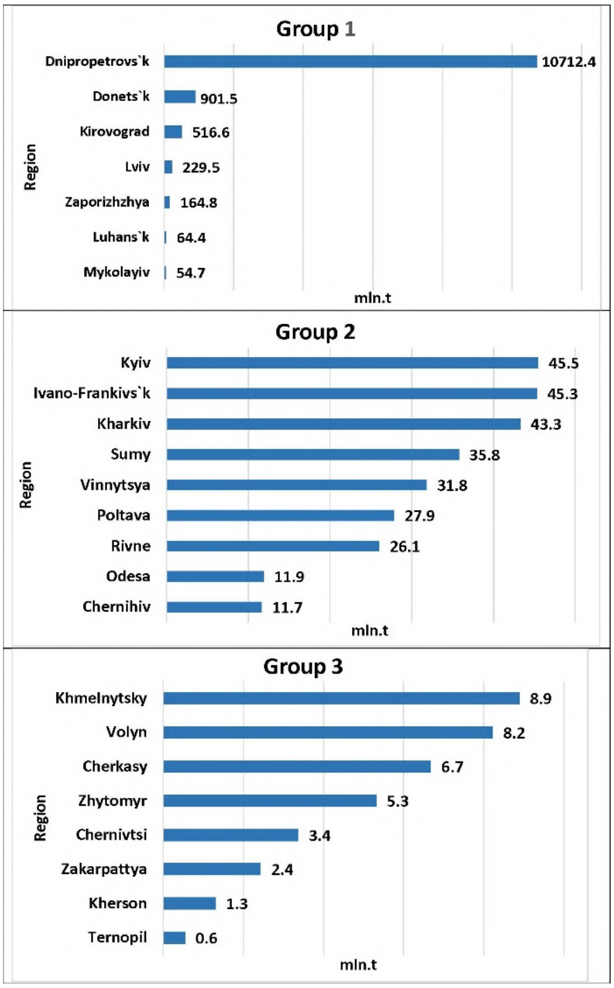

Fig. 10. Waste accumulation in different regions in Ukraine.

As can be seen from the chart, Dnipropetrovsk region accumulated 10 billion tons of waste at the disposal sites.

According to our estimates. More than 90% of it is waste from extraction and processing of iron and manganese ores (Kryvbas mining and processing integrated plant. Nikopol manganese ore field and metallurgical plants).

In Donetsk region, at the territory controlled by the Ukraine authorities most of the waste is accumulated at the coal mining and enrichment plants, coke plants and metallurgical plants. Dokuchaiv flux-dolomite plant which accumulated huge amounts of waste by 2013 is located at the temporarily occupied territories and the data are not available.

In Kirovohrad region, 99.9% of waste is accumulated at three enterprises: Petrivskyi quarry of the Central mining and processing complex, gulch “Shcherbakivska” and mine “Inhulska” of the Eastern mining and processing plant. Petrivskyi quarry’s disposal sites accommodate almost 80% of the waste accumulated in Kirovohrad region.

In Lviv region over 96% of waste is accumulated at four enterprises: JSC “Lviv Coal Company”. 6 mines of SE “Lvivvuhillia”. Novoiavorivske SE “Ekotransenergo” and Dobrotvirska TPP.

In Zaporizhzhia region almost 90% of waste was accumulated at 5 enterprises. i.e. JSC “Zaporizhstal” (metallurgical (iron) slag and sludge). Zaporizhzhia TPP (coal ash). LLC “Remondis Zaporizhzhia” (household waste). JSC “Zaporizhzhia Ferroalloy Plant” (ferroalloy slag and dust from gas purification plants) and JSC “Zaporizhzhia Aluminum Production Plant” (over 10 million tons of red sludge).

In Luhansk region, at the territory controlled by the Ukrainian authorities there are coal enterprises which generate coal mining and enrichment waste.

The second group comprises the Ukrainian regions which accommodate the most powerful TPPs (Trypilska, Zmiivska, Ladyzhynska and Burshtynska). These TPPs produce 60-70% of the total waste generated in a region.

The third group includes regions in which 70-99% of the total waste is municipal waste.

It should be noted that the volume of accumulated waste in Ukraine is much higher than the mentioned above. This is because the State Statistics Service receives information only from operating enterprises. Large volumes of waste are stored at enterprises abandoned after disintegration of the Soviet Union.

According to the Ministry of Energy and Environmental Protection data, 35 billion tons of waste have been accumulated in the country. 14 of the largest waste generators are located in Dnipropetrivsk region, 9 - in Donetsk, 3 - in Poltava, 2 in Kirovohrad and Zaporizhzhia and 1 in Ivano-Frankivsk, Mykolaiv, Ternopil and Lviv regions.

6 out of 35 largest waste generators are Kryvbas mining and processing enterprises which exploit iron ore deposits (Table 4) [6].

Table 4. Largest waste generators and polluters of the environment in Ukraine.

№	Company name	Generated waste. mln. tons
1.	Northern Mining and Processing Plant	81.34
2.	Inhulets Mining and Processing Plant	63.48
3.	Central Mining and Processing Plant	61.56
4.	ArcelorMittal Kryvyi Rih	27.65
5.	Southern Mining and Processing Plant	26.92
6.	Yerystivskyi Mining and Processing Plant	14.95
7.	Novotroitske Ore Mining Company	6.74
8.	Ilyich Iron and Steel Works	6.23
9.	“Ukrmechanobr” Ore Mining and Processing Integrated Plant	3.86
10.	Pokrovskyi Mining and Processing Plant	3.26
11.	Total	**295.99**

The enterprises listed in the table except for PJSC “Ilyich Iron and Steel Works” are the mining and processing plants that predominantly accumulate overburden iron and manganese ore enrichment waste.

In Ukraine, 14 mln. tons of iron ore waste from mining and processing plants are dumped on over 7 thousand hectares. The article [13] presents a list of alternative minerals which can be extracted from Kryvbas iron ore deposits. Technologic solutions for waste management and mineral extraction from tailings and host rock are described in the papers [16-18]. Enrichment technologies have been developed under laboratory conditions.

The problem of complex use of the deposits in order to reduce technogenic impact is predominantly the economic and political one. Extraction of iron ore concentrate from the enrichment waste at the Central mining and processing complex (Kryvyi Rih) has shown that its cost is 40% lower than the concentrate extracted from the quarried ore; its quality is only slightly lower.

We believe that it is possible to reduce the technogenic impact on the environment by recycling of tailings and more comprehensive and effective use of mineral deposits.

3 Conclusions

Analysis of industrial waste showed that the amount of its generation in Ukraine correspond to that in France. Poland and Romania (300-400 million tons per year). In Ukraine the largest amounts of waste are generated from the quarrying and mining (74.3%). and manufacturing (13.2%) industries. In Germany and France, for example, the largest amount of waste is generated from construction (55.6% and 70.2%. respectively), manufacturing (13.9% and 6.6%. respectively) and waste/water (11.9% and 6.8%. respectively).

The impact of industrial waste from mining and mineral processing on the environment can be reduced by application of innovative technologies in ore extraction and enrichment and in metallurgical industry. It will increase the degree of extraction of useful components from the mineral resources and improve the monitoring of waste disposal sites. Solution of the above problems depends on the legislation and the willingness of business to invest in diversification of production.

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Research of the impact on the ecology of the state of cybersecurity of the critical infrastructure objects

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Abstract. The analysis of the impact on the ecology of the state of cybersecurity of critical infrastructure objects and the factors influencing the state of cybersecurity of the information system of the critical infrastructure object is performed. An explanation is given of why cybersecurity violations in automated process control systems can lead to consequences in the industrial sector and environmental impact. The need to develop effective and adequate proposals and measures for cybersecurity of information systems of the critical infrastructure objects is shown. The classification of assets that are the objects of cyberattacks by attackers and the categories of impact on the critical infrastructure objects are given. Approaches to determining the cyber threat risk factor of the critical infrastructure object and the relevance of threats are presented. The method of assessing the degree of possible damage from the implementation of information security threats is considered. The results of this analysis can be used to develop proposals and measures to avoid the effects of cyberattacks on the critical infrastructure objects. The prospect of further research is to develop a methodology for determining the relationship between specific cyberattacks and possible quantitative damage.

1 Introduction

The current stage of development of society is characterized by the introduction of new technologies, which is a sign of the level of economic development of the country. The growing role of the information sphere for the economy of the state is associated with its rapid entry into the communications, transport, energy, financial, defense and other spheres.

Strategically important for the functioning of the economy and security of the state, society and population are the critical infrastructure objects - enterprises and institutions (regardless of ownership) of industries such as energy, chemical industry, transport, information technology and telecommunications (electronic communications), food, health care, utilities. Therefore, given that in modern society cyberattacks are becoming more frequent and tend to have a significant and lasting impact through enterprises on the economy, it is undeniable that reliable protection against cyberattacks actively affects the state of economic, political, social, defense and other components, national security of the state [1].

It is obvious that the disruption of the critical infrastructure objects of the state can lead to emergencies related to deaths, environmental disasters, causing great material, financial, economic damage or large-scale disruptions of cities and towns, etc. In these circumstances, security, including cybersecurity of the critical infrastructure objects of the state, plays an extremely important role.

Unlike traditional IT systems, in Automated Process Control Systems, which operate on the critical infrastructure objects, there is a fairly close relationship between automated systems and physical processes and actuators [2]. Therefore, the violation of cybersecurity in the Automated Process Control Systems can lead to consequences in the industrial sector and environmental impact.

In view of the above, it is necessary to analyze the impact on the environment, and, as a consequence, to develop effective and adequate proposals and measures for cybersecurity of information systems (IS) of the critical infrastructure objects to prevent such impacts.

2 Analysis of previous publications

A significant part of publications, in particular [3-8], is devoted to the study of problems related to the environmental impact of the state of cybersecurity of IS of the critical infrastructure objects.

In [9-12] shows along with the benefits of accurate and economic control of these digital I&C systems comes the challenges of cybersecurity. Especially with the growth of industry-targeted cyber-attacks in both numbers and capabilities, an overall understanding of the current cybersecurity status is important for further cybersecurity research and deployment improvement. Cyber-attacks against critical energy infrastructure have gone from

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possible to eventual to actual. With electrical generation sources in the United States changing under a wide range of pressures, the current fleet of nuclear power plants in the United States provides a reliable and sustainable source of electrical generation capacity. However, in order to extend the lifetime of the fleet, modernization upgrades to digital instrumentation and control systems are required. While this produces many opportunities for increased efficiency, it introduces a new level of complexity for securing and reliably operating reactors in the presence cyber-threats. The United States Nuclear Regulatory Commission recently began urging stronger cybersecurity efforts at nuclear power plants. As upgrades at nuclear power plants begin, the implementation of digital instrumentation and control systems to monitor and run the power plant introduces new vulnerabilities that must be addressed. This necessitates a more modern discussion of risk.

However, today, for all its importance, the issue of the environmental impact of the state of cybersecurity of the critical infrastructure objects remains insufficiently studied and researched and is in urgent need of development.

3 The research results

Cyberattacks are aimed at damaging assets. An asset is an entity that is valuable to an individual, organization, or state. Therefore, security programs are aimed at protecting assets from damage.

Assets of the critical infrastructure objects can be classified by type as follows [13]: physical, logical, human.

Consider in more detail each of the types of assets.

Physical assets include any physical components or groups of components that belong to the organization. In the critical infrastructure objects, they include: control systems, physical components of the information transmission network or any other physical objects that are in some way involved in the management processes and analysis of production processes.

Logical assets may include intellectual property, algorithms, expertise, or other information elements that include the ability of an organization or innovation to function. In addition, these types of assets may contain a public reputation, customer confidence, or other measures that, if damaged, directly affect the production process. Logical assets may be presented in the form of personal memory, documents, information contained on physical or electronic media and include test results, regulatory data, or any other information that is treated as confidential or private. Loss of logical assets often causes significant damage to the organization for a long time.

IS of the critical infrastructure objects assets are a special form of logical assets. They contain the logic of automation, which is involved in the implementation of production processes. These processes are highly dependent on the repetition or continuous execution of well-defined events. Therefore, damage to these assets, such as removal or unauthorized modification, may result in loss of integrity or availability directly to the process itself.

Human contain people, knowledge, as well as theoretical and practical skills that they possess and that are related to their production activities. These may include the necessary certificates or important skills needed to act in an emergency.

Assessment of asset losses can be expressed either quantitatively or qualitatively [13].

A quantitative assessment of an asset provides an accurate answer about the financial costs associated with that asset. This may be the replacement cost, the value of the lost sale or other monetary policy measures.

Qualitative valuation of assets is usually expressed more at the abstract level, such as percentages or relative values. Many assets can only be analyzed in terms of qualitative losses.

Losses in IS of the critical infrastructure objects can be classified as direct and indirect.

Direct losses are costs that are associated with the replacement of assets. Damage may occur due to physical damage to the asset, as a result of loss of integrity or availability, interruption of the exact sequence or change in the nature of the process. Logical assets have relatively low direct losses in relation to their usefulness, because the media used to store the asset, as a rule, has a low cost. Minor damage to human assets with a short recovery time can have low direct damage to the organization, even in the case of long-term consequences for the injured person.

Indirect losses are losses caused by loss of assets. These may include losses associated with downtime, recycling or other production costs due to loss of assets.

For physical assets, indirect losses typically include the consequences that arise from the loss of components. Indirect damage from equipment damage may result in repairs, reengineering, or other efforts to regain control of the industrial process. For logical assets, indirect losses are often very large. These include loss of public confidence, loss of business license, loss of competitive advantage from the issuance of intellectual property, such as confidential process, new technologies and so on.

You can correlate the types of losses for each type of assets by sorting the above data by type of assets and the way of expressing their valuation.

The danger of cyber threat in the critical infrastructure objects automated systems from many threats will be determined by assessing the possible consequences of its implementation from the standpoint of impact on the operation of the critical infrastructure objects automated systems, and the severity of such consequences - the risk factor of this threat [14].

Each threat to the cybersecurity of information system circulating in the information system of the critical infrastructure object can be described as follows:

$$n = f\{Z_n, U_n, K_n, H_n, C) \quad (1)$$

where Z_n is the source of the nth threat to cybersecurity of the information system;

U_n - vulnerabilities due to which it is possible to implement the nth threat to cybersecurity of the information system;

K_n - favorable conditions for the implementation of the *n*th threat to cybersecurity of the information system of the critical infrastructure object of the energy sector;

H_n - consequences of the implementation of the *n*th threat to cybersecurity of the information system of the critical infrastructure object;

C - assets of the critical infrastructure object, which may be damaged in the event of the *n*th threat to cybersecurity of the information system.

The threat to the security of information circulating on the critical infrastructure object will be considered relevant if for the specified object of critical infrastructure with the set structural and functional characteristics and features of functioning there is a probability of realization of the considered threat by the intruder with the appropriate potential and its realization will lead to unacceptable losses from violation of confidentiality, integrity or availability of information.

This is due to the fact that in automated systems of the critical infrastructure object there is a very close relationship between automated systems and physical processes and actuators [14]. Therefore, information security breaches in these systems can have consequences in the industrial sector.

Given the above, the risk of threat in automated systems of the critical infrastructure object from many threats will be determined by assessing the possible consequences of its implementation from the standpoint of impact on the operation of automated systems of the critical infrastructure object, and the severity of such consequences - the risk factor of this threat [14].

The relevance of the *n*th threat to cybersecurity of the information system in general can be described as follows:

$$A_n = f\{P(H_{nu}|K_n); H_n\} \tag{2}$$

where $P(H_{nu}|K_n)$ is the probability of realization of the *n*th threat using the *u*th vulnerability, provided there are favorable conditions for this K_n; H_n - the consequences of the implementation of the *n*th threat to cybersecurity of the information system of the critical infrastructure objects.

The probability of a threat can be determined based on the analysis of statistical data on the frequency of information security threats (occurrence of security incidents) in automated systems of the critical infrastructure objects and / or similar systems.

In the absence of such statistics, the relevance of the threat is determined by assessing the feasibility of the information security threat, which in turn is determined by assessing the level of security of automated system of the critical infrastructure objects and the potential of the intruder required to implement the threat.

The hazard ratio can be determined by assessing the extent of the consequences of the breach of confidentiality, integrity or availability of information in automated systems of the critical infrastructure objects.

The relevance of information security threats is determined in relation to the threats for which the following is determined by the expert method:

- opportunities (potential) of the intruder are sufficient to realize the threat to information security;

- in the automated system of the critical infrastructure objects there are potential vulnerabilities that can be used in the implementation of a certain threat to information security;

- structural and functional characteristics and features of the functioning of the automated system of the critical infrastructure objects do not exclude the possibility of using the methods necessary to implement a particular threat, i.e. there is a scenario of threat realization;

- the implementation of the threat to information security will lead to a violation of confidentiality, integrity or availability of information, which may result in unacceptable negative consequences, causing significant harm.

Sources of information on the initial data on information security threats and their characteristics can be basic and standard models of information security threats, defined by regulations for different classes and types of automated systems.

Let's estimate the probability of realization of the threat to information security. The probability of information security threat will be understood as an indicator determined by an expert, which characterizes the value of the probability of realization of a certain (*n*th) information security threat in the automated system of the critical infrastructure object with specified structural and functional characteristics and features. For this purpose it is necessary to enter gradations of this indicator concerning the nth threat which can be described as follows:

$$P(R_n) = f(K_n; S_n; q_n; \omega_n) \tag{3}$$

where K_n - the presence or absence of favorable conditions for the implementation of the *n*th threat;

S_n - the presence or absence of the necessary statistics on the facts of the *n*th threat (the occurrence of incidents of cybersecurity violation of the information system);

q_n - the presence or absence of potential intruders of motivation to implement the *n*th threat, internal and / or external destabilizing factors, i.e. the model of the intruder and the threat model of the information system of the critical infrastructure object of the energy sector;

ω_n - the possible frequency of the *n*th threat.

In the absence of the necessary data to assess the probability of implementation of information security threats or doubts about the objectivity of expert assessments in determining the gradations of the probability of information security threats, the relevance of the *n*th information security threat is determined by assessing its feasibility.

The possibility of implementing the *n*th threat to information security can be assessed based on the level of security of the automated system and the potential of the intruder required to implement this threat to information security in the automated system of the critical infrastructure object with specified structural and functional characteristics and features. Therefore, the possibility of realizing the *n*th threat can be described as follows:

$$W(H_n) = f(X_n; Y_n) \qquad (4)$$

where X_n - the level of protection of the automated system of the critical infrastructure object for the implementation of the *n*th threat; Y_n - the potential of the intruder required to implement the *n*th threat, i.e. the threat model.

It is obvious that when putting an automated system of the critical infrastructure object into operation, a high level of protection from the intruder with a given potential must be provided.

However, in the course of operation of automated systems of the critical infrastructure objects new vulnerabilities of systems, increase of potential of the intruder, change of structural and functional characteristics, importance of the processed information, features of functioning of the specified systems and other conditions leading to emergence of new threats to information security can significantly reduce the level of design security of these systems. In this case, in order to maintain the level of protection of automated systems of the critical infrastructure objects during operation, a regular analysis of changes in information security threats should be conducted, and current information security threats should be periodically re-evaluated.

Thus, the level of security of the automated system of the critical infrastructure objects can be determined based on the analysis of the following information:

- whether there are additional threats to information security during operation;
- whether information protection measures can be taken against additional information security threats that have arisen during operation;
- how quickly you can neutralize additional threats to information security that have arisen during operation.

The potential of the intruder to implement a particular threat to information security can be determined on the basis of data provided in the basic and standard models of information security threats, which are determined by regulations for IS of different classes and types.

To assess the degree of possible damage from the implementation of information security threats, the possible outcome of the information security threat in the automated system of the critical infrastructure objects, the type of damage that can lead to the implementation of information security threats, the degree of consequences of the implementation of information security threats for each type of damage.

As a result of the threat to information security, direct or indirect effects on the confidentiality, integrity, availability of information circulating in the automated control system of the critical infrastructure objects are possible [14].

Direct impact on the confidentiality, integrity, availability of information is possible as a result of the implementation of a direct threat to information security. In this case, the objects of the threat are directly information and / or other objects of protection that ensure the receipt, processing, storage, transmission, destruction of information in automated systems of the critical infrastructure objects, as a result of access to which or impact on which the impact on privacy, integrity or availability of information is possible.

Indirect impact on the confidentiality, integrity, availability of information is considered as a result of the implementation of indirect threats to information security. The implementation of indirect threats to information security does not directly affect the confidentiality, integrity, availability of information, but creates the conditions for the implementation of one or more direct threats to information security, which allow to implement such an impact. In this case, as a result of the implementation of an indirect threat, it is necessary to consider the results of the implementation of all direct threats to information security, which can be implemented in the case of the implementation of this indirect threat.

In determining the degree of possible damage, it is necessary to assume that depending on the goals and objectives of the automated system of the critical infrastructure objects, types of information processed, the impact on confidentiality, integrity or availability of each type of information contained in the system may lead to different types of damage. In this case, different owners of information will be characterized by different types of damage.

As noted in [13], the main categories of influence in automated control systems of the critical infrastructure objects are:

- physical impact - includes many direct consequences of accidents of the Automated Process Control Systems. The most important potential consequences are those that can lead to injury and death. Other consequences include loss of property (including data) and potential damage to the environment;
- economic impacts - the consequences of the second order from the physical impacts that are derived from accidents of the Automated Process Control Systems. Physical impact can have consequences for the system, which in turn can cause greater economic damage to the enterprise or organization. On a large scale, these effects can negatively affect the local, regional, national levels, and possibly the global economy;
- social influences - the consequences of the second order, which are derived from the loss of state or public confidence in the organization.

Given the above categories of impacts in automated control systems of the critical infrastructure objects, it is possible to list the consequences of these impacts [13]:

- violation of national security;
- facilitating the commission of an act of terrorism;
- loss or reduction of production;
- injuries or deaths;
- damage to equipment;
- emission (leakage, evaporation) or theft of hazardous materials;
- environmental damage;
- criminal or civil obligations;
- loss of private or confidential information;
- loss of brand image or customer trust.

These consequences may be supplemented by other types depending on the goals and objectives solved by the automated system of the critical infrastructure objects, as well as the type of information that is processed in it.

The degree of possible consequences of the implementation of information security threats is determined by the degree of negative consequences of the violation of confidentiality, integrity or availability of each type of information circulating in the automated system of the critical infrastructure objects.

Thus, the degree of negative consequences of breaches of confidentiality, integrity or availability of information is determined for each type of damage, depends on the goals and objectives performed by the automated system of the critical infrastructure objects, and may have different meanings for different information owners and operators, and is determined by experts.

If two or more types of information are processed in an automated system of the critical infrastructure objects, the degree of possible damage must be determined separately for each type of information circulating in the system. The final degree of possible damage will be determined by the highest value of the degree of possible damage, determined for the confidentiality, integrity, availability of each type of information.

Every cyber threat, if implemented, leads to destructive ones. The relationship between threats and destructive actions that arise as a result of the implementation of these threats can be represented as a matrix:

$$G = [g_{dn}] \tag{5}$$

where d varies from 1 to D; D - the number of possible destructive actions; n varies from 1 to N; N - the number of cyber threats.

The elements of the matrix (5) become 1 if the nth cyber threat leads to the implementation of the dth destructive action, and become 0 - otherwise.

Let B_d be the coefficient of danger of performing the dth destructive action, where d varies from 1 to D; D - the number of possible destructive actions.

Then, given that in the case of the implementation of the nth cyber threat may be several destructive actions, the risk factor of the nth cyber threat will be determined as follows:

$$B_n = \Sigma B_d g_{dn} \tag{6}$$

where B_d – the coefficient of risk of execution of the dth destructive action, determined by the severity of the consequences of this execution, as an indicator of the criticality of the energy sector; g_{dn} – a coefficient that is defined as an element of the matrix (5).

The analysis of existing information security systems allows to determine the main components of the cyber security system of information systems of the critical infrastructure objects:

- normative-legal;
- organizational;
- technical;
- training, retraining and advanced training of relevant specialists.

Each of the above components, in one way or another, affects the state of cybersecurity of IS of the critical infrastructure objects.

Thus, one of the topical issues is the availability of regulatory framework for cybersecurity of IS of the critical infrastructure objects, bringing the national regulatory framework for cybersecurity of the critical infrastructure objects in line with international regulations; fulfillment of the coherence of the conceptual apparatus used in the existing national legislative and regulatory documents; finalization (if necessary - development) of regulatory documents, requirements, methodologies for threat assessment of facilities that are critical to the life of the state, the general methodology for risk assessment for critical facilities and critical infrastructure in general.

In addition, it should be noted that managers and / or owners of the critical infrastructure objects should be aware of the possibility and likelihood of cyberattacks and the consequences, if any. The implementation of cybersecurity measures requires additional resources, to which the managers of these objects do not always agree, and there is no mechanism that would require these managers to implement the necessary measures. Therefore, without the introduction of this mechanism, all standards, instructions, etc. on cybersecurity of IS of the critical infrastructure objects will be of a recommendatory nature, because the information circulating, for example, in Automated Process Control Systems, does not belong to any type of information subject to protection in accordance with applicable law.

Cyberattacks of an external intruder are opposed by the information protection system of the information system of the critical infrastructure objects, the functions of which must include:

- protection of the network perimeter;
- ensuring the security of interconnections;
- security monitoring and audit;
- detection and prevention of attacks;
- data backup and recovery;
- security analysis and security policy management;
- data integrity control;
- protection against malicious software;
- content filtering and prevention of leakage of confidential information;
- installation of software updates;
- security administration.

According to the results of the analysis of threats and vulnerabilities [13], it can be noted that the protection of such systems should be considered in the following areas:

- protection of information and physical components of IS of the critical infrastructure objects;
- technical information protection of IS of the critical infrastructure objects;
- protection of processes, procedures and programs of information processing of IS of the critical infrastructure objects;
- protection of communication channels of IS of the critical infrastructure objects;
- suppression of spurious electromagnetic radiation;
- management and control of the protection system.

Thus, taking into account the above, it can be noted that the state of cybersecurity of IS of the critical infrastructure objects is influenced by the following factors:

- availability of the necessary and sufficient regulatory framework for cybersecurity of IS of the critical infrastructure objects;
- the presence of sources of cyber threats, their capabilities, type, purpose, motives, interest in cyberattacks;
- the presence of vulnerabilities in cyber defense systems that can be used in cyberattacks;
- the presence or absence of favorable conditions for the implementation of cyber threats;
- the attractiveness of the assets to which cyberattacks are actually directed;
- consequences of the possible implementation of cyber threats;
- the level of professional training of employees responsible for cybersecurity at all levels: organization, enterprise, industry, department, etc.

4 Conclusions

The analysis of the ecological impact of the state of cybersecurity of the critical infrastructure objects and the factors influencing the state of cybersecurity of the information system of the critical infrastructure object is performed. The method of assessing the degree of possible damage from the implementation of information security threats is considered.

The results of the analysis can be used to develop proposals and measures to avoid the effects of cyberattacks on the critical infrastructure objects.

The prospect of further research is to develop a methodology for determining the relationship between specific cyberattacks and possible quantitative damage.

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Modeling of electricity production by wind power stations of Ukraine

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Abstract. Based on the results of actual multi-year measurements of wind speeds, numerical calculations have been made of the forecast energy productions of 43 megawatt-high power stations of the leading world producers in the wind conditions of the North Black Sea region of Ukraine. The established correlation between the annual energy production of wind power station (WPS) and its basic parameters (nameplate capacity, diameter of the rotor and hub height) allowed to develop a mathematical model of the forecast annual energy production of WPS. The calculations for the mathematical model are well in line with the operational parameters of the generation. The mathematical model makes it possible to quickly and reliably select (or design) the optimal wind turbine for industrial wind power in the North Black Sea, thus taking a significant step in reducing the energy dependency, environmental protection and the transition to energy-efficient and environmentally friendly technologies enabling Ukraine to reach the level of advanced states in the development of wind energy.

1 Introduction

1.1 Problem statement

Wind energy (WE) is considered to be one of the promising sources of renewable energy at the present stage of energy development in economically developed countries. This fact guarantees the harmonious development of the planet. The Paris Agreements (Paris, December 2015) have identified renewable energy as the leading instrument in the fight against climate change on the planet. This is becoming one of the main areas of technology development in the world. Along with information and nanotechnology, renewable energy is becoming an important component of the new post-industrial technological structure. Ukraine urgently needs to switch to energy-efficient and environmentally friendly technologies, including WE.

Ukraine is a country with a long tradition of using wind. In the first two stages of the global development of renewable energy, it was a significant success. In the third stage, which began in the early 80s of the last century, Ukraine, which has a high wind potential, began the industrial use of wind with almost 40 years behind world leaders [1].

The wide-scale building of wind power stations (WPS) in Ukraine will make it possible to take a significant step in reducing energy dependence, protecting the environment and creating conditions for the country to join the European community.

By building efficient industrial WPS, the WE of Ukraine can and should be brought to the level of the advanced countries of the world with generation of 25–35% of the total energy consumption, which is of great social and economic importance. Some countries have already done so. Their share of electricity generated by WPS has reached: in Denmark – about 50 %, in Uruguay and in Ireland – more than 25 %, in Portugal – 23 %, in Germany – 20 %, in Spain – 18 % [2]. In the European Union WE since 2016 became the second (after natural gas) source in electricity generation [3]. However, this can be done only after solving the most important scientific and applied problem of the rational choice of multi-megawatt-class wind turbines (WT) for the wind conditions of Ukrainian wind parks.

1.2 The relevance and purpose of the work

Problematic issues of mathematical and computer modeling the parameters of large WT are far from being resolved. The choice of effective WT in Ukrainian wind conditions, which should generate as much commercial energy as possible and satisfy the price/quality ratio, remains open. This significantly limits the reliable selection of WT for a specific construction site of industrial WPS and does not contribute to closing Ukraine's lag behind world leaders. Therefore, the development and implementation of industrial wind energy in the strategic plan for the modernization of the electric power industry is super relevant, the most promising and priority.

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The purpose of the work is the development of methods and computer tools for optimizing the operational parameters of industrial WT in the wind conditions of Ukraine.

2 Materials and methods

2.1 The analysis of factors affecting the performance of WT

An analysis of literature on systematic studies of wind use with the main task to identifying factors that influence the efficiency of WT and the current state of research on the scientific and applied problems of mathematical and computer modeling of large WT has been carried out.

In the works of P.F. Vas'ko et al. [4–6 et al.] proposed a method for determining the performance indexes of WT in relation to the wind conditions of Ukraine. The method is based on the approximation of the empirical dependences of the wind speed repeatability using the three-parameter Weibull-Gnedenko distribution (WGD).

The most important influence factor in this method is the repeatability of wind speeds at the WT installation areas, which is one of the main components of the wind energy cadastre. It shows how much of the time during the working year winds at a certain speed are observed. It is the repeatability of wind speeds that largely determines WT performance.

Offered in the works of P.F. Vas'ko recommending for determination the repeatability by either conducting wind measurements followed by correlation according to the nearest weather stations (WS) over the past 12 to 15 years, or their approximate receipt by extrapolating data from the nearest WS, it is absolutely unacceptable for large WT. Indeed, these WS's data characterize the wind potential very approximately and cannot be used in assessing the performance of WT (WPS). The author himself agrees that the direct use of the WS's initial data causes significant errors in determining the annual generation of electricity. And confirms this with examples: for the Ochakov WS's data the results are reduced by 36 %, and for the Odessa WS – by 180 % in comparison with the open area [5].

The problem of finding the repeatability of wind speeds in the world is solved in different ways. In Japan, for example, this problem first solved it in two stages: at the first stage, the wind speed and direction were recorded for several years; on the second, a landscape model in an aerodynamic tube was purged. Based on the data obtained, the wind energy cadastre was determined for any point of the simulated landscape [7].

Much later, evaluating the sea prospect of wind around Japan for offshore WPS, measurements were organized in two places: offshore - on a platform for natural gas extraction in the Pacific Ocean at the height of 94 m, in 37 km from the coast and directly on the coast. Average annual and monthly wind speeds were calibrated for a height of 80 m above sea level to provide a comparison between offshore and land measurements. Simultaneous three-year measurements showed that the average annual sea wind speed is 70% higher than on land [8].

The atlas of winds has been developed in Denmark, in which this task is solved on the basis of models that take into account various factors of the orography of the area and data of the WS [9].

The creation of such an atlas for the wind conditions of Ukraine, as well as the use of Japanese experience, are associated with high material costs and unacceptable for Ukrainian conditions.

The problem of finding promising areas for WT installation has not yet been completely solved and remains relevant for many regions [10-12]. It requires a directed study of the wind regime of territories not only near the earth's surface, but also at different heights of the atmospheric layers near the earth.

The disadvantage in the proposed by P.F. Vas'ko method is to use the coefficient $m = 1/7 = 0.143$, taking into account the change of wind speed with height in the surface layer of atmosphere. In modern large WT, the heights of the hub vary widely and the problem of restoring the wind regime at the same height where the hub located is extremely important. A number of works are devoted to its solution.

Hellmann [13] recommended up to a height of 16 m to take the value of this coefficient equal to $m = 1/4$, and for larger heights $m = 1/5$. In studies of 50-60 years of the last century, this coefficient was assumed to be constant and equal to 0.2 [14]. Researchers from the USA recommend values of the coefficient $m = 0.23 \pm 0.03$, and when averaging wind energy, they use $m = 1/7$. Recently, experts from the USA suggest using a logarithmic dependence, which, in contrast to the power law, gives almost average values between the extreme values of wind speed at low and large heights [15].

Actual values of the power index m for different regions vary significantly from 0.1 to 0.4 and even exceed the values of 0.6 and 0.7. Various engineering methods continue to be developed [16], but as a result, none of the m values gives a good approximation of the data for different WT locations, and therefore the problem of restoring the wind regime at a given height has not yet been solved.

It is not surprising that the recommendations of P.F. Vas'ko, repeatedly cited by various authors [17, 18 et al.], who proposed a scheme of zoning of the territory of Ukraine according to average annual wind speeds, which today has become the basis for the building of industrial WPS in Ukraine, cannot be fully used for WT of multi-megawatt power. After all, the work was carried out at the end of the 50s of the last century, more than 60 years ago, and was studied on WT of low and medium power using the database of the State Committee for Hydrometeorology, when there were not enough experimental and operational data, which inevitably led to significant errors. Therefore, the work contains dubious and erroneous conclusions and recommendations. For example: "An intensive change in the technically achievable wind potential is observed up to a height of 60 m, and then the intensity decreases significantly." Or: "To ensure the capacity factor of wind turbines in Crimea at the level of 0.3, the rational value of the diameter of the rotor and the rated power of the installation are 48 m and 600 kW, respectively" [19].

As follows from the publications (and it has already become a global tendency), the efficiency of WT increases due to the growth of their rated power. Our studies show that focusing only on the rated power parameter leads to significant losses in electricity production.

On the process of choosing a WT is influenced by many factors: rated power, diameter and height of the rotor axis, operating time in certain zones of the power characteristic, capacity factor (CF). Therefore, a necessary condition for competent synthesis is only a differential approach to assessing each of the influence factors.

2.2 Electricity production of large WT in wind conditions of the Northern Black Sea region

For predictive calculations of the volume of electricity generated by any WT, it is necessary to have data about the wind potential on the area where the WPS equipped with these WTs is located, and a characteristic of the WT itself, i.e., the dependence of the electric power of the WT on the wind speed at the hub height.

The building of an industrial WPS in the Northern Black Sea region is planned in areas adjacent to the Adzhigol pilot WPS (AWPS), for which the distribution of probabilities of wind speed gradations for a period of 18 years measurements at a representative military aerodrome's WS, as well as measurements of wind speed and direction at the AWPS area by a Logger # 9200 device for 26 months at heights of 27 and 31.5 m and simultaneous measurements at heights of 31.5 and 10 m has been done.

The average wind speed over many years' studies, received from measurements data of a representative WS, reduced to the measurement conditions at the AWPS area (the windvane height 31.5 m), is 6.0 m/s. This speed is assumed to be the smallest in the calculations by different methods, which provides the most reliable forecast for a long period of WPS operation [20, 21].

For carry out the calculations of the volumes of electricity production by various WTs, the gradations of wind speeds at the height of the windvane to the hub heights of the studied WTs has been recounted. For recalculations of wind speeds from one height to another, the Hellman's power law has been used [12, 13]:

$$V_H \ / \ V_V = (h_H \ / \ h_V)^m. \tag{1}$$

Were:

V_V – wind speed at the windvane height h_V = 31.5 m;

V_H – the desired wind speed at a hub height h_H of the studied WT;

m – the coefficient of the vertical profile of the wind speed. As special tests have shown, on average for wind in AWPS area m = 0.227.

Converting the expression (1) to

$$V_H = V_V\,(h_H \ / \ h_V)^m = V_V\,(h_H \ / \ 31.5)^{0.227}, \tag{2}$$

determine the wind speed on the hub height of the investigated WT.

So, for the hub height, for example, h_H = 65 m:

$$V_H = V_V\,(65 \ / \ 31.5)^{0.227} = V_V \cdot 2.06349^{0.227} = \\ = V_V \cdot 1.17873.$$

For WT with h_H = 100 m

$$V_H = V_V \cdot 3.1746^{0,227} = V_V \cdot 1.29982 \text{ etc.}$$

Using expression (2), it is possible to convert the data of the annual distribution of wind speeds in the region of the AWPS at a height of h_V = 31.5 m into the annual distribution of the recurrence of wind speeds at different hub heights of the studied WTs.

The calculation of the annual potential power generation has been carried out according to the formula:

$$Q_n = \sum P_i \cdot T_i. \tag{3}$$

where:

Q_n – annual electricity production (AEP), MW·h;

P_i – generated power in the i-th range of wind speed V_i on the hub height, kW (according to the characteristics of the WT power);

T_i – duration of the wind speed V_i of the i-th gradation.

The duration of the year in hours was 365 days·24 hours = 8760 hours.

As a result of numerical simulation, the following predicted values for generating electricity of 43 megawatt WTs of leading world companies Leitwind, Enercon, Mitsubishi, Vestas and Fuhrlander in wind conditions of the Northern Black Sea region of Ukraine has been obtained (table 1).

The most important distinguishing feature of the obtained parameters is the use of actual multi-year real measurements of wind speeds and the distribution of their probabilities by gradations at the AWPS area. This is precisely their main difference from those hypothetical meanings that various authors used earlier. Therefore, these quantitative parameters are the basis for further computer modeling.

By numerical simulations, a multifactor dependence of the expected calculated electricity generation of a specific WT has been established.

As a result of computer simulations in first time, it has been found that, for example, LTW77 and LTW80 wind turbines with a nameplate capacity of 1.5 MW produce more electric energy than turbine LTW70 with a nameplate capacity of 1.7 MW; turbine E82-2.0 more than turbine E70-2.3; turbines MWT92-2.4 and FL 2.5-100 is more than turbine V90-3.0; and turbine V90-1.8 is more than turbine V80-2.0 (table 1). It follows that when choosing an effective wind turbine, accounting only for the index of its nameplate capacity will lead to significant losses in electricity production.

2.3 Development of a mathematical model of annual electricity production

One of the main goals of the work is a statistical study of the influence of individual parameters (explanatory factors): rotor diameter, rotor axis height (hub height), nameplate capacity, etc. on the AEP of WT and on the development of a mathematical model (MM) for this dependence. The resulting MM will make it possible to purposefully select on the world market (or design) the most effective WTs for the wind conditions of a particular area during the building of an industrial WPS.

Table 1. WTs performance parameters of some world companies.

Sl. No.	WT	*P*, MW	*D*, m	*H*, m	*Q*, MW·h	CF, %
1	LTW70	1.7	70	65	4167	28.0
2	LTW77	1.5	77	65	4471	34.0
3	—‖—	1.5	77	80	4792	36.5
4	LTW80	1.5	80.3	60	4541	34.6
5	—‖—	1.5	80.3	80	5155	39,2
6	E66	1.8	70	99	5295	33.6
7	E70	2.3	71	57	4564	22.7
8	—‖—	2.3	71	100	6221	30.9
9	—‖—	2.3	71	113	6491	32.2
10	E82	2.0	82	78	6284	35.9
11	—‖—	2.0	82	100	6899	39.4
12	—‖—	2.0	82	138	7819	44.5
13	MWT92	2.4	92	70	6746	32.1
14	V80	2.0	80	78	5440	31.1
15	—‖—	2.0	80	80	5599	32.0
16	—‖—	2.0	80	100	6095	34.8
17	V90	1.8	90	80	6126	38.9
18	—‖—	1.8	90	95	6599	41.9
19	—‖—	1.8	90	105	6806	43.2
20	—‖—	2.0	90	95	6882	39.3
21	—‖—	2.0	90	105	7171	40.9
22	—‖—	2.0	90	125	7454	42.6
23	—‖—	3.0	90	80	7855	29,9
24	—‖—	3.0	90	105	8497	32.3
25	V112	3.0	112	84	9895	37.7
26	—‖—	3.0	112	94	10622	40.4
27	—‖—	3.0	112	119	11269	42.9
28	FL2.5	2.5	80	65	5707	26.0
29	—‖—	2.5	80	85	6114	27.9
30	—‖—	2.5	90	85	7297	33.3
31	—‖—	2.5	90	100	7801	35.6
32	—‖—	2.5	90	117	8276	37.8
33	—‖—	2.5	90	141	8852	40.4
35	—‖—	2.5	90	160	9259	42.3
36	—‖—	2.5	100	85	8533	39.0
37	—‖—	2.5	100	100	9049	41.3
38	—‖—	2.5	100	117	9573	43.7
39	—‖—	2.5	100	141	10149	46.3
40	—‖—	2.5	100	160	10548	48.2
41	WTU	3.2	121	90	11665	41.6
42	—‖—	3.2	121	100	12102	43.2
43	—‖—	3.2	121	120	12759	45.5

—‖— – the same; *P* – nameplate capacity; *D* – diameter of the rotor; *H* – hub height.

At first, a correlation analysis of the statistical influence of all parameters from table 1 on the AEP *Q*, and then their pairwise influence of one on the other has been carried out [22–25].

The AEP of the turbine *Q* (MW·h) was considered as an explained variable, and explanatory factors: *X1* – nameplate capacity (MW); *X2* – diameter of the rotor (m); *X3* – the hub height (m); *X4* – CF (%).

To identify the statistical relationship between all factors of the table 1, we calculated the correlation matrix [22, 23, 25] (for this, the tool “Correlation” from the MS Excel-17 has been used). As a result, the next correlation matrix (table 2) has been obtained:

Table 2. Correlation matrix.

	Q	***X1***	***X2***	***X3***	***X4***
Q	1				
X1	0.845	1			
X2	0.928	0.765	1		
X3	0.629	0.337	0.373	1	
X4	0.706	0.229	0.676	0.732	1

From this correlation matrix it can be seen that the determining factor in the AEP of a wind turbine *Q* is the diameter of the rotor *X2* (correlation coefficient 0.928 – very high correlation); the next effect has the nameplate capacity of the generator *X1* (correlation coefficient 0.845 – high correlation); then follows CF *X4* (0.706 – high correlation) and the hub height *X3* (0.629 – average correlation) [24]. The average and high values of the correlation coefficients between the explanatory factors *X1* and *X2*, *X2* and *X4*, *X3* and *X4* indicate the possible presence of partial multicollinearity between them [26]. This means that in the further construction of the simplest linear model of multiple regression for the dependence of *Q* from *X1*, *X2*, *X3* and *X4* of the form:

$$Q = Q_0 + a_1X1 + a_2X2 + a_3X3 + a_4X4\ , \qquad (4)$$

partial multicollinearity can lead to significant instability of estimates of the model parameters Q_0, a_1, a_2, a_3, and a_4. The instability can result in an increase in statistical uncertainty – the variance of the estimates of the model coefficients, i.e., specific values of the parameters estimates can vary greatly for different samples despite the fact that the samples are homogeneous.

Given the full multicollinearity for a strict linear functional relationship between *Q* and CF, we exclude *X4* from the model, which subsequently eliminated partial multicollinearity and ensured the significance of the model by Student. We have:

$$Q = Q_0 + a_1X1 + a_2X2 + a_3X3. \qquad (5)$$

As a result of the application of “Regression” tool from MS Excel, the following summary table 3 has been obtained.

The obtained model has a high coefficient of multiple correlation *R* of the explained variable *Q* with all the explanatory factors *X1*, *X2* and *X3* (0.9939); high coefficient of determination R^2, normalized to the number of model factors (0.9870); relatively small standard error (272.09 MW·h). The model is significant as a whole according by Fisher ($P_F < 2.04\cdot10^{-37}$). The level of significance of the coefficients for explanatory factors by Student is extremely small, that is, MM has no visible limitations.

The obtained MM has the next numerical form:

$$Q = -7126.25 + 1348.594\cdot X1 + 97.526\cdot X2 + 28.811\cdot X3. \qquad (6)$$

It has a simple meaning: an increase in WT nameplate capacity by 1 MW leads to an increase in AEP by 1348.594 MW·h; an increase in rotor diameter by 1 m leads to an increase in AEP by 97.526 MW·h; increasing the hub height by 1 m leads to an increase in AEP by 28.811 MW·h. Or equivalent to the output is that an increase in the rated power by 1 MW, that a 14-fold increase in the diameter of the rotor or a 47-fold increase in the hub height.

2.4 Conclusion. Comparison of model studies with results of operation

The reliability and admissibility of accepted idealizations in the development of any dynamic model of a real system can be verified and evaluated only by comparing the results of theoretical studies with experimental data. The industrial operation of the first WPS in the wind conditions of Ukraine provided rich experimental material. In a comparative study, we use the actual results of their operation to increase the degree of credibility and validity of the conclusions.

Using the first obtained MM (6), we will estimate the possible annual electricity generation by the Dmitrovka Wind Cluster (DWC) of the Ochakov Wind Park (WP), equipped with the 12 WTs FL 2.5–100 for a five-year period (table 4).

At the up part of the table (highlighted in bold), explanatory factors of influence are presented. *X1*, *X2* and *X3* for WT FL 2,5–100 and the explained variable is calculated: annual production Q_M = 8879 MW·h and CF = 40.5%.

In the down part of the table 5 shown the actual power production Q_O with the actual values of CF [27].

The annual values of Q_O are less than the values of Q_M (and this is quite natural, because downtime is inevitable for all kinds of reasons): a minimum of 11% and a maximum of 18% (an average of 14.4% over 5 years).

Given the real actual values of the availability factor (AF), these ratios decrease from a minimum of 3.4 to a maximum of 14.7 (an average of 8.4% over 5 years), which is a completely reliable result.

Table 3. Regression analysis without CF.

Regression statistics						
Multiple R	0.993937					
R-square	0.987911					
Normalized R-square	0.986981					
Standard error	272.0896					
Account	43					
Analysis of variance						
	df	*SS*	*MS*	*F*	*Relevance F*	
Regression	3	2,36E+08	78651579	1062,388632	2,04E-37	
The remainder	39	2887278	74032,78			
Total	42	2.39E+08				
Coefficients		*Standard error*	*t-statistics*	*P-Value*	*Down 95%*	*Up 95%*
Y- interception	-7126,25	275,4174	-25,8743	3,62788E-26	-7683,33	-6569,16
X1	1348,594	128,4616	10,49803	6,34626E-13	1088,76	1608,43
X2	97,52617	4,586866	21,26205	4,66732E-23	88,2483	106,804
X3	28,81139	1,762862	16,34353	4,81734E-19	25,2457	32,3771

Table 4. Comparison of the DWC production.

Q_M, , $\frac{MW \cdot h}{\%}$	$\frac{8879}{100}$	**WT FL 2,5-100: *X1* = 2,5 MW, *X2* = 100 m, *X3* = 100 m DWC of the Ochakov WP LLC MC «Wind parks of Ukraine», Nikolayev region, Ukraine**				
CF, %	**40,5**					
Years of operation	2013	2014	2015	2016	2017	average over 5 years
Q_O, $\frac{MW \cdot h}{\%}$	$\frac{7828}{88,2}$	$\frac{7316}{82,4}$	$\frac{7275}{81,9}$	$\frac{7696}{86,7}$	$\frac{7900}{89,0}$	$\frac{7603}{85,6}$
CF, %	35,7	33,4	33,2	35,1	36,1	34,7
Ratio $Q_M > Q_O$, %	11,8	17,6	18,1	13,3	11,0	14,4
WT availability factor (AF)	0,959	0,890	0,961	0,941	0,921	0,934
Q'_M by AF	$\frac{8515}{100}$	$\frac{7902}{100}$	$\frac{8583}{100}$	$\frac{8355}{100}$	$\frac{8176}{100}$	$\frac{8296}{100}$
Q'_O by AF	$\frac{7828}{91,9}$	$\frac{7316}{92,6}$	$\frac{7275}{85,3}$	$\frac{7696}{92,1}$	$\frac{7900}{96,6}$	$\frac{7603}{91,6}$
Ratio $Q'_M > Q'_O$, %	8,1	7,4	14,7	7,9	3,4	8,4

3 Results and discussion

Comparison of the results of theoretical research and industrial operation is a convincing and indisputable proof of the legality of the computer simulation of MM developed for the first time.

An invaluable practically important feature of the developed MM is the absence of additional direct measurements of various parameters when using it, in particular, it does not require processing of weather data from representative WS, which contributes to a significant reduction in errors. And this is due to the fact that its development is based on actual long-term measurements by the automated system Logger (USA) of wind speeds at the pilot AWPS and the actual power-law index for measuring wind speed by height, which significantly increased the reliability of the calculations.

4 Conclusions

Developed for the first time by the method of computer simulation MM allows:

- quickly and reliably determine the optimal WT in terms of the parameters that are offered on the world market for a specific industrial WPS in a certain area;

- to develop and manufacture the necessary wind turbine in the absence of a world wind turbine with the necessary technical characteristics.

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Information technologies in local geophysical process management methodology

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Abstract. The authors propose an approach to assessing the possibility of stabilizing controlled impact on the ecological system, its climatic characteristics, within a limited space. Maintaining the necessary climatic parameters at an acceptable level ensures the stability of any ecosystem, the natural habitat of all living organisms, the preservation of biodiversity, including humans. The biggest potential threat is the rapid dynamics of global warming. Rising temperatures are the cause of extreme weather events, which directly affects environmental and food security. Given the urgency of the task, there is a need to study the controlled mechanism of influence on certain climatic factors in order to curb abnormal dynamics and bring the ecosystem into a state of stable equilibrium. The approach proposed by the authors is based on modeling the process of reducing the risk of crisis situations with abnormal fluctuations in ambient temperature. The mathematical model is represented by a system of ordinary differential equations, which is a consequence of the adaptation of Lagrange equations to oscillatory processes. The state of the studied climatic factor is matched by some random process, the amplitude of which depends on the values of the components of the control vectors and the function of external influence. The experimental parameter is ambient temperature. The problem was solved using statistical data for the Zhytomyr region (Ukraine). The main results of the simulation are to obtain a set of control vectors and functions of external influence, which will be taken into account in the information system for monitoring the environmental situation.

1 Introduction

The development of various spheres of human activity, especially technology, especially information, clearly contributes to the positive growth of the level of civilization in general, but at the same time carries a negative component, which at first seems invisible, and then often simply ignored. This component is the current environmental problems, the exacerbation of which is associated with the processes of negative anthropogenic impact. For example, the impact on natural processes of climate change in many regions of the globe, the trend of global warming, which, uncontrollably developing, lead to terrible catastrophic consequences.

This article is a continuation of previous research by the authors [1-4] and their colleagues [5-16] in the field of improving the efficiency of management decisions, environmental safety issues, development of appropriate software, etc.

The main purpose of previous author's study [2] is the presentation of the conceptual approach to the development of software tools for the analysis and synthesis of a geophysical monitoring systems model. To achieve this goal, two approaches are proposed to describe the interaction "humanity - the environment". The first approach is based on the use of "game principles". The "game principle" of humanity and the environment can be described using a system of ordinary differential equations, pre-determined with the phase coordinates and "controls" of the players, as "control" affects the phase coordinates. At the heart of the second approach, the environment is considered as a system characterized by fluctuations under the influence of anthropogenic load. Depending on the level of external influence, the system either returns to equilibrium or as a result of increasing the amplitude of oscillations is destroyed and not restored, which is equivalent to a catastrophic state. The paper [2] substantiates the model of the geophysical monitoring system based on the Lagrange equations for an oscillatory system with two or more degrees of freedom in the "factor space", and the model based on "game principles". Also shown the block diagram algorithm of the analysis and synthesis of geophysical monitoring systems models.

Some environmental, information, and other aspects of geophysical monitoring systems models are presented in papers [17-38].

For example, the author of [22] writes, that the

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technosphere metabolizes not only energy and materials but information and knowledge as well. The article first examines the history of knowledge about large-scale, long-term, anthropogenic environmental change. Also, the author proposes that knowledge infrastructures for the Anthropocene might not only monitor and model the technosphere's metabolism of energy, materials, and information but also integrate those techniques with new accounting practices aimed at sustainability.

The paper [26] presents a variational approach to solving direct and inverse problems based on the joint use of mathematical models and data monitoring of processes of geophysical hydro-thermodynamics. This approach is used to solve problems related to environmental protection.

A good illustration of interconnected geophysical processes in the environment on the example of the Arctic region is shown in paper [30].

A lot of game models for particular issues of human-environment systems are shown in papers [31-38] and others. For example, authors [33] to illustrate the applicability of their results analyze stochastic models of evolutionary games, Lotka–Volterra dynamics, trait evolution, and spatially structured disease dynamics. Analysis of these models demonstrates environmental stochasticity facilitates the coexistence of strategies in the hawk–dove game, but inhibits coexistence in the rock–paper–scissors game and a Lotka–Volterra predator-prey model.

The extreme urgency of environmental (climatic) problems gives a significant impetus to the study of such processes in ecological systems. Therefore, in order to study the mechanism of climate control, there is an urgent need to develop mathematical and simulation models using information technology (including artificial intelligence systems) in the interests of the safe development of society. The complexity of creating a perfect information system for managing global climate parameters leads to a narrowing of the task to the local level of a particular region.

The aim of the article is to develop a conceptual approach to modeling natural processes in the problem of studying the mechanism of climate control.

2 Methods

To solve this problem, we present the environment in the form of a system, which is characterized by fluctuations under the influence of anthropogenic load. In this case, depending on the level of external influence, the system either returns to equilibrium or, as a result of increasing the amplitude of oscillations, is destroyed and not restored, which is equivalent to a catastrophic state [1]. Since the result of general warming is an increase in the average temperature of the planet's atmosphere, it is advisable to choose the climatic parameter is the temperature. Accordingly, the mathematical model should describe the process of temperature control within the specified limits for a certain time of year in the selected local space.

The construction of the mathematical model assumes the availability of the necessary information about the factors influencing the temperature of the atmosphere, as well as the nature of the seasonal temperature dynamics of the selected research region: Zhytomyr (Ukraine), winter, December 2019. It is taken into account that solar activity, in general, is a slowly changing function of time [17], as well as the temperature component due to the distribution of radioactive substances in the earth's crust, the cloud layer is generally stable over time, natural emissions (e.g. volcanic activity) of pollutants in the atmosphere is absent, the movement of air masses is moderate.

Analysis of statistical data allows us to outline the main assumptions of the model: 1) seasonal dynamics of the region's atmospheric temperature is fluctuating; 2) temperature oscillating process is random; 3) surface air temperature is a function of such factors as solar activity, distribution of radioactive substances in the earth's crust, air mass movement, the stability of the cloud layer, emissions of pollutants of natural and anthropogenic origin, etc.

In the first approximation, it is expedient to consider the surface temperature of the region as a function of the concentration of emissions of harmful substances of anthropogenic origin and time at fixed values of other parameters of influence and external function of the thermal influence of anthropogenic origin. Thus, the task is to study the dynamics of the component of the temperature regime of the surface layer of the atmosphere of the selected region, which is due to the level of emission concentrations of pollutants of anthropogenic origin (mobile and stationary emission sources) and their thermal effects.

3 Results and discussion

3.1 Formulation of the problem

Consider the temperature θ as a function of two parameters: $\theta(t, c_S)$, where c_S is the average monthly concentration (mg/m^3) of emissions of harmful substances into the atmosphere of anthropogenic origin, $t$is the time (from the first to the last day of the selected month). At a fixed value of c_S, we obtain the dependence of $\theta(t)$, Fig. 1.

Since the studied oscillatory process is random, it is expedient to describe it using a set of systems of second-order differential equations, which are a consequence of the adaptation of Lagrange equations to oscillatory systems [2]. In this case, one phase variable $c_S$is fixed, and the second phase variable $\theta(t)$ is controlled.

Then, within the framework of this goal, it is necessary to obtain a set of control vectors of the form $\vec{\varphi} = \begin{bmatrix} a_0 \\ a_1 \\ .. \\ a_n \end{bmatrix}$, as well as the function of the external thermal influence $W(t)$ for each implementation of the random process $\theta(t)$.

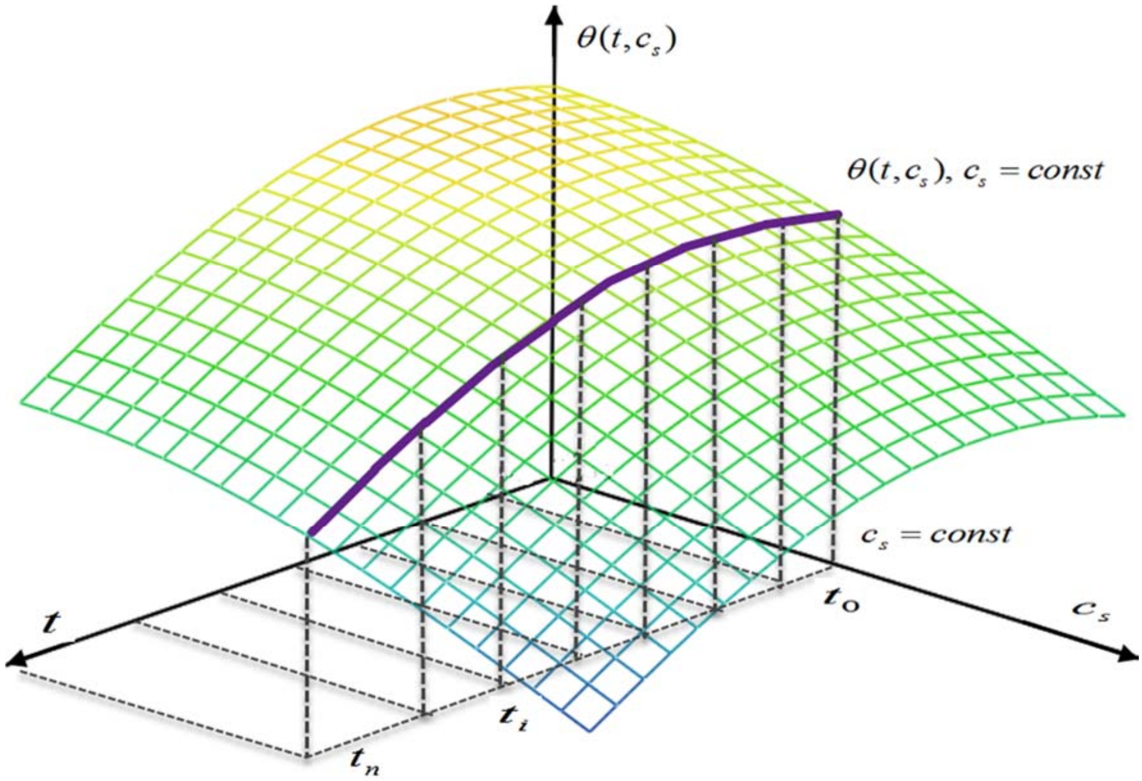

Fig. 1. Function $\boldsymbol{\theta(t, c_S)}$ at a fixed value of $\boldsymbol{c_S}$.

The values of the components of the set of control vectors $\vec{\varphi}$ must unambiguously ensure that the phase variable $\theta(t)$ is within certain limits, then the dynamics of the variable $\theta(t)$ is controlled. In contrast to mathematical models that extrapolate the dynamics of the studied process by a polynomial of degree n, the proposed model not only allows you to control the dynamics of the local process, but also to establish the type of function of thermal external influence.

3.2 The algorithm

The algorithm for controlling the temperature in a given space (region) is reduced to the following procedural steps: 1) generation of a set of control vectors $\vec{\varphi}$ and determination of the function of external thermal influence $W(t)$, at which the dynamics of temperature $\theta(t)$ does not exceed the specified limits (the authors solved this problem using the developed software in MathCAD [39] and Python [40]); 2) based on the obtained simulation results, a decision is made (for example, by an artificial intelligence system) to regulate the concentration of pollutant emissions into the atmosphere for a given region; 3) after the introduced corrections, the cycle of generation of control vectors and determination of the function of external thermal influence $W(t)$ is repeated until the dynamics of the variable $\theta(t)$ is stable within the selected limits.

The resulting system of differential equations is solved by the numerical Runge-Kutta method with a fixed step. The components of the control vector $\vec{\varphi}$ have a uniform distribution law.

3.3 The computational experiment and discussion

Zhytomyr (Ukraine) and the Zhytomyr region (see Fig.2) were chosen for the computational experiment.

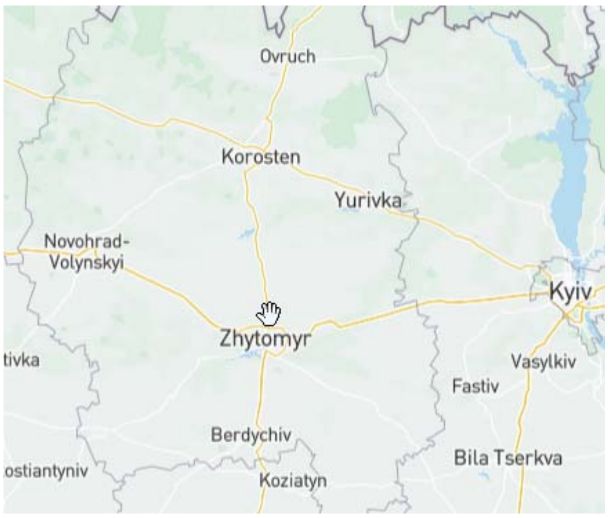

Fig. 2. Location of the research area: Zhytomyr (Ukraine), and Zhytomyr region.

Table 1 presents the statistical values of atmospheric air temperature provided by the meteorological complex (WMO Index 33325. Latitude: 50.270 °; longitude: 28.630 °) for December 2019.

After adapting the Lagrange equations [2] to the oscillatory system, we obtain the usual linear,

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inhomogeneous differential equation of the second order:

$$\frac{d^2\theta(t)}{dt^2} + A_0\frac{d\theta(t)}{dt} + A_1\theta(t) + A_2c_S = A_3W(t), \quad (1)$$

where A_0, A_1, A_2, A_3 - coefficients to be determined;

$W(t)$ - the function of external thermal influence, which is to be determined;

c_S is the average concentration of pollutants in the surface layer of the atmosphere in the study area for a fixed period.

Table 1. Atmospheric air average temperature values for December 2019, t ˚C.

1 decade	2 decade	3 decade
0.2	2.1	6.6
-1.3	2.2	5.6
-0.5	0.1	6.7
-0.4	0.5	7.8
1.9	4.2	5.5
0.8	7.2	3.7
0.7	6.5	1.1
4.2	8.4	0.1
3.6	6.7	-0.9
0.6	2.9	-3.6
**	**	2.0

Note that the components of the control vectors are different for each implementation of the dynamics of $\theta(t)$.

The dimension of the components of the control vectors and the functions of the external thermal influence, respectively:

$A_0 = [s^{-1}]$; $A_1 = [s^{-2}]$; $A_2 = [s^{-2}mg^{-1}m^3]$; $A_3 = [s^{-2}]$;

W(t) = [˚C].

The dimensionality of these coefficients can also be expressed in terms of units, namely [m] and [s]. That is, because of the spatial and temporal dimensions.

After the introduction of auxiliary functions, equation (1) will become a system of ordinary differential equations of the form:

$$\begin{cases} \frac{dy_2}{dt} = -A_0y_2 - A_1y_1 - A_2c_s + A_3W(t) \\ \frac{dy_1}{dt} = y_2 \end{cases}, \quad (2)$$

where $\theta(t) = y_1, \theta'(t) = y_2$ is the function of temperature change over time and the function of the rate of temperature change over time, respectively.

Fig. 3 presents the dynamics of statistical temperature values for December 2019, in accordance with the data in table 1.

For further processing of statistical data, we perform interpolation of statistical data by a power polynomial of the third-order by means of MathCAD.

The result of interpolation and the dynamics of statistical temperature data are presented in Fig. 4; time *t* – days of the month with a step of 0.31 days (total 101 steps).

The fragment of the matrix *Ys(t)*^{T} with the results of interpolation, is presented in Fig. 5

The next stage of modeling involves determining the composition of surface temperature that depends on the average monthly concentration of emissions of harmful substances into the atmosphere and the function of external thermal influence.

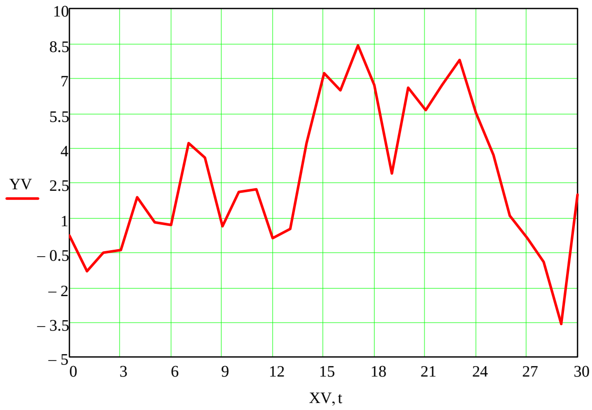

Fig. 3. Dynamics of *YV* statistical temperature values for December 2019, according to Table 1.

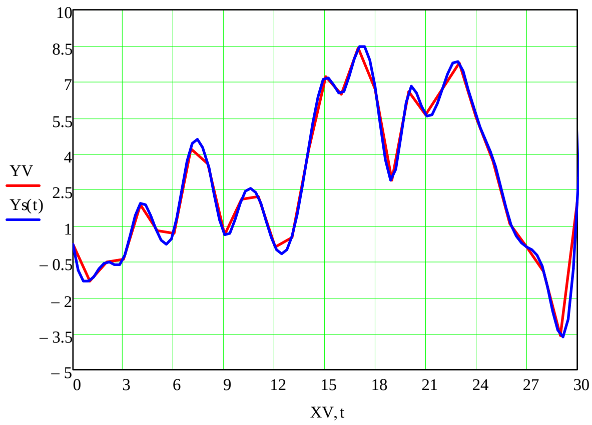

Fig. 4. The result of interpolation *Ys(t)* and the dynamics of *YV* statistical temperature values for December 2019.

$Ys(t)^T =$

	0	1	2	3	4
0	0.2	-0.835	-1.292	-1.332	-1.115

Fig. 5. The fragment of the matrix *Ys(t)*^{T} with the results of interpolation.

Preliminarily, we establish the form of the slowly changing time function *P(t)*, which reflects the dynamics of the temperature component as a result of the combined influence of other factors (the main factor is seasonal solar activity).

The results obtained using the MathCAD system, allow us to represent the function *P(t)* as follows:

$$P(t) = 0{,}1737\text{-}0{,}2792t + 0{,}0679t^2 - 0{,}002t^3 \quad (3)$$

The graph of the slowly changing time function *P(t)* is presented in Fig. 6.

Some of the values of this function are represented by a fragment of the TREND^T matrix in Fig. 7.

Then the rapidly oscillating component of the BOOSK temperature, which is due to the anthropogenic factor of influence will have the form shown in Fig. 8.

Accordingly, the values of the rapidly oscillating component of the BOOSK temperature, which is due to the anthropogenic factor of influence, are represented by a fragment of the BOOSK matrix in Fig.9.

From the graph in Fig. 8, the upper and lower limits of the range of oscillations of the fast-oscillating temperature component BOOSK, which is due to anthropogenic factor, and requires the determination of many control vectors $\vec{\varphi}$, providing a set control range for each implementation of the oscillatory process described by equation (1).

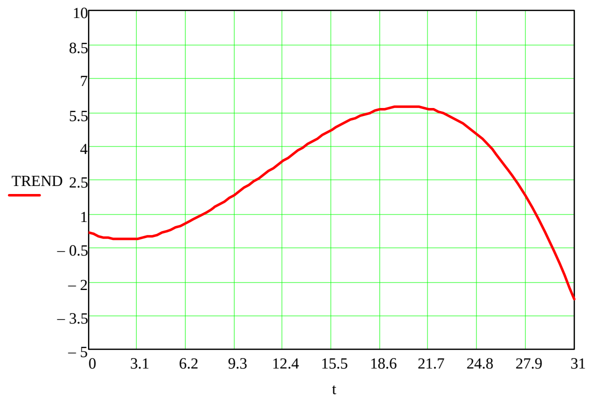

Fig. 6. The graph of the slowly changing time function *P(t)*.

$TREND^T =$

	0	1	2	3	4
0	0.174	0.094	0.026	-0.029	-0.072

Fig. 7. The fragment of the TREND^T matrix.

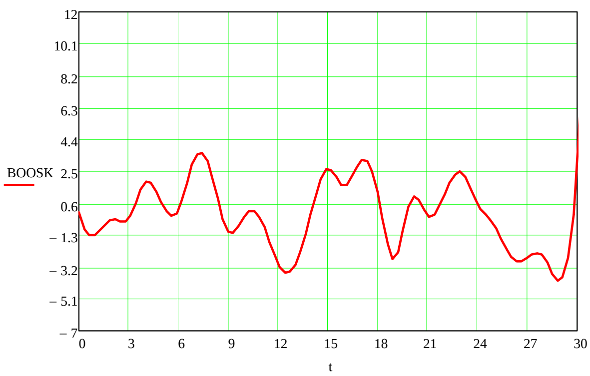

Fig. 8. The rapidly oscillating component of the BOOSK temperature, which is due to the anthropogenic factor of influence.

The final stage of modeling involves multiple implementations of the computational algorithm in MathCAD or Python. The experiment performed 901 iterations of the computational algorithm and obtained, respectively, 901 control vector $\vec{\varphi}$, which provides the dynamics of $\theta(t)$, i.e. the rapidly oscillating temperature component, which is due to an anthropogenic factor in a given range of fluctuations for a given month.

For example, three of the 901 calculated control vectors are shown in Table 2 (numbering begins with zero iteration).

Table 2. The values of the components of the control vectors $\vec{\varphi}$ for iterations № 0, № 110, № 700.

Control vector $\vec{\varphi}$ component	Iteration № 0	Iteration № 110	Iteration № 700
a_0	1.624×10^{-6}	1.298×10^{-6}	3.731×10^{-7}
a_1	2.986×10^{-6}	1.180×10^{-6}	4.574×10^{-6}
a_2	3.591×10^{-6}	1.343×10^{-6}	3.777×10^{-6}
a_3	2.967×10^{-6}	3.997×10^{-6}	5.086×10^{-7}

BOOSK=

	0
0	0.026
1	-0.928
2	-1.318
3	-1.303
4	-1.043
5	-0.698
6	-0.426
7	-0.377
8	-0.483
9	-0.485
10	-0.122
11	0.634
12	1.436
13	1.905
14	1.801
15	...

Fig. 9. The value of the rapidly oscillating component of the BOOSK temperature, which is due to the anthropogenic factor.

As noted above, the components of the set of control vectors $\vec{\varphi}$, ie a_0, a_1, a_2, a_3, are distributed according to the uniform law.

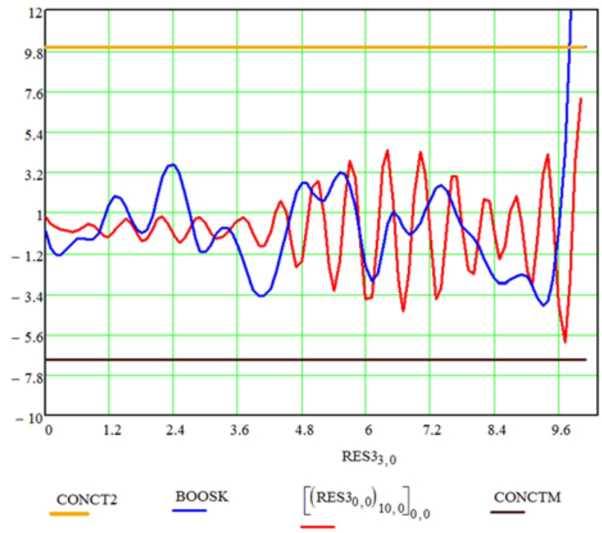

Fig. 10. The value of the rapidly oscillating component of the BOOSK temperature, which is due to the anthropogenic factor of influence. *CONCT2* - the upper limit of the range of temperature fluctuations, is + 10˚C. *CONCTM* - the lower limit of the range of temperature fluctuations is -7˚C. *RES3*$_{10.0}$ is a simulated implementation (as an example of iteration №10) of the dynamics of a function whose oscillation limits correspond to the set range. *RES3*$_{3.0}$ - days of the month with a step of 0.31 days.

In this case, according to the simulation results, the coefficients A_0, A_1, A_2, A_3 of the differential equation (1) will have the form: $A_0 = a_0 + 0{,}0005$; $A_1 = a_1 + 20{,}8$; $A_2 = a_2 + 0{,}4$; $A_3 = a_3 + 5{,}4$, and the function *W(t)* of external thermal influence for the controlled process of dynamics of $\theta(t)$ will have the form:

$$W(t) = (0{,}49t)^{2{,}1} Sin(10{,}2t) + 1{,}5tCos(9t\text{-}7) + 30 \quad (5)$$

The estimated average concentration c_S of pollutants in the surface layer of the atmosphere of the selected region is 400 mg/m^3.

Fig. 10 shows the dynamics of the rapidly oscillating temperature component, which is due to the anthropogenic factor of influence and is limited by the corresponding range of oscillations and simulates the results of the controlled process in the same range that was set.

The analysis of Fig. 10 shows that the set of solutions of equation (1) in general reproduces the dynamics of the rapidly oscillating temperature component, which is due to the anthropogenic factor of influence by emissions of pollutants into the surface layer of atmospheric air of the studied region.

For most of the period (31 days), the phase development of the simulated process is synchronous with the statistical. Partial amplitude discrepancies are observed.

In this case, a significant part of the statistical fluctuations is absorbed by the simulated process.

4 Conclusions

Based on the simulation results, it is proved that the set of solutions of equation (1) in general reproduces the dynamics of the rapidly oscillating temperature component, which is due to the anthropogenic factor by emissions of pollutants into the surface layer of atmospheric air of the studied region. The complexity of creating a perfect information system for managing global climate parameters leads to a narrowing of the task to the local level of a particular region.

For most of the period (31 days), the phase development of the simulated process is synchronous with the statistical. Partial amplitude discrepancies are observed.

In this case, a significant part of the statistical temperature fluctuations is absorbed by the simulated oscillatory process of the temperature regime.

Since the most important factor is to maintain a controlled temperature within the specified limits, the proposed mathematical model is adequate.

Unlike mathematical models that extrapolate the process, the proposed mathematical control model allows not only to determine the set of process control vectors but also to establish the form of the function of external thermal influence.

At small values of the component of the control vectors $\vec{\varphi}$, the process is easily controlled and there is a 901 process control vector within the specified limits. Therefore the criterion for the proven reliability of the obtained models is the power of the set of control vectors.

As the simulation results show, there are certain limits to the values of the control vector components and, as a consequence, the set of control vectors themselves can be significantly reduced when approaching the limit values of the control vector components.

That is, for example, from 901 computational iterations, only one control vector $\vec{\varphi}$ can correspond at fixed input parameters.

Since the simulation results are obtained solely through the use of information technology, the number of iterations of the computational algorithm is limited by hardware resources.

Thus, with the increase of computational steps in the Runge-Kutta method to 1000 and setting the number of iterations to more than 3000, there is a conflict between the computational algorithm and the hardware on which the computational experiment was conducted.

Further development of the proposed approach involves the use of artificial intelligence systems and the application to other similar geophysical phenomena of regional nature.

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The influence of environmental tax rates on the Levelized cost of heat on the example of organic and biofuels boilers in Ukraine

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Abstract. In December 2019, the European Commission officially presented The European Green Deal, a new EU economic development program aimed at achieving climate neutrality on the European continent by 2050. Many previous global, European, and national programs also aim to reduce emissions of pollutants into the atmosphere. In this context, one of the ways to reduce emissions is the development of alternative energy sources (in particular the wider use of biofuel boilers) and increasing environmental tax rates. When choosing the optimal heating boilers, the practice of using the levelized cost of heating (LCOH) indicator is common. Environmental pollution tax (as a component of LCOH) is calculated for the three most common types of boilers (for Ukrainian boiler houses) with a capacity of 4.65 to 58 MW, burning natural gas, coal, and fuel oil, as well as low-power boilers burning organic and biofuels, for existing environmental tax rates, for projected increasing in 4 times (according to the bill) and subject to the introduction of minimum and maximum rates in EU countries. It is established that at the current environmental tax rates in Ukraine there are almost no economic incentives for the introduction of technologies to reduce the concentration of pollutants in emissions, but increasing environmental tax rates may change this situation. This, in turn, once again suggests that changing environmental tax rates can be an effective tool for achieving sustainable development goals.

1 Introduction

At the present stage of development, humanity uses so many resources that for the future in the near future we will lack the resources of our planet. Therefore, the global concept for solving this problem has become "sustainable development" - a development that meets the needs of the modern generation without harming future generations.

In a situation of stability, two competing pillars of sustainable development: the economic and the environmental one, are in the lead – as long as the basic needs of most people are satisfied [1].

Ukraine has made a number of commitments to protect the environment and reduce pollutant emissions [2, 3, 4]. The EU has adopted Directive 2015/2193 of the European Parliament and of the Council of 25 November 2015 on the limitation of emissions of certain pollutants into the air from medium combustion plants [5]. As this Directive is a supplement to Directive 2010/75 / EC (for installations over 50 MW), Ukrainian medium-capacity installations will have to prepare to comply with its standards.

Among budgetary and fiscal instruments for stimulating and ensuring sustainable development, environmental taxes occupy a prominent place.

In scientific publications and legislation of different countries, you can find different definitions of "environmental taxes". In particular, the legislation of Ukraine contains two such definitions that to some extent complement each other:

1) Environmental tax - a nationwide mandatory payment, which is based on the actual amount of emissions into the atmosphere, discharges of pollutants into water bodies, waste disposal, the actual amount of radioactive waste temporarily stored by their producers, the actual amount of generated radioactive waste and the actual the amount of radioactive waste accumulated before April 1, 2009 [6].

2) Environmental tax - a tax with a specific object of taxation, which clearly has a negative impact on the environment, or is aimed at taxing certain activities, goods or services so that the cost of environmental protection can be included in their price and/or guide producers and consumers for activities that are best for the environment [7].

Many countries around the world have long used this powerful toolkit, many are just beginning, but common to most countries is that legislation in this area is constantly improving, including changes in environmental tax rates.

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Ukraine is no exception. As of December 2020, there are 3 different bills in the Parliament of Ukraine, about increasing the rates of environmental tax in Ukraine.

Given that one of the industries that are significantly affected by environmental tax rates is heat, it is advisable to conduct a study on the effects of changes in environmental tax rates on economic and environmental pillars of sustainable development.

2 Literature review

This article is a continuation of previous research by the authors [8, 9]. A lot of work has been devoted to the study of the impact of environmental taxes on sustainable development goals. Consider the main ones for 2018-2020

The study [10] employs the GTAP-E-Power model with additional improvements to include non-CO 2 emissions to examine the impacts of such a policy on the Vietnamese economy. Authors show, that higher tax on coal would foster the extension of renewable energy sectors faster than the impacts resulted from increasing tax on petroleum products. The increased demands by the private sector for electricity generated from renewable sources signal the potential for sustainable development of the renewable electricity generation sectors in Vietnam.

In paper [11] authors consider from an environmental policy-maker perspective, how carbon reduction policies impact the economic competitiveness of the manufacturing sector and note that the obtained results offer support to both environmental policy-makers and corporate production and sustainability managers to determine whether it is technically feasible and profitable to replace traditional scheduling strategies with environmentally friendly scheduling strategies.

Article [12] study how new sustainable business models in the energy sector work, and investigate their risk profile, especially concerning the risk of regulatory changes.

Paper [13] investigates the determinants of environmental tax revenue.

Findings [14] clearly indicate that (a) the proportion of tourism energy consumption to national energy consumption in China will increase over time, (b) the impacts of a carbon tax on China's tourism fossil energy consumption, electricity consumption, and energy intensity will become increasingly weak, (c) the impacts of a carbon tax on electricity use are greater than the impacts on fossil fuel consumption, and (d) the impacts of different carbon taxes on the levels of energy consumption and energy intensity will vary to a significant degree between the different tourism sectors.

The study [15] introduced an original interdisciplinary assessment model of performance-based contracting for SO_2 emission control in Chinese coal power plants that involves key environmental policies including command-and-control regulations, market-based approaches, and administrative measures, as well as technology, market, and capital variables (Fig. 1).

Paper [16] describes a new carbon price mechanism with full emission coverage which developed within the framework of a global computable general equilibrium model (GTAP-E-PowerS) to enhance the capacity and accuracy for climate change and energy policy assessment. The results indicate that South Africa is likely to move to low carbon and sustainable economy with such a policy.

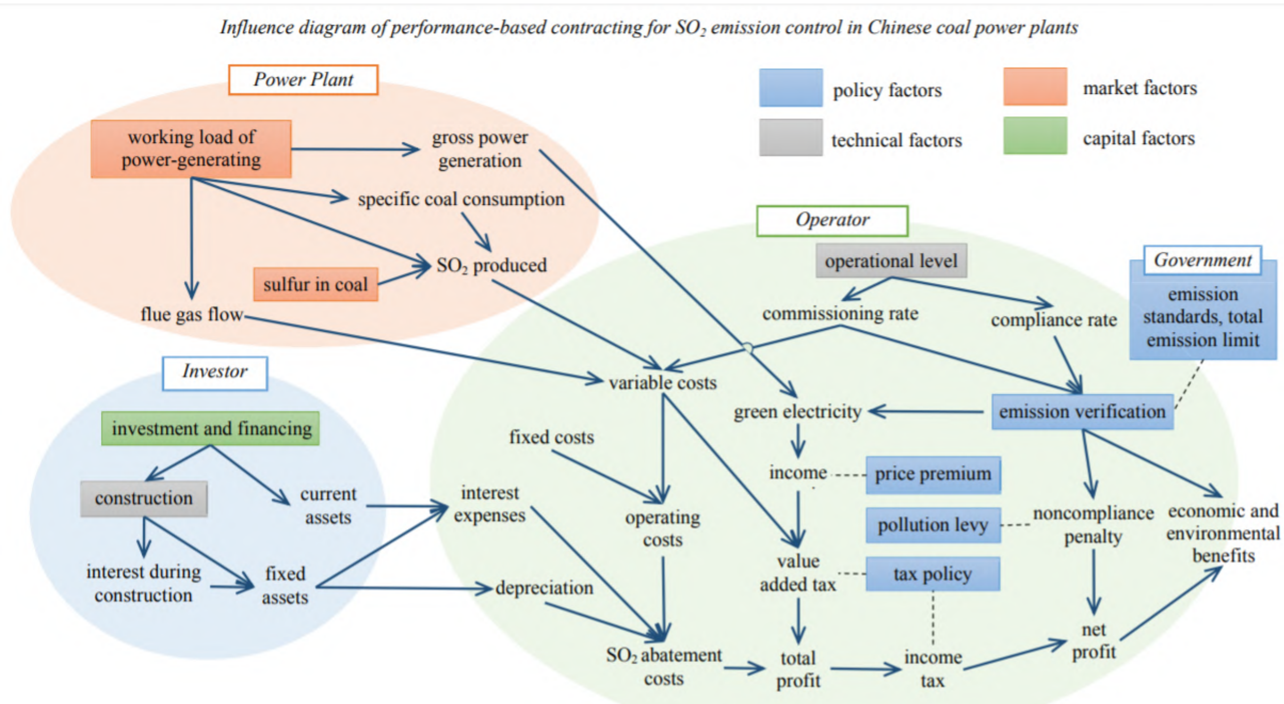

Fig. 1. Stakeholders, uncertain factors, and interactions in performance-based contracting for SO2 emission control in Chinese coal power plants. Arrows indicate the dependence; dashed lines indicate the environmental policy boundaries [15].

 https://doi.org/10.1051/e3sconf/202128009012

Article [17] shows, that the required carbon tax begins from $ 5.29/ton in 2020 and grows on average by 3.5% reaching up to $ 35.83 per ton carbon towards the year 2075.

In paper [18] is writing, that towards the reduction of greenhouse gas emissions, a carbon tax has been already introduced in 40 countries, but owing to different carbon prices among countries, there are potential risks of carbon leakage, where manufacturers transfer production operations to countries with lower taxes to pursue lower costs.

The paper [19] deals with the greening of tax systems in the European Union (EU) and reviews the achievements of the Baltic States in relation to greening their tax systems and implementing the sustainable energy development goals set by the EU's energy policies.

The Levelized cost of energy (LCOE) and its analog for heating - Levelized cost of heating (LCOH) are the widespread indicators, which is often used for cost comparisons for energy and heating generation [20-23 and other].

Paper [20] shows, that the application of the “traditional” LCOE formula has some problems, therefore authors present a modification to the traditional LCOE formula, which considers energy price rise and thus allows more accurate LCOE calculations.

The study [22] presents a new approach and methodology, which developed which uses the United Kingdom “audited” data, published in company accounts, that has been obtained from Companies House, to determine more accurate LCOE estimates.

The paper [23] provides the techno-economic comparative analysis of eight Biomass Integrated Gasification Combined Cycle (BIGCC) system designs that include the technology options of the biomass gasification, the power generation, and the CO_2 emission control. Results show that the LCOE of these systems is ranged from 0.131 $/kWh to 0.259 $/kWh.

3 Methods

The initial data for calculating emission taxes are the annual consumption of a particular type of fuel by the boiler plant (determined by the thermal capacity and efficiency of the boiler plant, its operating time, and installed capacity utilization factor), fuel calorific value, pollutant emission factors and eco tax rates.

Table 1 shows the emission factors of pollutants during the combustion of different fuels without the use of technologies to reduce emissions of pollutants.

Table 2 shows the tax rates for air emissions of certain pollutants by stationary sources of pollution, which include boilers of heating boilers, according to Articles 243.1 and 243.4 of the Tax Code of Ukraine [6].

In November 2019, 3 bills (draft laws) on increasing environmental tax rates were submitted to the Verkhovna Rada. The bill on Amendments to the Tax Code of Ukraine to increase environmental tax rates and implement European principles of modernization of Ukrainian industry 2367-1 of November 18, 2019, proposes to increase tax rates for air emissions from 2030. According to this bill the growth rate will be gradual: from 01 January 2021 to December 31, 2022, inclusive, tax rates are 75% of the rates provided by the bill, in 2023-2024 - 80%, in 2025-2026 - 85%, in 2027-2029 - 90%.

Bill 2367 of November 1, 2019 proposes to increase tax rates by 4 times (Table 2).

In EU countries, tax rates differ dozens of times, in Poland some of the lowest in the EU, in Sweden - the highest (Table 3), the rate - 34.64 UAH/EUR.

Sweden levies the highest carbon tax rate at €112.08 (US$ 132.17) per ton of carbon emissions, followed by Switzerland (€83.17, $98.08) and Finland (€62.00, $73.11). You’ll find the lowest carbon tax rates in Poland (€0.07, $0.08), Ukraine (€0.33, $0.39), and Estonia (€2.00, $2.36).

Table 1. Specific pollutant emissions from fuel combustion

Fuel	Specific pollutant emissions, kg/t fuel				Fuel pollutant emission index, g/GJ			
	NO_x	**SO_x**	**CO_2**	**PM_{10}**	**NO_x**	**SO_x**	**CO_2**	**PM_{10}**
natural gas	2.127 [*]	0 [*]	1943.4 [*]	0.00 [*]	64.31 [28]	0 [28]	58748 [28]	0 [*]
coal	2.065 [*]	51.30 [*]	1918.9 [*]	47.20 [*]	100.9 [28]	2506 [28]	93740 [28]	2305.9 [*]
fuel oil	2.494 [*]	19.40 [*]	2973.0 [*]	15.74 [*]	64.311 [28]	500.26 [28]	76662,63 [28]	405,81 [28]
wood chips	0.928 [*]	0.112 [*]	1020 [*]	0.903 [*]	91 [25]	11 [25]	100000 [26]	88.5 [25]
wood pellet	1.36 [*]	0.187 [*]	1700 [*]	0.51 [*]	80 [25]	11 [25]	100000 [26]	30 [25]
sunflower husk pellets	1.36 [27]	3.2 [27]	1816.1 [27]	0.091 [*]	75.56 [*]	207.4 [27]	100893 [27]	5.911 [*]
straw briquettes	1.38 [27]	2 [27]	1544.2 [27]	0.171 [*]	89.03 [*]	127.4 [27]	99624 [27]	10.892 [*]
firewood	1.228 [*]	0.149 [*]	1512 [*]	1.195 [*]	91 [25]	11 [25]	112000 [*]	88.5 [25]
peat briquettes	2.76 [*]	2 [*]	1860.3 [*]	0.51 [*]	178.1 [*]	127.4 [*]	106000 [*]	30 [*]

* calculated by the authors on the basis of data [24, 25, 26, 27, 28, 29]

Table 2. Actual and project tax rates for air emissions of some pollutants, UAH/t

Pollutant	Existing tax rates	Bill 2367-1 of November 18, 2019					Bill 2367 of November 1, 2019
		2021-2022	2023-2024	2025-2026	2027-2029	2030	
NO_2	2451.84	2758.32	2942.21	3126.10	3309.98	3677.76	9807.36
N_2O	2451.84	2758.32	2942.21	3126.10	3309.98	3677.76	9807.36
CH_4	138.57	155.895	166.29	176.681	187.07	207.86	554.28
PM_{10}	92.37	103.92	110.85	117.776	124.70	138.56	369.48
SO_2	2451.84	2758.32	2942.21	3126.10	3309.98	3677.76	9807.36

Table 3. Tax rates for air emissions of certain pollutants in Ukraine, Poland and Sweden

Pollutant	Ukraine	Poland	Sweden	Poland	Sweden
	UAH/t			EUR/t	
NO_x	2451.84	4387.8	18359.2	126.67	530
CO_2	10.00	2.4	3882.5	0.07	112.08
SO_2	2451.84	4387.8	10392	126.67	300

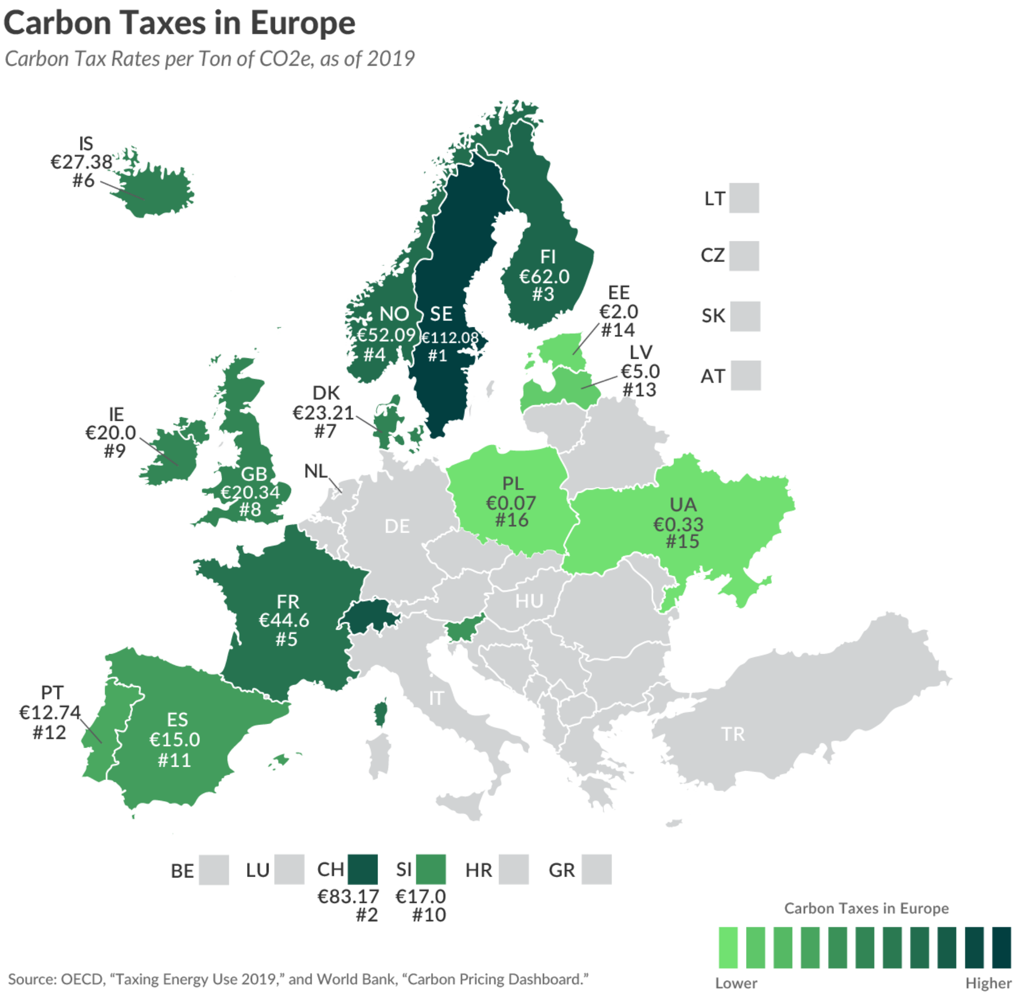

Fig. 2. Carbon Taxes in Europe [30].

It is proposed to calculate the levelized cost of heat taking into account the environmental tax, by the expression:

$$LCOH_{T_{eco}} = \frac{\sum_{t=1}^{N} \frac{I_t + M_t + F_t + T_t^{eco}}{(1+r)^t}}{\sum_{t=1}^{N} \frac{H_t}{(1+r)^t}} \quad (1)$$

where:
I_t is investment expenditures in year t
M_t is operations and maintenance expenditures in year t
F_t is fuel expenditures in year t
H_t is energy (heat) generation in year t
r is discount rate
N is lifetime of the technology
T_t^{eco} is environmental tax.

Thus, the change in LCOH due to the environmental tax is determined by the expression:

$$\Delta LCOH_{eco\ tax} = LCOH_{T_{eco}} - LCOH \quad (2)$$

Taxation of pollutant emissions in Ukraine is carried out in accordance with Section VIII of the Tax Code of Ukraine [6].

The expenditures included in the formula for determining the levelized cost of heat are divided into permanent (administrative) and variable (operational) costs.

4 Results and discussion

For the study, the authors used data from [9, 31], which was calculated the LCOH and the contribution of environmental tax in LCOH for three types of boilers with a capacity of 4.65 to 58 MW, burning natural gas, coal and fuel oil, which the most common for boiler houses of Ukraine [9], and for boilers on different types of biofuels with a capacity of 1 MW [31].

$\Delta LCOH_{eco\ tax}$ is calculated to an increase in eco tax rates by 50% and 4 times (according to Ukrainian bills) and the eco tax rates in Poland (one of the lowest in the EU) and Sweden (highest in the EU).

The contribution of the environmental tax to the LCOH indicator depending on the different rates of the environmental tax, which were given in tables 2 and 3, are presented in the table. 4

Table 4. $\Delta LCOH_{eco\ tax}$ at eco tax rates of Ukraine (current and project), Poland and Sweden for boilers on different fuels

Boiler, its power	Fuel type	LCOH without eco tax	$\Delta LCOH_{eco\ tax}$					
			Ukraine	Ukraine, Bill 2367-1 of November 18, 2019		Ukraine, Bill 2367 of November 1, 2019	Poland	Sweden
				from 2021	from 2030			
KV-GM-4-150, 4.65 MW	natural gas	1047.34	3.33	3.42	3.68	13.34	1.84	994.61
	fuel oil	1278.33	9.93	10.72	13.11	39.72	17.18	1359.99
KV-TS-4, 4.65 MW	thermal coal	705.27	36.75	40.68	52.48	146.98	87.38	1865.55
KV-GM -50-150, 58.2 MW	natural gas	1027.65	3.38	3.47	3.73	13.54	1.87	1009.66
	fuel oil	1241.06	9.85	10.64	13.01	39.41	17.05	1349.54
KV-TS -20, 23.2 MW	thermal coal	708.42	37.31	41.30	53.28	149.24	88.72	1894.23
KV-2.0, 2 MW	natural gas	1090.08	3.40	3.49	3.75	13.61	1.88	1015.15
ARS 1000, 1 MW	anthracite	720.45	38.61	42.80	55.40	154.42	93.49	2090.03
	wood	529.64	7.30	7.48	7.99	29.22	5.17	2313.97
	wood chips	687.35	6.59	6.75	7.26	26.34	4.95	2041.22
	natural gas	1125.28	3.79	3.90	4.20	15.18	2.16	1167.51
ARS 1000 BM, 0.98 MW	wood pellets	634.14	5.58	5.71	6.09	22.32	3.32	1774.06
	wood	492.70	6.71	6.87	7.34	26.84	4.75	2125.62
Gefest Profi-P 1000, 1 MW	straw briquettes	521.04	7.03	7.34	8.25	28.12	5.63	1793.16
	wood pellets	637.96	5.58	5.71	6.09	22.32	3.32	1774.06
	sunflower husk pellets	379.18	7.75	8.15	9.33	31.00	6.84	1798.75

In case of eco tax rates increasing for emissions of all pollutants in 4 times, the mentioned component of the LCOH will increase for natural gas boilers - from 3.40 to 13.34 UAH/Gcal, for fuel oil boilers will increase from 10 to 40 UAH/Gcal, for coal-fired boilers - from almost 40 to 150 UAH/Gcal.

For biofuel boilers the growth will be from 6-7 to 22-28 UAH/Gcal, namely from 5.58 to 22.32 UAH/Gcal for wood pellets boilers, from 7.75 to 31.00 UAH/Gcal for sunflower husk pellets boilers.

At current eco tax rates $\Delta LCOH_{eco\ tax}$ is from 0.3% for gas boilers to 5.3% LCOH, for biofuel boilers from 0.9% (wood pellets) to 2.0% (sunflower husk pellets). If the eco tax rates are increased in 4 times, it will be from 1.2% (gas boilers) to 21% LCOH (coal boilers).

Poland has the lowest environmental tax rates in EU, so the environmental component of LCOH (taxes), for their case will increase for fuel oil boilers by 70%; for coal-fired boilers it will more than double, and for natural gas boilers it will generally halve (due to a lower CO_2 tax rate).

If the highest rates in the EU (Sweden) are used, the environmental component LCOH (tax) for coal-fired boilers will be in 2.6 times larger as the investment, operating and fuel costs component, for gas boilers, the environmental component will be 95%, and for fuel oil boilers - 105%, for biofuel boilers – will be in 2.8-4.7 times larger. The largest contribution is the tax on CO_2 emissions, the tax rate of which is 388 times higher than in Ukraine. The environmental component LCOH (tax) under these conditions is tens of thousands of times higher than at existing tax rates in Ukraine.

With the introduction of Sweden tax rates, the cheapest will be heat from high-power gas boilers - 2040 UAH/Gcal, heat from boilers burning some types of biofuels (2728, 2843 UAH/Gcal) becomes more expensive even than heat from fuel oil and coal boilers (2570-2638 UAH/Gcal). This will stimulate further introduction and use of gas boilers, which contradicts the goal of increasing the share of local biofuels.

In many countries around the world, including EU countries, biofuels are considered CO_2 neutral and no CO_2 tax is levied. Subject to the introduction of Swedish tax-free rates for CO_2 emissions, the environmental component of LCOH (taxes) for biofuel boilers will range from 7.2 to 16.1 UAH/Gcal.

5 Conclusions

In December 2019, the European Commission officially presented The European Green Deal, a new EU economic development program aimed at achieving climate neutrality on the European continent by 2050. Many previous global, European, and national programs also aim to reduce emissions of pollutants into the atmosphere. In this context, one of the directions is the development of alternative energy sources (in particular the wider use of biofuel boilers) on the one hand and increasing environmental tax rates on the other (which will lead to reduced emissions).

Many leading countries in the world have long used changes in environmental tax rates as one of the tools to achieve sustainable development goals. Ukraine is also trying to join them. As of December 2020, there are 3 different bills in the Parliament of Ukraine, the adoption of which will change the rates of environmental tax in Ukraine, sometimes in times. However, as of December 30, 2020, none of these bills have been adopted.

It is established that at the current environmental tax rates in Ukraine there are almost no economic incentives for the introduction of technologies to reduce the concentration of pollutants in emissions, but increasing environmental tax rates may change this situation, and environmental tax rates will be an effective tool for achieving sustainable development goals in Ukraine.

The authors calculated the environmental component of LCOH (taxes) at eco-tax rates of Ukraine (current and project), Poland, and Sweden for boilers on different fuels. If the highest rates in the EU (Sweden) are used, the environmental component LCOH (tax) for all fuel type boilers will be equal to the investment, operating and fuel costs component for natural gas and fuel oil boilers, in 2.6-4.7 times larger for coal and biofuel boilers. The cheapest will be heat from high-power gas boilers - 2040 UAH/Gcal, heat from boilers burning some types of biofuels (2728, 2843 UAH/Gcal) becomes more expensive even than heat from fuel oil and coal boilers (2570-2638 UAH/Gcal). This will stimulate further introduction and use of gas boilers, which contradicts the goal of increasing the share of local biofuels.

Only increasing the rates of the eco-tax without its smart administration (for example, benefits, refund of part of the funds for the eco-modernization, etc.) will not ensure the effective use of these tools to achieve sustainable development goals.

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Human factor in emergency occurrence at NPP during the pandemic COVID-19: new potential risks and recommendations to minimize them

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Abstract. COVID-19 pandemic is an emergency that spread across the planet. It threatens lives and health of the population, with many dead and injured. Also, during pandemic there was (and continues to be) a violation of normal living conditions, significant material damage to economies of different countries. Quarantine restrictions affected social, educational, cultural and spiritual spheres of society. There is an urgent threat to operation of critical infrastructure as the pandemic led to large numbers of hospitalized or self-isolated people and being treated at home. At present, the operation of critical infrastructure, and in particular nuclear power plants, is strategically important for the proper functioning of any country. Also, the research describes causes of emergencies at nuclear power plants and identifies another factor - the mass disease of NPP personnel or their relatives on COVID-19. It is determined that timely detection and appropriate work to restore mental health during the pandemic is no less important area of work along with providing medical care to population. Stress associated with uncertainty, threat to health, can have negative consequences for well-being and mental health of workers. Depression, emotional exhaustion, anxiety, irritability, suicidal thoughts, etc. can also be consequences. Socio-psychological support especially for critical infrastructure workers is important to promote mental health during COVID-19 pandemic. Recommendations for socio-psychological support of NPP personnel were developed. Specialized mobile applications are described as convenient and economical way for primary psychological care.

1 Introduction

COVID-19 spread around the world. It is not only health problem, but it also affects the world economy and the environment in various ways. Although COVID-19 causes serious damage to society but environment state is improved as pollution decreased significantly. COVID-19 imposed restrictions on the movement of people and vehicles in various countries and suspended some industrial activities. Thus, emissions of greenhouse gases, nitrogen dioxide, carbon, etc. decreased. However, COVID-19 also has negative consequences for environment due to large amount of household and medical waste [1, 2, 3].

COVID-19 and the quarantine restrictions caused by it became an emergency situation that significantly affected well-being of people, families, communities. People experience such situations in different ways, someone without visible violation of ability to function at work or in a close relationship. That is, such people recover quickly, using their own strength. Others need only basic support to improve their well-being. And in the third, there are mental health problems (or the same problems that existed before) that require specialized psychological support. Therefore, response to emergencies is significantly different in each case, as each person experience the same event differently and has different resources and opportunities to recover [4].

Indeed, the pandemic is a challenge not only to physical health but also to mental health. The Secretary-General of the United Nations called on governments to address mental health needs of the coronavirus pandemic immediately, warning that COVID-19 could provoke crisis in this area. An important area for strengthening of mental health strategy during COVID-19 outbreak is psychological support of population, especially health

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workers. Stress associated with uncertainty, threat to health, can have negative consequences for well-being and mental health of employees, and can result in depression, emotional exhaustion, and anxiety. Therefore, recovery of mental health and psychosocial aspects during outbreak of COVID-19 are extremely relevant and require special research [5].

COVID-19 disease made many significant changes in activities of various enterprises and organizations, many employees were transferred to remote mode using digital technologies. However, there are enterprises, especially of critical infrastructure (nuclear power plants, thermal power plants, chemical facilities, etc.), where it is impossible to perform official duties remotely and you need to be in the workplace. Critical infrastructure facilities can include enterprises, institutions and organizations, regardless of ownership, which: operate and provide services in the energy sector, chemical, transport, information and communication technologies, electronic communications, banking and financial sectors; provide services in areas of life support of the population, in particular in areas of centralized water supply, sewerage, electricity and gas supply, food production, agriculture, health care; communal, emergency and rescue services, emergency services; included in the list of enterprises of strategic importance for the economy and safety of the state; objects of potentially dangerous technologies and productions.

Today in Ukraine there is developed nuclear energy industry. Its operation is provided by 4 operating nuclear power plants (NPPs): Zaporizhzhya NPP, Rivne NPP, South-Ukraine NPP and Khmelnytska NPP. They are objects of increased danger [6, 7], and therefore issue of their safe operation, civil protection of population and environment on the territory of the station is always relevant.

In Ukraine, NPPs consistently provide more than half of electricity production, which is important for economic and social development of the country and compliance with international obligations. In [6] it is noted that experience of NPP operation shows that causes of accidents and incidents are somehow related to behavior of people (human factor), namely - with their attitude to safety problems. Therefore, the focus of NPP management is, first of all, human resources, style and management methods. An important issue for the NNEGC “Energoatom” is to maintain health of its employees at the appropriate level and timely detection of diseases. This is especially important given that work of nuclear workers is associated with increased hazards, including radiation. To preserve the health and efficiency of NNEGC “Energoatom” NPP personnel, conducts constant explanatory work among the personnel about vital need to take care of one's own health, to objectively assess condition of well-being, timely treatment by doctor. In the NNEGC “Energoatom” units where high-risk work is performed, mechanisms of psychophysiological examination of employees are used. Psychophysiological examination is carried out in order to: ensure safety, reliability and efficiency of NPP operation through optimization of personnel; reduction of labor losses and accident prevention; selection of persons who, by the state of professionally important psychophysiological qualities, are able to master the profession and perform their duties effectively; working life of staff.

Monitoring of the psychophysiological condition of NPP employees is carried out during initial and periodic medical examinations. It does not reveal current situation of possible accumulation of fatigue and distress. Also, psychological climate controlin the teams is rare. Its constant implementation (taking into account recommendations of experts in psychophysiological laboratories of nuclear industry) will predict occurrence and influence of distress factors, as emphasized in the publication [7].

In 2020 for the first time unprecedented phenomenon of voluntary social isolation emerged as a way to effectively combat spread of COVID-19 virus. Following recommendations of the World Health Organization the most governments introduced quarantine measures. They severely restricted movement of citizens and effectively led to their self-isolation. Public, social, professional, scientific, religious life of people changed emphasis towards online presence. An integral part of the current quarantine is the Internet, mobile communications, Smart-phone, social networks and other digital technologies [5].

Therefore, number of problems need new understanding and research: professional activities of staff during the pandemic; human mental health; training of workers during the pandemic; social and psychological support of population and especially staff of critical infrastructure during the pandemic, etc.

2 Analysis of previous publications

Various aspects of software and hardware development for impact assessing of potentially dangerous objects on the environment are described in [8-30]. Features of prevention, occurrence and liquidation of emergencies, in particular at NPPs are considered in publications [7-43]. Provision of psychological support and assistance to victims in emergencies is described in the researches [4, 5, 44-49]. The use of digital technologies for psychological support of personality is considered in publications [50-55]. However, it is important to study impact of COVID-19 on emergencies at Ukrainian NPPs, psycho-traumatization of population during the pandemic and the search for tools and recommendations for socio-psychological support of population and NPP personnel.

The research aim – is to investigate new challenges of emergencies risk increasing at Ukrainian NPPs as result of the human factor during COVID-19 pandemic and to develop recommendations for their minimization.

3 The research results

3.1 Pandemic caused by COVID-19 as emergency

Every day there are various emergencies in different parts of the world: floods, earthquakes, landslides, hurricanes, dust storms, accidents, catastrophes and other natural disasters. In the beginning of 2020 the World Health Organization declared health emergency of international importance. And a pandemic was declared in early March. The pandemic caused by COVID-19 and quarantine restrictions also caused global socio-economic problems.

In the scientific literature [4] "emergencies" are understood as events that go beyond the ordinary life of man and pose a threat to their physical and mental integrity, lead to destruction of social structure of communities and social order. Such situations usually arise as result of accidents, catastrophes, natural disasters, terrorist acts, armed conflicts, epidemics, and others. Emergencies can spread to different scales in covered area, number of victims and so on. The Civil Protection Code of Ukraine [56] states that "an emergency situation is a situation on separate territory or a water body which is characterized by violation of normal living conditions caused by catastrophe, accident, fire, natural disaster, epidemic, epizootic, epiphytosis, use of means of destruction or other dangerous event that led (can lead) to threat to life or health of the population, large number of dead and injured, significant material damage, as well as impossibility of living in such territory or object, conducting economic activity on it. Also, victims of an emergency are people whose health was damaged in result of emergency.

In [56, 57] the *classification of emergencies* is given: 1) emergencies are classified by the nature of origin, degree of distribution, amount of human losses and material damage; 2) depending on nature of events origin types of emergencies are determined: (man-made nature; natural nature; social; military); 3) the following levels of emergency situations are determined depending on the consequences extent caused by emergency situation, amount of technical and material resources necessary for their elimination: state; regional; local; object; 4) classification of emergencies according to their levels is established by the Cabinet of Ministers of Ukraine [56].

The study [1] noted that level of air pollution is one of the important indicators that affects the transmission of COVID-19 and mortality. Therefore, COVID-19 can affect environmental factors and vice versa. Critical review of research of relationship between COVID-19 and the environment can formulate a current state of knowledge and guidance for further research. Critical analysis of scientific publications was conducted and 57 articles on interaction between COVID-19 and the environment were selected. Four research clusters were identified (Fig. 1): 1) COVID-19 and environmental degradation; 2) COVID-19 and air pollution, 3) COVID-19 and climate/metrological factors; 4) COVID-19 and temperature. The impact of COVID-19 on the environment and impact of environmental indicators on transmission of COVID-19 are considered. It is concluded that COVID-19 pandemic improved environment quality. During pandemic and quarantine restrictions imposed by the governments of different countries led to significant reduction in environmental pollution and improved environmental quality. There is a sharp reduction in carbon emissions, reduced air pollution, reduced noise pollution and beach pollution. Various environmental factors contributed to both spread and reduction of COVID-19 transmission [1].

Collective work [58] emphasizes that COVID-19 pandemic and its consequences can be rehearsal for fight against climate change in the future. The pros and cons of COVID-19 in terms of environmental impact were identified: improving air quality, improving surface water quality, reducing noise pollution and greenhouse gas emissions.

Humans, their life, health and safety are recognized in Ukraine as the highest social value. Geographical environment is the natural basis of her life [59, 60]. Mankind has extensive knowledge in the fields of geography, physics, chemistry, biology, and others, actively uses them in social production at the present stage of its development. At the same time it still remains dependent on natural manifestations of the nature forces. Processes that are beyond human control and are related to the life cycle of our planet and influence of external factors can cause emergencies of various kinds. Danger to humanity can be hidden in man-made objects and processes in addition to forces of natural origin: enterprises of various sectors of economy and technological processes, critical infrastructure, defense facilities, etc. Nuclear energy, use of electricity and heat, circulation of hazardous substances cause potential danger of emergencies. They are commonly called man-made [61].

Large proportion of industrial enterprises is potentially dangerous objects associated with the production, storage, transportation and processing of hazardous substances on the territory of Ukraine. Man-made emergencies risk at such enterprises is extremely high as the level of equipment wear in most enterprises is approaching critical. Accidents at such facilities are usually accompanied by environment pollution with toxic substances as well as fires and explosions [59].

People affected by emergencies can need medical care, psychological, material, legal assistance, social and information services, etc. [4]. Emergencies can lead to human casualties, damage to human health, significant material loss and disruption to people's living conditions. They can cause mental and psychological trauma to victims or their relatives and friends.

3.2 Causes of emergencies at nuclear power plants: domestic and foreign experience

Scientists in the publication [7] emphasizes that various negative circumstances (infringement processes, safety and mode of operation, natural disasters, technological accidents and incidents of sabotage terrorist purposes, fighting, etc.) at the plant can lead to different emergencies that pose a significant risk to environment, health of personnel and surrounding areas population. It is determined the nature of the action, the scale of destruction of buildings, the size of the material and economic losses by carrying out an analysis of emergency situation on the threat to human life. The most dangerous are emergencies that cause radioactive and chemical pollution. Confirmation of this are tragic experience of accidents at the Three Mile Island NPP (USA, 1979), Chornobyl (Ukraine, 1986), Fukushima-1 (Japan, 2011). Such emergencies can lead to significant radioactive contamination, cause significant damage to public health, natural and agroecological systems, etc.

In Ukraine, various normative documents emphasize importance of population protecting from emergencies.

The source [56] states that "civil protection is a function of the state aimed at protecting population, territories, environment and property from emergencies by preventing such situations, eliminating their consequences and providing assistance to victims in peacetime and in special periods".

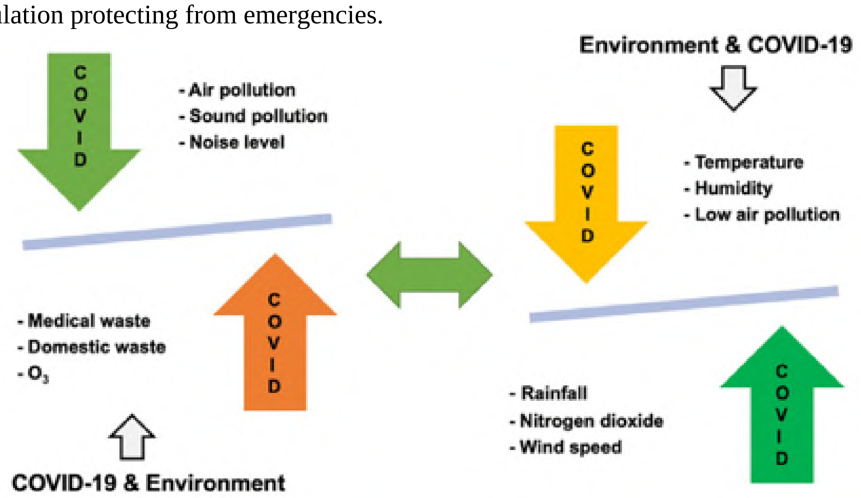

Fig. 1. Interaction of COVID-19 and environment (4 research clusters) [1].

Nuclear safety is ensured by consistent implementation of 5 defense levels in depth strategy. Implementation of measures last defense in depth - the fifth and, partly, in the fourth - in support of measures designed accident management. It is provided by system of emergency preparedness and response NNEGC "Energoatom" in accident and emergency at the plant. Important state task is to mitigate or prevent action of various factors and minimize accidents risk at nuclear power plants, as these stations are economically justified and necessary for normal development of industry, but only if the technical level of nuclear and radiation safety of nuclear power plants is provided [7].

Currently, Ukraine's nuclear energy sector is supplied by 4 operating nuclear power plants: Zaporizhzhya, Rivne, Khmelnytska and South-Ukraine. Analysis of violations at NPPs is carried out in accordance with industry standard "ND 306.2.100-2004 - Regulations on procedure for investigation and accounting of violations in operation of nuclear power plants". It is developed in accordance with international requirements. Work of investigating and accounting for violations in operation of nuclear power plants is very important for safety. This is an element of safety culture. Investigation and accounting of NPP operational events are part of professional culture of nuclear industry with its first steps [62].

Operation of NPPs of Ukraine is carried out in accordance with legal requirements. Their main purposes are: protection of health from possible damage associated with irradiation with sources of ionizing radiation; safe operation of NPPs; environment protection. NPP meets safety requirements when its radiation exposure does not exceed the limits prescribed dose irradiation plant personnel and the public, as well regulations on gas-aerosol emissions and liquid discharges, content of radioactive substances in the environment. NNEGC "Energoatom", NPPs and other separate units within it fully comply with requirements of nuclear and civil protection legislation - in terms of their obligations and responsibilities for development and implementation of emergency preparedness and response measures, civil protection [43].

According to experts from the World Association of NPP Operators, NNEGC "Energoatom" occupies a worthy place in the global nuclear community in terms of nuclear safety and organization of safety culture. Each Ukrainian NPP has examples of positive practices on safety culture. It corresponds to the best world experience, gained during implementation of international projects, etc. The company supports and encourages formation of safety culture among its employees and employees of other organizations that perform work for the NPP. The Council of nuclear safety culture was created in order to determine goals, objectives, optimize implementation of safety culture principles in the operation of Ukrainian NPPs exchange experience, assess the current level of safety culture at NPPs, as well as to review, approve and further monitor the implementation of specific actions of the NPP and the Company as a whole [6].

National emergency prevention organizations, together with research institutes, conduct joint research to increase Europe's preparedness to respond any radiation pollution caused by an emergency or long-term pollution, as part of the joint European EURANOS project. Threat of potentially dangerous situations remains even taking into account improvement of emergency preparedness and response systems emergency situations, the use of automated systems for monitoring technological parameters and the radiation situation at nuclear power plants [7].

Causes of emergencies at nuclear power plants [7]: violation of technological processes; violation of safety and operating conditions; natural phenomena and man-made accidents and incidents; fighting; sabotage for terrorist purposes. Small amount of news and events that take place at the nuclear fuel cycle facilities are posted on the site [63]. Also, more detailed information on nuclear and radiation events can be found in the IAEA Unified System for Information Exchange in Incidents and Emergencies.

Based on the analysis of scientific sources and specialized sites [7, 41, 43, 63] we will describe the occurred incidents at various nuclear power plants over the past few years. They were officially reported to the public.

1) in December 2015 at the Leningrad NPP (Russia) there was an accident at the second power unit. Pipeline burst in the turbine hall and the radioactive steam in it filled the room and spread outside the power plant. Cloud of radioactive release reached the territories of Estonia and Finland;

2) in January 2017 power supply of substation and the first power unit of the Armenian NPP was interrupted as result of accident on high-voltage power line. The accident cause on the power line was ice. It was formed as a result of frosty weather. There were no power outages;

3) in January 2017 in Japan a construction crane used for repair work at the Takahama NPP fell from strong wind on the second power unit and the spent nuclear fuel pool. The crane damaged part of outer wall and roof of the pool;

4) in February 2017 as a result of an explosion at the French nuclear power plant Flamanville, five workers were poisoned. The reactor reacted in operation was immediately shut down, although the explosion occurred outside the scope of nuclear fuel facilities;

5) in July 2018 in the city of Chernavode (Romania) there was an automatic disconnection from the National Energy System of the first power unit of the Romanian NPP. However, this sudden shutdown of the reactor did not affect the population, the station staff and the environment, and was most likely caused by an erroneous signal;

6) in July 2018 in Belgium at the Tihange NPP due electromechanical damage there was an emergency shutdown of the second reactor. The failure occurred due to problems with connection to the high-voltage network;

7) in September 2018 in Japan on the island of Hokkaido there was an emergency due to an earthquake. There was failure in operation of the main energy source that feeds pools cooling system with used nuclear fuel at the Tomari NPP. There was no radiation leakage;

8) in October 2018 in the west of Finland the first power unit of the Olkiluoto NPP of the company-operator Teollisuuden voima was disconnected due to turbine failure. It caused disconnection from the Finnish state grid. This incident did not affect nuclear safety of the facility.

9) in April 2019 a fire broke out at Rivne NPP in the evening. Due to damage to the 7AT communication transformer with its subsequent combustion the first 330 kV bus system was disconnected and the №3 power unit was disconnected accordingly. Rescuers put out the fire around 10 p.m. This event was classified as “zero” according to the international scale of events at the INES nuclear facilities;

10) in January 2020 an emergency situation occurred at the Ikata NPP (Japan). At the third NPP power unit, one of the 48 control cassettes was accidentally removed during withdrawal of fuel assemblies and no radiation leakage occurred.

The source of data on dangerous events that occurred at Ukrainian NPPs are reports on the investigation of violations in their work and the information system “Violations in the work of nuclear power plants”. Information reports on violations in the operation of Ukrainian NPPs during 2020 are presented on the website of the State Scientific Technical Center for Nuclear and Radiation Safety [41]. Fig. 2 shows number of violations in operation of Ukrainian NPPs during 2005-2019. Distribution of violations in operation of NPPs that occurred during 2019 by sites of Ukrainian NPPs is as follows: at Zaporizhzhya NPP - 6 violations; at Rivne NPP - 5 violations; at Khmelnytska NPP - 1 violation; at the South-Ukraine NPP - 1 violation [40]. There is a deviation from the normal mode of operation (abnormal event) during a failure in the operation of the NPP as stated in [43]. It may be caused by equipment failure, external influences, personnel errors or deficiencies in the procedure. 34 anomalous events were recorded in 2017, during the investigation of violations and deviations in the operation of Ukrainian NPP power units. Their distribution was: mechanical damage - 12 events; faults in the electrical part - 12 events; staff errors - 6 events; not defined - 2 events; faults in control and measuring systems - 1 event; hydraulic influences - 1 event. In the event of accidents at nuclear power plants in Ukraine number of NNEGC “Energoatom” guidelines are used to ensure safety and protection of population and territories from emergencies, to prevent their occurrence and to effectively eliminate the consequences.

Significant part (54%) of all violations in the operation of Ukrainian NPPs that occurred during 2019 led to reactor shutdown, unloading or disconnection of the unit from the network (categories P05, P08). It reduces residual design life of equipment important for safety, and reducing regulated number of load cycles of the reactor unit. Another 16% are violations (categories P03, P10) associated with the inoperability of security channels [40].

Also number and quality of cyber attacks on critical infrastructure are currently increasing. As an example Stuxnet is a computer worm that was created to attack Iran’s nuclear facilities and was discovered in June 2010 [64]. Using operating system vulnerabilities and the human factor, Stuxnet successfully hit more than 1,000 centrifuges at a uranium enrichment plant. Also in December 2014 a cyber attack was carried out on automated workplaces of nuclear power plant operators in South Korea [65]. As part of these cyberattacks thousands of phishing emails with malicious code were sent and valuable information was stolen. In autumn 2019 systems of the Kudankulam NPP station (the most powerful NPP in India) were attacked with one of the versions of the virus known as DTrack [66]. This malware was specifically compiled for distribution and operation in the

 https://doi.org/10.1051/e3sconf/202128009013

power plant network. Dtrack infected only the administrative network and did not reach the critical internal network used to control the plant's nuclear reactors. Thus threat of terrorist and cyber-terrorist acts against nuclear power plants exists and acquires new features every day.

We agree with the authors of the publication [7] who emphasize that human factor, inattention, equipment failure, natural disasters and fatal coincidence can lead to an accident at a nuclear power plant with human casualties.

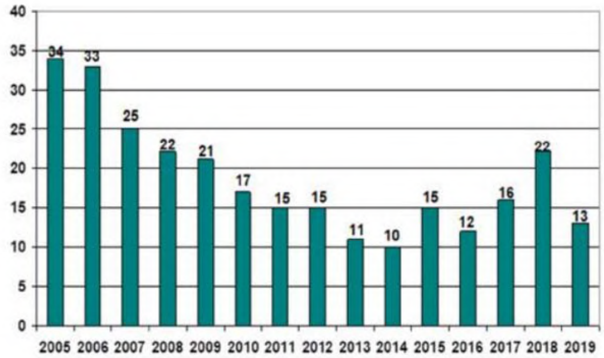

Fig. 2. Statistics on violations number in the operation of Ukrainian NPPs for 2005-2019 [40].

It should also be noted that Ukraine is still at the very beginning of creating of modern integrated system for responding to safety incidents and crises related to critical infrastructure. Thus, only in 2016 in the national legislation of Ukraine appeared definition of basic term for this area "critical infrastructure" [67].

NPP operation experience shows that accidents and incidents causes are somehow related to people (human factor) - with their attitude to safety issues. Therefore, NPP management focus is human resources, management style/methods, socio-psychological climate in production teams. NNEGC "Energoatom" is involved in process of safety culture forming in all staff beginning from the highest administrative level. There are permanent safety culture committees at the NPP. These are collegial bodies that coordinate NPP units activities in terms of maintaining and raising the level of safety culture [6].

Currently number of special measures are developed to prevent and eliminate accidents at Ukrainian NPPs, an Emergency Response System was created, special instructional materials were prepared, and so on. For example, Rivne NPP Emergency Response System is an interconnected set of human and technical resources, organizational and technical activities carried out by NPP personnel under the direction of the administration. It is done in order to prevent or mitigate impact of accidents or emergencies on personnel, the public and the environment. Main tasks of Rivne NPP emergency response system are following: ensuring readiness for localization and liquidation of accidents and other emergencies at NPPs and liquidation of their consequences; response to accidents and emergencies; implementation of measures to protect the station staff, population and environment; main tasks of the Rivne NPP emergency response system for population and environment protection; enhanced monitoring of radiation indicators of environment and irradiation of population; forecast of radiation doses of population in observation area; informing central and local executive bodies and local self-government bodies about monitoring results and forecasting of radiation doses to population; providing recommendations to central and local executive bodies and local self-government bodies on countermeasures to protect population [68].

Various measures are constantly taken to prevent emergencies at nuclear power plants. For example, mandatory psychological testing is important during employment and transfer to other positions for NPP personnel. It is stated in requirements for employeeson official websites [69]. Competition for various positions is held in following stages: 1) documents receipt; 2) psychological testing; 3) professional testing; 4) interview with commission.

The official website of Rivne NPP [70] contains a lot of information about the operation of the station and the work of staff. One of site publications states that person is a key factor in any production and its safety and enterprise production indicators directly depend on personnel working. The Rivne NPP staff development department has been operating for a year to improve the enterprise management system, improve and coordinate work with staff, assist managers in working with staff, monitor the socio-psychological climate in the power plant and improve safety culture through staff development. The personnel development department is entrusted with such important and urgent tasks as selection of personnel for certain positions, identification and development of leadership potential, organization of planning of work with personnel in departments, training of managers in management psychology and assistance in working with personnel. Specialists of the human factor management group of the personnel development department carry out number of important works with the operational personnel of the power plant on a regular basis. In addition to standard procedures, such as selection for positions at recruitment and transfer, routine surveys of working operational staff are carried out to ensure that position is suitable for professionally important qualities of the operational staff. Psychocorrectional trainings, sessions of psychoemotional unloading in a specially equipped room are carried out for employees of operational services, in case of reduction of their professionally important psychophysiological qualities. Classes are periodically held on the following topics to maintain the qualifications of operational personnel: safety culture, communication, methods of error prevention, conflict resolution, behavior in emergency situations and others. Another urgent task for the department specialists is psychological support operational personnel training on full-scale simulator [71]. Seminars for managers and their reserve on business psychology are very popular communication, leadership, teamwork and time management. For nuclear energy, openness and trust between staff and managers is important, because favorable psychological atmosphere in the team creates conditions for identifying hidden shortcomings that can be a prerequisite for serious incidents. Another important part of the specialists' activities of the personnel development department is socio-psychological climate in the NPP monitoring through anonymous questionnaires, surveys, and interviews in the units. Twice a year the specialists organize meeting of the Safety Culture Council at the Rivne NPP chaired by the General Director. Its main goal is to define strategy, plan, monitor and coordinate actions aimed at developing a safety culture. In March 2020 the survey was conducted on the Rivne NPP as whole to determine level of development of safety culture. The survey results confirmed high level of development of safety culture at the enterprise. The administration of Rivne NPP realizes that motivated, professional employees are valuable resource of organization. Staff needs constant careful work, improvement and expansion of professional knowledge and formation of safety and production culture, because safety issue at all levels of NPP activity is a priority [70].

Interview with the Rivne NPP CEO [72] highlighted main issues concern public and the power plant staff today. “Today nuclear power plant is not only the largest energy company in the region, but also local largest employer and taxpayer. Life of its entire satellite city practically depends on Rivne NPP. The main thing is that staff and equipment work reliably and safely. During pandemic we spend a lot of money to purchase personal protective equipment for staff, tests, preventive measures, including the isolation of operational staff - hotel accommodation, meals. In addition, mode of operation of our company changed significantly. It applies to certain activities such as staff training, detours, including work performed by contractors, because we have limited access to industrial site of involved employees. For some time, all this is justified and will not affect production. In the event of pandemic continuation it will certainly negatively affect work of the team” [72].

In 2020 due to pandemic COVID-19 another important factor emerged that could lead to emergencies at existing NPPs because personnel also had cases of COVID-19 and such cases continue. The NPP management takes many different measures to preserve employees health, comply with quarantine restrictions, daily check of body temperature of personnel, issue personal protective equipment, transfer to remote work of individual employees, etc. However, NPPs are enterprises where it is not possible to transfer large number of employees to remote work because many work processes have to be performed by people. Therefore, there is a risk with critical number of station employees who have to be at work every day or in shifts. Table 1 presents data on personnel number at Ukrainian NPPs for November 2020. Of course employees’ number is not accurate due to monthly changes.

Table 1. Data on personnel number at Ukrainian NPPs for November 2020.

NPP	Number
Zaporizhzhya NPP	More than 11000 workers
South-Ukraine NPP	More than 8500 workers
Rivne NPP	More than 7800 workers
Khmelnytska NPP	More than 5000 workers
Total	32300 workers
South-Ukraine NPP	More than 8500 workers

Fig. 3 shows location of nuclear power plants in Ukraine with their characteristics according to [73]. According to Fig. 2 Zaporizhzhya NPP has 6 VVER-1000 units and it is the largest in terms of staff (over 11,000 employees), South-Ukraine NPP has 3 units VVER-1000 and it is the second largest in terms of staff (over 8500 employees), Rivne NPP has 2 power units VVER-1000 and 2 power units VVER-440 and it is the third in terms of staff (over 7800 employees) and Khmelnytska NPP has 3 power units VVER-1000 and is the smallest (over 5000 employees) in terms of staff among operating stations.

Fig. 4 contains data [74] on the spread of COVID-19 coronavirus infection in Ukraine by region for of December 23, 2020. It shows number of already confirmed cases and the total number of COVID-19 patients in each region since the epidemic beginning. Also, the total number of people infected with COVID-19 is 989,642, among them 615,660 are recovered, and there are 17,172 deaths. If we compare Figures 4 and 5 we can assume that at the moment the staff of Rivne NPP and Khmelnitsky NPP is in high danger zone. They therefore need special safety measures, social and psychological support because they are located in the areas with large number of cases of COVID-19. It can not be NPP employees, but for example their relatives, close friends, neighbours and others. Therefore, it is necessary to pay attention not only to physical condition of employees, but also to the psychological health of staff.

3.3 Measures and recommendations for social and psychological support of NPP personnel

The world community faced uncertainty period due to COVID-19 pandemic. In many countries, the pandemic threatens not only human life but also economic, social and other spheres of public life [5]. Social consequences of the pandemic are: breaking family ties, disrupting social networks, destroying community structure and resources, declining trust, increasing gender-based violence, and more. Psychological consequences of emergencies are their impact on different levels of mental functioning - emotional state, behaviour, relationships. They can be related to: problems that existed before (mental disorders, alcohol or other chemical abuse); problems that arisen a result of emergency (non-pathological distress, mental disorders: depression, post-traumatic stress disorder (PTSD), anxiety disorders, adaptation disorders) [4]. Mankind found itself in situation of change and uncertainty for which it was not ready. The pandemic provokes increased anxiety, distress and other reactive states in people. Also, one of the specific features that causes socio-psychological problems is quarantine restrictions and inability to contact directly in usual circle of social interaction [5]. Each person’s response to emergencies is different because each person has different resources and opportunities to recover [4]. Therefore, wide range of citizens began to need psychoprophylaxis, crisis counseling and socio-psychological support.

Currently, the pandemic regime was introduced in the world. This period is characterized by alarming information content, increased psychological pressure due to unfavorable epidemiological situation. Symptoms of frustration, hopelessness, fear, anticipation of threat, loneliness, social isolation and alienation, sleep disturbances and nightmares, irritability and outbursts of anger are just a few of PTSD symptoms seen in people in different countries. Such manifestations are observed in the population of Ukraine. The work [5] identified socio-psychological consequences of the pandemic for individual:

• loss of basic sense of safety;

• increase in anxiety and fear (for example, get sick, lose your ability to work);

• new living and working conditions (remote work in online format);

• mixing social roles (for example, home office, when you need to combine several roles of wife-mother-specialist/husband-father-worker, etc.).

Fig. 3. NPP placement in Ukraine [73].

Fig. 4. Statistical data on COVID-19 spread in Ukraine by the regions [74].

In 2007 the United Nations together with the governments of various countries adopted the "Guide to Mental Health and Psychosocial Support in Emergencies". The document states that the main goal is to provide humanitarian actors and communities with strategy to plan, implement and coordinate system of minimum multisectoral response to protect and improve mental health and psychosocial well-being of population in emergency midst [4].

The article 38 "Psychological protection of the population" states [56]: 1) measures of psychological protection of population are aimed to reduce and neutralize negative mental states and reactions among population in case of threats and emergencies and include: planning activities related to psychological protection; timely application of licensed and permitted in Ukraine informational, psychoprophylactic and psychocorrectional methods of influencing individual; identification with help of psychological methods of factors that contribute to emergence of socio-psychological tension; use of modern psychological technologies to neutralize negative impact of emergency factors on population; implementation of other measures of psychological protection depending on current situation; 2) organization and implementation of psychological protection measures of population are entrusted to central body of executive power which ensures formation and implementation of state policy in the field of civil protection.

The publication [5] identifies current research problems in the field of health psychology of personnel of organizations and enterprises in the pandemic COVID-19:

1) *in organizational psychology*: essence of psychological health and well-being of staff in the organization in "normal" conditions and in the pandemic COVID-19; psychological features of personnel activity in self-isolation conditions; ensuring Work Life Balance in crisis situations; psychology of change management in organization in the context of the COVID-19 pandemic (adaptation to change, introduction of new forms of work, teamwork, etc.); new forms of personnel communication in organizations during the COVID-19 pandemic, new manifestations of conflicts in the organization during the COVID-19 pandemic; prevention of occupational stress and burnout in representatives of risky occupations (military, doctors, firefighters, etc.) and in other occupational groups of personnel during the COVID-19 pandemic; psychology of gradual exit of organizations from quarantine etc.

2) *in the field of psychological assistance and psychological training of personnel in the organization*: distance learning of personnel during the pandemic COVID-19: opportunities and limitations; psychological features of digital technology use, etc.

Also, psychologists-practitioners in [5] noted trends in client requests to psychologists and psychotherapists during COVID-19: a) existential issues: isolation, meaninglessness of life and what is happening (deprivation of meaning), suicidal thoughts, etc.; b) psycho-emotional states: fears (especially fear of death), anxiety, neurosis, stress, panic attacks, exacerbation of phobias, depression, impulsive-compulsive disorders; increased emotionality, exacerbation of neurotic states, etc.

Consider social system "NPP Staff" it should be noted that for NPPs of Ukraine such group can be on average 5000-10000 people - from worker to control panel operator or management of NPP. Subsystems are easily identified in this system: operational personnel, repair and maintenance personnel, seconded personnel, managers. Also, each subsystem is divided into shops, sections, changes according to NPP structure. Each of subsystems consists of tens or hundreds of elements (individuals) that form certain group (team) united by common goals and objectives. Each group performs specific (regulated) task, has its own hierarchy and living space. Of course, each individual has its own specific responsibilities but all are interdependent [62].

Decision on candidate's professional suitability for work at NPP is made by the commission on professional selection taking into account recommendations of the personnel department, incoming knowledge control, results of the interview with the structural unit head to which the candidate comes and conclusion of psychophysiological examination [6].

During the pandemic NPP personnel received an additional stress as work on critical infrastructure is considered to be quite complex and responsible.

Considering impact of negative stress on employees activities it is necessary to study conditions that contribute to optimization of their activities in extreme situations. An important factor in increasing psychological readiness ispresence of action plans in different types of extreme situations, their internal modeling and their activities in them. This not only increases psychological readiness but also helps to master new algorithms [47].

At present it is important for organizational psychologists and special departments to work with NPP personnel to diagnose mental health problems in organization during the COVID-19 pandemic and to provide appropriate psychological assistance to personnel. Such socio-psychological support can be implemented through webinars, psychological training, online and "regular" psychological counseling, etc.

Taking into account the above recommendations will create controlled situation of verbal support and jointly develop rational behavior and strategy to overcome situation and solve pressing psychological problems. Of course, all these global crisis processes require new approaches not only in individual psychological counseling but also in group of work and in creating psychological support for organizations staff. After all employees who are in state of anxiety lose concentration, perform tasks longer, make difficult decisions, become more conflicted, and so on [5].

Analysis of the NPP official websites showed that various measures for psychological support were developed for station staff: 1) people who undergo psychological testing are accepted to work at station as NPP is a potentially dangerous object; 2) various trainings are conducted (development of leadership qualities, conflict prevention, development of stress resilience, teamwork, etc.); 3) special rooms of rest and relaxation are created.

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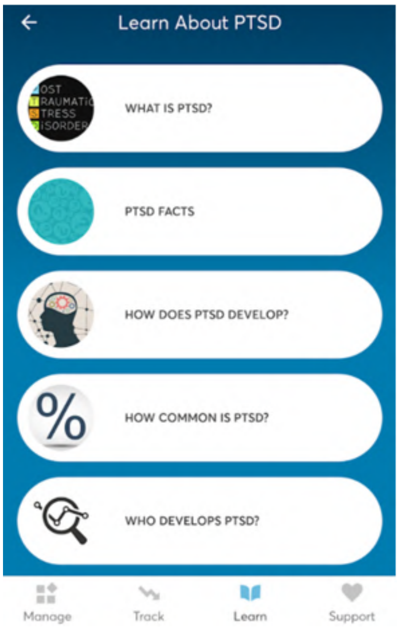
Psychologists working at NPPs can use special questionnaire to establish referral criteria in event of serious mental problems occurring in staff. In [4] it was emphasized that stress can cause various reactions, including psychological (can be manifested in certain emotions, thoughts, behavior), physical (certain bodily manifestations) and others. Need for referral to receive the necessary services becomes clear depending on severity of these symptoms, their duration and the impact on daily functioning.

As a result of analysis of the scientific literature [4,5, 46-52] it was determined that there are certain types of mobile applications for mental health. People can use them on their own without psychologists help. They contain various methods and recommendations of psychologists, social workers for psychological support of the affected population.

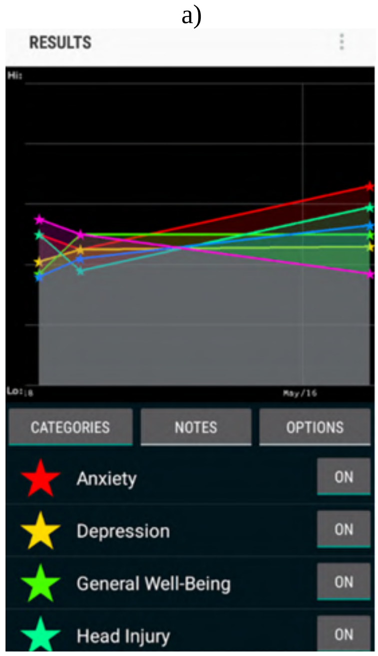
Early provision of information and training to cope with stress can prevent dangerous consequences of psychotrauma. Educational orientation of mobile applications can be key in providing psychological assistance. Because it is very important to get clear and orderly information about their condition and understand what to do next for victim of stressful events. Studying typical consequences of psychotrauma helps to better understand one's own reactions to stress, and knowledge of one's resources (constructive coping strategies) provides sense of control over these reactions. It is important to explain necessary information about mental health, psychological problems and their consequences to people. It contains the following elements: information transfer, emotional relaxation, explanation and application, self-help training [51].

Varieties of electronic services that can be used to process traumatic experiences are quite wide: informing, diagnosing, monitoring, support, reminders, communication. Mobile applications with such functions can be used at any stage of socio-psychological work in the pandemic and psychotrauma. Specialized applications contain necessary information suitable for processing various experiences (increased anxiety, avoidance of social contacts, conversations about traumatic experiences, symptoms of intrusions or hyperexcitability, etc.). Obtaining specific information can prevent prevalence of post-stress disorders and contribute to spread of good practices for maintaining mental health [51].

Mental health mobile applications are applications to support mental health. Most of them are aimed primarily at promoting of healthy lifestyle, self-assessment, self-monitoring, prevention, as well as step-by-step treatment of various disorders. Such functions can be used by person both independently and as material to provide psychologist or psychotherapist. Effectiveness of such electronic interventions in depression, psychosis, increased anxiety was proven. Apps for tracking mood swings, coping with stress, sleep disorders and eating habits are effective and popular. For example, the *PTSD Coach* supplement is used to prevent and overcome the symptoms of PTSD as an extreme manifestation of psychotrauma. *Bust PTSD, Breathe2Relax, Beat PTSD, Tactical Breather* applications are aimed to improve self-healing skills through meditation and concentration on breathing. You can effectively monitor mood changes with the *T2 Mood Tracker* monitoring application. *Provider Resilience, LifeArmor, AZNG Be Resilient Program, Develop Your Resilience* applications offer useful psychological skills. And the *PFA Mobile* and *Care4Caregiver* applications are designed specifically for professionals as guides to working with victims [50]. Examples of mobile applications are presented in Fig. 5.



a)



b)

Fig. 5. Examples of mobile applications work: PTSD Coach (a) and T2 Mood Tracker (b).

The service "Mobile psychological assistance" is presented on the site [54]. The program allows user to assess its own condition in such categories as sleep quality, depression and PTSD, as well as contains text materials sorted in menu and notes on symptoms of PTSD; anger management; depression control; alcohol and drug addiction; stress; relations with relatives; psychological resilience. There are also tools to assess your own condition; videos about PTSD; as well as list of psychological care services. The application "PFA Mobile Ukraine" contains recommendations for providing first psychological assistance to both victim himself after receiving a trauma and those who find themselves next to such a person - colleagues and relatives. However, it is important to remember that use of psychological mobile application cannot replace deep-seated methods of psychotherapy. So it should be considered as primary psychological assistance of individual. Advantages of using specialized applications are following [50]:

• it saves time that would be spent for specific information or specialist searching;

• it overcomes barrier of space and resource base;

• it can be used on different devices by linking to virtual account;

• it is free (in the vast majority) or has much lower cost than individual meetings with specialist;

• it to the user, providing his autonomy;

• it is suitable for those who are wary of contact or have prejudices against psychologists;

• it corresponds to specific psychological problem and is aimed at its solution;

• it allows you to track changes in the state, which encourages the user to continue working, cultivates in him a commitment to self-help and help.

4 Conclusions

In 2020 COVID-19 led to the pandemic and caused an emergency worldwide, threatening lives and population health with large number of deaths and injuries. Also, during the pandemic there was (and continues to be) a violation of normal living conditions, significant material damage to economies of different countries. Quarantine restrictions affected social, educational, cultural and spiritual spheres of society. There is urgent threat to operation of critical infrastructure because the pandemic led to large numbers of hospitalized people or being isolated and treated at home. Operation of critical infrastructure facilities is strategic importance for proper functioning of any country. It includes energy, chemical, transport and other enterprises, and in particular nuclear power plants.

Scientists determined that threat of potentially dangerous situations remains and can cause radioactive and chemical contamination of the environment and harm the health of personnel and the public despite introduction of technologies and automated monitoring systems at nuclear power plants. Also one of the key means to ensure NPP safety operation and its further improvement is to take into account previous experience of operation and elimination of initial stage of emergencies. It includes accounting and analysis of disturbances in operation of stations, implementation of corrective measures to prevent violations. Analysis of violations statistics in operation of Ukrainian NPPs over the past few years shows that violations above the 1st class (anomaly) on the international INES scale have not occured at these power units. Indeed, in energy sector of Ukraine in recent years no threats were identified associated with emergencies risk due to equipment failures or extreme natural phenomena. However, there are additional risks associated with growing threats of nuclear terrorism, armed conflict in southeastern Ukraine and problems related to the COVID-19 pandemic (diseases of NPP personnel or their relatives). Therefore, problem of psychological health of NPP personnel during the pandemic is one of the relevant topics for research.

Currently, number of special measures were developed to prevent and eliminate accidents at Ukrainian NPPs, special instructional materials were prepared and the Emergency Response System was created. It is interconnected set of human and technical resources, organizational and technical measures or mitigating impact of accident or emergency on personnel, public and environment.

Also, psychological testing is mandatory for plant personnel during employment and transfer to other positions in order to prevent emergencies at NPPs. Various trainings (development of managerial qualities, conflict prevention, emotional burnout, etc.) are conducted and rooms for relaxation and rest are created.

Currently, extreme situations of activity are analyzed in three main aspects in psychological research: as features of situation itself, as a set of conditions of activity; as features of subject of activity in extreme situations, its readiness; as features of consequences of activity in difficult conditions of professional activity. Therefore, work of NPP personnel can be considered as a "set of operating conditions", i.e. work on potentially dangerous object. Ukraine is also implementing an international "Guide to Mental Health and Psychosocial Support in Emergencies". The terms "mental health" and "psychosocial support" mean measures aimed at protecting and promoting psychosocial well-being, as well as prevention and/or treatment of mental disorders.

Socio-psychological support is important to promote mental health during the COVID-19 pandemic especially for critical infrastructure workers. Stress associated with uncertainty and threat to health can have negative consequences for well-being and mental health of employees and can result in depression, emotional exhaustion, and anxiety.

Timely detection and appropriate work to restore mental health during the pandemic is an equally important area of work along with providing medical care to the population. Psychological mobile applications should be considered as economical way of primary care - proper psychological information of the population [51].

NPP is a potentially dangerous object, so, recommendations were prepared for social and psychological support of NPP personnel:

1) organize a system of informing staff about measures to prevent and reduce the risk of COVID infection; it in turn will help restore sense of safety and reduce anxiety level of employees;

2) conduct trainings or webinars on organizational issues online; it will discuss rules, advantages and difficulties faced by employees during the quarantine

period, ways to overcome these difficulties, introduction of mentoring system;

3) organize team building, meetings, rituals online (for example, morning online meetings over cup of coffee to stabilize psycho-emotional state of employees);

4) carry out personnel screening procedure; if disorders of adaptation take place against background of more pronounced psychological trauma and depression it is necessary to refer to psychotherapist or psychiatrist;

5) carry out once every few months testing and interviewing staff;

6) create positive image and commitment to psychological counseling and seeking psychological help;

7) advise NPP employees to independently use specialized mobile applications for psychological support.

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Modeling the influence of factors on the level of environmental safety

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Abstract. There has been established in the article the correlation and regression relationship between the factors of the country's development and the level of environmental safety on the basis of identifying the patterns of certain factors sets influencing the volume of harmful emissions into the atmosphere. On the basis of modeling, there has been carried out the analysis of individual groups of factors influencing the volumes of harmful emissions in the countries selected for the study. The nature and degree of influence of the selected factors on the resulting indicators (volumes of harmful emissions) have been determined. It has been found that the number of these factors is significantly higher in France than in Ukraine. This is due to both the political and economic situation in the country. The level of energy efficient technologies implementation and environmental restructuring of business entities are no less significant. The ranking of factors has been carried out based on the value of the correlation coefficient within a separate group and each country. There are also highlighted differences in the research results and their reasons.

1 Introduction

In today's world, among the dominant problems, there are environmental ones associated with climate change as they threaten the further development of mankind. The countries participating in the United Nations Framework Convention on Climate Change (1992) have assumed international obligations defined in the Kyoto Protocol (1997) and the Paris Agreement (2015) regarding the reduction of greenhouse gas emissions. This necessitates states with different levels of development to form and implement an effective environmental policy, which will reduce anthropogenic influence and stimulate the development of a "green" economy.

Researchers often focus on identifying and establishing the nature and types of relationships between various phenomena and processes occurring in society (for example, the level of economic development, urbanization, the increase in the use of alternative and traditional types of energy, research, investment and innovation activities) and their influence on environment. For example, to analyze the relationship between emissions, natural resources, revenues and renewable energy in the BRICS countries, there has been applied the AMG method [1]. Natural resources were used as a control variable that showed the relationship between revenues and emissions in the EU-5 countries [2]. The relationship between income, energy consumption and carbon emissions in the United States was studied by [3].

The studies of countries with different income levels were conducted by [4]. The results have shown that energy consumption per capita is the main cause of carbon dioxide emissions. Studies [5, 6] have shown that green innovation is the main factor affecting carbon emissions.

There are proposed a modern information and analytical system for monitoring atmospheric air pollution and considered the features of the air quality index in [7, 8, 9, 10]. A schematic diagram of the structural organization and relationships between the subjects of environmental monitoring has been developed in [11]. New forms of data presentation on monitoring technogenic loads and risks, reflecting the dynamics of ecological situation in the space of informational features, were proposed in [12].

A prototype of a monitoring system is presented to solve monitoring problems [13, 14]. There are combined methods that enable us to predict the influence of technogenic activities on human health and are an effective complex of environmental monitoring studies in [15]. There are presented the developed mathematical models that allow predicting atmospheric pollution and are an effective tool for supporting decision-making on the problems of environmental safety of the atmosphere in [16].

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The risks to public health associated with air pollution have been analyzed and evaluated in [8, 17, 18]. Mathematical models have been developed to reduce the spread of pollutants in the atmosphere [19, 20].

A significant influence on air pollution is carried out by the quality of the fuel; the study of the fuel quality management system, the environmental and economic analysis of the developed system is made in [21, 22]. New mathematical tools have been developed in [23, 24, 25] to determine the distribution in space and time of the technogenic load on the atmospheric air from gas wells. The issues of modeling the dispersion of the atmosphere taking into account the mathematical modeling of the emissions formation are shown in [26] and ways of automating the process of scenarios development modeling are highlighted in [27].

The results of scientific research on the reduction of pollution by the oil and gas complex that allow avoiding the ingress of harmful substances into the environment are presented in [28]. The species composition and life status of biocenoses located on the territory of the wells are investigated in [29]. The extent of the environment destruction and the decline in biodiversity are investigated in [30].

An approach and recommendations for increasing the level of environmental safety in areas of oil and gas fields' development are offered in [31, 32]. Offers and their implementation to reduce the influence from the activities of oil and gas facilities in the process of wells drilling are presented in the following scientific papers [33, 34, 35, 36, 37, 38].

The influence of renewable energy on sustainable development was studied in [39, 40]. The main directions of ecological modernization with the use of economic levers to reduce the negative influence on the environment are considered in [41]. The study of functional dependences of factors influencing the amount of waste using the praximetric method, variance and regression analysis was carried out in [42, 43]. The influence of social and scientific-intellectual factors, namely the relationship between the education quality of employees and results of their work are studied in [44, 45].

2 Objective and tasks of research

The aim of the study is to analyze the patterns of social, environmental, economic, scientific and intellectual factors influence on the volume of harmful emissions, such as carbon dioxide, sulfur dioxide and nitrogen oxide, in order to determine possible ways of affecting the level of environmental safety.

To achieve the goal, the following tasks were set:

- to carry out a correlation analysis for assessing the proximity of the relationship and the nature of the factors affecting the level of harmful emissions;

- to analyze the influence of certain factors groups on harmful emissions for countries with developed economies and developing countries;

- to identify priority causes that lead to changes in factors affecting emissions.

3 Materials and methods

Statistical data of Enerdata, World Bank, World Statistics, Eurostat, Index Mundi, OECD, Statista, International Energy Agency for 1999-2018 were used as materials for the study, namely the level of harmful emissions in the atmosphere: CO_2, SO_2, NO_x and such parameters - factors as: energy intensity of GDP, investment level, rent payments, population density, energy consumption, etc. The object of the research is France as a country with a high level of economic development and Ukraine as a country with a low level of economic development.

Correlation analysis was applied to determine the nature and degree of social, economic, scientific and intellectual factors influence on the amount of harmful emissions, such as carbon dioxide, sulfur dioxide and nitrogen oxides. The study has been based on the coefficients of correlation and determination (approximation), linear and nonlinear (quadratic, logarithmic, inverse, power) functions. The value of the correlation coefficient sign allows us to assess the direction of the selected factors influence on the resulting indicators (the number of emissions). The type of function enables us to understand the nature of the influence: if it is a simple linear one, then the increase or decrease in the indicator occurs evenly. If it is a non-linear one, then we get different levels of acceleration or deceleration of the indicator change depending on the factor change.

4 Results and discussion

A change to the climate policy was the adoption of the Kyoto Protocol, which has been in effect since 2005. Despite all the positives of the Kyoto Protocol, it had several drawbacks. One of the main drawbacks was that not all states adhered to it in good faith, in particular the United States never ratified the Protocol despite the fact that all states proclaimed the importance of combating climate change. Therefore, the Paris Agreement came to replace the Kyoto Protocol in 2015. Both documents are based on the principles of the "green economy" and aim to prevent climate change, but contain a number of differences, the main of which are:

- in the Paris Agreement, any sanctions for greenhouse emissions were canceled and each country determined for itself the amount of emission reductions. Thanks to this approach, more than 160 countries have joined the new agreement, some of which have not previously assumed commitments to reduce emissions;

- the Kyoto Protocol allows cross-border trading in quotas. This practice gave rise to opacity in the national accounting of greenhouse emissions and made it possible to implement corruption schemes, incl. in Ukraine.

- the Paris Agreement does not provide for interstate trading in quotas. Countries will be able to use market mechanisms to achieve their emission reduction targets, buying international carbon credits, which should reflect real emission reductions, and detailed rules for the operation of new market mechanisms should be approved at the next Conferences of the Parties to the UN Framework Convention on Climate Change.

- the Paris Agreement provides for the technological and financial assistance by developed countries in emissions reduction to developing countries.

One of the most difficult issues of this agreement is the adoption of a new differentiation of countries into developed and developing countries in order to resolve the issue of who will provide financial and other assistance, and who will receive it. Traditional donors - the EU, USA, Canada and other developed countries do not give up their commitment and continue to be the leaders, providing and increasing funding to combat climate change. At the same time, among the countries that do not fall under the definition of "developed" - Saudi Arabia, South Korea, Singapore, there are those that are able to provide assistance, but do not want to do so. However, the Agreement states that they can provide assistance voluntarily [46].

Since the object of the study is Ukraine and France, based on the above, we note that France, as a result of the adoption of the Paris Agreement, is a country that provides financial assistance and Ukraine, in its turn, is a developing country and is applying for donor funds to fulfill the terms of this agreement.

For a deeper analysis of the level of such emissions as carbon dioxide, sulfur dioxide and nitric oxide into the environment, we select social, environmental and economic indicators from the groups of factors, which, in our opinion, have great influence on the level of harmful emissions and determine the main reasons for this influence, and opportunities to change them using the tools of the "green economy".

The criterion for assessing the closeness of the relationship between the studied pairs of emission indicators and the corresponding factors is the correlation coefficient. The influence assessment is carried out, assuming the possibility of the existence of not only a linear relationship, but also the possibility of various forms of nonlinear influence existence. For the study, there were chosen the following forms of non-linear connection: power, exponential, quadratic, inverse and logarithmic. Based on the analysis of the correlation coefficient value, there is selected the corresponding form of relationship, for which the value of the correlation coefficient is the largest (Tables 1-8).

Table 1. The results of analyzing the influence of the social factors set on harmful emissions in Ukraine.

Name of the factor, designation	Form of the detected relationship	The nature of the identified relationship
Human Development Index, X1	For SO_2 and NOx - not detected for CO_2 – a square relationship	The factor increases, the indicators decrease
Population density, X7	For SO_2 and NOx - not detected for CO_2 – an inverse relationship	The factor increases, the indicators increase

In our opinion, it is interesting to compare individual factors for the two countries, which have a different effect on the resulting indicator, in particular, the rent for the use of natural resources $ in Ukraine increases, and at the same time, the level of SO_2 and NOx emissions show an upward trend, and in France, in its turn, this factor also increases and the level of emissions decrease.

Table 2. The results of analyzing the influence of the social factors set on harmful emissions in France.

Name of the factor, designation	Form of the detected relationship	The nature of the identified relationship
Human development Index, X1	Quadratic	The factor increases, the indicators decrease
Population density, X7	Inverse	The factor increases, the indicators decrease

Table 3. The results of analyzing the influence of the environmental factors set on harmful emissions in Ukraine.

Name of the factor, designation	Form of the detected relationship	The nature of the identified relationship
	Ukraine	Ukraine
Energy intensity of GDP at constant purchasing power parities (koe/$ 2015), X2	For SO_2 and NO_x - not detected for CO_2 – 1/X) (a direct relationship)	The factor increases, the indicators increase
Domestic consumption of coal and lignite (Mt), X8	Power	The factor increases, the indicators increase

Table 4. The results of analyzing the influence of the environmental factors set on harmful emissions in France.

Name of the factor, designation	Form of the detected relationship	The nature of the identified relationship
	France	France
Energy intensity of GDP at constant purchasing power parities (koe/$ 2015), X2	Quadratic	The factor increases, the indicators decrease
Share of renewable energy sources in electricity production (%), X3	Power	The factor increases, the indicators decrease
Domestic consumption of coal and lignite (Mt), X8	Power	The factor increases, the indicators increase

This is due to the fact that the rent for the use of natural resources in Ukraine is not large and it does not induce to reduce emissions, and in France it is an effective tool as high rent encourages enterprises to reduce emissions in accordance with EU legislation.

The production factor (value added) in Ukraine and France tends to increase, which is a positive phenomenon, however, in France, emissions show a decrease, while in Ukraine they are growing. The reason for this situation may be the use of extensive factors of production, which give an increase in production volumes, raw materials prevail, services, tourist services, the use of intensive factors of production, and the latest technologies prevail.

Table 5. The results of analyzing the influence of the economic factors set on harmful emissions in Ukraine.

Name of the factor, designation	Form of the detected relationship	The nature of the identified relationship
Rent for the use of natural resources, $, X4	A linear relationship (for CO_2 – not detected)	The factor increases, the indicators increase
Production, value added (current USD), X5	Quadratic (for CO_2 – not detected)	The factor increases, the indicators increase
Foreign direct investment, net inflows (BoP, current USD), X6	A linear relationship (for CO_2 – a low level of relationship)	The factor increases, the indicators increase
Grain harvest (kg per hectare), thousand, X9	For SO_2 i NOx – not detected, (for CO_2 – a quadratic one)	The factor increases, the indicators decrease
Total energy consumption, X10	Power	The factor increases, the indicators increase
Transport services (% of commercial services import), X12	For NOx – a power relationship, for SO_2 – a logarithmic one, for CO_2 – a quadratic one	The factor increases, the indicators increase
Unemployment, total (% of total labor force) (ILO modeled estimate), X13	Inverse (for CO_2 – not detected)	The factor increases, the indicators decrease
Exports of ores and metals (% of merchandise exports), X14	Logarithmic (a low level of relationship)	The factor increases, the indicators decrease

With an increase in research and development costs, emissions in Ukraine increase, while in France they decrease. This gives grounds to assert that money is spent on the wrong developments in Ukraine, and in France, intellectual developments are sufficiently introduced at enterprises that ensure emissions reductions.

In accordance with the obtained calculations, we will rank the factors within each group according to the values of the correlation coefficient (Tables 9-10): 1 - the highest level of influence, 3 - the lowest level of influence (for social, environmental, scientific and intellectual factors), 1 - the highest level of influence, 8 - the lowest level of influence (for economic factors).

Summing up, we can say that for all groups of factors for both countries, it is worth highlighting a number of effective tools that make it possible to reduce emissions by decreasing the negative influence of individual factors, as evidenced to a greater extent by statistics on the main indicators of France. In its turn, Ukraine has the opportunity to study the experience of France and other countries, in order to implement effective socio-economic and environmental policies, measures in the context of reducing emissions in various fields of activity, thereby observing the foundations of a green economy.

Table 6. The results of analyzing the influence of the economic factors set on harmful emissions in France.

Name of the factor, designation	Form of the detected relationship	The nature of the identified relationship
Rent for the use of natural resources, $, X4	Quadratic	The factor increases, the indicators decrease
Production, value added (current USD), X5	Inverse (for CO_2 – a low level of relationship)	The factor increases, the indicators decrease
Foreign direct investment, net inflows (BoP, current USD), X6	Power (low level of relationship)	The factor increases, the indicators increase
Grain harvest (kg per hectare), thousand, X9	Not detected	
Total energy consumption, X10	Power	The factor increases, the indicators increase
Transport services (% of commercial services exports), X11	Power	The factor increases, the indicators increase
Transport services (% of commercial services import), X12	Quadratic	The factor increases, the indicators increase
Unemployment, total (% of total labor force) (ILO modeled estimate), X13	Exponential (a low level of relationship)	The factor increases, the indicators increase
Exports of ores and metals (% of merchandise exports), X14	Inverse (a low level of relationship)	The factor increases, the indicators decrease

Table 7. The results of analyzing the influence of the scientific and intellectual factors set on harmful emissions in Ukraine.

Name of the factor, designation	Form of the detected relationship	The nature of the identified relationship
Property Fees, Payments (BoP, Current US Dollars) Research and development costs $, X15	Quadratic (for CO_2 – not detected)	The factor increases, the indicators increase
Research and development costs, $, X16	A linear relationship (for CO_2 – not detected)	The factor increases, the indicators increase
Patent applications, residents, X17	Logarithmic for CO_2 (a low level of relationship)	The factor increases, the indicators increase

Summarizing the reasons that lead to changes in the factors affecting the volumes of emissions, it should be noted that they take place at all levels, namely at the levels of cooperation between different countries, unions (global), state, local and individual. In particular:

1. Key global initiatives that demonstrate attempts to find a global consensus around the increasing importance of the environmental factor in the activities of international organizations, institutional investors and TNCs, as well as in the politics of the countries of the world, reflected in the foundations of the transition to a "green" economy.

Table 8. The results of analyzing the influence of the scientific and intellectual factors set on harmful emissions in France.

Name of the factor, designation	Form of the detected relationship	The nature of the identified relationship
Property Fees, Payments (BoP, Current US Dollars), Research and development costs $, X15	For NOx and SO_2 – a logarithmic relationship. For CO_2 - a linear relationship.	The factor increases, the indicators decrease
Research and development costs, $, X16	A linear relationship	The factor increases, the indicators decrease
Patent applications, residents, X17	Inverse (for CO_2 – 0,46 a low level of relationship)	The factor increases, the indicators decrease

Table 9. Ranking of factors by the value of the correlation coefficient (France).

Factor rank	CO_2	$S0_2$	Nox
Social			
1	X7	X7	X7
2	X1	X1	X1
3	X9	X9	X9
Economic			
1	X12	X12	X12
2	X10	X4	X4
3	X4	X10	X10
4	X11	X5	X5
5	X6	X11	X11
6	X5	X14	X6
7	X13	X13	X14
8	X14	X6	X13
Environmental			
1	X2	X2	X2
2	X8	X8	X8
3	X3	X3	X3
Scientific and intellectual			
1	X15	X15	X15
2	X16	X16	X16
3	X17	X17	X17

These initiatives are, first of all, declared in the documents as the goals that must be achieved by a specific time (the 2030 Agenda for Sustainable Development, the Sustainable Development Goals and the Paris Agreement), at the level of the European Union, the European climate law. Responsibilities for the implementation of the measures in these documents are assigned directly to the governments of each country that ratified these regulations. Therefore, both in Ukraine and in France, the following documents were adopted on their basis at the state level. The political and legislative framework for the climate policy in Ukraine is provided by the Law "On the Basics of Monitoring, Reporting and Verification of Greenhouse Gas Emissions", Ukraine 2050 Low Emission Development Strategy (LEDS), the CONCEPT of State Climate Change Policy Implementation until 2030. In France, the main regulatory documents on the implementation of international agreements are the Law on Energy Transition for Green Growth (LTECV), the National Adaptation Plan for Climate Change, and the National Low Carbon Strategy. That is, the legislative base has been formed, but there are a number of shortcomings. In particular, it is necessary for Ukraine to create an integral and effective regulatory framework for a system of regulating harmful emissions, fully adapted to global international agreements. The priority here should be a set of legislative actions that are relevant to improve taxation of emissions, as well as the use of funds received from tax revenues for emissions. After reviewing the French regulations, a minor flaw can be considered the difficulty of understanding them, as they cover different areas together with very detailed provisions for implementation at different levels and with different time frames.

Table 10. Ranking of factors by the value of the correlation coefficient (Ukraine).

Factor rank	CO_2	$S0_2$	Nox
Social			
1	X9	X9	X9
2	X7	X7	X7
3	X1	X1	X1
Economic			
1	X10	X4	X4
2	X12	X12	X5
3	X6	X5	X12
4	X10	X13	X6
5	X13	X6	X13
6	X14	X10	X10
7	X4	X14	X11
8	X5	X11	X14
Environmental			
1	X8	X8	X8
2	X2	X3	X3
3	X3	X2	X2
Scientific and intellectual			
1	X17	X16	X16
2	X16	X15	X15
3	X15	X17	X17

2. The next tool that can ensure the reduction of emissions and funding budgets for improvement of environmental situation and promotion of green business development is the application of effective state fiscal policy. Today in Ukraine, rates for harmful emissions remain one of the lowest in Europe (as an example, 0.33% per ton of CO_2 emissions in 2019), while in France they are one of the highest and grow from year to year (€35 per ton of CO_2 emissions in 2019). In addition, the list of environmental taxes has 20 items in France, and according to Eurostat, they are classified into the following categories: energy, transport, pollution, subsoil. In Ukraine, however, there is no clear classification of the

environmental tax to the object of taxation. Also, revenues from the environmental tax are spent opaquely and ineffectively. Companies that pollute the environment have been paying fees since 2011, but most of environmental problems still remain unsolved. In addition, low rates of environmental taxes do not stimulate business entities to invest in environmental protection measures. In France, however, high environmental tax rates are often the cause of strikes in the country. One of the reasons is high fuel rates. However, not all funds are used for environmental activities, and most of them are directed to pay for the budget deficit (from 34 billion euros that the French government received from a fuel tax in 2018, 7.2 billion euros were allocated for environmental activities).

3. Studies show that environmental taxation of European countries has proven its effectiveness in the implementation of environmental policy. This contributed to the rapid production of innovative technologies in environmental protection measures and the reduction of harmful emissions [46].

4. Renewable energy sources help solve sustainable development challenges by reducing air, water and soil pollution [47]. It is the increase in the use of renewable energy that is one of the priority directions for the implementation of the countries state policy in the field of energy efficiency. In France, utilities use the Energy Efficiency Certification Scheme (also known as "white certificates") to meet their energy reduction targets, which in turn include performing energy audits, government granting targeted subsidies for energy efficient equipment, using renewable energy sources and the like. The white certificate scheme started in France back in 2006. Improving energy savings in the residential sector, which is one of the largest consumers of energy resources, is also the main task of the climate and energy policy of each country. In France, an important part of the country's Policy Strategy for Decarbonizing the Buildings Sector is a tax credit scheme for costs associated with energy efficient renovation works, the so-called The Energy Transition Tax Credit (CITE). In Ukraine, the instruments of state support for the population in the sphere of energy efficiency are two nationwide programs to improve the energy efficiency of the housing stock: the so-called "Warm credits", handled by the State Agency on Energy Efficiency and Energy Saving of Ukraine "SAEE", and the Energy Efficiency Fund program "Energodim".

5. One of the most important roles in the development of innovative processes in the energy sector is played by the governments of countries, which often fund high-risk research, as well as new low-carbon technologies, which, as a rule, are not cheap and are characterized by a plurality of market prices. One of the most effective ways to assess the implementation of clean energy technologies is to assess the level of public investment in energy R&D and demonstration activities (R&D and DA) and identify the relationship between these investments and technology development. The total amount of state funding for energy R&D and DA in 2018 in France is 1.526 million euros, which puts it in first place among the EU countries, in Ukraine this information is absent. The assets received are often intangible, the returns are uncertain, and the investment in innovation is not always easy and quick to return. This is where government support is an important resource for long-term finance. Policy instruments can be used to ensure access to financing risky projects. As a result, many high-risk private sector innovations are based on early stages of publicly funded research and programs.

5. Conclusions

Based on the analysis, there have been identified effective legislative, organizational and management tools that will contribute to reducing emissions for developing countries:

- formation, bringing up to European standards of the legal framework on regulation, management and control in the field of the environment;
- maintaining an effective fiscal policy in matters of rent payments, environmental taxes and fines;
- intensive use of "green investment" instruments, namely "green" bonds;
- reduction in energy consumption due to the use of certification schemes for the result of energy conservation, the so-called "white certificates";
- an increase in the amount of public investment in energy R&D and demonstration activities;

The research results allow in the future building multivariate econometric models to assess the complex influence of such factors on emissions and formulating recommendations for improving social, environmental and economic policies to ensure the reduction of harmful emissions.

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Mechanisms for ensuring the environmental safety of tourist destinations

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Abstract. Modern tourism is a sector of the economy that is developing very fast, for the last 10 years the growth was 25%. According to UNEP and the WTO, tourism is seen as a growing sector in contrast to the manufacturing sector. According to experts, the growth rate of the tourism industry will remain high, although global and regional structures of tourism change over the years (in recent years due to terrorism, the development of various diseases, natural disasters, pandemics, etc.). In 2019, about 1,500 million international trips were made. The same data indicate that the growth of tourism is due to developing countries. In countries with weak regulation of the market economy, tourism development can become a real threat to the quality of the environment. Therefore, the further development of tourism, in general, is possible only through its greening and finding a balance between economic and social development, taking into account environmental factors.

1 Introduction

Current scientific publications in this field relate mainly to the formation of concepts, conceptual framework and general principles of sustainable tourism development. Tourism can be defined as a system of balanced tourism, which deals with the growth of the developing market due to the growing interest in the natural environment. With the growth of tourist services, the expansion of tourist infrastructure, the ecological situation in the territories in connection with their recreational use can reach a threatening state. However, the literature on balance often contains broad definitions based on an immeasurable ideal state, which can be governed by a number of basic principles, which are often vague and contradictory.

The issue of sustainable tourism development is relevant on the agenda of world meetings on environmental protection and tourism development in recent years.. In Ukraine was developed "Strategy for sustainable development of tourism and resorts" [1, 2]. Scientific publications of recent years are devoted to substantiation of scientific bases of balanced development of tourism, separate aspects of maintenance of balanced development of tourist regions [3-5]. The components of sustainable tourism development are identified, the main environmental problems associated with the expansion of tourism, the features of environmental aspects of tourism development in mountain tourist destinations. Ensuring the sustainable development of recreational areas is carried out through the establishment and maintenance of a balance between the preservation of natural, historical and cultural resources, economic interests and social needs and the development of tourism.

Basic concepts and principles of sustainable tourism development, characterized by environmental, economic and social aspects of its development were outlined by us [6]. A practically unresolved problem in the development of the concept of sustainable tourism development is the development and practical implementation of tools (means) to implement the principles of balance in practice. Therefore, our main goal is to analyze these issues.

2 Statement of the main material

Tourism is a constant and quite intensive user of natural resources. At the same time, the tourism industry not only makes extensive use of natural resources, but also pollutes the environment. On the other hand, the favorable ecological condition of tourist areas is considered by tourists as a separate tourist resource, which is in steady demand, especially in the period of recovery from the pandemic and the need for recovery in environmentally friendly living conditions. Negative aspects of the impact of mass tourism on the environment and tourist resources were noted in the 70's in foreign studies. The rapid development of the tourism industry has led to a high concentration of production - hotel chains appear, the construction of tourist centers begins. Investing significant funds in the development of tourism, large capital requires maximum profit in the shortest possible time. The rapid development of tourism is supported in order to ensure economic development and increase the level of currency inflows. For example, the development

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of tourism in the Mediterranean region since the 1960s and until recently illustrates the significant amounts of ecological degradation of geosystems that may occur as a result of large-scale tourism development [7]. The natural landscape and the local population were perceived only as a means to an end. Not surprisingly, the result of the growth of mass unregulated visits to recreational natural complexes was an extremely negative impact on them, as well as on the local socio-cultural environment. The wild originality of unique natural places, as well as local economies and cultural values of tourist destinations are under threat. Examples of the negative consequences that accompany excessive visits by tourists to recreational natural areas are known today in large numbers. The most convincing examples are the degradation of a number of major US national parks, the Geyser Valley in Kamchatka, recreational areas in the Alps, the accumulation of debris on Everest in Nepal (Fig.1) and the Inca Trail in South America [8]. In 1983, the famous Austrian journalist L. Lukshanderl published his book “Save the Alps! Garden on the roof of Europe in danger ", in which in popular science form outlined the main environmental problems of tourism development [9]. The degradation of natural areas for tourism development has necessitated the introduction of systematic nature protection measures in tourism practice. Since the tourism industry is mainly seasonal, the number of tourists in a given area at the height of the season is several times higher than in the "dead season". This situation leads to uneven anthropogenic pressure on ecosystems. The study of the consequences of tourism activities for ecosystems and the introduction of environmental management technologies in the practice of recreational nature has emerged as the most pressing problem of further development of tourism. However, the definition of objects of environmental research remains controversial and ambiguous.

Fig. 1. Campaign to clean up and remove rubbish from Everest left by tourists and climbers on the world's highest mountain, Nepal, March 17, 2018, photo: EPA-EFE / BIKAS KARKI.

Today, anthropogenic impact on ecosystems is characteristic of all sectors of the tourism industry and types of tourism and is observed in the vast majority of tourist destinations. It is tourist destinations of different hierarchical levels that are the objects of ecological research and are considered as natural-technogenic systems from the point of view of ecological research. The term "tourist destination" in the practice of tourism research appeared not so long ago. In foreign literature on the theory and practice of tourism, this term has been used for several decades. The most famous works of Leiper, Cooper, Fletcher, which give the definition of tourist destinations and their systematization. In a more general form, the tourist destination is the territory of arrival and location of tourists. According to N. Leiper, a tourist destination is a place of arrival of tourists and is considered as a geographical category [10].

The World Tourism Organization defines a tourist destination as follows: «A destination is a physical space in which a tourist stays for at least 24 hours. It contains tourist products such as services and attractions, as well as tourist resources within at least one day of stay. This space has physical and administrative boundaries that determine the form of its management, image and reputation, which affect its competitiveness in the tourism market». It should be noted the thorough works of domestic scientists in this field T. Tkachenko, L. Dyadechko, A. Holovchan, S. Melnychenko, Y. Leontieva, Y. Maltseva and others [11-15]. In the work of Matrishenko N.S. tourist destination is presented as a "center (territory) with all kinds of amenities, facilities and services to meet all the needs of tourists". According to him, now the destination is a geographical area that has certain boundaries, which can attract and meet the needs of a wide range of tourists [16].

In most modern interpretations, a tourist destination is considered as an economic and socio-economic system, as an object of integrated management. To do this, the tourist destination combines all the elements for the provision of tourist services. A tourist destination arises precisely as a geographical unit, as a territory, route or localized object that is a place of tourist interest ("tourist destination"), other components, such as elements of tourist infrastructure, should be considered "superstructure", gradually revealing the essence of a tourist destination in the course of evolutionary development. Thus, a tourist destination is defined as an economic and geographical category, where the basis of its operation is a territorial resource with possible problems of using nature, including environmental. Despite the rather broad and detailed interpretation of the concept of a tourist destination, the ecological aspects of its optimal functioning are ignored. A tourist destination, in the context of its balanced development, is a natural-technogenic system of tourist-recreational type, due to the specialization of tourist activity and certain factors of environmental impact that will determine its ecological safety. The structuring of natural and man-made systems of tourist destinations, their hierarchy, approaches to the systematic study of environmental aspects of their activities require further research.

At present, a scientific direction on the environmental safety of natural and natural-man-made systems of different levels has been formed. In the works of A.B. Kachynski, G.I. Rudko, S.V. Hoshovsky, V.M. Shmandiy, S.V. Rudenko, L.E. Shkitsa, B.M. Danylyshyn, V.O. Kosovtsev, Binko I.F., V.M. Shestopalov, M.S. Malovany etc. scientific and methodological approaches to ensure environmental

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safety in natural and man-made natural systems, as well as applied aspects of environmental safety [17-25]. Methodological and applied mechanisms of researches of technogenic changed ecosystems and maintenance of their ecological safety are developed [26-35]. On the territory of Ukraine there are large oil fields - explored, abandoned, some and unexplored. They also pose a risk of contamination of soils, water resources, air, which in turn impairs the tourist attractiveness of tourist destinations. Therefore, the latest technological and economic methods of regulating this activity should be used to reduce the impact on the environment [36, 37].

Less studied are the issues of environmental safety research and management in the conditions of man-caused load, which is not pronounced extreme, for example, the territories of tourist destinations. The analysis of certain aspects of environmental safety in the development of the tourism industry, as part of its balanced development, engaged in A.P. Hunger, N.V. Korzh, V.I. Kutsenko, T.L. Mironova, V.V. Sharko and others [38-41]. Some scientists consider the objects of such research to be elements of infrastructure and their impact on the environment, some consider determining the ecological boundaries of activities by calculating the recreational load on the territory. Analysis of publications in recent years has identified the main impacts of tourism on the environment. Tourism can have a negative impact on local energy resources, water resources, land resources, the use of which in tourism is constantly increasing.

3 The research results

With the growth of the tourism industry, there is a direct impact on natural landscapes and changes in primary landscapes as a result of the construction of tourism infrastructure. Intensive construction of accommodation facilities, roads, airports, use of land resources as a building material for housing infrastructure leads to degradation and depletion of landscape elements, its radical change. The problem of traffic jams, insufficient number of parking spaces, a sharp increase in the cost of land have become a reality in such areas. Intensive tourism development absorbs land resources and has led to the loss of agricultural land and natural landscapes. Territories are becoming highly urbanized. The construction of marinas, breakwaters and other structures leads to changes in natural landscapes - changes in the direction and strength of currents, then - changes in the coastline and coastal erosion, which leads to the loss of beach areas. Although the pace of construction of tourist infrastructure in Ukraine is not so high, but the problems of degradation of the Black Sea coast, sampling of sand from beaches, destruction of large forests in the construction of tourist infrastructure in mountainous areas of Ukraine are very pressing environmental issues. Thus, the tourist complex "Bukovel" according to the original project occupies a considerable area: the total area for the construction of cottages and hotels: two-storey cottages - 100 hectares; hotels - 50 hectares, infrastructure of cottage - hotel complex (25-30% of housing) - 45 hectares; total area for ski slopes and lifts (at the rate of 30 to 50 m width of one track) - approximately 300 hectares; total area for water reservoirs intended for snowmaking of 60 ha of ski slopes (three reservoirs with a depth of 3 m and a volume of 16 thousand m^3 each) - 0.55 ha. The tourist complex is constantly expanding, now occupying about 822 hectares, with a total length of ski slopes of more than 100 km (Fig. 2) [42].

Fig. 2. Tourist complex "Bukovel", p. Polyanitsa.

Intensive use of water resources and their pollution is also an environmental problem of tourist destinations. Construction of hotel and entertainment complexes often leads to overload of sewer systems. Wastewater treatment plants do not always cope with large volumes of wastewater in the height of the season, wastewater is sometimes discharged into seas and lakes without treatment, negatively affecting not only flora and fauna, but also the quality of the recreational environment for vacationers.

In Ukraine, the problem of pollution of water and land resources from tourist facilities is very acute. Tourist infrastructure, especially on the coasts, is developing chaotically, without proper environmental justification. It is not uncommon for direct discharges of wastewater into the sea, the construction of hotel complexes on beaches, within water protection zones, the development of unorganized tourism on the coast in the absence of sanitary facilities. Thus, the tourist complex "Bukovel" uses groundwater for domestic and drinking water supply, production of artificial snow, which leads to the extraction of significant amounts of water from underground horizons. Sewage from small hotels and rural estates remains a problem, as the vast majority of tourist destinations do not have centralized drainage systems. Sample observations of water use in Ivano-Frankivsk region showed that the average water consumption in rural estates is about 100 liters per day, uncategorized hotels - from 120 to 300 liters per day, in star hotels - more than 300 liters per day, depending on the offers of hotels for health and recreational services (availability of swimming pools, spa treatments, etc.). These results fully confirmed the WTO data on the water consumption of hospitals: with increasing category and comfort, these figures are growing. Moreover, the indicators of water use by tourists in accommodation establishments are higher than their average consumption by the population of tourist destinations. According to approximate

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calculations, with an average tourist stay of 4 days, the volume of tourist water use in the region is about 2.4 million m^3.

Using of energy. Hotels and other tourist infrastructure use a lot more electricity than the average local. Thus, according to EU energy saving experts, the use of energy per 1 m^2 in a non-star hotel is 157 kWh, in a four-star hotel - already 380 kWh [43]. That is, with increasing comfort of the means of placing energy consumption increases. In many areas of tourism development, the energy system is not designed for such significant energy consumption. Thus, a significant reconstruction of the local energy supply system has been carried out in the area of the Bukovel tourist complex for uninterrupted power supply. The issue of energy supply in the tourism sector can be solved through the use of renewable energy sources, scientists have made such a justification [44-46] (Fig.3). For energy companies that are within the impact on environmental facilities, recreational areas, scientists have proposed technical solutions and new methods and means of measuring the volume of oxygen to improve the accuracy of determining the ratio of excess air during fuel combustion [47]. Also, great attention should be paid to the training of specialists in the field of energy, as well as the use of modern methods and approaches to training, the use of GIS technologies [48, 49].

Fig. 3. Vacuum solar collectors are used to heat water in the sanatorium "Carpathian Stars", Yaremche.

Air pollution and the problem of solid waste are also environmental problems of tourist destinations. The growth of the tourism industry leads to a high concentration of tourists and the corresponding infrastructure. This leads to air pollution from road, rail and air transport. For example, 60% of all air traffic in the world is directly related to tourism, so tourism is also "responsible" for air pollution. Noise pollution from transport, and sometimes from tourists themselves, is another important problem. On the other hand - air pollution is also a problem for the organizers of tourist activities, because the tourist expects from the rest areas, first of all, clean air and the absence of noise discomfort. Sources of air pollution are usually vehicles (cars) (Fig. 4). So, in the tourist complex "Bukovel" in a peak season arrival of about 900 units of motor transport is fixed daily. Atmospheric air pollution by vehicles leads to the accumulation of pollutants in soils and their subsequent migration along the food chain. In the scientific works of various authors there is work to determine the risk assessment for the population as a result of air pollution [50, 51].

Fig. 4. Dangerous car tours in the Carpathians.

For many tourist destinations there is a problem of solid waste management of tourism enterprises: the amount of waste is growing faster than the possibility of their disposal. The problem is complicated by the need to transport solid waste over long distances. Scientists have modeled the formation of solid waste within the Ivano-Frankivsk region and justified the need to take into account the increased flows of tourists in the development of roadmaps for waste management in tourist destinations [52-54].

Thus, the environmental impact of tourist destinations increases with the development of the industry and there is a need to systematize the mechanisms for implementing environmental safety within the territories of tourism. We have analyzed and summarized information on the application of various measures and mechanisms to ensure the environmental safety of natural and man-made systems. We propose to classify them into regulatory, economic, controlling and voluntary mechanisms for ensuring the environmental safety of tourist destinations (Fig. 5).

Regulatory tools make it possible to reduce the impact on destinations from tourism by regulating the capacity of the territory, setting limits and limits on the activities of enterprises providing services to tourists, through environmental impact assessment of tourism, environmental monitoring and sustainability of territories. Regulation of the number of tourists on the territory is an important factor in the balanced development of tourist areas. Territorial communities and environmental structures in the territories of which tourism is developing can regulate the flow of tourists, offering alternative routes and optimizing tourist flows quantitatively. This factor must be taken into account when planning recreational settlements. The system of monitoring potential impacts on the territory is a necessary tool for monitoring the environmental parameters of pollution and indicators - indicators of balanced development of territories. In the system of observations at the first stage it is necessary to carry out inventory of the basic recreational resources, definition of objects of monitoring, a choice of estimation parameters, a mode of supervision.

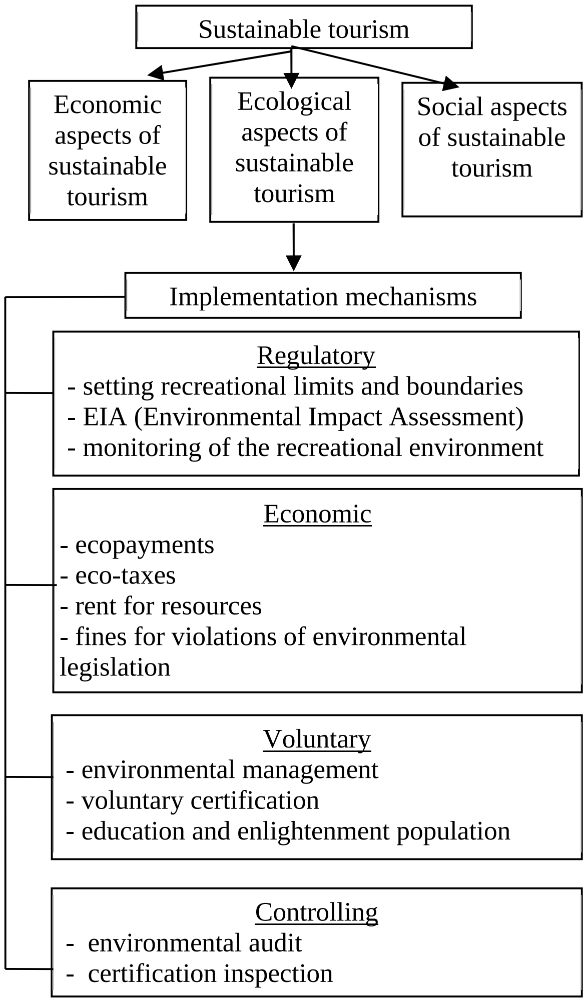

Fig. 5. Mechanisms for ensuring the environmental safety of tourist destinations.

In the process of forecasting the state of the recreational environment determine possible negative trends in its development in various aspects, such as increasing the functional hazard of tourist and recreational equipment, deteriorating ecological condition of tourist destinations, reducing the attractiveness of tourist facilities, etc. Together, these processes can lead to the degradation of tourist destinations, reduce the flow of tourists. The results of forecasting can be a factual basis for the development of measures to manage the recreational environment. Managment is considered as practical activities in the field of regulation of recreational systems in accordance with the needs of the economy and tourists on the basis of objective laws of nature and socio-economic development. The success of management measures is determined by the effective functioning of tourist destinations, namely the positive dynamics of the tourism industry and related industries, the optimal load of the recreational environment by vacationers, favorable environmental conditions of tourist destinations and safe use of recreational resources. Thus, this monitoring system fits into the traditional framework of monitoring concepts.

Setting limits on the environmental impact of tourism facilities is seen as an effective mechanism for ensuring the environmental safety of tourist destinations. Compliance with environmental standards is the most important component of the mechanisms for implementing the principles of balanced tourism. Environmental standards are uniform and mandatory for all objects of this type and level of the system of norms and requirements for the environment.

The main economic mechanisms for ensuring the environmental safety of tourist destinations are financial incentives, monetary rewards, financial support for projects aimed at implementing the principles of balanced tourism, balanced tax policy and procedures for subsidizing balanced tourism projects. Tourist eco-taxes and payments are taxes paid by tourists for the ecological needs of territories. This practice is common in the most environmentally vulnerable tourist destinations in the world.

The main control mechanisms for ensuring the environmental safety of tourist destinations are to implement actions to control the activities of tourism entities in the field of environmental safety of tourist destinations. Conducting an environmental audit is an important management tool, which is a systematic, documented periodic and objective assessment of the organization's compliance with the management system, equipment for environmental safety and environmental policy of the enterprise.

Certification is a process of assessment and monitoring that confirms in writing that a business, product, process, service or management system meets certain requirements. This process is important in enterprises of different directions [55]. In the practice of environmental certification of accommodation establishments, there are about 30 eco-labeling systems. In Ukraine, a method of voluntary environmental certification of rural tourism homes "Zelena sadyba" has been developed.

The main additional mechanisms to ensure the environmental safety of tourist destinations include the introduction of environmental management in the structure of general management, marketing and demarketing, training of tourists and locals. Professional environmental management in the tourism industry, especially hospitality, such as energy saving measures, reducing water consumption, waste minimization, the use of environmentally friendly materials can reduce the environmental impact of tourism development. Training of tourists and locals can take place various forms. This is the implementation of educational programs, social advertising, printed materials, volunteer work, etc. This activity becomes especially relevant in the process of organizing ecological tours, visiting natural, nature reserves.

4 Conclusions

Thus, the main problem in the development of the concept of sustainable development of tourism is the development and practical implementation of tools (means) to implement the principles of balance in practice. Ensuring the environmental safety of tourist destinations is one of the main priorities for sustainable tourism development.

Favorable environmental situation within tourist destinations is considered by tourism experts as an equivalent factor in the development of the tourism industry. Mechanisms for ensuring the ecological safety of tourist destinations are proposed, the use of which will allow to implement the ecological component of sustainable tourism development. Research on the effects of man-made load on the ecosystems of tourist destinations is a promising scientific field in the field of environmental safety.

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Geomodels of space monitoring of water bodies

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Abstract. Theme of the paper is the solution of flooding geomodels creation for Dniester river basin territory, which uses contact and remote measurements. Natural and anthropogenic factors causing groundwater level rising were analyzed for localization of flooded zones and forecasting of geometric characteristics. Geographic information systems for researched area include the spatial binding of the hydrological elements and observation points, digital model of relief preparation, basin allocation catchment, flooded areas modeling. Structural features include the size and shape of object, brightness disposal within the object, image texture, some others. Possibility of available remote sensing data use allows reducing temporal and economic cost for conducting additional ground measurements for possible flooded areas determining. These methods of geomodels creation are realized for the territory of Dniester Canyon, the hydrogeologic feature of which is connected to the Upper Cretaceous horizon and groundwater.

1 Introduction

This research objective is to create cartographic models of potential flooded zones in the Dniester river basin in Ukraine. Environmental researches, particularly in the context of anthropogenic influence, show negative dynamics of flood events statistical frequency. In order to make well-timed decisions of possible negative consequences preventing or eliminating, remote sensing methods are being actively used. Development of new and improving the existing geomodels creating methods, just as potential flood zones definition, is possible on the basis of remote and contact measurements comprehensive using. It also requires considering hydrogeological conditions diversity and geographical conditions of the researched area [1-3].

Every year the problem of new and new territories groundwater flood is growing. It leads to sanitary and epidemiological deterioration, to groundwater and soil chemical composition changing, to corrosion activity increasing which relate to engineering structures foundation, to dangerous geological events activation, etc.

Experimental researches of anthropogenic factors that were associated with flood in the Dniester river basin are based on expert assessment and information technology methods. Geomorphological researches, geological researches of Dniester canyon, Dniester terrace formation history was made by O. Adamenko, A. Bohutskiy, A. Yatshishin, S. Rudnitskiy, E. Romer. Current environmental situation researchers in the territory of Dniester anti-flood area are considered by Y. Adamenko, D. Zorin, Y. Semchuk and some other scientists. Scientometric analysis results showed a number of environmental problems in this area which need to solve.

2 Results

The aim of the research is to solve a scientific and practical task of potential flood geomodels creation substantiation in Dniester river basin, which has to base on aerospace and ground measurements.

Prevention of emergencies associated with flood in Dniester river basin requires continuous monitoring with analysis and assessment of received data. Flooded areas detection is carried out using remote and contact methods.

The ecological danger of flooding occurs in such landscapes as river valleys terraced bottoms. It takes the form of destructive coastal erosion, while high water disasters take place in foothills within the boundaries of floodplains. Among geomorphological processes, most hazardous for the environment, are landslides. This phenomenon is wide-spread in areas of erosion-shifting interfluve and hilly lowlands, landslides and shoals – in mid-high mountains with stiff slopes [4-7].

Chemical pollution of the territory does not have a strong coherence with landscape type; it tends to local sources of influence, around which anthropogenic geochemical anomalies are formed. Totally, there are nearly 18 man-made anomalies in the Dniester Canyon which occupy southern boundary of Ternopil region.

Contact methods allow accurate measurements of the groundwater depth, but some errors can occur in the process their boundaries establishment [8-13]. These methods also require large quantity of material and labor resources.

In the process of degree of risk for the geomodels hierarchical structure formation determining, interval estimates method using helps to make operational decisions

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to prevent consequences of dangerous engineering-geological processes in uncertain conditions. This method requires establishing dependencies between model parameters that characterize various possible situations of researched areas, using expert assessment and statistical analysis.

This way contributes to increase the accuracy of flooded zones localization with different degrees of danger [17,18].

Geographic information systems for researched area include the spatial binding of the hydrological elements and observation points, digital model of relief preparation, basin allocation catchment, flooded areas modelling (Fig. 1).

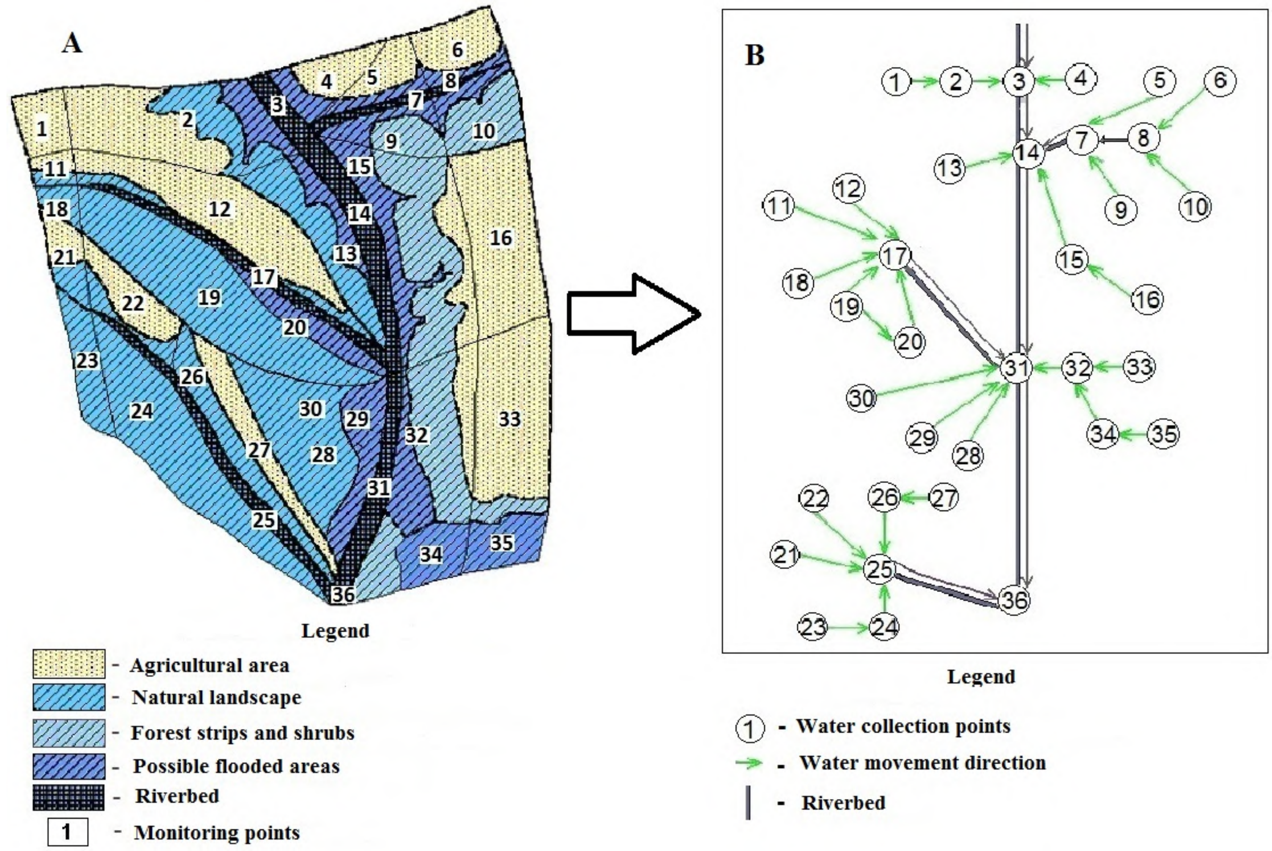

Fig. 1. Cartographic and graph model of the flood on Dniester river segment in rainy weather: A) Map of flooded territory; B) Graph representation of the model.

Proposed flood mapping representation and graph model representation of the Dniester region are basing on aerospace and ground survey using, which include data analysis for obtaining topographical or special maps and digital relief model construction.

Constructed graph shows the points of research and catchment area branching peculiarities on the territory. The final aim of proposed methodology is to assess and to consider actions of flood and deformation accidents struggling [14-16].

Natural and anthropogenic factors leading to groundwater level rise were adjusted for flooded zones localization and geometric characteristics dynamics forecasting. Possible unfavorable processes in flooded zones were established factored in the characteristics of the territory. Four flood categories depending on groundwater lever occurrence, causing factors and possible consequences were separated. Categories I and II accords to areas with groundwater depth is less than 2.5 m, where dangerous phenomena occur. Category III accords to possible flooded areas with a groundwater depth from 2.5 to 4 m, where tendency to groundwater level rise can be noticed. Areas in category IV cannot be flooded, because there are no predictions for flooding if groundwater level is deeper than 4 m.

Cosmobioindication method (by G. Krasovskiy) enables to make monitoring of waterlogged lands. This method [19-21] is based on vegetation conditions (determined by vegetation indexes measurement) depending on land waterlog degree. The application of this method is limited to unpowered soybean soils.

It is necessary to assess possible risk of groundwater shallow occurrence to determine degree of danger for researched territory. Creation of new and improving existing methods of geomodel developing for potential flooded areas is possible only after comprehensive remote sensing results and ground measurements using. Also requirement is to take hydrogeologic conditions diversity and geographical specific of the area into account.

Fig. 2 shows the structural scheme to develop geomodel for probable flooded zones according to danger degree.

There are four stages to make cartographic model with different flooding probabilities. At the first stage, it is necessary to create cartographic models of probable flooded areas based on the rules of fuzzy production system. Also SRTM (radar topographic survey) data and available ground measurements data have to be used. [22,23].

At the next stage, thematic decoding of aerospace images is made in order to identify geomorphologic

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elements and potential sources of anthropogenic impact for developing of cartographical models of natural and man-made flood based on only classification characteristics assessment scale. If it is necessary, photogrammetric image processing is executed. Third stage is to specify the flooding geomodel through overlay operations on cartographic models built on the base fuzzy production system rules and interval scale of evaluation. At the final stage, a complex hierarchical geomodel of probable flooding zones (based on danger degree) is created. It is made through specified geomodel and anthropogenic flood overlaying.

Let us consider the features used in visual analysis of remote survey materials or formalized in the methods of space images computer analysis. Decryption features can be divided into two main groups – brightness and structural. During visual analysis of images bright features group includes image photon (for monochromatic images), such color characteristics as color tone, color saturation and “lightness” (for color, spectrozonal and synthesized images). During decoding of digital images rendered on the display screen, brightness equivalents of image (for panchromatic), zonal brightness equivalents (for multi-zonal survey) and equivalent of effective scattering area (for radar images) are the brightness features. If synthesis procedure is being used in conditional colors for multi-zonal images visualization, then the color characteristics are also being analyzed.

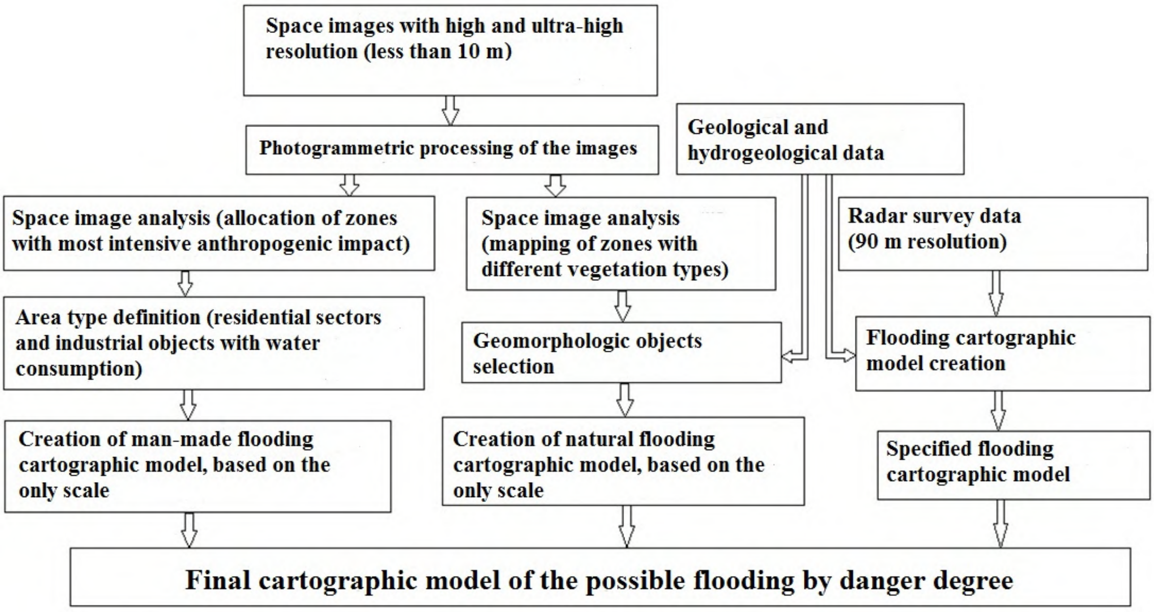

Fig. 2. Method of creating flood cartographic model by danger degree.

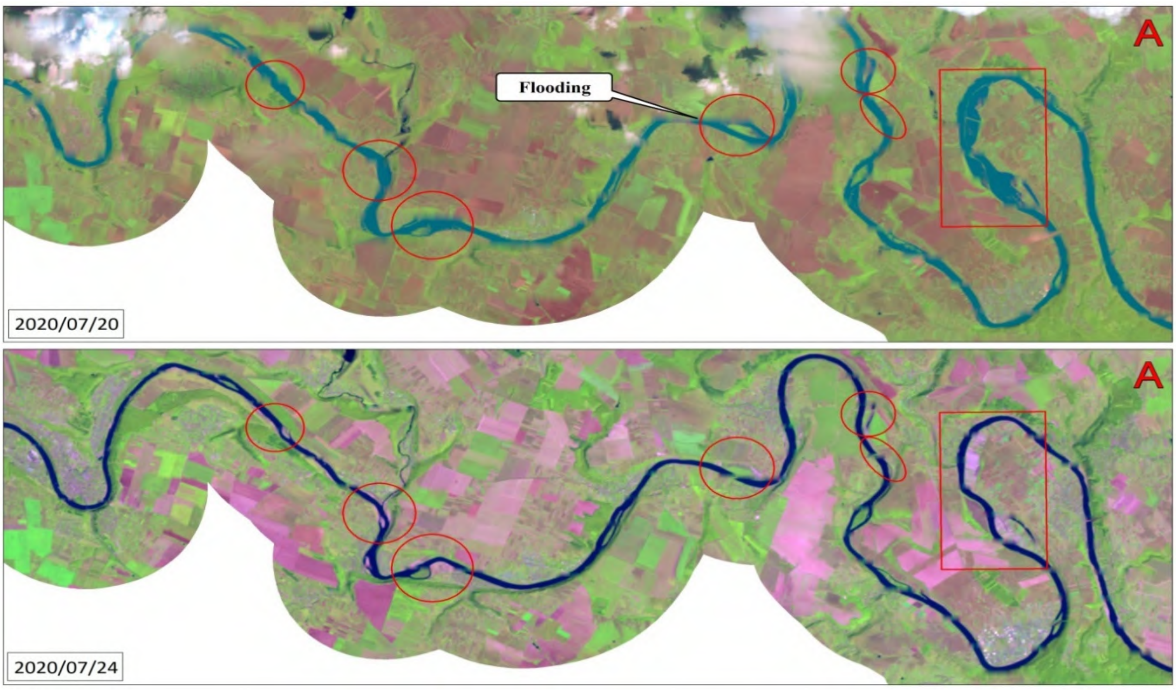

Fig. 3. Flooded areas in Dniester river basin between Dobrilyany and Ustia villages in 2020 is on a fragment of space image SENTINEL 2 (10 m resolution).

Structural features include the size and shape of object, brightness disposal within the object, image texture, some others [24-35]. The initial source for the space images thematic analysis is various thematic maps. Together they give information about localization of objects and spatial disposal of indicators. This disposal characterizes ecological situation in the environment or anthropogenic impact level in its components, localization of impact sources and its scale. Therefore, main processes in space images thematic analysis are represented as images segmentation for planar and linearly extended objects identifying, as Fig. 3 shows.

Remote sensing methods allow to make flood monitoring and to analyze its dynamics, but they have a number of disadvantages due to high difficulty of data analysis and delay in obtaining the space images.

Flooded zones localization on space images is carried out on indirect features, such as presence of floodplains, swamps and relief depressions. Flooded areas mapping is possible on threshold values of mathematical expectation and dispersion of color intensity on red, green and blue channels [36-49].

Digital panchromatic image with a 10 m-resolution (4800 x 4800 pixels) was analyzed in ERDAS IMAGINE software using controlled classification method.

3 Conclusions

Methods for geomodels making for probable flooded zones were developed and implement for territories in Dniester river basin. Its geomodels consider degrees of danger which formed in conditions of insufficient information.

Scientometric analysis of geomodels creating methods for flooded territories showed that possible flooded areas timely detection and prediction of dangerous accidents is possible only with complex use of remote and ground measurements with their subsequent rationing and analyze.

Possibility of available remote sensing data use allows reducing temporal and economic cost for conducting additional ground measurements for possible flooded areas determining. While the accuracy of predictive parameters do not reducing.

The developed cartographic models of possible flooding areas allow determining and visually assessing the degree of flooding under different modes of pressure horizons use, which have a hydraulic connection with groundwater. These methods of geomodels creation are realized for the territory of Dniester Canyon, the hydrogeologic feature of which is connected to the Upper Cretaceous horizon and groundwater.

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Modern means of assessing the impact of emergencies on the environmental condition of the ground layer of atmosphere

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Abstract. The problem of emergencies will not leave humanity as long as it exists, and therefore it is necessary to at least create conditions under which it is possible to reduce the risks of injuries, diseases and deaths of people who are in the emergency zone. This can be achieved by raising awareness of the nature of the emergency, the hazardous substances that are released in connection with it. Theoretical analysis of various remote means of assessing the impact of emergencies of man-made areas on the ecological state of the atmospheric air of the surrounding areas. It has been found that the use of remote sensing equipment greatly simplifies the procedure of operational monitoring of the environment during emergencies, as well as contributes to the health of professionals. A comparison of different remote means of environmental monitoring of air quality was performed: In particular, stationary automatic stations, mobile automatic stations, probes, and unmanned aerial vehicles (UAVs) were compared. It is proposed to use UAVs as remote means of operational monitoring of air quality. The functional scheme of UAV system implementation for the needs of operative ecological monitoring is offered. The legal features of the use of unmanned aerial vehicles as remote means of monitoring air quality during emergencies are analyzed.

1 Introduction

With the growth of the technological and economic crisis, the absolute number of the new man-made emergencies and accidents at enterprises and infrastructure of settlements is growing. The introduction of new technologies and timely modernization can reduce the number of accidents, but the risk of their occurrence cannot be reduced to absolute zero.

The rational usage of nature involves not only ecologically balanced management of natural resources, but also the creation and maintenance of a safe environment for future generations. This is achieved through the implementation of the provisions of the concept of sustainable development not only in the objects of entrepreneurial activity, but also in the processes of control and management of environmental quality.

The deterioration of qualitative and quantitative characteristics of the surface layer of air leads to negative consequences [1] not only for the biosphere as a whole, but also to increase the impact on public health [2] and the increasing number of diseases and allergies. The reverse effects observed by scientists around the world related to the SARS-CoV-2 epidemic are also possible [3-5].

Nowadays the solving of the problems related to the state of the environment involves the usage of the latest technologies and developments, as well as the application of approaches to sustainable development and the functioning of environmental quality management systems.

This is especially important for the control of man-made objects and territories, as well as for the detection and elimination of emergencies and their consequences. Within the framework of this direction the state programs are formed, important researches are carried out [6-9].

The related research requires the use of modern scientific and technological progress, the creation and use of the latest information-measuring and software-hardware complexes. The effectiveness of their use depends on the level of development, the use of hardware and software measurement tools and the ability to work effectively with the information obtained.

During emergencies at man-made sites, large volumes of mostly toxic substances are usually released into the air, but the low speed of response of specialists, as well as physical defects do not allow to quickly identify the location of harmful substances in the environment. As a result of lost time, the company, service organization or country incurs significant economic and social and labor losses for each unit of time.

The usage of remote multispectral and multisensory means will reduce the response time of specialists to a call in case of an emergency or threatening situation on the territory, as well as reduce the risk of injuries and diseases of specialists in performance of official duties.

The aspects of this issue were considered by many well-known scientists. Thus, O.O. Popov, A.V. Iatsyshyn, V.O. Kovach, V.O. Artemchuk, T.M. Iatsyshyn, A.O. Zaporozhets, V.M. Isaenko, S.M. Majd, J. Burgués, S. Marco, A. Arfire, A. Marjovi, A. Martinoli, N. Castell, M. Kobernus, H.-Y. Liu, P. Schneider, W. Lahoz, A.J. Berre, J. Noll and others were engaged in solving problems of ecological safety of energy and public utilities, but the issue of developing new or improving existing means to improve the environmental safety of man-made areas during emergencies in case of non-radiation pollution of surface air remain relevant and important for many developed countries.

The study was conducted to analyze the existing means of monitoring air quality during emergencies in man-made areas and potentially dangerous objects to develop and implement a more effective means of operational monitoring of atmospheric air.

Within the framework of the aim it is planned to solve the following tasks:

- identify the features of the mechanisms of the ecological management system of the techno-ecosystem;
- to analyze pollutants that require special control in the emergency area;
- Investigate approaches to the mathematical description of the movement of pollutants in the ground layer of the atmosphere;
- propose the approach to optimize crisis monitoring and management of the ground layer of atmospheric air in areas of emergencies or potential emergencies.

2 Materials and methods

This study was mainly conducted on the basis of domestic and foreign publications on methods of management and monitoring of man-made objects and areas during planned activities and during emergencies, as well as on the basis of the authors of this study.

The following research methods were used: method of comparative analysis, modeling and evaluation of the impact of emergencies on the quality of the ground layer of atmospheric air.

3 The research results

3.1 Ground layer of atmospheric air, features of definition

Nowadays there is no clear definition of the term "ground layer of the atmosphere" in Ukrainian terminology, so State standard of technical conditions of Ukraine (DSTU) 3513-97 “Meteorology: Terms” [10] indicates the surface layer of the atmosphere as "The lower part of the boundary layer of the troposphere, which interacts most intensely with the underlying surface". In spite of, this formulation is not very accurate and does not indicate the boundaries of the layer of the atmosphere that is most affected by the underlying surface, i.e. the habitat of most living organisms, and in particular humans.

According to Directive 2008/50 / EC of the European Parliament and of the Council of 21 May 2008 about air quality and cleaner air for Europe [11], the optimal level of measurement of pollutants to be considered safe or unsafe for human health the height of 1.5 m above ground level is determined, in other words, the average statistical height of a person. At the same time, for the description, modeling and forecasting of pollutant levels in the surface layer of the atmosphere, the data obtained from a height of 1.5 m is not enough, so it is necessary to determine the highest point of the range of air quality parameters.

O.G. Shevchenko performed studies [12] of the influence of physical processes potentially caused by the influence of the earth's surface on the concentration of pollutants: sulfur dioxide and nitrogen dioxide, at an altitude of 10 to 500 meters above ground level. According to this study, at altitudes of 251-500 m, pollutants that enter the atmosphere from high emission sources (enterprise flares) are significantly affected by meteorological phenomena and changes in the trajectory. At altitudes of 10 m to 250 m, low and medium emission sources are the main influence.

However, at heights from the direct underlying surface (conditionally zero height) to 1.5 m, there is also a significant and direct impact of the surface on atmospheric air: erosion of soils, evaporation of water, release of pollutants from leaks and exhaust pipes of some types of vehicles. Most of the substances released in this way after entering the atmosphere thus rise to a height of more than 1.5 m and are carried further.

Therefore, in accordance with the above, the authors consider that the ground layer of the atmosphere is the airspace at altitudes from 1.5 m to 500 m inclusive.

3.2 Features of the impact of emergencies on technogenically loaded objects on the environment

The peculiarities of the distribution of pollutants in the air were described in the 1970-s by M. Berland [13], who determined that the main factors influencing the spread of impurities in the atmosphere are wind and the distribution of air temperature with altitude.

Industrial emissions can come from sources of different heights: from industrial pipes (flares), from sources at ground level, and so on. If the temperature of the gas released from the source is higher than the ambient air, the former are characterized by a certain dynamism. According to the research of M. Berland, and a group of scientists led by O.O. Popov [14] in the vicinity of the emission source creates a field of vertical velocities, attenuating with distance from the source, which sometimes extends over long distances and helps to raise the impurity up.

The process of transferring impurities to the upper atmosphere is called atmospheric stratification and can be defined as the category of stability of the atmosphere.

The state of the atmosphere can be equilibrium, stable and unstable. The degree of stability of the atmosphere determines the behavior of the air particle (elementary

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volume of air), removed from the original position, in the upper or lower layer of the atmosphere.

According to the laws of physics, a particle of warm air rises and a particle of cold air descends.

In the troposphere there is a decrease of temperature with increasing altitude, which has a direct impact on the "state of the atmosphere". The atmosphere in a particular place can be in several different states in their physical characteristics:

1) the state of equilibrium stratification – air particle moving in a certain direction, takes the temperature of the ambient air and its density becomes equal to the density of the surrounding particles, therefore, the cause of its rise or fall is leveled;

2) the state of stable stratification of the atmosphere – if the vertical temperature gradient in the atmosphere is less than at equilibrium, the particle moving up will cool and will soon become colder than the surrounding air, and heavier than it. Therefore, it will fall and return to its original position;

3) the state of unstable stratification – if the vertical temperature gradient is more than equilibrium, the air particle, starting to move up or down, will continue its movement with increasing acceleration. The farther it goes from the initial position, the more its temperature deviates from the ambient temperature [13]. In this case, we talk about unstable stratification.

Another characteristic of the description of the state of the atmosphere is the so-called inversion, which is defined as an increase in temperature with altitude. Temperature inversion can occur both near the earth's surface (surface inversion) and at a certain height (altitude inversion). If the inversion occurs at a certain height above the ground, it is called elevated. Increased inversion can create dangerous conditions for the population living in white man-made areas, due to the fact that emissions cannot rise above a certain level - the "ceiling", the effect of which such an inversion creates.

Information on the fundamentals of the functioning of the atmosphere in its various parts is very important for determining the qualitative and quantitative indicators of air quality at any time, in particular during the operational monitoring of air quality in the emergency zone or during a technogenical accident. It is especially important for forecasting the consequences [14] and effective environmental safety management in areas of such situations. For example, it is also important for the effective assessment and management of the atmosphere that pollutants enter the atmosphere not only from certain stationary or mobile sources of emissions, but can be discharged from the surface of the earth, which has been man-made and anthropogenic, in particular in Ukraine. scientists [16] on the territory of Boryspil International Airport.

3.3 Remote atmospheric research tools as the first and important link in the crisis monitoring system during emergencies

Unfortunately, modern measuring instruments do not provide enough attention in the scientific community, and the instruments used in the national practice of Ukraine are often difficult to call modern. This primarily affects the accuracy of measurements and, consequently, the reliability of control over the quality of the environment. At the same time, when it comes to technical means and systems of air pollution control, the most effective, accurate, operational are optical, in particular, multispectral systems and multisensory systems, that allow express and at the same time high-precision control of air pollution in selected research ranges.

Multispectral research devices are imaging devices (image or set of images) in which data are recorded in certain wavelength ranges in the electromagnetic spectrum [17]. Wavelengths can be separated by optical filters or by sensors sensitive to specific lengths waves, including light having frequencies outside the visible range, such as infrared and ultraviolet [18]. Spectral visualization allows you to get additional information that cannot be seen by the human eye with limited receptors for the vision of blue, green, red. Such tools are usually part of geographic information systems that are built on the basis of satellites [19].

In contrast, multisensory devices are based on a number of different types of sensors, including optical, which allow to obtain a more informative and accurate conclusion about the quality of atmospheric air in a particular study area.

When the research is performed manually, using any research tools, there is an error of measurement caused by the human factor. Proven accurate remote sensing tools should be used to minimize human exposure during studies that require high accuracy and time.

Remote means of environmental quality research (Fig. 1) can be in the form of meteorological probes, remote manned or automated robots, unmanned aerial vehicles (UAVs) with installed video, infrared cameras and almost any sensors.

The most common remote means of air quality control are state (municipal) systems built on the basis of a set of stationary automatic stations (Fig. 1 a). Such systems have proven to be the main means of systematic air quality monitoring of large cities, suburbs, industrial regions, protected areas, etc. They allow to conduct fundamental research [20-22] of the patterns of movement and deposition of various pollutants [10], as they have a very high accuracy of equipment, the ability to work around the clock. The main disadvantages of these systems are the high cost of placement and operation, stationary, the overwhelming inability to quickly disassemble and move the observation station to another location (extremely low mobility).

One of the rather new methods of studying the historical levels of air pollution is the method of dendrochemistry [23], which was considered by a group of Italian scientists led by Edoardo Alterio, who proved the convenience and accuracy of this method of historical analysis of air quality. Without regard to, this method is not suitable for determining the actual levels of air pollution at the time of measurement.

The use of small cheap analogues of stationary atmospheric air monitoring stations - portable stations - is also quite widespread. Based on a system of municipal (large) and portable cheap (small) stations, there are online services (Fig.2.) that disseminate information about the relative air quality at a certain point. These relative readings are called the "Air Quality Index", which is calculated [49-50] on the basis of basic measurable indicators - dust particles, carbon oxides, nitrogen and sulfur.

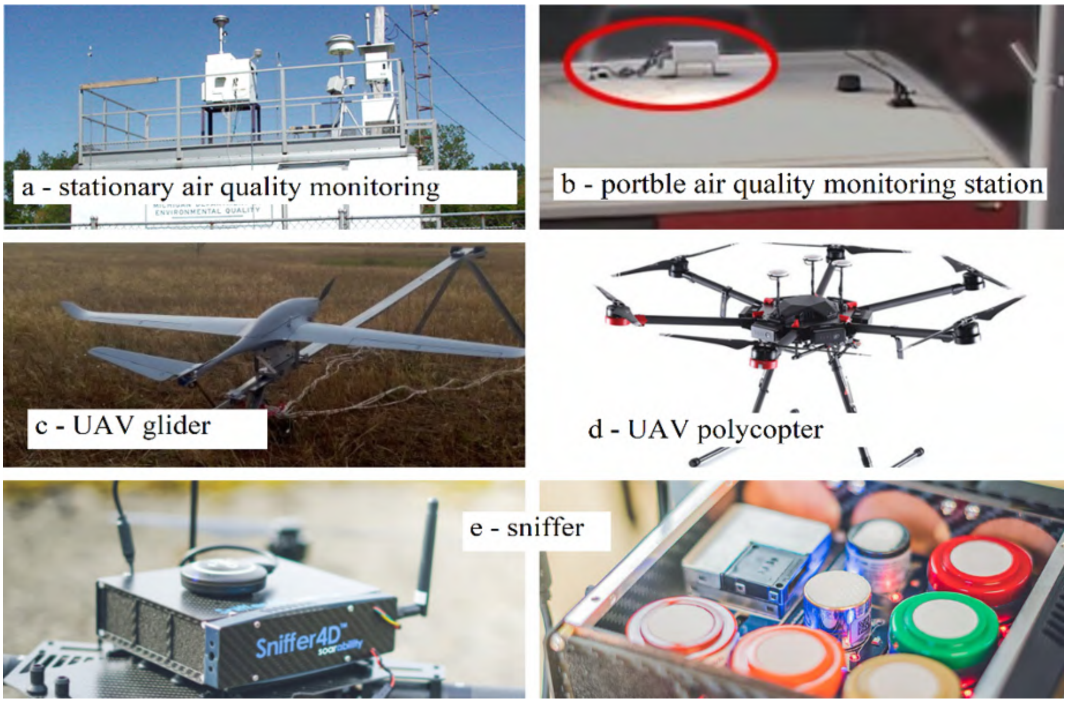

Fig. 1. Remote Environmental Monitoring tools [39,45-48].

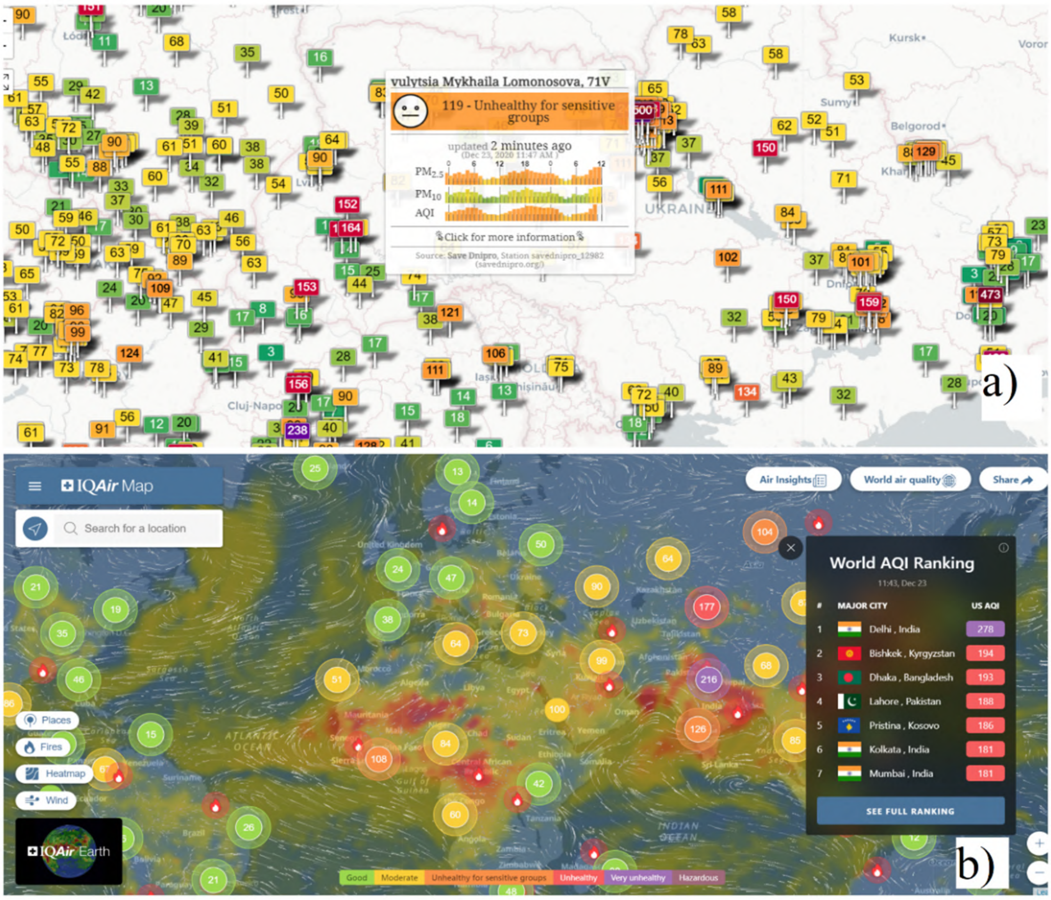

Fig. 2. Examples of online services for information about air quality and air pollution: a) aqicn.org and b) iqair.com.

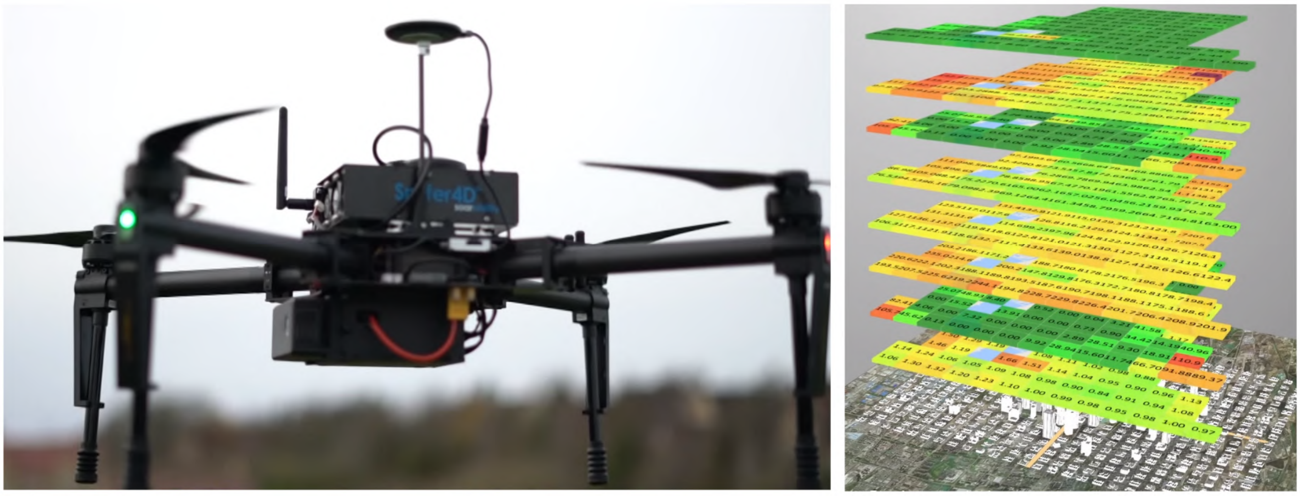

Fig. 3. Effective use of UAVs for manual air quality monitoring [39].

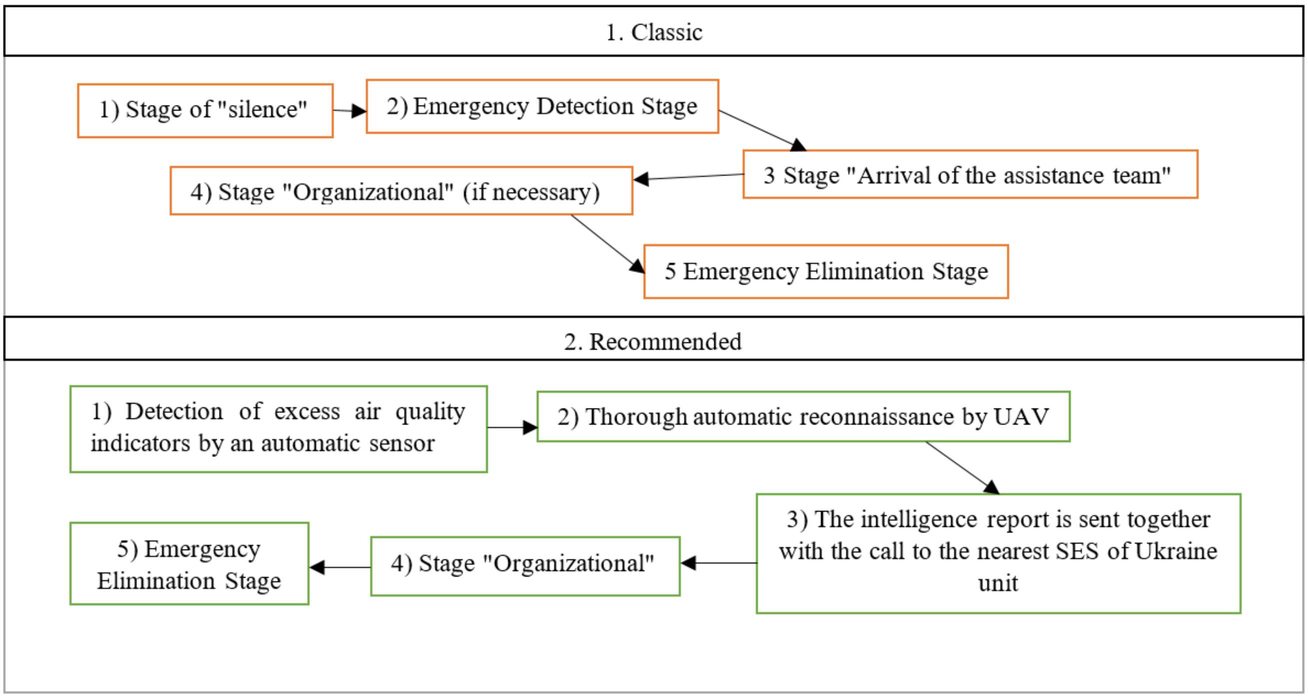

Fig. 4. Simplified response scheme of the rescue service (SES of Ukraine) to emergencies.

In the world of rapid development, the use of various sensors located in the systems of public, leased and private transport to study the parameters of air quality (Fig.1 b). In particular, A. Arfire, A. Marjovi, A. Martinoli, N. Castell, M. Kobernus, H.-Y. Liu, P. Schneider, W. Lahoz, A.J. Berre, J. Noll, L. Kang, S. Poslad, W. Wang, X. Li, Y. Zhang, C. Wang, G. Lancia, F. Rinaldi, P. Serafini, L. Liu, J. Duan, Z. Xiao, H.P. Raju, P. Partheeban, R.R. Hemamalini at al. have their scientific achievements in this field [24-30]. It is based on the use of the concept of the Internet of Things, to create and group sensor systems that are in some way placed on vehicles and combine them with computer centers that transmit information about the state of the air in the city to the Internet. Such systems are currently used successfully in cities and regions such as Chennai (India) [29], Lausanne and Zurich (Switzerland) [24] and Rome (Italy) [27]. Similar systems are also being tested in several regions of China [26, 28]. Such means of studying the quality of atmospheric air can be considered remote, due to the lack of a direct person-performer of measurements, the latter are performed automatically. In some systems, even the sensors are calibrated by a measuring device without assistance in an autonomous automatic mode [25].

Radioacoustic sounding of the atmosphere as a means and method of remote environmental monitoring, presented in the works of E.G. Tolstih [31]. This method is based on the passive radar spot of scattered electromagnetic oscillations and allows you to remotely measure such characteristics of atmospheric air as humidity, temperature, pressure and other physical indicators of air quality. Notwithstanding, radioacoustic sounding does not allow to determine the qualitative and quantitative values of aerosol and dust air pollution, as well as its chemical components in relative and / or absolute form - gases, water vapor, etc.

The studies based on the introduction of unmanned aerial vehicles into active scientific, industrial and public use have become very popular and widespread. At present contemporary UAVs are used: in biology to explore new, previously inaccessible corners of the planet and studied their flora and fauna [32]; in emergency services for the introduction of effective means of searching for victims of disasters and emergencies, in particular in the rubble of buildings [33-34]; in the fields of marketing and logistics for the development of services of delivery and dissemination of unimpeded provision of the population of remote places with the necessary means of subsistence [35], in the military sphere for search and general intelligence [36] and in the socio-cultural sphere for entertainment and leisure filming, video-blogging, photo and video shooting of sports competitions and concerts [37]. In the field of environmental safety, A.O. Zaporozhets, J.Burgués, S. Marco, R. Noori and D.P. Dahnil are using UAV-based technologies.

The use of UAV-based monitoring systems has found its use not only to study air quality, but also to perform research on the reliability of power grids and other energy and infrastructure facilities. [51-53].

Researcher of the Institute of Technical Thermophysics of the National Academy of Sciences of Ukraine A.O. Zaporzhets carried out a research project to create an air quality monitoring system based on the use of a set of methods for obtaining information on the state of the atmosphere: UAVs and the existing system of planned monitoring based on stationary and mobile air quality monitoring posts. In his work, he focused on planned, i.e. continuous monitoring of industrial facilities and proposes to study the air for the content of O_2, CO, CO_2, NO, NO_2, SO_2, H_2S at an altitude of 50m to 1km using UAV glider (fig. 1 c) and helicopter types [38].

Spanish scientists J. Burgués & S. Marco have developed an effective device (Fig. 1 e) for air sampling during monitoring of polycopter type UAVs - sniffer (sensor unit) of atmospheric quality [39], performing a significant analysis of research conducted today on the location and execution of sniffers for use in unmanned aerial vehicles during continuous scheduled monitoring of air quality in cities (Fig. 3.). The problem with their sensor unit is: too dense placement of sensors, which can affect the work of each other and interfere with the uniform blowing of all sensors, as well as the narrow specialization of the sniffer and the impossibility of its use on various unmanned aerial vehicles, as Burgués, J., & Marco, S specialized in their invention for use with only three models of helicopters brand DJI M100/210/600, as well as on cars.

Researchers R. Noori & D.P. Dahnil from the University of Malaysia Kebangsaan proposed the use of a six-beam polycopter (Fig. 1 d) for use in studies of environmental quality indicators [40]. In their work, they tried to test the efficiency of the polycopter to determine the effectiveness of various equipment for measuring the concentration of four indicators of air quality: smoke, hydrogen, carbon monoxide and liquefied petroleum gas given the turbulence of air generated by UAV propellers during its movement and optimize the complex these features. The scientists concluded that their system has the highest measurement accuracy only at UAV speeds up to 6 m/s, and at speeds above this value there is a significant decrease in the accuracy of the obtained data.

3.4 Legal features of the use of UAVs in the system of operational monitoring of the atmosphere during emergencies in Ukraine

As noted in the previous section, currently unmanned aerial vehicles have an unsurpassed impact on the speed and quality of research in various spheres of life: economy, industry, science, socio-cultural life.

The rapid development of the scope of UAVs has led to the rapid development of interception technologies for remote-controlled unmanned aerial vehicles. These technologies propagate a large number of signals in a certain frequency range, which prevents the exchange of information between the control station and the radio transmitter of the aircraft with a radius of several kilometers, but most modern unmanned aerial vehicles have protection against radio noise and interception. Radio interception can be hindered by the use of an autopilot module in the UAV, with a preset task of the desired flight route to the program of the aircraft, which in this case has a mediocre value of data exchange with the control station - can transmit real-time images and data not used during flight.

Anyhow, the use of UAVs for any purpose in Ukraine is clearly regulated by regulations, in particular: The Air Code of Ukraine [41]; Regulations on the use of airspace of Ukraine [42] and the Rules of use of airspace of Ukraine [43].

The State Aviation Service of Ukraine has published a map of zones [44] with restrictions on the flight of unmanned aerial vehicles. The UAV flight area has a specific character and is strictly regulated by such organizations as the State Agency of Civil Aviation and the Armed Forces of Ukraine. The result of regulation are areas where flights are prohibited in whole or in part limited by the size of the UAV or time of day. In accordance with the requirements of paragraph 4 of section II of the Rules of use of airspace [43], flights of unmanned aircraft weighing up to 20 kg inclusive are performed without submitting applications for use of airspace, without obtaining permits for use of airspace, without informing the Air Force of the Armed Forces of Ukraine and bodies of the joint civil-military system of air traffic organization of Ukraine, bodies of the State Border Guard Service of Ukraine, air traffic service bodies and departmental air traffic control bodies, subject to compliance with certain requirements space".

Though, emergencies may be defined by Ukrainian law as force majeure, or endangering the health and well-being of the population, and unmanned vehicles, which are registered on the balance of the State Emergency Service as means of performing special operations to search and eliminate emergencies, their consequences, as well as for the search for victims, as defined in the Air Code of Ukraine, section 4 “use of airspace of Ukraine”, Article 24, paragraphs 1-5 [41].

4 Discussion

After analyzing the above studies, we conclude that the most promising area of environmental research is the use of modern remote, including *multisensory*, means of prevention and during emergencies in man-made areas and facilities.

Comprehensive development and implementation of new remote multisensory and multispectral means technical means of environmental control, taking into account the impact of their characteristics and parameters on the effectiveness of the process of controlling ground air pollution and assessing the ecological state of the atmosphere of technogenically loaded areas and objects has the aim of operational monitoring of the quality of the ground layer of atmospheric air, reduction of risks to health and life of specialists working in the emergency zone, or one that requires rapid surgical intervention for further localization and elimination.

Based on the analysis, we propose an improved scheme (Fig.4) of work of units of the State Emergency Service of Ukraine (SESU), which shows two algorithms for responding to an emergency - classic and recommended. In classical algorithm we distinguish five basic steps:

- the first stage is the time from the objective beginning of the emergency situation, to the moment when the fact of the emergency is noticed by people;
- the second - starts from the moment of detection of emergency and attempt of independent reconnaissance by non-experts (people nearby) to a call of crew of SESU;
- the third is the arrival of the rescue service team and reconnaissance of the scene by specialists, with or without special means;
- the fourth is creation of a staff of liquidation of emergency situations, development of the plan of liquidation, adjustment of structure of crew, etc.
- the fifth stage, which is directly to take action to eliminate this emergency.

The classical algorithm has two main disadvantages. The first is the response time, which increases significantly in areas where there are no people, or their number is insignificant (for example, land plots of warehouses, landfills, slag dumps, and other objects of man-made origin). The second significant disadvantage is the high risks to life and health of all people in contact with the emergency zone, especially if they do not have adequate personal protective equipment against any dangerous effects that occur in this area. These two shortcomings are interdependent, as due to the increased response time, the scale of the emergency increases, and therefore not only the natural area but also the people there are more negatively affected.

In contrast to the classical response scheme, the recommended scheme, provided it is properly implemented, is as free as possible from the shortcomings of the classical response scheme, and significantly simplifies and speeds up the work of units of the SES of Ukraine.

5 Conclusions

Emergencies will accompany humanity as long as society exists, and therefore it is very important to pay attention to the sustainable development of the response to emergencies, including environmental ones.

The article considers the features of the study of the surface layer of atmospheric air, reviews the existing remote means of monitoring the condition of this layer and also proposes a new functional scheme of response of the State Emergency Service of Ukraine to emergencies.

In order to talk about the monitoring of the surface layer of atmospheric air, it was necessary to determine the boundaries of this layer. Based on literary and logical theses, the authors of the article determined that the airspace at altitudes from 1.5 m to 500 m inclusive.

Based on the comparison of different remote means of environmental air quality monitoring, it can be stated that of all analyzed means, in particular - stationary automatic stations, mobile automatic stations, probes and unmanned aerial vehicles, it is proposed to use the latter as a remote means of operational air quality control. time of emergencies at the enterprise.

The proposed functional scheme of implementation of the UAV system for the needs of operational environmental monitoring of Ukraine will significantly reduce the response time to emergencies at enterprises, although it requires closer relationships "enterprise-unit of the SES of Ukraine" than those that exist now - mostly verifiable. The problem of implementing this functional scheme is the predominant distrust of entrepreneurs to regulatory authorities, which also indicates the need to restructure and reorganize the state emergency service of Ukraine to strengthen its basic functions to protect the population and property of Ukraine from natural and unnatural factors.

Analyzed legal features of the use of unmanned aerial vehicles as a remote means of air quality control during emergencies suggest that the use of UAVs as an additional means of monitoring air quality in the enterprise, as well as its sanitary protection zone is not only possible but also easily implemented. the existing regulatory framework of the state.

The use of modern means of remote monitoring of environmental quality, including unmanned aerial vehicles, will make the field of operational (crisis) monitoring of Ukraine more effective and timely, compared to the existing system of emergency response, which could potentially be responsible for environmental disasters in the region, region, country or even in a cross-border arena. In addition, such optimization will not only optimize the response time to emergencies, but will also be the first link in the whore to develop the scope of rapid response in the concept of sustainable development.

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Effect of liquid glass type on hygienic characteristics of coated electrodes for arc welding of tin bronzes

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Abstract. The results of investigations of chemical composition and emission rates of the welding fume, generated during welding using electrodes for copper alloys, are presented with the aim of improvement of their sanitary and hygienic characteristics. It is shown that in order to create new grades of welding electrodes with improved hygienic characteristics, it is necessary to have the data of the initial sanitary and hygienic evaluation in accordance with international standards. It was established that the use of binder based on pure lithium liquid glass in the coating of electrodes for welding copper alloys, increases the rate of welding fume emission into the air, as well as the content of manganese and copper oxides in it. The minimum rates of harmful emissions were recorded during the use of sodium-potassium binder, which is recommended for mass production of this type of electrodes.

1 Introduction

Manual arc welding of copper and copper alloys using coated electrodes is widely used in different industries, i.e. power engineering, metallurgy, foundry, etc. It is characterized by a number of harmful and hazardous factors that affect not only welder but also supporting personnel [1-3]. From a hygienic point of view, one of the most hazardous harmful factors is the presence of welding fume (WF) in the air, the toxic effect of which depends on the chemical composition of welding electrodes. The methodical standards DSTU ISO 15011-1:2008 [4] and DSTU ISO 15011-4:2008 [5] provide an opportunity to obtain the necessary information about the chemical composition of WF and approximately calculate the risk of their harmful effect on the body of welder.

2 Processes of welding fume generation during manual arc welding of copper and its alloys

A schematic view of the zone of manual arc welding is shown in Figure 1. Under the effect of the arc heat, at the end of the electrode a droplet of liquid metal is formed and growing, which is maintained by surface tension. Moreover, melting of the coating usually occurs little bit slower than melting of the electrode rod. As a result, a "casing" is formed, from which a partial evaporation of the coating materials and the metal melt occurs. A relatively small part of the metal evaporates as a result of a high boiling point of the metal and a significant heat of evaporation. A part of vapours is lost, getting into the atmosphere surrounding the arc, where the metal vapours condense into droplets, oxidize and transfer into fine solid particles of metal oxides, which form a fume and always surround the welding arc. [6].

3 Classification of welding fume according to degree of harm

During manual arc welding of tin bronzes, in the composition of WF such harmful substances as manganese, copper, their oxides and other components of welding material may be present. In all developed countries of the world, sanitary services control harmful substances in the air of the working area of production rooms for their compliance with the maximum allowable concentrations (MAC) according to special methodological standards. In particular, in Ukraine the MAC value for manganese, when its content in WF is lower than 20%, amounts to 0.2 mg/m^3, and when its content in WF starts from 20%, it amounts to 0.1 mg/m^3, the MAC of copper amounts to 1 mg/m^3. These elements belong to the second category of hazard. They may cause inflammation of the mucous membrane, problems with the nervous system and fever of metal smoke.

4 Choice of material and procedure of experiments

To investigate the rates of emissions and chemical composition of WF during manual arc welding of tin bronzes, the electrodes with a specific composition were used, which were developed at the E.O. Paton Electric Welding Institute [7]. Their composition is associated with the presence of chemically active substances related to the binder, such as liquid glass, components of sodium salts (hexafluorosilicate and hexafluoroaluminate), as well as non-traditional metal components (tin and copper-phosphorus powders).

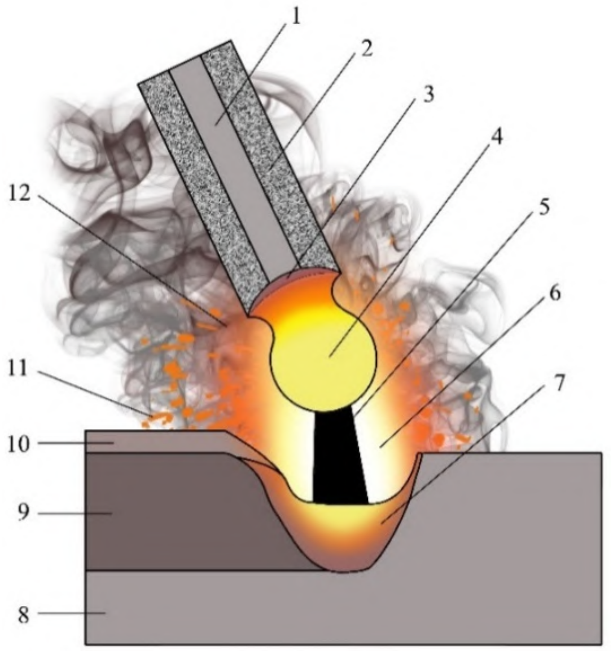

Fig. 1. Formation of welding fume: 1 - electrode rod; 2 - electrode coating; 3 - molten electrode rod and coating; 4 - droplet of electrode metal; 5 - arc column; 6 - arc flame; 7 - welding pool; 8 - base metal; 9 - weld; 10 - slag; 11 - sparks (splashes) of liquid metal and slag; 12 - gases and welding fume

The main aim of the study is to choose the optimal type of alkaline silicate binder, the properties of which largely determine the manufacturing technology, quality, welding and sanitary properties of electrodes.For this purpose, standard (sodium, potassium and mixed sodium and potassium) [8] and experimental (lithium and lithium-containing) samples of liquid glass were prepared, which provide unique properties to some grades of electrodes [9]. Their physicochemical characteristics are given in Table 1.

The experiments were performed on the electrodes, manufactured on copper rods, and a charge consisted of marble: cryolite, sodium silicon fluoride, tin, copper-phosphorus, nickel and manganese powders [10]. For comparison, the mass-production electrodes OZB-2 and UTP-32 were also studied.

Sampling of WF for their dissolution is carried out in accordance with the standard [5] applying the method of complete capture of the fume, generated during welding with the use of the special bench with the FPP filter installed on a way of movement of WF from a shelter of a welding zone. The following indices of WF formation were determined: intensity of V_a emission, g/min; specific emission of G_a, g/kg; chemical composition of WF, wt. %. For each variant at least three experiments were performed. Welding was performed at direct current (150 A) of reverse polarity using VDU-504 rectifier.

5 Results of investigations

The welding conditions and general indices of welding fume emission are given in Table 2.

As the results of the investigations showed, the highest general values of intensity and specific emission of the welding fume were observed during welding using mass-produced grades of electrodes UTP-32. Among the experimental electrodes, the highest values of V_a and Ga were observed during welding using the electrodes with a binder based on lithium glass. The mass fraction of chemical elements in the welding fume during welding using mass-produced and experimental electrodes for welding tin bronzes is given in Table 3.

According to the obtained results, the chemical composition of copper in the composition of WF does not differ significantly for all experimental grades of electrodes, whereas the intensity and specific emission are different (see Fig. 2-3). Moreover, the rate of emission of manganese differs both in chemical composition as well as intensity of its emission (see Fig.4-5). The lowest value of lithium among the experimental electrodes of grade ANBO with the content of lithium glass was obtained during welding using electrodes ANBO-Na-Li. Among the electrodes based on sodium glass, the highest value of sodium in WF was determined during welding using electrodes ANBO-Na. The content of potassium is the lowest in WF, obtained during welding using electrodes ANBO-Na.

Table 1. Physicochemical parameters of liquid types of glass [11]

Type	Density ρ, g/cm³	Toughness, η+20°C, MPa·s	Chemical composition, wt. %				Module
			SiO_2	Li_2O	Na_2O	K_2O	
Na	1.430	392	29.03	-	8.83	2.15	2.93
Na-K	1.435	606	28.80	-	6.94	4.56	2.99
K-Na	1.428	304	27.85	-	4.00	8.79	2.94
K	1.415	260	26.92	-	0.03	13.78	3.05
Na-Li	1.396	526	30.19	2.69	0.99	5.17	2.73
K-Li	1.421	554	27.93	1.42	0.94	10.67	2.65
Li	1.258	287	25.08	3.19	-	-	3.91

Table 2. Indices of emission rates of welding fume during welding of copper alloys

Grade of electrode	Iw, A	Uw, V	g, kg/min	V_a, g/min	G_a, g/kg
OZB-2,mass-produced, 4 mm diameter	120	24-28	0.0430	0.3359	7.59
UTP-32,mass-produced, 3.2 mm diameter	100	28	0.0336	0.7654	22.78
ANBO-Li, 4 mm diameter	120	28	0.0447	0.4693	10.50
ANBO-Na, 4 mm diameter	120	24	0.0413	0.3006	7.28
ANBO-K, 4 mm diameter	120	24	0.0366	0.3010	8.22
ANBO-Na-Li, 4 mm diameter	120	24	0.0380	0.2594	6.82
ANBO-K-Li, 4 mm diameter	120	24	0.0396	0.3948	9.97
ANBO-K-Na, 4 mm diameter	120	24	0.0304	0.2874	9.45

Table 3. Mass fraction of chemical elements in the welding fume.

Grade of electrode	Mass fraction in WF, %				
	Cu	Mn	Li	Na	K
OZB-2,mass-produced, 4 mm diameter	35.50	1.56	-	-	-
UTP-32,mass-produced, 3.2 mm diameter	36.78	2.93	-	-	-
ANBO-Li, 4 mm diameter	33.38	3.16	0.82	-	-
ANBO-Na, 4 mm diameter	33.42	2.50	-	9.14	-
ANBO-K, 4 mm diameter	33.35	2.40	-	-	13.15
ANBO-Na-Li, 4 mm diameter	33.49	2.81	0.68	7.57	-
ANBO-K-Li, 4 mm diameter	33.33	2.41	0.85	-	9.06
ANBO-K-Na, 4 mm diameter	33.26	1.95	-	7.82	12.34

The obtained results clearly show that the highest values of specific emission and intensity of WF formation were determined during welding using mass-produced grades of electrodes UTP-32 and experimental electrodes ANBO-Li.

To determine the final estimated indices of hygienic evaluation of welding materials in compliance with the standard DSTU ISO 15011-4: 2008, the limit value of the welding fume was determined by the following equation:

$$LV_{WF(A)} = \frac{100}{\sum_1^n \frac{i}{LV_i} + \frac{(100-\sum_1^n i)}{LV_{WF}}} \qquad (1)$$

where $LV_{WF(A)}$ is the total limit value of the welding fume, in mg/m^3; n is the number of main components of the welding fume; i is the fraction of *i-th* main component of the welding fume in %; *LVi* is the limit value (MAC) in mg/m^3 for *i*-th main component of the welding fume; LV_{WF} is the limit value in mg/m^3 for the welding fume, which contains chemicals with a low and medium toxicity, if such a limit was established, or a limit value in mg/m^3 for inhaled dust, if no limit value for the welding fume was established.

Due to the fact that the procedure [12] does not allow determining the content of all components of WF to bring its composition to 100%, it was assumed that in addition to the revealed components, the residue of WF represents a non-toxic dust with MAC of 10 mg/m^3. The results of the calculation are shown in Table 4.

Regarding the hygienic category of all test specimens of welding electrodes according to DSTU ISO 15011-4: 2008, determined by the formula 1, all of them belong to a one category 1b, except for the electrodes UTP-32, which belong to the category 1c (Table 4). It implies a harmful category "1" according to the limit value of WF (from 0.5 to 1.5 mg/m^3) and a moderate category "c" as to the level of its emissions (from 8 to 15 mg/s).

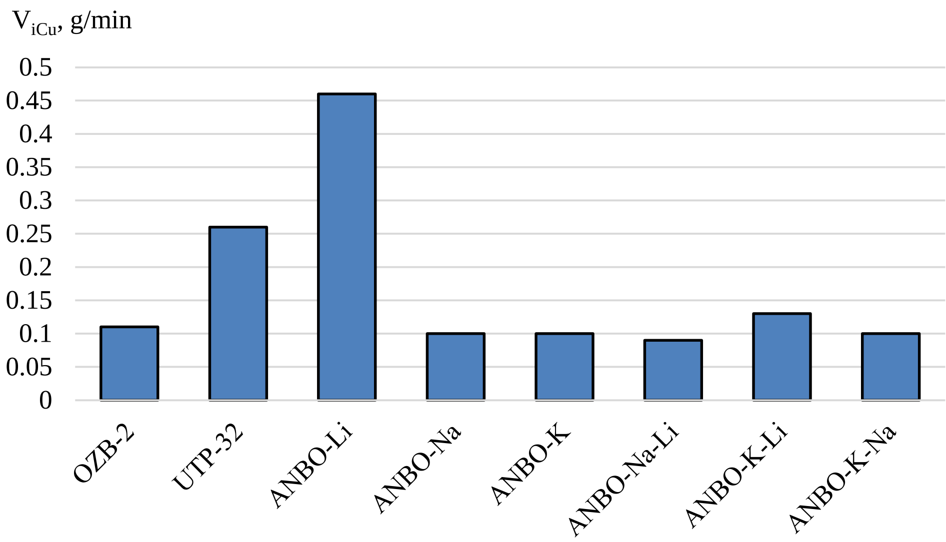

Fig. 2. Intensity of copper formation in the composition of WF.

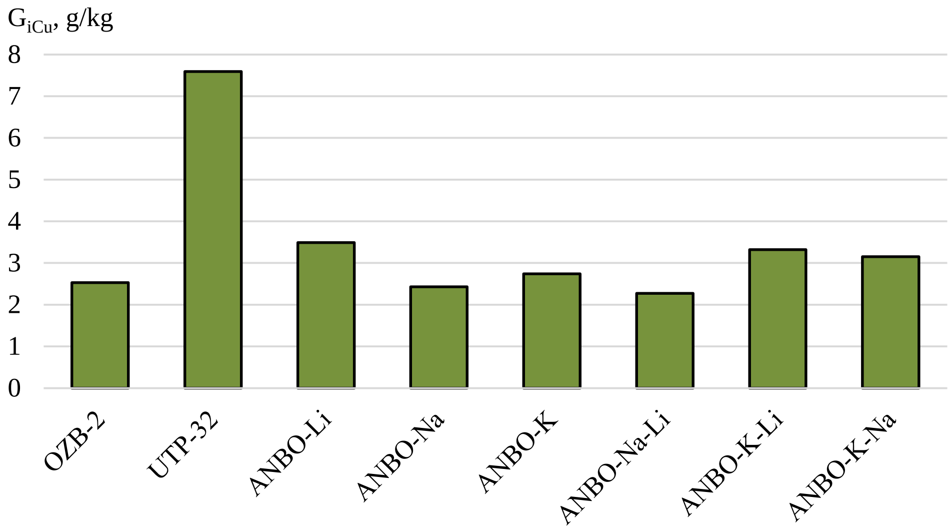

Fig. 3. Specific emission of copper in the composition of WF.

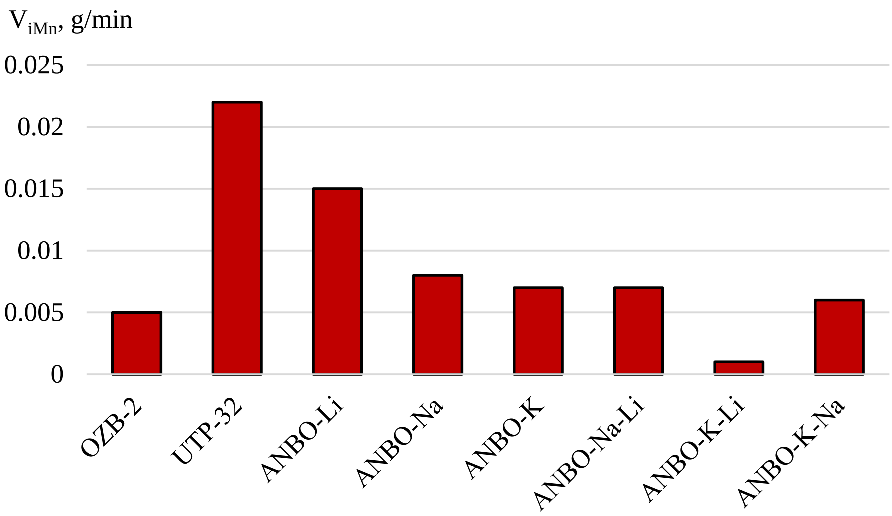

Fig. 4. Intensity of manganese formation in the composition of WF.

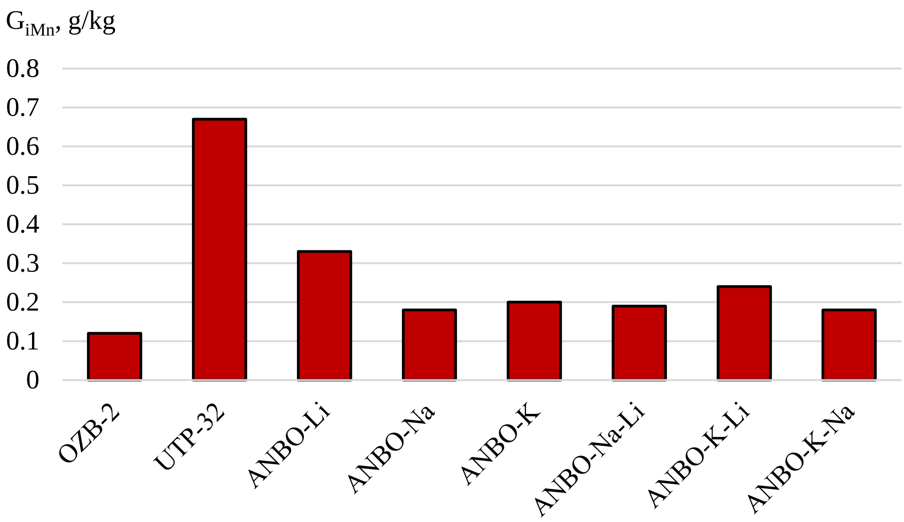

Fig. 5. Specific emission of manganese in the composition of WF.

Comparing the electrodes according to the total limit value of the welding fume, which is an index of toxicity, the most harmful grade of electrodes will be ANBO-Li, followed by mass-produced grades UTP-32 and ANBO-Na-Li.

As a result of investigations with the use of electrodes for welding tin bronzes, a high intensity of the welding fume emission was established, that is explained by existence of volatile compounds and a high basicity of a slag phase in the coating.

The performed analyses show that the basis of WF consists of such components as compounds of alkali and alkaline earth metals (Na_2O; K_2O; Li_2O), copper, manganese, etc. As to the total limit value of the welding fume, among the experimental electrodes, WF emissions are the least toxic during welding using electrodes ANBO-K-Na. During welding using electrodes made of potassium-sodium glass, the highest indices of welding-technological characteristics were also established [12]. Therefore, during the subsequent experiments the electrodes were used made on the basis of potassium-sodium type of glass, which were given the index EOF-50.

6 Methods of reducing emissions of harmful WF components into the working area during manual arc welding of tin bronzes

Reducing the harmful effect of welding fume on the body is fulfilled by the use of technological and sanitary-technical measures, as well as the use of means of individual protection [13, 14, 15]. A particular interest of developers of welding materials and technologies is attracted to technological methods of reducing the rate of WF emission, which are aimed in improvement of welding materials, technologies and equipment in terms of hygienic protection and selection of optimal welding conditions.

The carried out investigations on the effect of a type of electrode coating on hygienic characteristics of welding fume may be based on the calculation of the value of a required intensity of ventilation air exchange, which is denoted as NHL and expressed in m^3/min [16].

The further investigations were performed in accordance with the international standard DSTU ISO 15011-4:2008 using $LV_{\mathrm{WF(A)}}$ indices (see equation 1), category of welding material, intensity of WF emission, as well as *NHL*.

The results of NHL calculation are shown in Table 5.

The worst values according to the $LV_{\mathrm{WF(A)}}$ index were noted during welding using electrodes ANBO-Li, although not all experimental electrodes differ significantly as to the limit value, whereas *NHL* for electrodes UTP-32 one and a half times increases. As to the totality of these changes, in this case an increase in the degree of a harmful effect of WF on a human by about 1.5 times can be reported.

7 Conclusions

The main method to improve hygienic characteristics of welding materials is certainly a change in the chemical composition of welding material. This task is not easy, because the main requirement of the welding process is to provide a high quality and the required mechanical properties of a weld. Therefore, welding materials always contain toxic chemicals, without which it is impossible to provide the necessary properties of welded joints. However, some improvements in hygienic characteristics of welding materials (minimization of harmful emissions) can be achieved.

Table 4. Indices of hygienic evaluation of welding materials determined by the calculation method in accordance with the standard DSTU ISO 15011-4: 2008.

Grade of electrode	V_a, mg/s	$LV_{\mathrm{WF(A)}}$, mg/m^3	Category of electrode
OZB-2,mass-produced, 4 mm diameter	5.598	1.059	1b
UTP-32,mass-produced, 3.2 mm diameter	12.757	0.989	1c
ANBO-Li, 4 mm diameter	7.8217	0.978	1b
ANBO-Na, 4 mm diameter	5.01	1.01	1b
ANBO-K, 4 mm diameter	5.017	1.015	1b
ANBO-Na-Li, 4 mm diameter	4.323	0.994	1b
ANBO-K-Li, 4 mm diameter	6.58	1.014	1b
ANBO-K-Na, 4 mm diameter	4.79	1.038	1b

Table 5. Hygienic indices of WF emissions during welding of copper alloys using experimental electrodes.

Grade of electrode	Va, g/min	$LV_{\mathrm{WF(A)}}$, g/m^3	NHL, m^3/min
OZB-2,mass-produced, 4 mm diameter	0.3359	$1.059 \cdot 10^{-3}$	317.186
UTP-32,mass-produced, 3.2 mm diameter	0.7654	$0.989 \cdot 10^{-3}$	773.913
ANBO-Li, 4 mm diameter	0.4693	$0.978 \cdot 10^{-3}$	479.8569
ANBO-Na, 4 mm diameter	0.3006	$1.01 \cdot 10^{-3}$	297.6238
ANBO-K, 4 mm diameter	0.3010	$1.015 \cdot 10^{-3}$	296.5517
ANBO-Na-Li, 4 mm diameter	0.2594	$0.994 \cdot 10^{-3}$	260.9658
ANBO-K-Li, 4 mm diameter	0.3948	$1.014 \cdot 10^{-3}$	389.3491
ANBO-K-Na, 4 mm diameter	0.2874	$1.038 \cdot 10^{-3}$	276.8786

The emission rates and chemical composition of WF are determined by the content of chemical elements or compounds in welding electrodes. As a result of melting the coating and the electrode rod, at the end of the electrode evaporation of elements with a high vapour pressure occurs. One of the most harmful substances contained in WF, generated during welding of tin bronzes, are compounds of manganese and copper.

The analysis of the obtained results of the investigations and literature data allowed concluding that to provide the maximum improvement in hygienic characteristics of welding materials, it is necessary to be guided by a comprehensive approach. To minimize the harmful properties of WF and its effect on the body, it is necessary to choose the optimal combination of the following technological methods for reducing the rate of harmful substances emission:

1. If possible, it is necessary to use those types and grades of welding materials that provide a reduced level of WF emissions.

2. Taking into account hygienic characteristics while choosing electrodes for welding copper alloys, between the grades ANBO and UTP-32 the preference should be given to the first one. As far as during the use of the electrodes of experimental grades ANBO with a different type of binder, the specific WF emissions are 1.7-3.0 times lower as compared to the mass-produced grade UTP-32.

3. The obtained results of the carried out investigations can be used during calculation of the systems for mechanical ventilation: determination of amount of air L (m^3/h) which needs to be supplied or removed from the room. To calculate the ventilation of production rooms where welding is used, air exchange is required, which is usually determined by the calculation method based on specified data on the amount of harmful substances emissions.

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The region as an object of projecting of neo-spheric existence in the depth of anthroposphere

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Abstract. The article deals with the problem of the modern education system perfection and at the same time seeks to reach the limit of the possible in the transformation of the educational space to meet the demand of time, its ability to provide social consciousness in the conditions of the ongoing crisis and those changes that caused the intensification of the dialogue between Man and Nature. The development with the participation of humans becomes of a more targeted nature – noospheric and educational, global one. This is a new way obliges a modern general education institution to look for better approaches to the production of personality and promote the development of modern man – the carrier of new values. The state of society's consciousness should be inclined to act in the direction of its spirituality. The correlation between the social and morphological organization of a human being should not be beyond the problem of profile education. he human world to a large extent begins in a human being itself, therefore, the objective of this article is the search for ways to change the educational system of the region for the sake of further formation and development of the democratic society of the anthropospheric era.

1 Introduction

In the 21st-century mankind is rapidly turned into the active creator of the world due to their appropriately educated intelligence, as ideally, all people of the planet are dimensions, connected by education and mediated by God whose means the Word. The main issue for the contemporary school system is to retrieve this "correct" rule of education for the contemporary person.

At this time, all occurrences of our life can be dealt with success only via an empirical way of perception, but not hypothesizes into account. Only by doing so, we are able to introduce new opportunities, new principles, and axioms into science, according to the opinion of Vladimir I. Vernadsky (from Diaries, May 1921) [1]. At this moment we are approaching the stage of our development, whos has already been reached by the genius persona of Vladimir I. Vernadsky. Scientist left us an all-pervasive sign of the guidance of his supreme intelligence: life is omnipresent and ceaseless in time, the mineral essence of the world stems from the aspect of life itself and the geological role of the person in particular and humanity in general. This stage is a shift from the biosphere to anthroposphere and explosion-like viral spreading of scientific awareness. Meanwhile, the organization of science is the anthropospheric feature, provided by the appropriate education [2].

The research is the empirical summarization of the issues of the current time and is the complex hypothesis with the outlined attitudinal guiding lines, which interprets the tendencies of development of the contemporary educational system, that urgently and spatially requires the appearance of essential basic points of life projecting, based on the incomplete theory of the region of the biosphere.

It is worth noting, that the term "region" is common in many languages. Predominantly it is prone to reflective modelling of some imaginable locations on some territory and is more frequently used in the sphere of administrating or economics where it introduced as the separate dimension. In Ukraine there was a politically active "Party of the regions", but their policy has nothing to do with everything highlighted in this paper.

The *goal of this paper* is search of ways the improve the educational mechanism of formation of the personal potential, aimed for the successful and efficient changes of the educational system of the region of the biosphere for the sake of further formation and development of the democratic society in anthropospheric era.

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2 Materials and methods

In 2018, the Club of Rome for its half-century anniversary prepared a report "Come On! Capitalism, myopia, population and the destruction of the planet". The report, at first sight, was in line with the ideas of Vladimir I. Vernadsky, but in view of a probable procedure, its solution did not correspond to the humanist scientist's plans who upheld the triumph of the individual in the biosphere and believed in the possibility of scientific piloting of the biosphere.

The co-author of the report "Come On! …" was Elvir Weizsäcker, who emphasized follow: "In the heart in our main idea is the difference between an empty world and a full one. In the period of the "empty world" mankind was small, and nature was many. This period ended in the 70s and 80s. Now we have a "full world", a huge number of people, three times more than in 1945. But the planet is not growing. This is one of the main problems that the Club talks about" [3].

His viewpoint in this issue Volodymyr I. Vernadsky expressed in 1925: such synergetic and dual entity surely causes the correct stream of the mind flow about making the demand for a decent education, "causes the element of creativity, which will engage the capital of knowledge, and ability to retrieve the necessary elements even from the strangest and the most unknown creatures for some person" [2, p. 125].

Therefore, in this study, it will have used follow methods such as theoretical analysis and generalization of worldviews of Vladimir I. Vernadsky [1], Lev N. Gumilev [4], Olexandr P. Kovalyov [5], Yuriy M. Lotman [6], Frederick Schelling [7], Oswald Spengler [8]; correlation and comparison of the theory of the biosphere region, the theory of the biosphere of Vladimir I. Vernadsky and the theory of the noosphere by Pierre Teilhard de Chardin [9]; as well as observation and modelling. These problems were comprehended and considered in publications of Vlail P. Kaznacheev [10], Olena O. Lavrentieva [11], Lina M. Rybalko, Oleh M. Topuzov [12], Anatoly Samondrin [13] and others.

The presented research is an empirical generalization of the issues of modern times in the design of the neo-sphere existence of the biosphere and outlines the trajectory of the formation of personal educational potential in modern educational institutions.

3 Theoretical background

The term "region" (de. Gebiet and Region f; lat. regio – kingdom, domain) – in the past was the name of the land, area, county, etc and nowadays this term denotes the big territorial unit, and in physical geography, it stands for the general name of the unit, which is the part of the physical and geographical division of any taxonomic rank, and in historiography, it means the historical and geographical region, as well as the name "economical region" used for economical for studies. Methodologists emphasize the validity of the geographical theory of regional development. The scientific perception of this definition remains unclear, especially concerning the pedagogical aspect, which has always been the supplementary element of social and economic development, but, unfortunately, not the core of projecting [13].

There are qualities that are taking place as factors defining the region as a complex social system. They cover the relative apartness, integrity, complexity, structurdness, the subordination of the single objective to ties with the external factors.

The term "region" was quite thoroughly explored by a Ukrainian scientist Olexandr P. Kovalyov. He made the following statement, that defines his biospheric essence comparing to others, examined by other researchers, namely: relatively closed territorial, non-state, socially-productive formation, that is characterised by the relative autonomy and capability of self-reproduction of socially-productive functions and that phenomena, what has the appropriate infrastructure and integrated into the functional structure of cosmobiotic geospacer [5].

In contemporary economical science, the classification of Ukrainian regions provides the following categories: problematic, underdeveloped, recessionary, and depressive ones. These terms are generally and contextually similar, but also bear several differences. The issue of clear classification of regions is very actual in a whole for the elaboration of the strategy of territorial development as well as for the construction of the model of educationally-studying space of a region.

On the current level of development of Ukraine, along with the central organs of administration, the local organs are engaged in more and more activities for the solution of the problems of economic and social development of the regions, for the implementation of modern mechanisms of their support. Primarily they are used for helping "depressive" and "recessionary" territories within the scope of the goals of sustainable development. Conditionally, the monitoring of the territory of the region can be performed by introduction of several indicators, which, depending on the variety of properties, will gain a certain level of "problematic", "underdeveloped", "recessionary" or "depressive" level [13]. We are going to clarify the general characteristics of their basic properties (see Fig. 1).

The *underdeveloped region* is that one, whose rates cannot keep up with the average state rates, more than one third.

The *problematic region* should be considered such one that retains the situation requiring the supplementary (usually external) aid for its solution. They can be the ecological conditions, proximity to the border, the availability of conflict occurrences, etc.

The *recessionary region* must be called such one in the case of the probability of irreversible tendencies to recession of production there, the increase of unemployment, the decrease of life standards, the deterioration of health conditions, the decrease of the index of life duration.

Recessionary territory, whose recessionary state is retained for a long time, must be classified as a depressive one. *Depressive territory* cannot overbear the crisis without external aid. Such territory might be switched to the steady development stage only in the case of obtaining complex support and the accumulation of all resources (internal aid and the external one, gained from the greater organization, area or state).

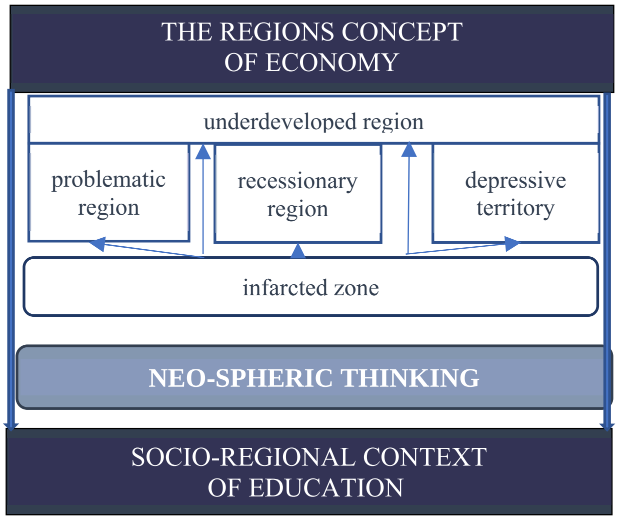

Fig. 1. The transformation of the regional concept in the sustainable development era.

It's worth noting, that recessionary and depressive territories can be part of relatively prosperous regions. Besides, the level of "underdeveloped", "problematic", "recessionary" and "depressive" levels of classification can be differentiated for various particular zones (Carpathian region, Donbas region, and Chornobyl region, etc).

One can freely state that today, the significant levers, improving the lives of the regions, are not the major driving elements of society namely education and science. Practice demonstrates the weak engagement of economical and administrative aid for the respective educationally-scientific base. Governing body of the regions regard the economy of education exclusively as the "provision of educational services for some amount of money" [5].

Moreover, all territories require individual approach and construction of certain strategy as a programme of development for a future prospect, bearing the internal nonlinear dynamics. There is a particular part of territories in the region, which are characterised by the complexity of administrative management, when a metropolis lies within the range of several administrative provinces, interacts with the territories of several agricultural districts (city-states), etc. The cultural development of the population from such regions becomes deformed. The contemporary village blindly and mechanically "delivers" its capital of labour force to the bordering country, another administrative province, single-handedly approaching its own demise. In this case, the problem of reforming borders or appropriate coordination policy of the range of regions arises.

As a rule, depressive and recessionary territories are situated near (or right in) the zones of ecological disaster, whose management requires the different quality and concentration of administrative decisions, aimed at preserving and replenishment of natural resources. The interaction between metropolis (a city or a system of cities) and polis (city-states e.g., settlements or villages) is remarked by the availability of "*infarcted zone"* spreading from the centre of a metropolis in a concentrated way (pollution of the atmosphere, subsoil waters and poisonous leakages of technical fabrication). Relating to the agricultural sector it can be presented as the phenomenon "on the brink" [10]. Usually, it is a certain segment that bears its own dynamics of development. This exact territory requires the most scrupulous attention during the process of estimation, carried out by specialists, and the real state of this territory and the estimation of this state create the largest disproportions of the estimation of development of the certain region, impacts on compensatory factors and, subsequently, on the level of improvement of living standards.

Today such "infarcted" territory exists in the country, although, it lies out of the rules of the estimation, made for assessment of regional development. The scientific and educational capital of the country must be focused primarily on the support of such territories for the solution to the problems of sustainable development.

It should be noted, a modern person does not control the biosphere, they only participate in its evolution, which means that they evolve as a part of the biospheric system. The scientific approach as a natural feature fundamentally changes the energetics of the planet. This stream of energy has its own velocity, which is provided by the educational system as a primary source. Anthroposhere is active in real-time and it is not the sphere of technologies, people or society. It is the sphere of intelligence as an evolutionary process in the biosphere, that is ongoing by human influence within some region. That is why the biospheric region itself becomes the basis and the beginning of certain anthroposheric educational channels.

Further, it will have considered the possibilities of socio-regional design of educational systems for the implementation of sustainable development goals.

4 The main directions of creating educational systems of anthropospheric type

4.1 Education as an anthroposhere phenomenon

Anthroposhere is the seizing of the biosphere by human intelligence with the purpose of provision of the constant development of ecumene. It is the last stage of the numerous ones of the evolution of the biosphere in geological history is the contemporary stage. It is the sphere of the interaction of society and nature, where intelligent and aware human activity becomes the crucial factor of development. It is the process, where anthropotisation is transformed into anthropologisation, within the whole planet. Anthroposhere is also the sphere of intelligence as the evolving process in the biosphere, that is performed personally in some particular region (it shown at Fig. 2).

The education of the era of anthroposphere must be anthroposophical. Anthropospheric education is aimed at the creation of the general synthesis of the human spirit, the inclusion of human consciousness and human activity into the global Universum, the formation of the inner world of personality, of mental freedom for realisation and mental responsibility for their doings. By means of it, science transforms from the tool of the technical progress into the natural element of social and cultural development, that features not only the human attitude towards nature but also the attitude of the personality towards other people and themselves [13]. It is also a particular programme that centrally the emphasised objective is society's development. In this way, the educational system becomes the completed mindset, which is capable to provide both the appropriate ecological awareness and mental part at the same time and consequently forms *personality's anthropospheric mindset.*

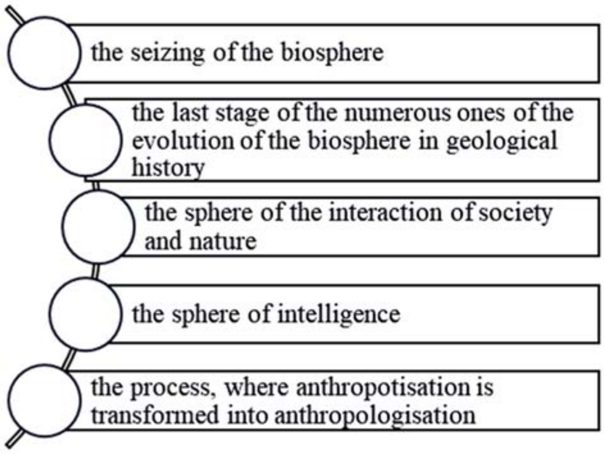

Fig. 2. The concept of Anthroposhere.

Anthropospheric the educational process is multi-vectored; at the same time, it is the multi-levelled system due to its naturally open and organised methods of setting objectives. It is included in anthropospheric culture and based on the principles of the creative evolution of personality. It is the *profile education* that is the channel of the anthroposheric educational system, that outlines the path of the evolution of Intelligence against the background of Space, the object, that it be defined as the "*true person*". In heart of this education is an idea that means a person is a central object of the study of anthroposphere [14].

The significant social request to the educational system during the period of anthroposphere is the organisation of the regular school, which would not only be focused on obtaining some extent of knowledge by pupils in the course of the educational and disciplinary process but also on *personality's development* (the role of this process is defined as the leading one, whereas any other co-occurring processes have to be perceived exclusively as the supplementary ones) and additionally on their *capability of vital creativity in the World*. In fact, the educational system has to clearly *restate the answer to every individual* "What is a person?" [13].

We know that *socialisation* is, primarily, the transformation of the personal one into the general one, which is also am "impersonal one" and a "commonly neglected one". Socialisation is a bilateral process, as it not only includes the assumption of social experience, but also the personal realisation of social ties by a person. Their sociological essence is focused on the combination of the adaptive and separative images, that leads to the preserving of a person's autonomy in the environment of a certain society. On the stage of reforming by society, the personality can lose their uniqueness [12]. The schools of the 21st century mechanically perform such activity, mainly because of the principle of the "pedagogical conveyor", but due to the resistance of the personality, combine the method of socialisation, (the habitual method of industrialisation era) with the neoteric method of *sociamisation* (the natural process of the rise of the anthropospheric era, whose fast implementation happens because of the rapid integration of the achievements of the IT industry in people's lives), which is the process and the result of the formation of active and creative personality in combination with their equal and full-fledged integration to the society, as the unity of the citizens respecting the democratically adopted regulations and rules of the life. Sociomisation of graduates includes the fulfilment of values such as integrated ecological thinking, general liability, sense of justice, spirituality and cultural abundance, independence, initiativity, adaptive capability and readiness to manifest mobility on the labour market with the help of one's secondary education. Together with the obtained speciality and level of training added to the previous requirements, the ultimate result of sociomisation will be the "*life competence*" of a person [14].

The pedagogical science of the 21st-century states, the *profile training* (it usually includes a naturally-scientific basis, rests upon the leading type of person's activity, as well as the level of their cognitive development, polyvariety of the studying process, etc) is the basis of sociomisation and is also the best way of the realisation of the principles of differentiation and individualisation of the educational process, which is capable to embrace the issue of the development of particular personality with the help of integrative education in conditions of the contemporary development of civilization [11].

Presumably, it must be defined that *educational profile* is the synthesis of conceptions "en face" (fr. en face – with one's face forward) and "profile" (fr. profil, which stems from Latin – filum – "string" and "side view") is quite complex pedagogical construction, which provides for the organization of democratically basis for development of the educational content, centralised and decentralised management of the educational system, educational institution, some particular kind of organisation of didactic entities, the corresponding pedagogical culture. It represents the certain technology of assistance for mental training. The profile can be found in the personality, who explores themselves with the help of the educational system [15].

The technology of organising profile training as a process is quite scientifically-based and requires significant intellectual resources of the educational system for its implementation. As a result, the principle that has proven to be the most adaptive in this situation on all levels of management is a *static principle* (or the principle of template) for the organisation, which is focused on internal regulation, accordance, and interaction of the entity parts, and is caused by its structure and objectives as a part of educational material as the steady and invariable basis. It can be called a "paper specialisation". At the same time there is necessary organising as an ongoing process – *the accumulation of deliberate actions*, that stipulate the creation of indispensable ties "inside the personality" and on the way of their development, where there is a valid principle of *pedagogical organization of the biosphere region as the organization of types of education, the formation of real profiles (the offers) for the real trajectories of personality's development (i.e., the personal demand)*.

In fact, from the beginning, any child's development must be regarded as a complex process, which is additionally optimised by a propaedeutic function of their own origin, as well as that one from the community or some social groups. What is more, the child must be correctly "placed" in the technological sense of this word. This targeted continuum of their destination must be described as "Self-concepts" in its epicentre, and "I in the segment of Space" is about their closest social partners – the family, the native school, and the agency of psychological aid agency [13].

The active segment of the trajectory of the ceaseless education, where the speciality-focused approach is realising, is a regular school (educative and pre-professional type) and a higher (speciality-based) school. In light of this opinion, the pedagogical science ideally shaped approaches to the formation of personality within the scope of their genetic origin, as well as examined the objectives of the preparation of the person for the social life as a creative personality, who is fully aware of the meaning of their own life and adequately realise their intentions in some particular field of professional activity. However, the most progressive pedagogical technologies, which rely on the theory of development, are poorly studied by the total pedagogical community and can occasionally be disharmonised with their definitions, and therefore, they may be problematic for frequent usage. But only they explored the concept of personality and the pedagogical steps in a thorough way and deserve being common. This occurrence encourages further modernizing changes to the educational system (including the postgraduate one) [8; 13].

It should be emphasized, the necessity of searching activity, self-identification, the awareness of one's own social prospects are the important needs of the young person and the tasks of implementation of the system of profile training as the structural and dynamic organisation of cooperation between personalities. At the same time, such organization requires a much broader vision of the school along with the integration of the social and psychological basis of management as the *social-and-ecological-and-pedagogical system of the biospheric region*.

Such *synergetic and dual phenomenal occurrence* surely causes the correct stream of the mind flow about making the demand for a decent education, "causes the element of creativity, which will engage the capital of knowledge, and ability to retrieve the necessary elements even from the strangest and the most unknown creatures for some person" as Vladimir I. Vernadsky said in 1925 [1].

Authors agree with the scientist about the understanding of democracy as a social organization of the popular rule, whose main objective is to increase the level of knowledge of the popular masses, according to the requirements of some particular period, and share scientists' views of the main educational tasks. The leading of them is to create "the studying populace", which has to be done immediately, right on this stage of the development of the educational system that is projected during the conditions of biospheric cells. Otherwise, due to the interaction of the generations, different by age, significant internal resistance is likely to occur [16].

4.2 Features of the socio-regional aspect of education

Nowadays is the time of born the *biospheric regionology*. As it can be clearly seen, that the viability of the region is tightly dependent on the knowledge of regional information and the ability to apply it in the course of the process of regional management. Let us look at the experience of Switzerland, the USA, Sweden, Germany from this viewpoint [13].

In Switzerland, the educational and scientific spheres are highly prioritised. The country, where the total population barely reaches 7.5 million people, there are 1.1 million school children and students. With its 26 cantons united (cantons, are basically, "mini-states" or regions of the biosphere) Switzerland became the place of the fusion of three major cultural and linguistic traditions – German, French and Italian ones. Approximately 65% of the population speaks German language, French is spoken by 19% of people and Italian speakers are estimated to be 12% of the total population. However, Swiss people can never be called separated because of their multilingual cultural feature. In the 19th century, the compulsory secondary education was introduced as the "greatly important social task of the decent guidance of new generations" and all cantons adopted their own educational legislation, whose basic regulations are preserved until now. That is the reasons why Switzerland has 26 cantonal "educational systems" [13].

The USA does not have any standardised educational system. Each of the states has its own particular organization of the educational system and their own special aspects, that is why the main trait of the educational system in this country is decentralization [17].

The remarkable property of the educational system of Sweden is a democratic approach, which is all about the development of the new generation as modern Europeans. The democratic character of the educational system in Sweden is manifested with the freedom of choice on all levels of education without exceptions and the fact that any pupil is free to choose not only the subjects, that they want to study, but also the study modes, the language of studying (Swedish or English) and even a teacher. The Swedish legislation clearly defines the regulations concerning the teachers' behaviour and the forms of teaching, which means that teacher must not impose their opinion on the pupil or perform any kind of pressure on them. A teacher must only share their knowledge with their pupils and provoke their need and abilities of independent thinking and description of their vision of the verity [17].

The sphere of the culture and education in Germany belongs to the jurisdiction of the lands (there are 16 of them in total in the country), that is why the conditions and the programmes of studying in different lands can differ one from another. Germany possesses not only the framed Law of the education but also has 16 educational constitutions, which uniquely characterise each of their lands [17].

The issues of the educational system belong to the competency of the special organ – the Constant conference of the ministers of the culture of the lands. The mentioned organ inspects the quality of the educational system all over the country in order to maintain it on a decent level.

Ukraine is also on its own way to the differentiated educational system, because of its multiculturalism and historical regional originality. Nowadays the new form of the reflection of objective reality becomes more distinctive and particularly, social and regional one with its possibility of *informational reflection and creation informational and social polygons* for performing different kinds of social experiments as social projecting, making the new models of development of reality and a possibility to control it. *Informational regionology* provides for the creation of the common informational space of the objects of the research – the region, that realises the informational reflection of social space with its all ties within the scope of the biosphere [13].

In that way, the *region* is regarded as the social system with its all incoming and outcoming features, functions, that provide its viability. The *informational regionology* provides for the solution of problems of the region with the usage of informational technologies as a system of methods of collection, accumulation, storage, search, transmitting and processing of the information with the relying on the usage of IT means. It allows the creation of the united automatized informational system, the united IRC (informational resourcing centre) for the solution of regional problems [19]. Moreover, the informational system, reflecting the social space of the region, additionally becomes the educational polygon of the social projecting and construction of the models of management is based on such projecting. The elaboration of the mechanisms of the realization of projects and discovering the tendencies of the regional development as a part of the biosphere and as a neighbour of other regions.

For the educational study, the region is represented as an integrated, spatially-organised form of the vital function of society as a system. This process is a sophisticated and complex entity and a segment of the life sphere (biosphere). Such kind of form has its own content. The *regional content of education* cover parts, that presented at Fig. 3.

For this reason, the simple upgrade of educational programmes in this sphere will not lead to manageable anthroposhere. It is vital to assure the appearance of the conditions when the population can unanimously be on the stage of studying. This issue is based on anthroposheric mindset and provides for the following primary steps for construction of the educational system within the certain region for getting the result of appearing of profile education:

– it is the development of enlightenment – the perception, understanding and responsible attitude of the popular masses towards the ongoing events;

– it is the cultivation of the idea of the unity between the person and nature;

– it is the focus on the educational on conceiving of fundamental natural principles;

– it is the supplement the principle of anthropocentrism in the educational process by the principles of biocentrism and cosmocentrism, as well as with principle of anthropocosmism as a final result of their fusion.

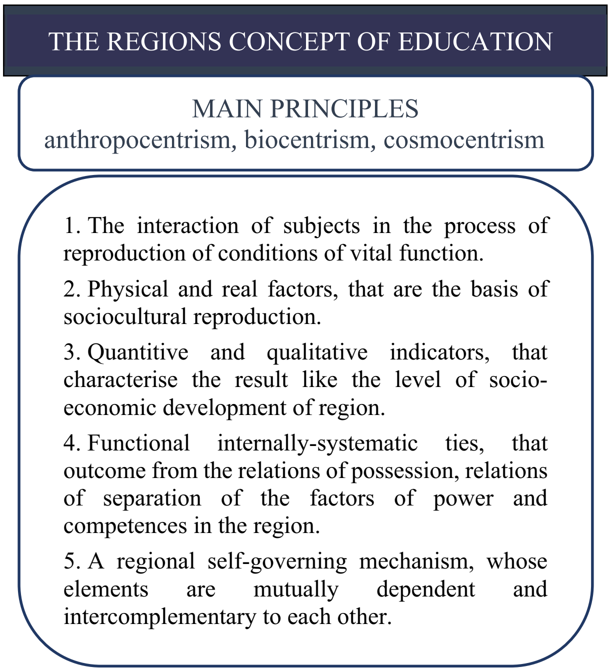

Fig. 3. The concept of region educational content.

4.3 The process of regionalization in the context of the formation of educational area

The environment, where the human is being and existing, is classified with a certain organization (it named as geographical one). It includes several special complex dynamic elements – geosystems, which create a unique space (geographical chronospace) because of their interaction. The formation of this process is tightly related to the term of "*geoprocess*", which denotes the process of *geospatial self-organising*. Exploring the geospace, a person generates its reflection in their consciousness for the regulation of their economic activity.

Economic sphere encourages people to aim their own activity at the culturally-economical evolution, which leads to the creation of regional anthroposhere, as well as the regional cell. However, this process primarily impacts on a person. It manifests the phenomenon of regionalization as a process of initiation and formation of anthropospheric structure. Nowadays, the point of leading the regional policy is stuck with the task of provision of educational system for some region, and with the problem of the elaboration of the best methodology. The methodology has to answer on the question how in the best way to find the fundamental points, around which will be founded on learning any particular person and population in general. Clearly, regionalisation is a process of infringement of the symmetry of geospace, which initiates its renovation and stands out as an excess of anthropotisation and raises the problem of anthropologisation [12].

On the other hand, human activity, which can be involving or not involving the energy from outside (if it is concerning several ecosystems), tends to several spatial correlations and modelling (enforcing or weakening) of some coherence. In this way, the region transforms from the socially-productive sphere (with the support from the scientific sphere) toward a socially-natural organization. Additionally, the understanding of the distinctive features of some region expects the adress of biospheric and productive pedagogics. Anthropotised territory must create separate autonomous production (autotrophy) instead of the assumption of different economies (heterotrophy) [12].

Regionalisation as a biospheric feature embraces the whole range of processes of anthropic type, which can be quite or very complex themselves because of their interaction with each other and interplay between the processes of evolution and deformation of the environment. These processes are self-organising and are carried out as an evolution of geospace. Regional infrastructure bears its own topology, which eventually evolves towards quite repetitive productive cycle. According to the result of our analysis, in the course of self-organising, geospace (besides the tendency to unite into one system), tends to autonomy and relative independence, which is represented as an objective reality. Energy, as well as the information (with the educational systems included), is the common and different feature, that the region contains.

The educational system of the region gradually reflects the whole range of cultural traditions about the interaction with other regions and subregional creations, as well as the competition with other regions for energy, raw materials, population, territory, productive, cultural functions, and whatever. It gradually evolves into the global structure of anthroposphere with the elements of complementation, cooperation, and connection with other regional structures, and is included to the cultural sphere which leads to the creation of the second nature (in this way the process of ceaseless separation of the person and nature takes place).

The production net (the labour source), which is accompanied by the appropriate education, capable to reverse the person back to their connection with nature, becomes a major correlator and determiner of the development of the region. In the course of evolution of anthropospheric educational system the biosphere region functions like a cell of nature (in other words it is harmonically), but only in the case of having the consciously intelligent completion of the connection between a person and nature, as a part of the regional educational component. Analysis of the geosphere clearly indicates that the *points of growth of anthroposphere* create the *ethno-cultural clusters* inside biosphere that provoke the huge "quality leap" – the shift from the regional humanity to self-management of biospheric regions-cells like a movement *from anthropotisation toward anthropologisation of the territory*. The places of the cultural gaps manifest the wholly different picture: there is a tendency to biospheric federalization and autonomisation of societies [13]. This process is shown in fig. 4.

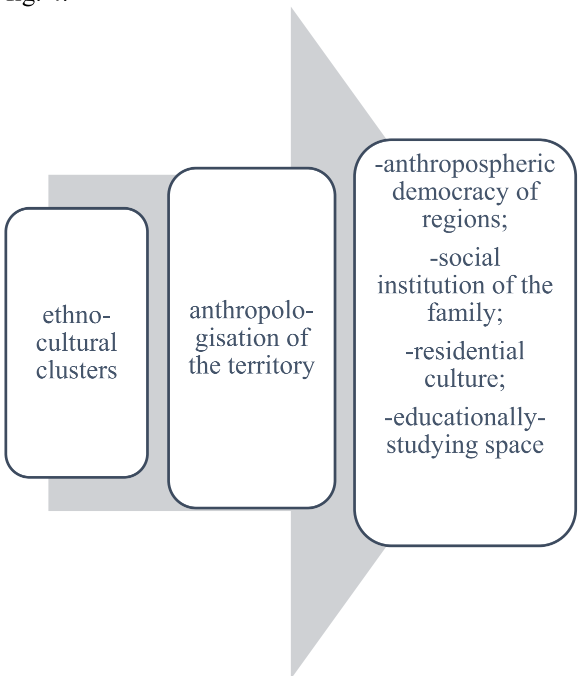

Fig. 4. Process of anthropologisation of the territory.

The particular ethnocultural "pluripotential" cluster of anthroposphere of the planet in 2019 (Top-20 countries of the world where the average life duration is 75 years for male and female population together: Japan, Singapore, Switzerland, Spain, Andorra, Australia, France, Italy, Iceland, Israel, Luxembourg, Norway, Sweden, Canada, Finland, the Netherlands, Austria, New Zealand, Malta and England (material is taken from Wikipedia). The named countries abide by the *democratic mode of governing*, are sufficiently wealthy with the high level of cultural development, based on the scientific, educational and religious spheres.

So, the *criteria of formation of ethnocultural anthropospheric synthesis* can be named as "several average durations of life, achievable for ethnocultural class", which currently is a duration of 75 years for male and female population together on the condition of democratic lifestyle. The vocation of "new paradigm" or "anthropospheric educational paradigm" being drafted to unite the world population into one entity, has not elaborated the *tradition of anthropospheric democracy of regions as a culture of projecting* due to the absence of methodology (authors consider this fact by). At the same time, unfortunately, some nationalities' mentality still bears the intermission, pause, some indifference, primarily caused by the change of some guidelines of evolution, relative to which the local educational systems are being late [13].

The most specific problem for anthropospheric educational system is the *social institution of the family*, which not only serves for the satisfaction of the main human instinct of preserving and reproduction of their kind as well as the tradition of the existence of the family. The institution of the family also represents the state of creative human evolution, which involves the implementation of new "anthropospheric order" in the *mental atmosphere of residential culture* in general, and particularly the familial orders. In this way the code of the regulations and rules insides the society will historically and democratically change in order to get the further preserving and harmonization of the social space.

As it could be seen, philosophy, science, education and religion are yet to agree on the integration of their own subcultures into the anthropospheric one as a potential of enforcement of cephalisation with the result of the creation of anthropospheric democracy.

The alternative to globalization with the creation of global monoculture (term by Vladimir I. Vernadsky) is a biospheric regionalization of ethnocultural development as a part of multicultural, interregional cooperation of educational and labour systems, is partially carried out as an ethnocultural clustering with the formation of united territorial hromadas (UTH). The next step is the formation of territorial districts or lands. However, the *regional component of educational content* in Ukraine is delayed in both its elaboration and implementation. Such a step would be able to relieve the tension in bordering lands like Zakarpattia, Donbas, the Crimean Peninsula, etc [19].

This statement must urge *the creator of a new textbook for pupils* to initiate the objective dialogue, primarily with the fundamental science, with the actuality of 25-30 years ahead in the given study material, along with the elaboration of the instruction about the application of didactic means during the pedagogical process. Without the correct objective, the educational process is focused on the study content, that is the historical trap, which cultivates civility instead of civilization, and consequently opens the way to *necrosphere* (term by Vlail P. Kaznacheyev [10]), to the devastation of residential culture.

People created the culture as a "second nature" or "symbolic universe" and this way of perception presents culture as a consequence, not as a cause. Cultural baggage should be noticed, relying on the causes, which provoked its creation or formation. In this way all school subjects must be created. Terms, meanings, artefacts and cultures, uniting them are the product of human personality's activity, as a part of Vernadsky's "Live liquid" *as the basic principle of the selection of educational content for the construction of pedagogical mindset* [18]. The presentation of knowledge and its perception during the course of studying humanitarian subjects, in the majority of cases is being the process of "turned upside down" that is the key problem of linguodidactics.

The educational process for the upcoming new generation must be constructed substantively and the main method of studying must be the *method of problematic studying*. The educational process for adults must be formed according to the professional problems, and the main method of perception must be the *substantive vision*: concrete, critical, systematic, the vision of synergy, vision of a project and the vision of effect [17].

The *humanitarian education*, as a part of educational profiles, ideally must become the anthropospheric education, the one, that accompanies the development of the pupil, both synchronically and diachronically, as a state of trophism, and on the base of complementary principle.

The real criteria of success of educator of the 21st-century is not only their lesson, their subject and his authority (category, title and academic degree) but also our life, measured by human development index "HDI" (combines the indicators: gross domestic product per capita, literacy rate and life duration) as a part of the biospheric region. These indicators can be used as a proof of the pedagogical efficiency during the switch to anthropospheric pedagogics.

4.4 Synergetics in the design of the educational process

Considering the fact that phylogeny transforms into ontogeny not in an accidental way, but in the case of a certain amount of visible external conditions, we are likely to deal with the sufficiently imbalanced educational process, that tends to be even more imbalanced at the beginning of the 21st-century. It is in the course of a search of the model for internal restructuring and new reorganization. Hence, using the language of synergy, the task is to generate the administrative decision as to the preparation of ordering of all elements of the pedagogical system – internally-systematic moving to the goal: to generate the educationally-studying space and provide the reality of "understanding the understandable one" on the deeper level and subjectively level toward lead the studying process to the laws of informational systems.

Educationally-studying space from the synergetic point of view is a differentiated quantum (it is being in the particular state) self-regulating and open macroscopic system, subordinated to laws of development in the material world (in its whole manifestation), where the pedagogical energy is spread for harmonic construction of the image by the educational system. More exactly, it is the system of ties between the personality and the Universum, like the objective reality in time and space. The state of this system should be comprehended as a multitude of relations of independent properties, which characterise the system at some particular temporal moment [12].

The multitude of states of this system forms the space of states. The course of educationally-studying space from one state toward another (new) state is a particular trajectory of motion (a complicated attractor) in the space of states (it means states of the educational system and state of learning). The transition from one state to another one can be done in two ways: 1) the accidental transition when the term "objective" cannot be applied to such action; 2) the deliberate one when the action does with a

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concrete purpose. In the second case, the deliberate movement towards the goal is determined from outside or by the state of the internal environment of the system (the state of studying in this particular case). But the constructed system does not tolerate the imposing of external structures. During the creation of the new educational system, there is one remaining thing to do: to assume the laws, that are used for running such systems and create managing impacts, whose functional character is close to the character of the functionality of the targeted system [13].

Therefore, educational space with its internal element possesses the space of teaching, and its external element – the space of studying. Education is represented as the state of consciousness, as the measurer of information, the state of accumulation and arrangement of the information of the internal system (it is the system of teaching) and the state of connection with the general informational net (it is the current state of society of anthroposhere).

To manage educational space, one must possess the theory, which can be the base for the operation of planification and prediction of the multisided vital process. The development of personality stimulates their personal educationally-studying space to develop along, that is a balanced part between the educational space of the society and educationally-studying space of the particular region (see Fig. 5).

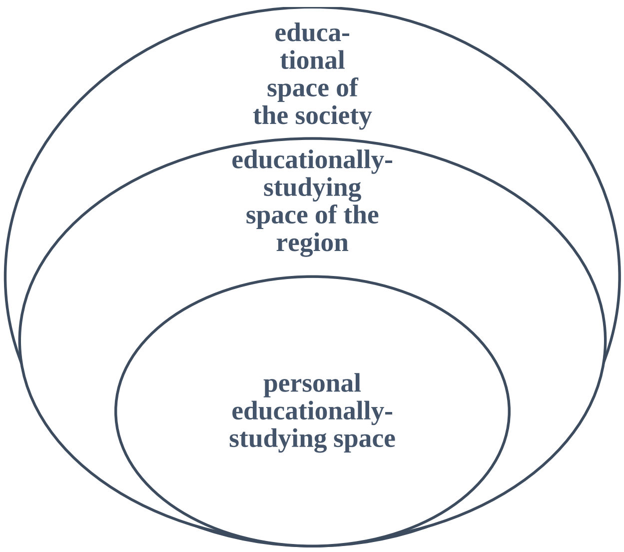

Fig. 5. The personal development space.

Thus, the personal development is realised as the intersection of the global informational net (educationally-studying space of the region) and personality's educationally-studying space [20].

Due to ordering of the person via to the sort of action, in the social cooperation will create, within quasi-ceaseless process, "the critical factor of potential action" – the activation of thinking and, as a result, the explosion of creativity, and finally as the stream of kindred work – the innovative activity.

This process is provided by the educational system via the system of promising concepts of educating and developing of a particular individual and the society in general. The sense of life of the modern Person is their adaptation to Space with the mediation of the identification of the personal aspect into the social one, along with the creation of synthesis of public and professional mindset in conditions of vastly-growing oikumene, ruled by Intelligence.

5 Conclusions

Any nation possesses not only the local geographical dimension (within intersection of physical and economical geography) – as a country on the global map and a state, but also the global and spatial ones – its body, soul and spirit. Their point of intersection is an aware and reflecting person. To become a nation the nationality must assume the humaneness as a mindset and invoke their culture and mental efforts. The *following ideas are included in the anthropospheric humanism of Ukraine*:

1) Projecting of the future as a part of educational and ideological triad like "social state – civic society – ecological mindset" must be initiated in the conditions of the educational system of the region as a completely natural territory, where the public, regional and studying components of the content of education (academic and supplemental parts) are function.

2) Educational system of the country has to be ruled by the framed law about education, as well as the regional educational specimens – the regional educational constitutions. At the same time, studying component of the educational content must be elaborated on the base of regulatory documents of the educational institution, created and coordinated by the community in a favour of some particular personality's development.

3) The educational path begins as a psychologically-pedagogical issue and the part of some personality; it lasts as the polymorphism of interests (formless one – broad one – vital one) towards the possibility of their realisation with the help of social efforts via the profile mode of educational.

4) The beginning of comprehension is cultivated by the correct immersion of personality into nature, as well as into life by means of the creation of ecological tracks with the points for contemplation and examination of an environment with the possibility of comparing the things to the ideal. This way allows to deepen of the content of educational material, realises decomposition of the problem of the life quality perfecting on the base of scientific emphasis of the method.

5) The educational environment has to develop according to democratic principles, where the atmosphere of justice is present, the balancing of all branches of government on all level of organisation is available as well as the respect towards the personality is exist.

6) Anthropospheric educational system of profile type releases the potential of the synthesis of natural and historical processes, considers the rate of formation of global democratic social relations as a combination of labour, intelligence, and scientific research, related to the religious context in favour of civilization.

7) Awareness is a result of evolution, whose origin bear genealogical character, personal embodiment and collective usage, which can be direct and indirect. A

person's world predominantly begins inside them, is constructed by them "settles down" inside them on the final stage of its development, that is why the profile of learning must be mentioned as the duration, where the vital energy circulates.

8) The new motivating of human life as the immortality of personality, who is a part of space is necessary because the comprehension of something possible, the awareness of something necessary and scientific clarification of something conceived is one unanimous idea of the people from the planet Earth.

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Potential of environmental responsibility and financial potential of innovative mechanical engineering enterprises in Ukraine

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Abstract. In the era of sustainable economy, the environmental responsible companies provide an important background both for particular industry and national economy competitiveness. In particular, mechanical engineering plays an important role in the economy of Ukraine. In accordance with national statistic, the Ukrainian mechanical engineering provides 6.4 % in total volume of industrial products and ~4 % of the gross value added in the GDP of Ukraine. At the same time, the global mechanical engineering industry environmental friendly activity is related to SDG 9 and SDG 12. In March 2020, the Cabinet of Ministers adopted its Programme, reaffirming the commitment to the SDGs and their importance for Ukrainian economy development. Thereby, research problem lays upon the financial potential of innovative mechanical engineering enterprises in Ukraine providing the background to increase the potential of their environmental responsibility. The paper aims to provide scientific support on mechanical engineering industry representatives that tend to be environmental friendly. The research methodology is based on Ukrainian mechanical engineering enterprises data (5 years and 337 industry representatives) processed by statistical analysis. The financial and environmental indicators are represented in results section on the basis for six groups of mechanical engineering enterprises' analysis, namely: big unstable – 16; big stable – 17; medium unstable – 44; medium stable - 26; small unstable – 188; small stable – 46. Thus, the environmental dimension is increasingly taken into account by Ukrainian innovative mechanical engineering enterprises to be competitive. Big and medium stable enterprises are organizationally oriented to be environmentally sustainable. The main disadvantage of big and medium unstable enterprises is lack of financial resources for achieving sustainable goals. Small enterprises are lack of general capacity to conduct environmental support policy, but they are the most flexible ones that provide advantages in environmental management. The study results can be used within industrial and business programs of environmental responsible activity and its financial support. In relation to other branches or countries, more extensive study is required.

1 Introduction

1.1 Research question

In the global economy, the 21st century brought forth new social challenges along with the technical problems and their solutions. New technological advancements and communications tools make new innovative ideas available in a wide range of social and economic areas. However, the technological progress often causes the lack environmental and societal ethics within business structures.

Profitability is at the heart of our understanding of successful business. At the same time, determining the impacts of vast expansion of economic activity into the environmental decline is becoming important worldwide. The economic activity is consuming vast quantities of resources from the environment, simultaneously returning the vast quantities of waste products into the environment. However, in the new global economy, the issue of environmental friendly business has received considerable critical attention. It is rather important to pay attention both to the financial prosperity and environmental policy of the company. Despite economy and ecology are often pitted against each other in the "profitability versus environment" debate, the modern companies are taking care of financial prosperity and environmental influences.

Reduction of man-caused load on the environment with simultaneous preservation of production capacity can be realized through a comprehensive greening of production processes in all sectors of the economy. Greening of production depends on greening of its individual components, the most important of which are technological solutions.

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Modern economic realities prove that mechanical engineering is one of the most important branches for national economy development, because it plays an important role in accelerating both scientific and technological progress. Mechanical engineering provides the means of production to other sectors of the national economy, contributing to the renewal and accumulation of capital. In addition, mechanical engineering is one of the leading industries, concerning product value, investment attractiveness and employment increase globally. However, serious environmental problems are caused by activity within mechanical engineering, including environmental pollution, soil erosion and deforestation and climate changes. Thereby, the concept of profitable and environmental friendly mechanical engineering industry is at the heart of sustainable development understanding.

Since 2015, world leaders at the United Nations agreed to the 17 Sustainable Development Goals (SDGs) covering the three main dimensions of sustainable development: economic, environmental and social [1]. In particular, sustainable manufacturing, including sustainability of mechanical engineering industry, is related to SDG 9 and SDG 12 [2].

In accordance with SDG 9 "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation", environmental investments are among key business themes within sustainable society development. By 2030, the SDG 9 contain the measure of targets, including the following ones: to promote inclusive and sustainable industrialization, and raise significantly industry's share of employment and GDP in line with national circumstances; to upgrade infrastructure and retrofit industries to make them sustainable, with increased resource use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, all countries taking action in accordance with their respective capabilities [3].

SDG 12 "Ensure sustainable consumption and production patterns" suggests that societies need to find just and equitable ways to meet individual needs and aspirations within the environmental limits of the planet. Sustainable practices in the production phase of products and services will not provide sufficient responses to meet science-based emissions reduction targets, natural resource constraints or the growing demand for basic needs such as food, water and sanitation, and access to energy. Furthermore, demand for materials will likely outpace efficiency gains in supply chains as well as overwhelm already stretched ecosystem services. Consumption patterns need to be made sustainable, particularly lifestyles in industrialized societies, and reduce their environmental footprint to allow for the regeneration of natural resources on which human life and biodiversity depend. By 2030, the primary targets of this SDG contain substantially reduce waste generation through prevention, reduction, recycling, and reuse; encourage companies, especially large and trans-national companies, to adopt sustainable practices and to integrate sustainability information into their reporting cycle [4].

Mechanical engineering is one among the leading industries in Europe and globally. For instance, the industry produces about 9.1 % of all production in manufacturing industries in European Union. The mechanical engineering companies are characterized by a relatively high manufacturing depth. The share of mechanical engineering value added of total manufacturing is higher than that of production, reaching around 11.5% [5]. Thus, mechanical engineering has both rather high financial potential and potential of environmental responsibility. Thereby, it is important to pay attention to above-mentioned issues within theoretical researches and applied conclusions.

Although the scientists payed attention to questions of sustainability within mechanical engineering industry. However, there is a great diversity of interpretations and ideas associated with the concept of sustainable manufacturing, including the consideration of financial potential and potential of environmental responsibility [6 - 8].

In light of recent trends of sustainable manufacturing, it is more difficult to find studies that provide a comparative analysis of indicators of its financial and environmental capacity and potential for further development. Thus, the current study tends to highlight the tendencies of mechanical engineering in Ukraine, namely their financial capacity and potential of environmental responsibility. The genesis of this thesis can be traced back to the time the authors became interested in sustainable development of innovative mechanical engineering enterprises in Ukraine and abroad.

1.2 Previous researches

Several previous studies and international organizations reports have found that innovative mechanical engineering enterprises have a significant potential to support sustainable development worldwide, including boosting social growth and environmental protection [9-11].

More recently, some governments, non-governmental organizations (NGOs), companies and academics have defined the unsustainability of our development model as one of the main problems faced in our society [2; 12]. In particular, the connection between growth of industrialization activity, increase in natural resource consumption and pollution was analyzed by Robinson et al. [13]. At the same time, the essence and industrial nature of sustainable development are also concerned within analytical reports of international organizations. In particular, the significant milestones of sustainable development, including environmental component, are considered within the "Our Common Future" report by the United Nations [14]. The above-mentioned researches created the basis for further applied researches, including estimation of the 17 Sustainable Development Goals (SDGs) covering the three key dimensions of sustainable development: economic, environmental and social [1].

Due to the industrialization widespread, there is also a measure of researches on sustainable mechanical

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engineering issue. So far, however, there has been little discussion about the mechanical engineering activity influence on environment. A search of the literature revealed few studies which define the potential of environmental responsibility of entities. However, there are some detailed investigations and published researches on cluster concept, considering sustainable development of mechanical engineering. In particular, the "cluster concept", based on sustainable development, is determined within the researches of Ketels and Schmitz [15, 16]. Bergman and Edward paid attention to economic, social and ecological components of industrial clusters development [17]. The macroeconomic patterns of industrial entities development are considered within Steiner and Hartmann researches [18].

The above-mentioned patterns consider the nature of the anthropogenic impact of the cluster on the environment and determine the potential of such impact widespread. To ensure main consideration of the industry patterns, the definition of the term "metallurgical industrial cluster" was mentioned.

However, there is still a rather little published researches on financial potential and potential of environmental responsibility of mechanical engineering enterprises. Thus, the chosen problem is of a significant scientific interest nowadays.

1.3 The scientific problem

The scientific problem of this article lays upon the potential of providing flexible environmental support policy by innovative mechanical engineering enterprises, providing the basis for sustainable industry development in Ukraine. The hypothesis of the paper has both theoretical and applied background, concerning the profitable industry impact on sustainable development process, including influence on environmental conditions, which aims to activate sustainable development strategies implementation by innovative mechanical engineering enterprises. *The aim* of the current study is to identify similarities and differences, discover the best sustainable practices and present the strengths and weaknesses of the different groups of mechanical engineering enterprises in Ukraine to develop both financial potential and potential of environmental responsibility, based on their statistic. The *object* of the research is sustainable development boost within different groups of innovative mechanical engineering enterprises in Ukraine. The *subject* is financial potential and potential of environmental responsibility of above-mentioned industrial entities, contributing the social and economic growth of national and global economies.

1.4 The research methodology

The *research methodology* is based on Ukrainian mechanical engineering enterprises' data processed by statistical analysis. Data on financial position and indicators of effectiveness were collected by authors directly from financial and non-financial statements. A time period of research is 6 years: 2014 – 2020; the number of mechanical engineering enterprises: 337. During the analysis, the following data were studied: indicators of production and productivity, income and expenditures, profitability and profit margin, EVITDA, the indicators of business sustainability, environmental and energy efficiency, estimation on ecological management practices. The financial and environmental indicators are analyzed on the basis of six groups of mechanical engineering enterprises definition, namely:

Big unstable – 16 (big mechanical engineering enterprises with rather unstable trends and indicators of activity);

Big stable – 17 (big mechanical engineering enterprises with stable trends and indicators of activity);

Medium unstable – 44 (medium mechanical engineering enterprises with rather unstable trends and indicators of activity);

Medium stable -26 (medium mechanical engineering enterprises with stable trends and indicators of activity);

Small unstable – 188 (small mechanical engineering enterprises with rather unstable trends and indicators of activity);

Small stable – 46 (small mechanical engineering enterprises with stable trends and indicators of activity).

The scientific novelty of the methodology is as follows: in the study, both the financial indicators and indicators of environmental influence of different groups of innovative mechanical engineering enterprises are analyzed through compartment of their strengths and weaknesses. On the one hand, this provides opportunity to define the role of financial stability for enterprises' sustainability for each group representative. On the other hand, this allows to estimate the influence of concentration of efforts on sustainability into the risks of failure and financial results.

1.5 The current research structure

The current research consists of the following parts: primarily, the theoretical and applied framework based on financial indicators of Ukrainian mechanical engineering enterprises activity is provided; secondly, the sustainable development phenomenon is described; the current situation of Ukrainian mechanical engineering enterprises' efforts concentration on sustainable development, including environmental challenges, is represented; then, the research conclusions on environmental and financial potential of mechanical engineering enterprises in Ukraine are provided.

The research practical implication is that results can be used within national innovative environmental strategies to accept community challenges both on national and regional levels.

2 Main theoretical and applied assumptions of the research

2.1 Concepts of innovative enterprises ecological management

The concepts of ecological management provide a useful account of how the theoretical background for ecological potential development by innovative enterprises. The primary modern investigation on environmental responsible activity by profitable enterprises dates to the end of the XX century. At this time Nelson, Winter, Silverberg and other researchers formed an evolutionary economic theory, in which economic development was provided in the form of a non-uniform, impulsive process, most of which consisted of innovative and innovative changes affecting "natural" capital. The economic processes are considered as stable and depended on external factors [19]. The emphasis is made mainly on the periodic change of innovation within the above-mentioned theories. At the same time, the attention is paid on the interdependence of economic processes and environmental phenomena.

The theoretical backgrounds on environmental problems and their financial solutions are considered within the following approaches (Figure 1):

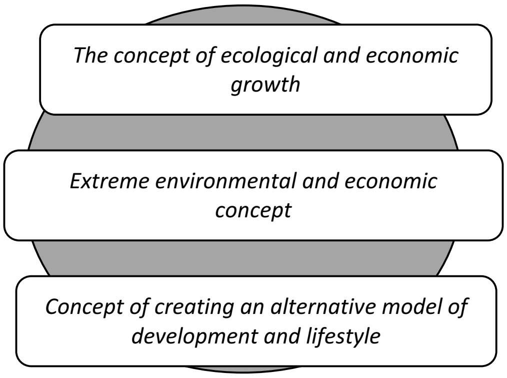

Fig. 1. The concepts on environmental growth.

The extreme environmental and economic concept represents concepts that are based on rather negative attitude to social and economic development on the basis of environmental component (Forrester, Meadows, Boulding, Michelle, Dame, Mansholt, Taylor, Puru). The concept of ecological and economic growth represents the system of sustainable development (Baroque, Jenks). The concept of creating an alternative model of development and lifestyle focuses on the social factors and environmental development (Reimers) [20-22].

The environmental concepts of a relatively stable dynamic system of equilibrium is based on the principle of systematic development. In accordance with above-mentioned principle, the "ecosystem" concept as the combination of both inorganic and organic factors of economic and financial development is introduced by Tensley. The issues of systematic development and equilibrium are also considered within the concept of "environmental sustanability", which represents a qualitative and quantitative ratio of human-modified and natural environmental components and processes. At the same time, the definition of "ecosystem" becomes widespread within the business development concepts. According to Boyet, in order to succeed in business, the manager has to develop the "environmental awareness" along with managerial goals. The attention is also paid to "business ecosystem", which provide the environment for strategic business development. The definition of the concept of "environmental management system" was primarily defined in the UK Standard BS 7750 (Environmental Management Systems) in 1992 and described as part of a generalized management system, which includes planning processes, organizational structure, practical work, division of responsibilities, as well as resources and procedures for the development, implementation and evaluation of the obtained results (ISO 14001. Environmental management systems - Specification with guidance for use).

The American Society of Mechanical Engineers (ASME) paid attention to the social (including, environmental) responsibility in mechanical engineering. The principles of force, energy and motion are being concern, mechanical engineers use their knowledge of design, manufacture, and operational processes to advance the world around us, improve safety, ability to manage economic with strength and responsibility throughout the world [23, 24].

The Mechanical Engineering Industry Association (VDMA) analytical researches provide evidence on the role of the mechanical engineering industry growth for sustainable development and growth within the European economy. In particular, the importance of investment into the inclusive growth and ecological development within mechanical engineering industry is considered by industrial experts in developed economies [25].

The environmental management in Ukraine is considered as a market-oriented (economic) mechanism for improving the environment at all levels of management and is contrasted to the administrative-command mechanism of environmental regulation. This creates a number of "ambiguities" that make it impossible to perform the main task of environmental management, namely the introduction of an effective system of environmentally friendly management at the enterprise level.

2.2 System for mechanical engineering entities environmentaly responsible development management

Taking into account the targets of sustainable development of the enterprise, including reducing the burden on the environment, increasing environmental competitiveness, it is important to justify the mechanism of environmentaly responsible development management and financing (Figure 2).

The basic element of the proposed system is a chain of "environmentally responsible development goals - processes of environmental and economic drivers' mobilization – financial and environmental results", which characterizes the internal existing and potential of the enterprise and the possibility of its implementation. The complex application of functional, systemic, parametric, target and process approach is based on certain principles of ecological and economic management. Achieving priority goals is possible by mobilizing resource-saving drivers and optimizing the ratio of growth rates of the final product and the cost of natural resources: increasing the resource-saving effect of the introduction of new technology; ensuring the integrated use of raw materials, the introduction of advanced technologies for its processing; gradual dematerialization of production.

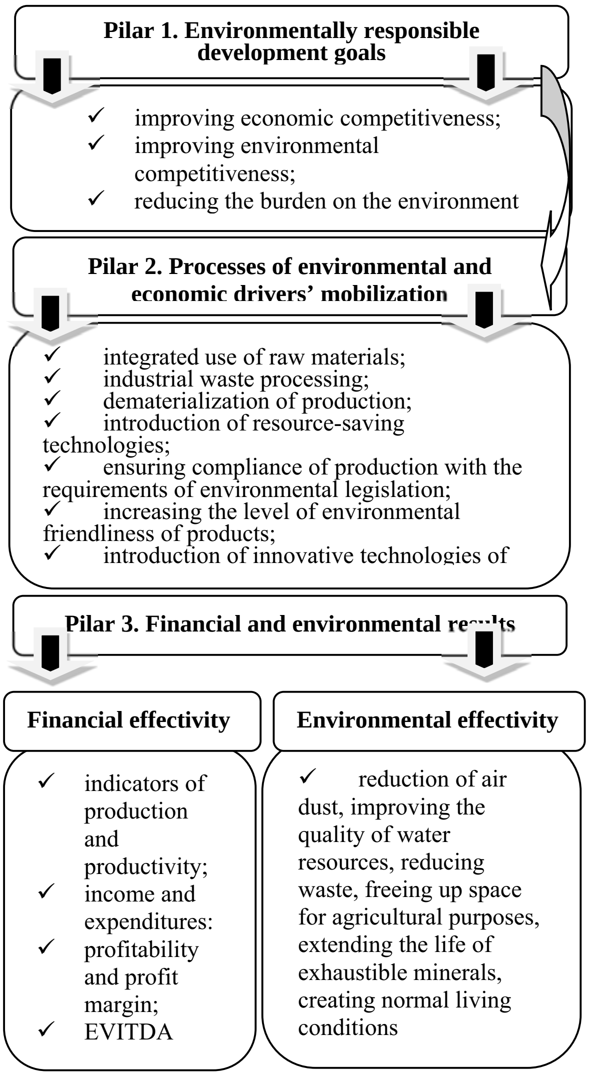

Fig. 2. Mechanism of environmentaly responsible development management: mechanical engineering case.

3 Research results

3.1 Groups of mechanical engineering enterprises and indicators of their financial potential

The potential of innovative development of mechanical engineering enterprises depends on the main economic characteristics that determine the features of their current activities and the prospects for their further development. The current research is based on the mechanical engineering enterprises classification in accordance with the criteria of their size and stability.

The primary indicators of financial potential are trends of changes in the average values of revenue from sales for each group of mechanical engineering enterprises (Figure 3).

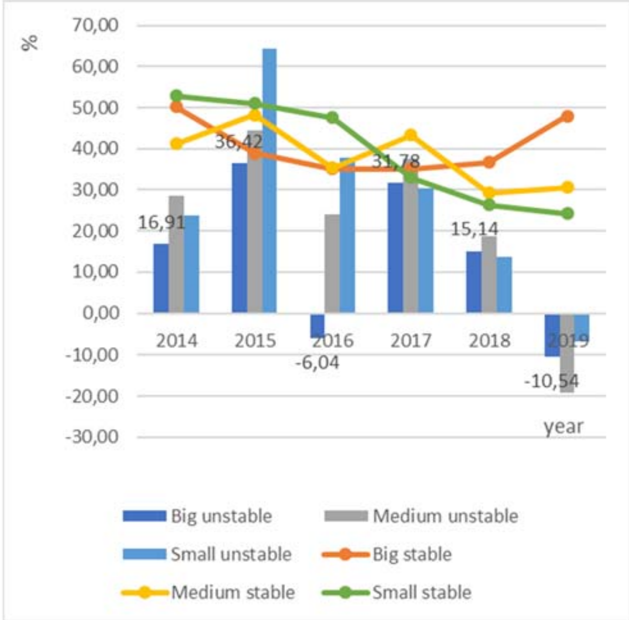

Fig. 3. The average values of revenue from sales.

The maximum growth rates are typical for 2015 and 2017. In 2019, we observe a slight decrease, which does not affect the overall upward trend during the study period. Such trends create the financial conditions for further implementation of innovation. However, the general tendency for unstable companies represents the maximum decrease in revenues in 2016 and 2019 years. Thereby, in accordance with the revenue indicator, currently the Ukrainian stable companies, independent of their size, have financial potential for environmental policy conduction.

At the same time, the tendencies to change the degree of depreciation of fixed assets are quite contradictory for Ukrainian mechanical engineering enterprises. It is possible to observe an increase in the degree of fixed assets deterioration over the last five years. The trend of the rate of outdated fixed assets increase is rather negative for further environmentaly responsible development and innovative growth. However, in this case there is a growing potential to replace these outdated fixed assets with innovative ones that will create the basis for innovative and environmentally responsible growth on a new technological basis.

The share of intangible assets in the total value of assets is insignificant, averaging from 0.3% to 0.5% during the chosen timeframe. These tendencies are available due to the peculiarities of the mechanical engineering industry. At the same time, this characterizes the contradictory basis for innovative development. However, the share of fixed assets in the total value of assets ranges on average from 25% to 35%. This makes fixed assets the basis for future environmentally responsible and innovative growth on a scientific and technical basis.

Due to the above-mentioned contradictory tendencies of mechanical engineering enterprises in Ukraine, the trend of changes in revenue and asset value per employee becomes an important indicator of financial potential (Figure 4 and Figure 5).

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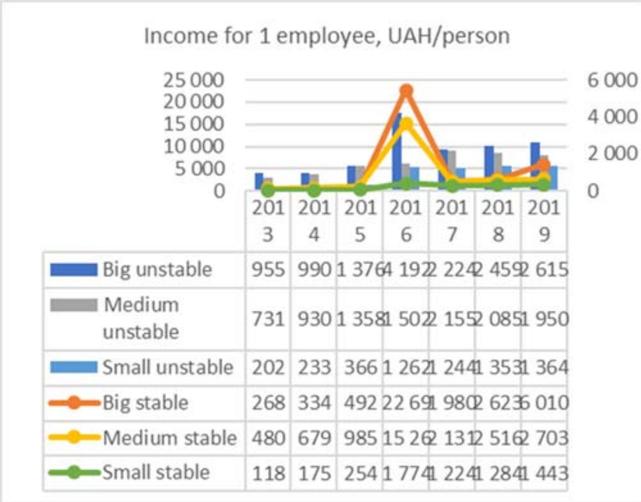

Fig. 4. The average values of revenue from sales per employee.

The compartment of data from different groups of representatives shows that the main increase of indicator is typical for stable big and medium enterprises. At the same time, instead of their stability, the small stable mechanical engineering enterprises have rather low indicators of revenue per one employee. Thus, they are the weakest ones for achieving environmentally responsible development goals in the group of stable enterprises in accordance with revenue indicator.

The second important indicator is the average asset value per employee (Figure 5).

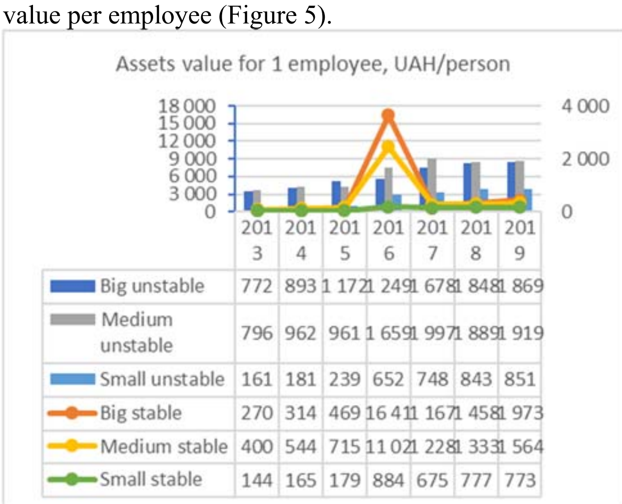

Fig. 5. The average assets values per employee.

The tendency of average assets values per employee is the same as the above-mentioned tendency of revenue changes. Thus, the enterprises that represent the group of big and medium mechanical engineering enterprises have the most appropriate basis for innovative activity implementation and environmentally responsible goals achievement.

One more important indicator of financial potential is the value added indicator that represent the key to assessing the effectiveness of existing innovative solutions and technologies (Figure 6).

The maximum value added indicators are appropriate for big stable enterprises. The medium stable enterprises represent the growing tendencies of increase. Both the small stable and small unstable enterprises have the weakest positions in accordance with value added indicator.

Fig. 6. The value added indicator.

At the same time, the value added trends are not always comparable to EBIDTA and EBIDTA profitability (Figure 7).

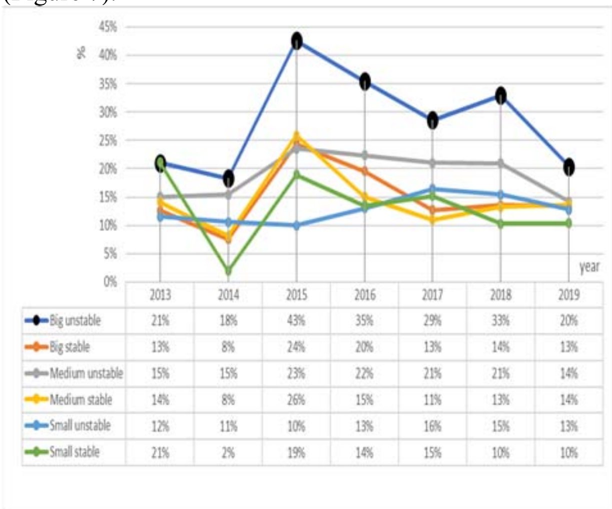

Fig. 7. The changes of indicators of EBIDTA profitability

The indicators of EBIDTA profitability have the increase tendency for all groups of mechanical engineering enterprises. This shows the available financial for further environmentally responsible development of industry in Ukraine. At the same time, the represented indicators of financial potential show that the groups of big and medium stable enterprises have the highest potential for further environmentally responsible development.

3.2 Indicators of Ukrainian mechanical engineering enterprises' potential of environmental responsibility

The potential of environmental responsibility of mechanical engineering enterprises in Ukraine is estimated, based on evaluation of social responsibility strategies and their effectiveness in mitigating environmental impacts.

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The research is conducted for each group of mechanical engineering enterprises, namely big stable, big unstable, medium stable, medium unstable, small stable and small unstable. The research methodology is based on the following set of indicators:

– the level of environmental friendliness of production;

– a quantitative indicator of the *i*-th type of contamination of environmental components due to production;

– a specific indicator of economic losses caused by the unit of the *i*-th type of pollution;

– a quantitative indicator of the *j*-th type of eco-destructive influence on landscapes;

– specific indicator of economic losses caused by the unit of the *j*-th type of eco-destructive impact on landscapes;

– a quantitative indicator of the *z*-th ecodestructive effect directly on the human body:

– a specific indicator of economic losses caused by a single indicator of the *z*-th ecodestructive impact on the human body;

– a quantitative indicator of irrational extraction of minerals from the extracted rock mass;

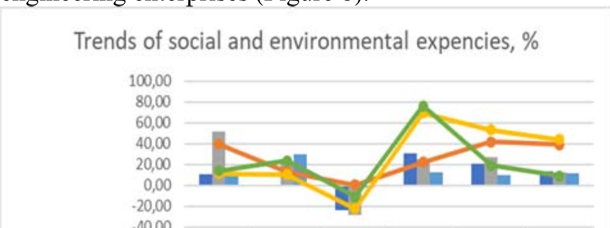
– specific indicator of economic losses caused by irrational use of minerals;

– a quantitative indicator of the *g*-th type of environmental impact on biological objects;

– specific indicator of economic losses caused by this type of eco-destruction;

– the volume of production that caused the processes of eco-destruction.

Currently, only the primary three components of losses can be fully estimated. Thereby, the current research is based on analytical estimation of environmental friendliness level of production, estimating the social and environmental expenses of mechanical engineering enterprises (Figure 8).



	2014	2015	2016	2017	2018	2019
Big unstable	10,87	-1,58	-23,60	30,46	20,30	12,96
Medium unstable	51,13	21,77	-28,62	25,28	27,32	12,37
Small unstable	12,32	29,55	-2,15	12,65	9,47	11,65
Big stable	39,41	13,24	0,44	21,97	41,49	39,00
Medium stable	11,22	10,43	-22,40	69,61	53,09	43,91
Small stable	13,76	23,55	-11,03	76,23	19,05	8,98

Fig. 8. The social and environmental expenses changes of mechanical engineering enterprises.

The above-mentioned data represent the tendency of mechanical engineering enterprises' expenses on achieving social and environmental goals. Thus, the most stable growth is represented by big stable enterprises. However, the worthiest timeframe in the context of environmental support was 2016 year. Simultaneously, the worthiest financial potential of mechanical engineering enterprises was also in 2016. Thus, there is dependence between financial potential of mechanical engineering enterprises and potential of their environmental responsibility.

3.3 Ukrainian mechanical engineering enterprises' straights and weaknesses (SWOT analysis)

In accordance with this new trend of promoting environmental friendly remanufacturing and social responsible business, it is essential to tackle the design of strategies and new technological developments to advance the mechanical engineering enterprises' innovativeness. It is clear that all of this is going to have a great impact on how the national mechanical engineering industry will be involved within national and global innovative process. The increasing attention should be paid to the strengths and weaknesses, represented for each group of enterprises, dependent on their financial potential and potential of environmental responsibility.
These strengths and weakness are analyzed in accordance with SWOT-analysis (sustainability SWOT - sSWOT) within the context of financial potential and potential of environmental responsibility. This will assist within driving action and collaboration on environmental challenges creating real business risks and opportunities. Moreover, this may motivate entrepreneurs for sustainable activity, particularly those with limited knowledge of environmental issues or corporate sustainability.

In accordance with previous research, big and medium stable mechanical engineering enterprises are the most environmentally sustainable. However, there are also some weaknesses along with strengths (Figure 9).

Strengths	*Weaknesses*
Financial capacity for achieving environmental goals Possibility to manage separate branch that is responsible for sustainable development Availability of environmental strategy Progressive informative support system	Large-scale production that influences environment Lack of environmental problems' understanding by some employees Failures in the performance of functions by individual units, duplication Marketing system that may be ineffective
Opportunities	*Threats*
Low competitiveness within the group representatives Availability of high technological and environmental standards	Taxation policy, concerning environmental influence High requirements to entrepreneurs' social and environmental responsibility

Fig. 8. Sustainability SWOT for big and medium stable enterprises.

Big and medium unstable enterprises are also rather important environmental friendly players. However, their instability creates some problems, concerning lack of financial resources for environment protection (Figure 9).

Strengths	*Weaknesses*
Rather strong market position Highly qualified staff that concern environmental sustainability as one of competitive advantages Organizational culture and image that makes the basis for further sustainable activity	Outdated equipment in some areas Lack of financial resources for environment protection during the instable timeframes
Opportunities	*Threats*
Availability of high technological and environmental standards Barriers for potential competition to entry the segment	Instability of social and economic development within global and national economy Demand instability

Fig. 9. Sustainability SWOT for big and medium unstable enterprises.

Both stable and unstable small enterprises are rather flexible in their decisions on environment protection. However, these enterprises have insufficient financial capacity to boost progressive initiatives on environment protection and sustainable development support (Figure 10).

Strengths	*Weaknesses*
Flexibility in environmental management Flexibility in environmental strategies building	Lack of product range Insufficient range of innovative technologies implementation Lack of financial resources for environment protection
Opportunities	*Threats*
Upward trends in the target market Demand on innovative ideas both at national and global markets	High-quality substitutes High competitiveness, concerning price policy

Fig. 10. Sustainability SWOT for small enterprises.

Thus, the environmental dimension is increasingly taken into account by Ukrainian innovative mechanical engineering enterprises to stay competitive. However, primarily big and medium stable enterprises are organizationally oriented to be environmentally sustainable. The main disadvantage of big and medium unstable enterprises is lack of financial resources for achieving sustainable goals. Small enterprises are lack of general capacity to conduct environmental support policy. At the same time, small enterprises are the most flexible that provide advantages in environmental management.

4 Conclusions

Given all that has been mentioned so far, one may state that environmental potential is getting growing importance within sustainable society. The primary analytical research of Ukrainian statistics shows the increasing deepening of mechanical engineering enterprises' environmental responsibility from their financial capacity.

There is an urgent need to concentrate more efforts on the potential of environmental responsibility of all groups of mechanical engineering enterprises in Ukraine. In accordance with the research sample, the mechanical engineering industry in Ukraine has the following structure:

– big stable enterprises make about 5 %, but this group representative have both financial capacity and experience in achieving environmental goals;

– around 18 % of Ukrainian mechanical engineering enterprises may be concerned as big or medium, but unstable. Their environmental responsibility is particularly influenced by such instability, creating the barriers for sustainable development;

– 8% of medium stable enterprises also have enough financial capacity to be environmentally friendly and growing rapidly;

– the main part of mechanical engineering enterprises is small, namely 13 % of them are concerned as stable and 55 % of them are unstable. However, these enterprises produce the smallest share of production. They are rather flexible to be innovative, but have the lowest financial potential to support environmental friendly activity.

The study results of the current research can be used by their top-managers and spatialized branches that provides organizational and financial support for innovative projects in part of environmental protection.

In particular, the Ukrainian mechanical engineering industry stakeholders tend to pay attention on the following activities:

– stimulating the development of environmental management system within mechanical engineering enterprises;

– ability of top-managers to gather a network of enthusiastic stakeholders, who will assist at the initial stage of environmental support campaign, despite the lack of financial resources;

– ability of project managers to provide an environmental friendly business plan and its clear explanation for future stakeholders;

– creation of a centralized national system of informing the national business entities and investors regarding the need and advantages of environmental support;

– ability to provide an effective system for environmental stakeholders' stimulation at the national level;

– intensification of cooperation between public and private sector, concerning the strength of environmental support policy.

The essence of environmental responsibility potential is both applied and theoretical question. Thereby, there is a need for further research, considering environmental responsible model's practical implication within mechanical engineering enterprises activity. In particular, in relation to other countries, these studies should be applied with caution due to the national economies peculiarities. More extensive study is required. Thereby, this is the subject for future researches.

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Landscape approach to formation of system of ecologically balanced use of natural resources: legal framework

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Abstract. The article is devoted to the analysis of legal framework and theoretical provisions of the landscape approach to the formation of the system of ecologically balanced use of natural resources, the definition of its essence and content, highlighting of conditions and principles of its functioning. Proposals for elimination of legal problems in the field of development and realization of the concept of ecologically balanced use of natural resources are covered. It is determined that the legal formulation of landscape approach principle to the use of natural resources will ensure unity, integrity, comprehensiveness of nature management, coherence and balance of interests in this area, implementation of ideas for the formation of system of environmentally sustainable use of natural resources and sustainable development concept, and the adoption of relevant regulations will solve our state's urgent task on the path to further European integration.

1 Introduction

The priority of further development of civilization is the harmonization of interactions of society and nature. However, the ecological situation continues to deteriorate relentlessly thus posing a real threat to the existence of mankind. And unrestrained pursuit of economic growth is leading to the destruction of natural resources potential. Intensive development of scientific and technological progress has led to a number of global environmental problems, each of which can threaten the destruction of our civilization.

Simultaneous resolution of environmental protection and socio-economic development issues is one of the main activities of any civilized state nowadays. Today there is a dilemma – how to combine the interests of nature conservation with the interests of economic development and social sphere, how to ensure systematic consideration of environmental and economic interests, which is a condition for sustainable (well-balanced) development as a new paradigm of interaction between society and nature (Fig. 1). It is necessary to solve a difficult task – to find a balance in the system «environment – economic development».

There is a need to develop and implement the concept of environmentally sustainable use of natural resources which should be based on reaching a compromise between economic, environmental and social needs of society and on the principles of sustainability. For this purpose, the need to develop the legal framework of landscape principle in nature management, which involves changing approaches to the use of natural resources taking into account negative consequences of human intervention in natural processes and the balance of interests of nature and society development, acquires special urgency.

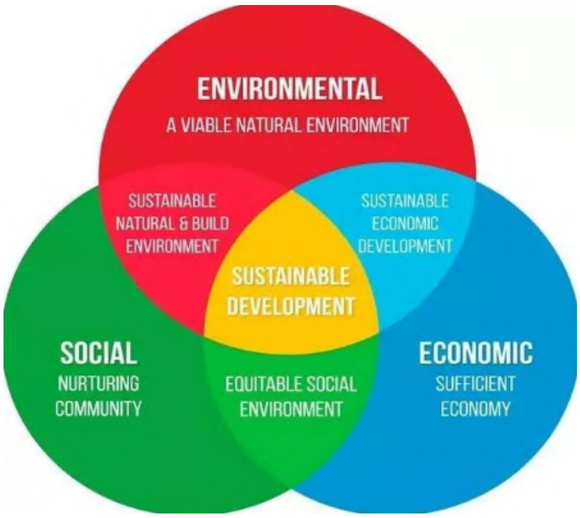

Fig. 1. Sustainable development [1].

The formation of the system of ecologically balanced use of natural resources is the subject of research by the following nature and economics scientists. Legal aspects of environmentally sustainable use of natural resources concept remain a little-researched problem. Specific proposals and projects of models of legal mediation of landscapes as a component of environment, as a source of satisfaction of ecological interests of humans and society as a whole were substantiated in scientific works.

The purpose of the article is to analyse the legal framework and theoretical provisions of the landscape approach to the formation of the system of ecologically

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balanced use of natural resources, the definition of its essence and content, identification of conditions and principles of its functioning.

2 Results

In 2015, the UN Summit on The issue of environmentally sustainable use of natural resources was first addressed at the World Summits on Environment and Development: in Rio de Janeiro in 1992 and Johannesburg in 2002. However, a breakthrough at the civilization level has not been achieved. Therefore, the XXI century should become a bifurcation point in the system «society – nature» that should be accompanied by specific human actions to harmonize the relationship between society and nature.

In 2015, the UN Summit on Sustainable Development adopted «Sustainable Development Goals» (hereinafter – SDG) – key areas of countries development for the period up to 2030 with 17 Global goals and 169 targets relevant to them (Fig. 2). Among the Global goals are: «Sustainable consumption and production patterns» (goal 12) aimed at reducing the impact on the environment by changes in production patterns and consumption of natural resources; «Conservation of marine resources» (goal 14) which involves conservation and sustainable use of oceans, seas and marine resources in the interests of sustainable development; «Protection and restoration of terrestrial ecosystems» (goal 15) aimed at promoting their rational use, rational forest management, combating desertification, stopping and reversing the process of land degradation and halting biodiversity loss, and others.

Fig. 2. Sustainable Development Goals [2].

Ukraine, like other UN member states, joined the global process of sustainable development. At the initiative of the Cabinet of Ministers of Ukraine and with the assistance of the UN system in Ukraine, an open and inclusive process of adaptation of the SDGs continued for a year. In 2017, the Cabinet of Ministers of Ukraine presented the National Report «Sustainable Development Goals: Ukraine» which defines basic indicators for achieving the SDG. The report presents the results of the adaptation of 17 global SDGs (86 tasks and 172 indicators of national development by 2030) taking into account the specifics of national development. Among the tasks envisaged by the National Report, the need to reduce the resource intensity of the economy, reduce the volume of waste generation and increase the volume of their processing and recycling based on innovative technologies and industries is identified under the Goal 12 «Sustainable consumption and production patterns».

However, the economic growth that everyone in the country aspires to and which is expected by the society will inevitably lead to an increase in natural resources use and consumption waste which in its turn will increase the anthropogenic burden on the environment. The understanding of the importance of responsible consumption and production implementation is present in the country but a balanced settlement of these issues requires a balanced and long-term political and economic effort focused on both production and consumption. According to the National Report, the National Policy should be based on 10 Year Framework of Programmes on Sustainable Consumption and Production Patterns (Rio, 2012), which is a global platform for capacity building and partnership in sustainable production and consumption.

The Law of Ukraine «On the Basic Principles (Strategy) of State Environmental Policy of Ukraine for the Period up to 2030» of 28.02.2019 defines as one of the main tasks the creation ecologically balanced system of natural resources use. The draft Strategy for Sustainable Development of Ukraine until 2030 envisages achieving a balanced and efficient use of natural resources and reducing the resource intensity of GDP by 40%. At the same time, the formation of the system of ecologically balanced use of natural resources is possible, first of all, in case the provisions of the concept are implemented in strategic and programme documents.

In this regard, there appears a need for a scientific study of the essence and content of the system of ecologically balanced use of natural resources, defining the conditions and identifying the basic principles on which this system should be based (Fig. 3).

Fig. 3. Balance of nature [3].

In 1972, Secretary General of the Stockholm Conference M. Strong, covering the essence of the concept of ecological development, for the first time at the official level made a demand for the balance of use of natural resources, the possibility of economic growth within acceptable ecological and economic balance, when society controls the regulatory balance «between total anthropogenic impacts on the natural environment with its

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self-renewable capacity, with its endurance in relation to these impacts» [4, p. 95].

The scientific definition of ecologically balanced use of natural resources was first covered in the works of economist P.G. Oldak. The scholar described the equilibrium (balanced) use of natural resources as the one in which «society controls all aspects of its development, ensuring that the total anthropogenic load on the environment does not exceed the self-renewable capacity of natural systems» [5, p. 24].

M.M. Prykhodko researches the problems ofthe formation of the system of ecologically balanced use of natural resources (resource use). The scientist notes that ecologically balanced use of natural resources is an equilibrium ratio between the use of renewable natural resources and the intensity of their restoration, as well as the economical use of non-renewable natural resources [6, p. 93]. In the context of ecologically balanced use of natural resources it is very important to comply with the regulatory balance between the available amount of natural resources (resource potential) and the amount allowed for use, which is determined by the ecological potential of ecosystems, their self-renewable capacity [6, p. 94] Thus, ecologically balanced use of natural resources should be based on economic activity in the cycle «extraction of natural resources – resource-saving production with low resource intensity – economical use – expanded reproduction – waste disposal».

In this regard, ecologically balanced use of natural resources should meet the following conditions: use of natural resources with minimal labour costs, with simultaneous contribution of funds for their renewal and taking protection measures; full use of natural resources (without losses during extraction, transportation, processing); renewal of natural ecosystem from which a natural resource is extracted; use of renewable natural resources only in the amount of their annual growth; use of non-renewable natural resources only to meet the most urgent needs; waste-free production.

The related scientific literature also distinguishes the principles on which ecologically balanced use of natural resources should be based: the principle of systematic approach to the use of natural resources; the principle of consideration of natural conditions and resources zonality; the principle of integrated management of natural resources; the principle of conservation, restoration and reproduction of naturalness and biodiversity; the principle of inexhaustibility (annual use of renewable natural resources should not exceed 10 % of their total amount); the principle of waste minimization (introduction of low-waste production, use of recyclables, waste disposal); the principle of observance of laws, rules and principles of natural resources use [6, p. 95].

Introduction of ecologically balanced system of nature management is directly related to the application of landscape approach to the use of natural resources. According to scientists, the landscape approach to the use of natural resources contributes to the restoration of ecosystems, mitigation and adaptation to climate change [7, p. 203], and can bring positive social benefits (e.g. employment or the return of valued wild species) and potentially contribute to improvements in human health and wellbeing [8, p. 21].

Legal codification of the principle of landscape approach to nature management is stipulated by Pan-European Biological and Landscape Diversity Strategy (1995), according to which the countries of European Community took responsibilities to significantly reduce the threat to biological and landscape diversity in Europe, of which Ukraine is a part. The strategy was proposed by the Maastricht Declaration «Conserving Europe's Natural Heritage» (1993), which was based on the European Nature Protection Strategy (1990), the results of Dobris and Lucerne Environment Ministers Conferences (1991 and 1993) and the UN Conference on Environment and Development (1992), etc.

In 2000, to ensure the sustainable development based on balanced and harmonious relationship between social needs, economic activity and the environment, the European Landscape Convention of 20.10.2000 was adopted, ratified by the Law of Ukraine of 07.09.2005. Pursuant to Article 1 of the Convention, «landscape» is defined as an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors.

According to the Convention, Ukraine is obliged to: 1) to recognise landscapes in law as an essential component of people's surroundings, an expression of the diversity of their shared cultural and natural heritage, and a foundation of their identity; 2) to establish and implement landscape policies aimed at landscape protection, management and planning through the adoption of the specific measures; 3) to establish procedures for the participation of the general public, local and regional authorities, and other parties with an interest in the definition and implementation of the landscape policies; 4) to integrate landscape into its regional and town planning policies and in its cultural, environmental, agricultural, social and economic policies, as well as in any other policies with possible direct or indirect impact on the landscape.

As a party to the European Landscape Convention and other international agreements, Ukraine has committed itself to implementing landscape policy into national law. However, currently, the landscape as an object of legal regulation in the legislation of Ukraine is defined only in the Laws of Ukraine «On Environmental Protection» of 25.06.1991, «On Approval of National Programme of Formation of National Ecological Network of Ukraine for 2000–2015» of 21.09.2000, «On Ecological Network of Ukraine» of 24.06.2004 which contain general norms related to legislative provision of use and protection of landscapes.

The concept of a landscape approach to nature management, the recognition of the landscape as an object of legal regulation and the need to protect it began to develop in the scientific literature in Soviet times. In 1983, the first attempt was made to disclose the legal meaning of the «landscape». I.A. Brinke, exploring the essence of the legal regime of landscapes, described the landscape as a set of legally defined areas of land or water consisting of interacting natural or natural and anthropogenic components characterized by typicality or beauty, which are protected by the state in the interests of science, education, culture and recreation [9, p. 9].

Landscape relations are the subject of research of many foreign scientists. Thus, in particular, N. Ockendon characterizes landscapes as large, heterogeneous and multifunctional environments that provide diverse services and values to multiple stakeholders [7, p. 199]. Ch. Albert defines the landscape as the result of the action and integration of natural and/or human factors [10, p. 15].

In national science of environmental and land law, the problem of recognizing the landscape as an object of legal regulation is just beginning to be discussed. In scientific works, the term «landscape» is explained from different points of view. V.I. Andreitsev, V.V. Nosik, M.V. Shulga define the concept of «landscape» by describing the legal significance of land as a national value, the object of property rights of Ukrainian people, the most important part of environment. So V.I. Andreitsev considers landscapes as complex objects of legislation, points out that national land value is the immensity of its properties for meeting physical, spiritual, aesthetic, cognitive, health and medical, recreational, historical, cultural and other needs, formation of natural and natural-anthropogenic landscapes [11, p. 15].

At the same time, as noted by S.V. Yelkin, the mentioned views of the above scholars on the definition of the landscape as a whole do not reveal its legal features. In legal sense, the concept of «landscape» is physical and legal features of the landscape set out in the law, as well as the competence of a subject of law on the landscape, where physical features are objective factors that will directly affect the definition of the specifics of the legal regime of the landscape, the absence of which does not allow to formulate the definition of the landscape as a legal category [12, p. 11]. S.V. Yelkin characterizes the landscape as a territory with a set of natural and artificial components, which form a single whole and are in the optimal quantitative ratio as defined by law, where land acts as a spatial basis [12, p. 14].

Comparative analysis of legal regulation of landscape protection in Ukraine and the European Union was carried out by O.V. Lozo who characterized the landscape as a territorial complex with a specific location recognized by existing legislation and law, within which natural and/or anthropogenic components are in constant interaction and adaptation to each other and constitute a united system [13, p. 7]. The scientist recognizes natural resources (land, water, flora, fauna, subsoil, air, etc.) as natural components of the landscape to the extent they affect it; buildings, transport routes, other man-made objects – as anthropogenic ones [13, p. 9].

Thus, the landscape as an object of legal regulation is a holistic natural or natural-anthropogenic system, which is characterized by relative homogeneity of interacting structural elements.

It should be noted that nowadays landscape planning is actively spreading as one of the ecologically oriented means of nature management in most developed countries of the world (Fig. 4). For example, the Wicken Vision in the Cambridgeshire fens, Cairngorms Connect project in the Scottish Highlands, Wild Ennerdale [7, p. 206]. In our country, only the first steps are being taken to introduce landscape planning into the policy of territorial development. In the future this will help to strengthen the relationship between environmental requirements in the field of nature management and economic, social and cultural interests of people, encouraging them to adhere to the sustainable development goals.

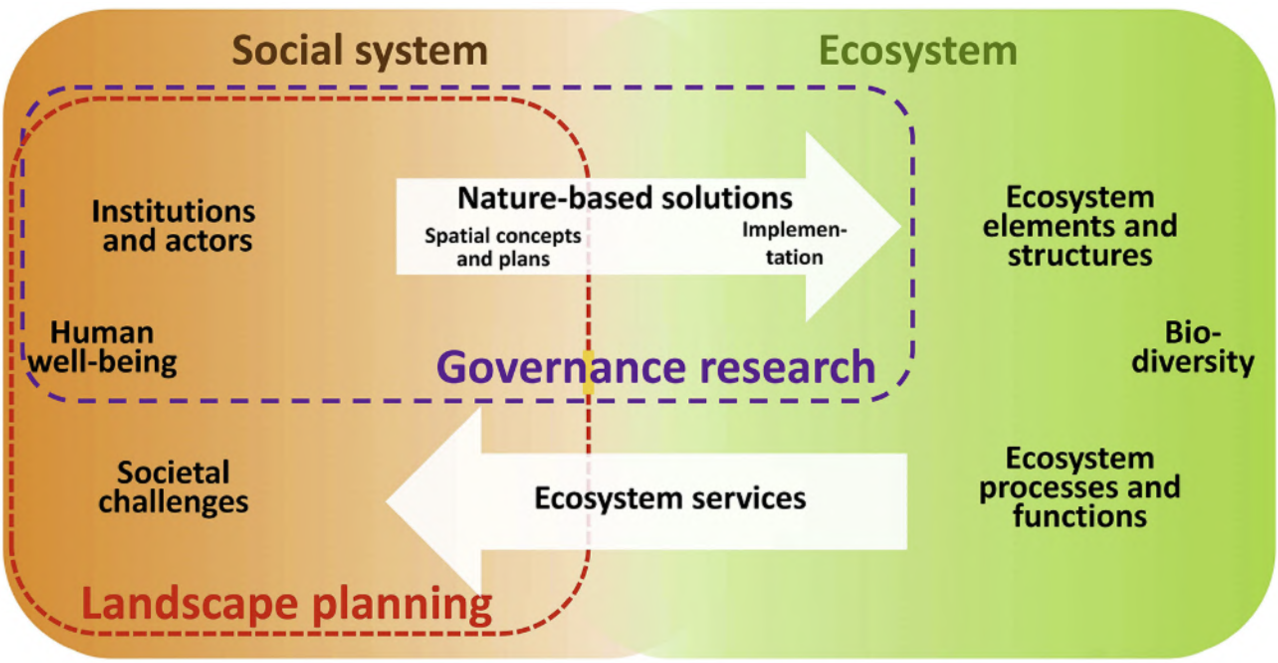

Fig. 4. Landscape planning [14].

Indeed, the need to implement the principles and approaches of modern landscape planning (especially in its European sense) into the practice of national natural resource planning is a close relationship of landscape planning with the concept of sustainable development, which Ukraine adheres to. Landscape planning is a strong forward-looking action to design, enhance or restore landscapes that serves at the interface between science and practice [10, p. 13]. According to the draft Law of Ukraine «On Landscapes», landscape planning itself is designed to ensure sustainable nature management. Besides, the spatial planning procedure in Ukraine is characterized by the dominance of town-planning approach, a strict focus on general schemes and the subordinate role of environmental requirements. This imbalance will help to correct the implementation of the principles of landscape planning.

According to the draft Law of Ukraine «On Landscapes», landscape planning is the development of a project for use of landscapes or a project to change the goals and methods of their management using a set of methodological tools used to build such a spatial organization of society activities in specific landscapes, which ensures sustainable nature management and preservation of basic functions of these landscapes as a life support system. As it is seen from this definition, landscape planning is becoming one of the primary tools for ensuring sustainable development in Ukraine.

Landscape planning has a potential to suggest land use options to achieve environmental objectives, to explore the respective impacts, and to provide recommendations for implementation in practice [15, p. 152]. One aim of landscape planning is to craft comprehensive and spatial strategies for developing multifunctional landscapes that minimize societal challenges and provide diverse ecosystem services to different groups of people [10, p. 16].

Taking into account that landscape planning ensures the implementation of the basic directions of sustainable development policy, it is deemed necessary to form and implement landscape policy in Ukraine, develop legislation, as well as intensify research in the field of landscape planning and its practical use.

Research and analysis of scientific approaches to the outlined sphere of public relations allowed to define the principle of the landscape approach in nature management as an ecologically oriented system of means of planning, designing and organization of landscapes used for construction of such spatial organization of nature management that will provide sustainable and complex use and reproduction of natural resources, preservation of their main functions as a source for meeting material and spiritual needs of humans and the society. This principle has not yet become widespread in the field of natural resources legal relations, only the first steps are taken to enact it in the norms of natural resources legislation. At the same time, the Constitution of Ukraine emphasizes that the most important environmental relations, in particular, the principles of using natural or partially altered landscapes, should be regulated exclusively by laws.

On 14.06.2011, the Verkhovna Rada of Ukraine approved in principle the draft Law of Ukraine «On Landscapes» aimed at ensuring protection, regulation and planning of landscapes. According to the draft Law, a landscape is defined as an integral comprehensive natural-territorial (geographical) complex which is the result of action and interaction of natural and/or anthropogenic factors and consists of interacting natural or natural and anthropogenic components and complexes of lower taxonomy rank. The draft Law formulated the goals and principles of legal regulation of landscape planning and protection, legal aspects of state regulation, the system of legal measures in the field of landscape protection, etc. However, on 15.03.2012 the draft Law of Ukraine «On Landscapes» was rejected as inconsistent with the Constitution of Ukraine, legislation framework in the field of environmental protection, as the one that does not provide for comprehensive settlement of the outlined issues and does not introduce fundamentally new approaches to landscape protection.

Indeed, the legalization of the principle of a landscape approach to the use of natural resources will ensure the unity, integrity, comprehensiveness of nature management, coherence and balance of interests in this area, implementation of ideas for an ecologically balanced system of natural resources and the sustainable development concept put forward at the UN conference in Rio de Janeiro in the «Agenda for the XXI century» (1992), and the adoption of relevant regulations is a necessary step towards solving the urgent task of our state on the path to further European integration.

3 Conclusions

At the beginning of the XXI century, Ukraine still ranks first in the world in terms of consumption of natural resources per GDP unit and has the highest rate of industrial waste per capita. As a result, our country has an extremely degraded natural resource potential. And the mechanisms for regulating the natural foundations of life are not effective and efficient. As a result, natural foundations of socio-economic development are undermined, ecological conditions of human life and their health are rapidly deteriorating. At the same time, Ukraine's natural resource potential is estimated as one of the largest on the planet. It is determined that under conditions of efficient use, Ukrainian lands are able to feed 6 times more people than we have today. However, occupying only 6 % of Europe, Ukraine has 35 % of its diversity [16, p. 9].

Therefore, the most important task is to optimally and rationally use this potential in the interests of well-being of present and future generations. We are talking about the possibility of balanced environmental development of Ukraine based on an innovative model of economic development. It should include the latest achievements of science, modern knowledge-intensive high-tech industries, advanced energy and resource-saving technologies and provide for the application of environmentally sound principles of development.

It is time to form a system of nature management, ensuring its strategic orientation on sustainable development principles. The main strategic direction of Ukraine's development should be the ecological restructuring of its economy and the priority elimination of excessive technogenic pressures on the environment.

Ecologically balanced use of natural resources is a decisive factor in preserving the life and health of every human, ensuring the national security of the country.

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Quality of drinking water in rural areas: problems of legal environment

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Abstract. The article is devoted to the scientific and theoretical analysis of the current state of legal provision of drinking water quality in rural areas. It was stated that in recent years there has been a steady trend of deteriorating quality of water used for drinking in rural areas, including due to increasing levels of nitrate pollution. Proposals have been made for: further implementation of Council Directive 98/83 / EU on the quality of water intended for human consumption and Council Directive 91/676/ EEC on the protection of waters against pollution caused by nitrates from agricultural sources in national legislation; elimination of substantive inconsistencies between State sanitary norms and rules 2.2.4-171-10 "Hygienic requirements for drinking water intended for human consumption" and National Standards of Ukraine 7525: 2014 "Drinking water. Requirements and methods of quality control "in terms of drinking water quality indicators; inclusion in the subjects of state water monitoring of the central executive body that implements the state policy in the field of health care (regarding the monitoring of drinking water); development of the Procedure for state monitoring of nitrate content in surface and groundwater as a component of state water monitoring; forecasting at the level of the National Target Program "Drinking Water of Ukraine" for 2021-2025 "development and operation of a single state information resource - Interactive map of drinking water quality in Ukraine.

1 Introduction

Currently, one of the urgent problems facing Ukraine is to provide the population with drinking water of proper quality and in sufficient quantities. Our country already has a water shortage, ranking 111th in the world out of 152 in terms of available water resources [1]. From year to year, there is a process not only of reducing water supplies in general, but also the rapid deterioration of its quality characteristics, which makes it impossible to use such water for human consumption or has a very negative impact on public health. There are many reasons for this, including intensive pollution of water sources with wastewater and other industrial emissions, and unsatisfactory condition of water mains, aging and wear of water treatment systems, and weakening of state control over the state of drinking water sources, and so on.

The situation is especially difficult in rural areas, where only 32.3% of residential buildings are equipped with centralized water supply [2, p. 222], and most residents of villages and settlements use drinking water from wells, wells, catchments of springs. Published official data (the latest - as of 2019) on the state of sources and systems of drinking water supply in rural areas clearly illustrate the existing problems in terms of providing drinking water to the rural population of Ukraine (Fig. 1 and Fig. 2) [3, p. 71].

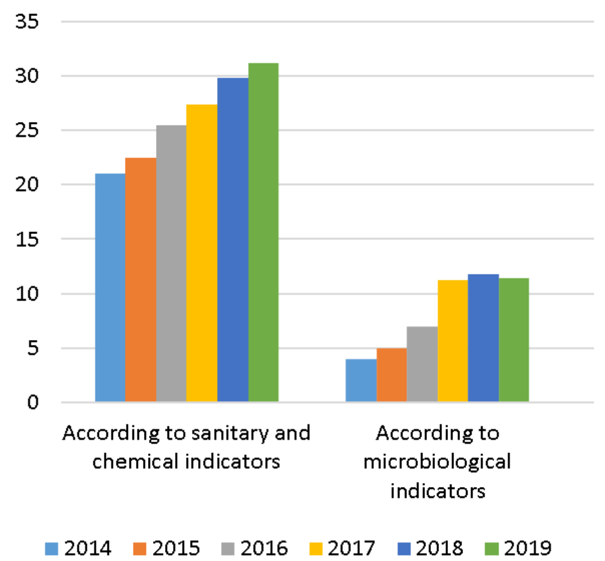

Fig. 1. Proportion of non-standard drinking water samples taken from rural centralized water supply sources, %.

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The problem of contamination of drinking water sources in rural areas with nitrates should be singled out, as agricultural activity is the main cause of this type of pollution, and drinking water with excessive content of these substances is potentially dangerous for all, and especially harmful for children, provoking water-nitrate methemoglobinemia, other diseases.

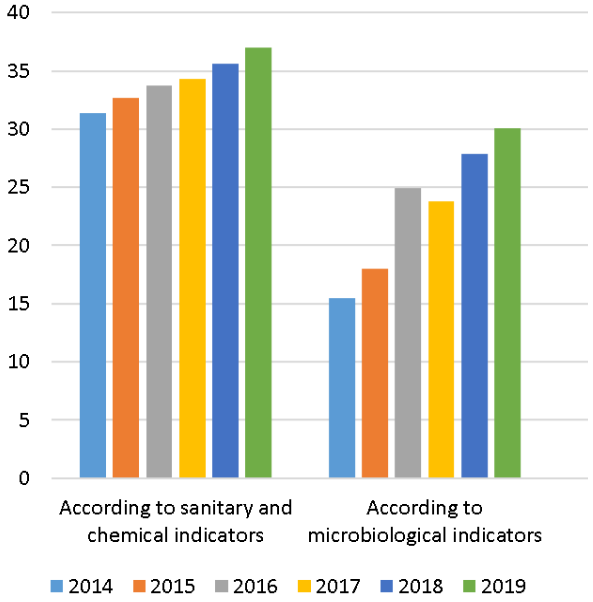

Fig. 2. The proportion of non-standard samples of drinking water taken from mine wells, %.

Data on monitoring the content of nitrates in water for 2016-2019 are shown in Fig. 3 [3, p. 73].

According to statistics, the number of registered cases of nitrate poisoning is growing: if in 2018 there were three, in 2019 there were already seven cases of nitrate poisoning, non-communicable disease of water-nitrate methemoglobinemia (in Zhytomyr, Poltava, Kharkiv and Chernihiv regions) [3, p. 74]. From the given data the wide geography of distribution of nitrate pollution of sources of drinking water supply is visible.

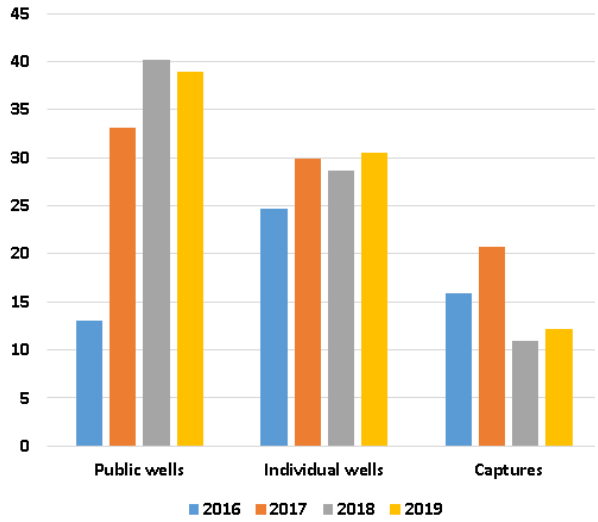

Fig. 3. The proportion of drinking water samples taken from rural decentralized sources of drinking water supply that do not meet the requirements for nitrate content, %.

Data on the average content of nitrates in artesian and groundwater in different regions of Ukraine are shown in Fig. 4.

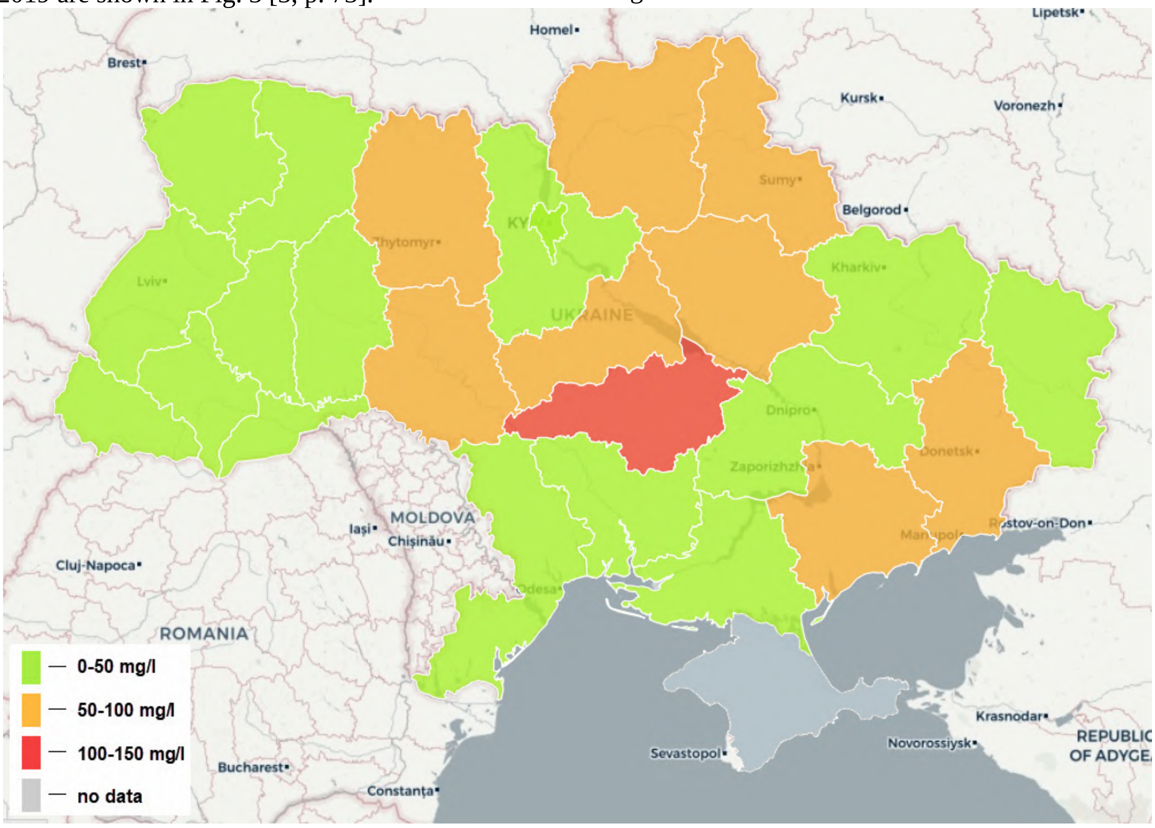

Fig. 4. Average nitrate content in artesian and groundwater in different regions of Ukraine (according to: https://waternet.ua/quality_map).

Along with the above, in 9 regions of Ukraine (Dnipropetrovsk, Donetsk, Zaporizhia, Ivano-Frankivsk, Kirovohrad, Mykolaiv, Odesa, Poltava and Kherson) imported water is used for drinking [4].

One of the ways to improve drinking water supply in rural areas should be clear and effective legal regulation. And the basis for developing an effective mechanism for providing the rural population of Ukraine with quality drinking water should be: establishing criteria for drinking water quality and regulation at the regulatory level of monitoring in the field of drinking water and drinking water supply in rural areas to determine relevant data on drinking water sources. The study of these issues and the formulation of relevant proposals is the purpose of this article.

2 Results

According to the international (Article 4 of Council Directive 98/83/EU on the quality of water intended for human consumption [5]) and domestic (Article 1 of the Law of Ukraine “On Drinking Water, Drinking Water Supply and Sewerage” of 10.01.2002) legislation, drinking water is considered safe and clean if it meets the established requirements for organoleptic, microbiological, parasitological, chemical, physical and radiation parameters. These indicators are regulated: firstly, at the international level - in Annex I, parts A and B of Council Directive 98/83/EC, and secondly, at the national level. Ukraine has State sanitary norms and rules 2.2.4-171-10 “Hygienic requirements for drinking water intended for human consumption”, approved by the order of the Ministry of Health of Ukraine dated 12.05.2010 № 400 and National Standards of Ukraine 7525: 2014 «Drinking water. Requirements and methods of quality control” [6].

As the generalization of the results of existing scientific research shows, the above-mentioned State sanitary norms and rules 2.2.4-171-10 and National Standards of Ukraine 7525: 2014 do not fully take into account international standards for drinking water, although the Implementation of Council Directive 98/83/EU Articles 360-363, 365, 366, Annex XXX of the Association Agreement between Ukraine, of the one part, and the European Union, the European Atomic Energy Community and their Member States, of the other part (hereinafter referred to as the Association Agreement) [7], and the introduction to the National Standards of Ukraine 7525: 2014 explicitly states the implementation of the basic requirements of Council Directive 98/83 /EU.

As rightly noted by O.S. Pronevych State sanitary norms and rules 2.2.4-171-10 in terms of fixed indicators of drinking water quality are generally correlated with Council Directive 98/83/EU, but the domestic document differentiates the requirements for tap water, water from wells (catchments of springs) and packaged water, in contrast to Council Directive 98/83/EU, which sets uniform general requirements for indicators of drinking water quality and safety. In our opinion, the approach enshrined at the international level is more correct, as the basic minimum requirements for drinking water quality should be the same regardless of the source of such resources. Differentiated (for sources of centralized and decentralized drinking water supply), it is advisable to set additional requirements or expand the list of indicators of quality and safety of water intended for human consumption. Another significant drawback: the establishment of State sanitary norms and rules 2.2.4-171-10 permissible levels in drinking water from wells and catchments of nitrite sources (not more than 3.3 mg/l), while Council Directive 98/83 / EC allowed the content of these substances is not more than 0.50 mg / l [8, p. 183]. Note that the National Standards of Ukraine 7525: 2014 sets the standard for nitrite content in water of decentralized drinking water supply at a level not exceeding 0.02 mg / l. Another significant difference between State sanitary norms and rules 2.2.4-171-10 and Council Directive 98/83 / EU - domestic sanitary rules, in contrast to the international standard, do not provide for control of the content of benzopyrene, bromate, cyanide in drinking water, epichlorohydrin, tetrachlorethylene and trichlorethylene, vinyl chloride. At the same time, National Standards of Ukraine 7525: 2014 sets permissible standards for all these substances, except epichlorohydrin and vinyl chloride.

In addition, between the National Standards of Ukraine 7525: 2014 and State sanitary norms and rules 2.2.4-171-10 there are other inconsistencies in terms of epidemic safety indicators, the maximum allowable content of chemical and toxicological indicators [9, p. 401]. In order to eliminate such conflicts, in our opinion, it is first necessary to bring State sanitary norms and rules 2.2.4-171-10 in line with Council Directive 98/83 / EU in terms of drinking water quality indicators, and the next step should be to bring National Standards of Ukraine 7525: 2014 in accordance with State sanitary norms and rules 2.2.4-171-10. This follows from the fact that the State sanitary norms and rules 2.2.4-171-10 are binding on the executive authorities, local governments, enterprises, institutions, organizations, regardless of ownership and subordination, whose activities are related. with the design, construction and operation of drinking water supply systems, production and circulation of drinking water, supervision and control in the field of drinking water supply, and citizens. This provision is enshrined both in the State sanitary norms and rules 2.2.4-171-10 (paragraph 1.1 of the Section “General Provisions”) and in the basic Law of Ukraine “On drinking water, drinking water supply and drainage” (Articles 9, 23, 28, 38, 39, etc.). As for the National Standards of Ukraine 7525: 2014, at present in accordance with Art. 4 of the Law of Ukraine “On Standardization” of 05.06.2014, national standards are applied voluntarily, unless otherwise provided by regulations. The instruction on the recommended nature of application is contained in the National Standards of Ukraine 7525: 2014 (item 1.2). In addition, the Law of Ukraine “On Amendments to Certain Legislative Acts of Ukraine in Connection with the Adoption of the Law of Ukraine” On Standardization “of September 20, 2019 in the text of the Law of Ukraine” On Drinking Water, Drinking Water Supply and Sewerage “ and “standard” in all cases is replaced by the words “state sanitary norms and rules”, thus putting an end to the question of the type of document that sets requirements for drinking water quality.

The next aspect we would like to focus on is the legal regulation of monitoring the quality of drinking water in rural areas. Currently, the Law of Ukraine “On Drinking Water, Drinking Water Supply and Sewerage” provides in Art. 39 state monitoring in the field of drinking water and drinking water supply, determines the entities authorized to implement this measure and delimits their competence. However, in fact, monitoring in the field of drinking water and drinking water supply is carried out within the framework of state water monitoring. We will note that in 2018 for replacement of the Order of implementation of the state monitoring of waters (approved by the resolution of the Cabinet of Ministers of Ukraine from 07/20/1996 № 815), the resolution of the Cabinet of Ministers of Ukraine from 09/19/2018 № 758 the Procedure for implementation of the state monitoring of waters was approved. This document corresponds to Annex XXX to Chapter “Environment” of Chapter V “Economic and Sectoral Cooperation” of the Association Agreement, and to Directive 2000/60 / EU of the European Parliament and of the Council of 23.10.2000 establishing a framework for Community action in the field of water policy [10]. According to experts, the new procedure eliminates duplication of functions between different subjects of monitoring, provides a clear procedure and systematic approach to monitoring the status of terrestrial, groundwater, marine waters, expands the list of biological, hydromorphological, chemical and physicochemical indicators for monitoring [11].

Considering the provisions of the current Procedure for state water monitoring through the prism of monitoring in the field of drinking water supply, we consider as a shortcoming the lack of a list of subjects of state water monitoring of the central executive body implementing state health policy. Thus, in the previous Procedure for state water monitoring, monitoring of sanitary norms of chemical, bacteriological and radiological indicators of water bodies used for drinking purposes was entrusted to the State Sanitary and Epidemiological Service of Ukraine, which until 2017 was part of the executive branch. in the field of health care and ensured the implementation of state policy in the field of sanitary and epidemiological well-being of the population. The consequence of such institutional transformations has been a significant reduction in the material, technical and human resources of laboratories engaged in the analysis of water quality indicators. This, in turn, led to a decrease (compared to 2014) in the number of samples from mine wells (2.6 times) and from catchments of springs (1.5 times) [12], and we have already indicated that it is decentralized sources drinking water supply is essential for providing rural settlements with drinking water. Given all the above, we support the existing proposals on the need to separate from the structure of the State Service of Ukraine for Food Safety and Consumer Protection of the State Sanitary and Epidemiological Service of Ukraine and propose to include this body in the state monitoring of water (for drinking water).

Also important for determining the state of drinking water sources in rural areas is the issue of monitoring the nitrate content in surface and groundwater. The obligation to carry out such monitoring is provided by Council Directive 91/676/EEC of 12 December 1991 on the protection of waters against pollution caused by nitrates from agricultural sources [13].

Implementation of the Nitrate Monitoring Program in Surface and Groundwater for Ukraine is provided for in Annex XXX to Ch. 6 of the Association Agreement and included in the Action Plan for the implementation of the Association Agreement between Ukraine, on the one hand, and the European Union, the European Atomic Energy Community and their Member States, on the other hand, approved by the Cabinet of Ministers of 25.10.2017 № 1106. However, despite the expiration of these tasks on 31.12.2020, they remain unfulfilled at present. So far, only draft documents have been developed that indirectly affect the protection of water resources from nitrate pollution from agricultural sources. These are the draft Methodology for identifying areas vulnerable to nitrate compounds and the draft Code of Best Agricultural Practices [14]. Accordingly, no work is being done to identify nitrate-vulnerable areas; creation of their register, as well as monitoring of nitrate content in surface and groundwater [15, p. 46].

As noted in Art. 39 of the Law of Ukraine “On Drinking Water, Drinking Water Supply and Sewerage” the purpose of state monitoring in the field of drinking water and drinking water supply is “collection, processing, storage and analysis of information on drinking water quality, status of centralized drinking water supply, forecasting its changes and development of scientifically substantiated recommendations for making appropriate decisions in this area”. In turn, one of the principles of state policy in the field of drinking water, drinking water supply and drainage of Art. 6 of the same law calls for free access to information on the quality of drinking water, the state of sources and systems of drinking water supply and drainage, and in Art. 9 - every consumer of drinking water is guaranteed the right to free access to information on drinking water quality. To do this: 1) the central executive body that implements state policy in the field of housing and communal services prepares and publishes the annual National Report on drinking water quality and drinking water supply in Ukraine (according to the Procedure approved by the Cabinet of Ministers of Ukraine from 29.04.2004 № 576); 2) provides interested public authorities, public organizations, enterprises, institutions, organizations and citizens with information on cases and causes of drinking water pollution. These provisions correlate with international requirements - Art. 13 and other Council Directives 98/83/EU and directly relate to the realization of the human right to drinking water.

We would like to note that the human right to drinking water is recognized in the world as one of the fundamental rights. Thus, UN General Assembly Resolution № 64/292 of 28 July 2010 and the comments of the UN Committee on Economic, Social and Cultural Rights № 15 of 2002 defines the right to drinking water and adequate sanitation as a mandatory component of the fundamental human right to life and health [16]. Another document, the UN Declaration on the Rights of Peasants and Other Persons Working in Rural Areas, identifies the right to safe and clean drinking water and sanitation for this category of people as fundamental to a full life, the exercise of all human rights and human dignity. 17]. To ensure this right, as K.D. Yanishevska and A.D. Skoryk absolutely rightly prove, it is necessary to ensure the connection between the right to information, primarily environmental, and proper management, public participation in decision-making by public administration bodies [18, pp. 701].

In our opinion, the above methods of informing the population about the quality of drinking water through the publication of the annual report and in case of pollution of drinking water do not fully guarantee compliance with the right to information about the state of drinking water. For example, the National Report on Drinking Water Quality and the State of Drinking Water Supply in Ukraine in 2019 has been published so far, ie we have official information a year ago, so to speak, in retrospect. Prompt informing the population about the current state of drinking water quality is very limited, and available resources vary in the amount of information and presentation. For example, the website of Kyivvodokanal constantly updates microbiological and physico-chemical indicators of drinking water quality control at control points of the distribution water supply network of Kyiv [19]. The website of Ternopilvodokanal contains average microbiological and sanitary-chemical indicators of drinking water quality as of the third quarter of 2020 [20]. There are also data on the quality of drinking water in some observation points (water intakes) (Fig. 5). With regard to rural settlements, there are no such resources in free access at all.

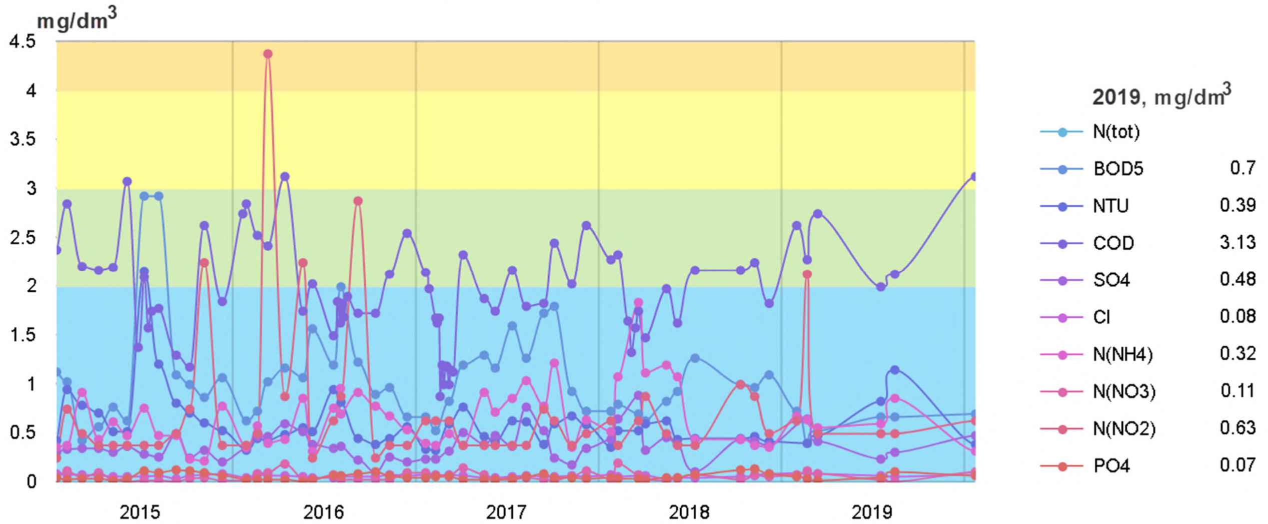

Fig. 5. Data on water quality (water intake of Kyiv). Full name of the observation point: Dnipro, 897 km, Vyshhorod, Kyiv HPS, drinking water intake, Kyiv (according to http://openenvironment.org.ua/).

Instead, commercial structures propose the development of a very important and promising tool for local communities to accumulate data on the state of drinking water sources, influence those responsible for the provision of water supply services and plan measures to improve drinking water quality, drinking water supply, protection of sources and systems, drinking water supply, restoration of drinking water supplies - interactive maps of drinking water quality [21]. However, these initiatives remain unpopular in practice due to limited local budgets. Hence, we propose to include in the National Target Program "Drinking Water of Ukraine for 2021-2025", the project of which is currently being developed [22] as a separate measure to develop an interactive map of drinking water quality in Ukraine and providing funding.

3 Conclusions

Thus, the priority measures to improve the legal regulation of providing the rural population of our country with quality and safe drinking water should be the following. Continue work on the implementation of Council Directive 98/83/EU on the quality of water intended for human consumption into national law. Elimination of substantive inconsistencies between State sanitary norms and rules 2.2.4-171-10 "Hygienic requirements for drinking water intended for human consumption" and National Standards of Ukraine 7525: 2014 "Drinking water. Requirements and methods of quality control "in terms of drinking water quality indicators. Inclusion in the subjects of state water monitoring of the central executive body that implements the state policy in the field of health care (for drinking water monitoring) and development of the Procedure for state monitoring of nitrate content in surface and groundwater as part of state water monitoring. Provision at the level of the National Target Program "Drinking Water of Ukraine for 2021-2025" to develop and ensure the functioning of a single state information resource - Interactive map of drinking water quality in Ukraine.

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Prospective directions of state regulation of “green” energy development in the context of Ukraine’s energy safety

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Abstract. The article describes the leading world trends and factors of state regulation of “green” energy development as a key element of energy safety of mankind at transition stage to globalized society. Paradigm change of energy safety of mankind, problems and obstacles on the way to abandon hydrocarbons use as the main energy sources and replace them by renewable environmentally friendly sources are analyzed. International and national normative legal documents regulating functioning and “green” energy development are characterized. Mechanisms for strengthening Ukraine’s energy safety by acceleration stimulating of construction of new generation power plants using exclusively renewable energy sources in our country were proposed.

1 Introduction

The modern world is characterized by two interrelated global phenomena: level of energy consumption and level of environmental pollution. Ozone holes in the atmosphere, entire continents of floating wastes in the ocean, emissions of carbon and other harmful substances at the present stage of human development are acute issues of human existence safety.

Today, it is clear that focus on hydrocarbon energy sources - coal, oil, gas - as dominant in energy production, has exhausted itself and can lead to death of humanity. Oil and gas economy reached its historical impasse. Global problems of economic, energy and environmental safety of all mankind and the vast majority of countries around the world are interconnected. It is especially felt in modern Ukraine, where the war in Donbass demonstrated all helplessness of the national economy with its almost dominant energy dependence on the aggressor country (at the level of 60% [1]). Yes, Russian aggression exposed all problems of energy safety of our country. It forced the Ukrainian government to start reforms to diversify energy sources, but these measures are unsystematic and insufficient. Level of their implementation does not meet today’s challenges. It is evidenced by at least such shameful statistics for us, given in December 2018 by the authoritative financial analytical center “Carbon Tracker” (Fig. 1): heat generation in Ukraine is the most inefficient and most expensive in the world (the cost is higher than European Union prices by 40% and from the Russian Federation by 75%!) [2, 3]. Therefore, it is important to study the world’s advanced approaches, mechanisms and tools of state regulation of “green” energy development as a key element of energy safety.

Issue of world energy modernization in the direction of gradual abandonment of hydrocarbons and transition to environmentally friendly renewable energy sources as a guarantee of further energy, economic and environmental safety of mankind was debated in scientific discourse of the early XXI century. In particular, among recent publications in this field it is worth noting such foreign researchers as Born [4], Sopian and Khan [5], Mateus and Tan [6], Nahi [7], Kherbs and Frih [8], Tvidell [9]. A number of important issues regarding the functioning of energy facilities and their impact on the environment are disclosed in articles [10-24]. In recent years, in Ukraine following scientists have researched issue of “green” energy development: Benedyk [25], Bila [26], Herasymchuk [27], Kudria [28], Kuzmina [1, 29], Lehka [30], Prokip [31], Riazanova [32], Stoian [33], Tkachuk, Rechun and Priadko [34], Trofymenko [35], Cherniak [31] and other. We will try to generalize their scientific achievements in this article.

The research aim is to analyze and summarize the world’s leading trends and factors of state regulation of “green” energy development as a key element of energy safety of mankind at stage of transition to a globalized society.

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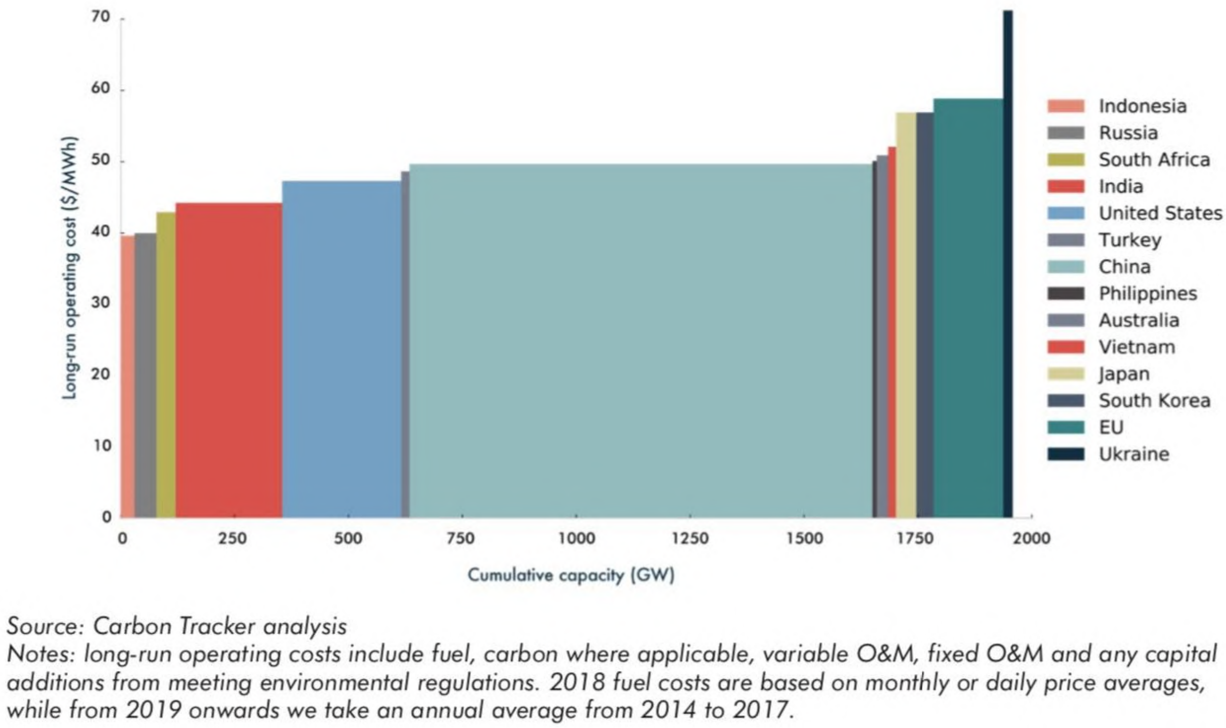

Fig. 1. Global long-run operating cost curve of coal capacity existing and under construction [3].

2 Results

Beginning of the third millennium was marked by transition to new energy policy of the world's leading states and international community capable to ensure sustainable development and energy, environmental and economic future. J. Bjorn said that states and governments need to make difficult choices in the shortest possible time and these government decisions will forever change not only energy and economy, but also environmental, social, cultural, etc. living conditions of mankind [4].

According to Stoyan transition to green economy and Ukraine's integration into the world energy space given need to form effective system of mechanisms for state regulation of renewable energy development in our country [33]. This opinion is shared, in particular, by A. Prokip. He is convinced that in this case the cumulative effect of developing measures to ensure energy and national safety, in addition to minimizing the country's dependence on energy suppliers and concern for the environment, will reduce social tensions [31].

It should be noted that given existing disparities in needs and opportunities for obtaining fuel energy resources, there are four models of energy safety:

1. Model of guaranteed energy safety (is typical for countries that are not only able to fully meet their own energy problems, but also have their significant reserves for sale: UAE, Venezuela, Russia, other OPEC countries);

2. Model of self-sufficient energy safety (typical for countries whose own energy resources are sufficient for domestic needs, but not enough for exports, e.g. India);

3. Model of insufficient energy safety (typical for countries whose energy needs require import of energy and measures aimed at diversifying energy sources, stimulating the introduction of alternative energy technologies. Such countries include the EU, Ukraine, etc.).

4. Model of crisis energy security (when a country is forced to import more than 50% of the required amount of energy, e.g. Japan).

The European Union's policy on energy supply safety in the European energy space due to the EU countries among the third group of countries with insufficient energy security is formed in several directions with the main goal - to accelerate transition to the second group (self-sufficiency) obtaining and consuming the necessary energy. M. Kuzmina names following components of the EU energy security system: energy saving and energy efficiency, diversification of energy resources both own and imported (natural gas, coal, oil, RES) [1].

What is the key difference between a traditional economy and a "green" one? Traditional economy was based on use of non-renewable energy sources such as wood, coal, oil and gas. According to N. Riazanov generation of fossil fuel-based electricity was the most important driver of economic development since the beginning of the industrial revolution. Environmental consequences of this development were not taken into account for a long time, until nature declared itself: rising world temperatures, rising sea levels, ocean pollution and other effects of climate change began to seriously affect coastal areas and coastal countries. Existence of many communities and biological life support systems on the planet was threatened. Growing negative effects of climate change increasingly led to the realization that if you follow the previous course of development without taking into account environmental imperatives it will lead to catastrophic consequences [32].

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So-called "green economy" (term of journalistic nature) or "alternative energy economy" (scientific publications also have another synonymous definition "energy economy based on renewable energy sources") abandons dominance of non-renewable hydrocarbon resources in favor of virtually endless sources. Renewable energy sources (RES) include wind and solar energy (wind and solar power plants); aero-, geo- and hydrothermal (heat extraction from atmospheric air, from the surface of the earth and from the surface waters of terrestrial reservoirs); river, tidal and ocean energy (small hydropower, tidal power plants); biomass and biogas (biological share of products, waste and residues of biological origin from agriculture, including plant and animal substances, forestry and related industries, including fisheries and aquaculture, as well as the biological part of industrial and domestic waste; gas from organic waste, gas from treated wastewater, etc.).

Key advantages of renewable energy sources are their environmentally friendly nature, practical inexhaustibility of stocks over historically long period, availability of modern energy services in rural areas, climate change mitigation, promoting "green jobs" and improving quality of life. That is why J. Matheus and H. Tan call renewable energy technologies one of the most important strategies in addressing sustainable development of mankind [6]. In order to set large-scale tasks and develop new markets O. Chernyak notes international cooperation and active investment in RES by all countries of the world are necessary. The use of RES worldwide is an important step towards stable future for all mankind [36].

It is no coincidence that these issues are periodically raised and important political and legal decisions are made regarding the transition of mankind to energy based on renewable energy sources (RES) at the planetary level. Thus, at the Paris Climate Conference on November 30, 2015, 100 of the 195 participating countries (including Ukraine) supported the decision to move to 2050 for the full use of renewable energy sources [36]. However, the commitments are quite divergent, especially in terms of the pace of such a transition. For example, Ukraine, as a member of European Energy Community made the lowest commitment to increase the share of RES in the country's energy balance by only 11% by 2020 (and the current situation shows that Ukraine will not reach half of the planned), while Switzerland plans to have 49% of renewable energy in 2020, Latvia - 40% Finland - 38% Austria - 34%.

Fig. 2 shows the breakdown of primary energy that is shown based on the 'substitution' method which takes into account inefficiencies in energy production from fossil fuels. Particular one is based on the global energy production for 2019 year. It can be seen that in 2019, almost 16% (15.7% if to be precise) of global primary energy came from low-carbon sources. Low-carbon sources are the sum of nuclear energy and renewables – which includes hydropower, wind, solar, bioenergy, geothermal and wave and tidal [38]. 11.4% came from renewables; and 4.3% came from nuclear. Hydropower and nuclear account for most of our low-carbon energy: combined they account for 10.7%. Wind produces just 2.2%, and solar 1.1% – but both sources are growing quite rapidly. Despite producing more and more energy from renewables each year, the global energy mix is still dominated by coal, oil, and gas. Not only does most of our energy – 84% out of it – come from fossil fuels, we continue to burn more each year: total production has increased from 116,214 to 136,761 TWh in the last 10 years [37].

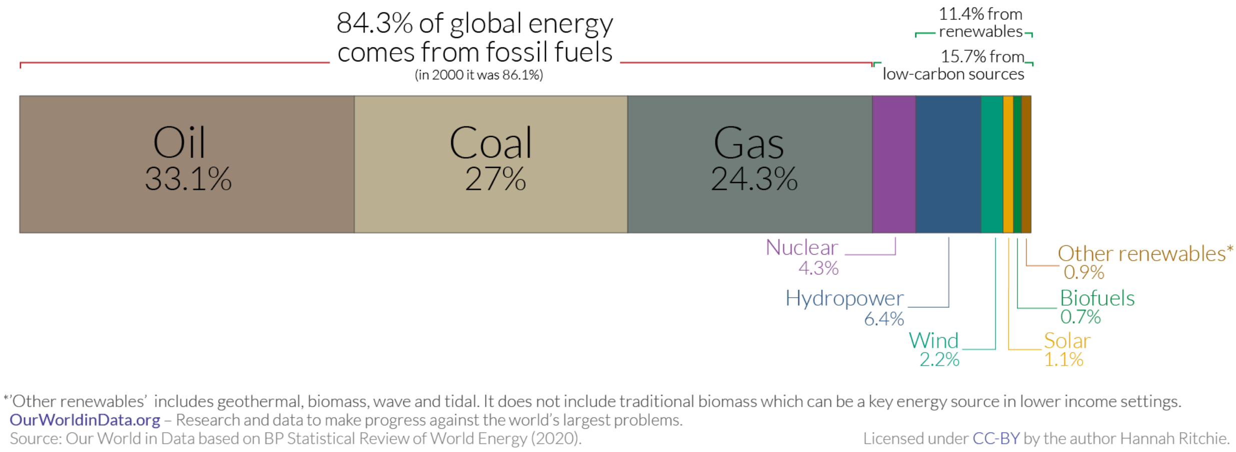

Fig. 2. Global primary energy consumption by source [37].

Numerous international and intergovernmental organizations coordinating in the field of "green energy" were established. International Energy Agency, established in 1974, is the central intergovernmental institution in the field of energy in addition to aforementioned European Energy Community. Initially, the organization was created to consolidate efforts of developed countries to maintain their own energy safety. Today, as J. Benedyk notes, this agency is at the heart of global energy dialogue, providing authoritative statistical reports, analyzes and recommendations, focusing on four areas, the so-called "4":

• energy safety - by promoting diversification, efficiency and flexibility in all energy sectors;

• economic development - by ensuring stable energy supplies to member countries and free markets development to stimulate economic growth and eliminate energy poverty;

• environmental awareness - through analysis of possible policy decisions and measures to compensate negative impact of energy production and consumption on the environment and climate change;

• global engagement worldwide - by ensuring close cooperation with countries that are not members of the IEA, especially with the largest producers and consumers, to find solutions to common energy and environmental problems [25].

B. Nagy in the book "The Age of Clean Energy" prioritizes following among the main areas of institutional support for international economic cooperation in the development of renewable energy: organization of international consultations on framework programs development for use of renewable energy; promoting development of technology and knowledge transfer in the field of renewable energy; creation of regional centers for research, development and exchange of experience in the field of renewable energy development; dissemination promoting of successful world experience in the renewable energy use; planning of financial support of renewable energy sources (RES) programs; collection and processing of statistical data in the field of renewable energy development; monitoring and adjustment of plans (strategies) for renewable energy development [7].

An important place in transition regulating to "green energy" dominance is occupied by state, interstate and international programs to stimulate research, technological and practical developments in the field of RES. Thus, S. Bila notes that the EU countries are characterized by such incentives use that facilitate transition from traditional to renewable energy: tariff benefits ("green" tariffs - FITs, and "green" surcharges - FIPs); quotas regulation on electricity production and use of "green certificates" system sold on the market and promote the attraction of free investment funds in the field of renewable energy (TGC); soft loans, grants and credit guarantees, government subsidies and investment grants [26].

Positive results are observedt. In particular, share of renewable electricity in the German economy is growing steadily. If in 2000 share of German RES was 7%, then in 2010 - 17%, by 2020 this figure will increase to 35% and in 2050 - up to 80%. However, the world leader is already China and, according to J. Matheus and H. Tang, this leadership will only grow due to the huge public investment in the renewable energy sector [6].

The director of the Institute of Renewable Energy of the National Academy of Sciences of Ukraine, Doctor of Technical Sciences S. Kudria, claims that our country has all prerequisites for large-scale development of technologies based on renewable energy sources. First of all, it has significant energy potential (wind, solar energy, small river energy, biomass, geothermal energy and environmental energy), as well as a developed scientific, technical and industrial base. In addition, the key factors in the development of RES in Ukraine are need to improve environmental situation; exhaustion of traditional fuel and energy resources; urgent need to overcome dependence on energy imports; international obligations; need for urgent renovation of fixed assets of energy equipment in the country. This industry is one of the most attractive for investment [28]. V. Gerasymchuk and O. Romanyuk estimated annual potential of Ukraine's renewable energy at 100–110 million tons. In particular, average annual potential of solar energy in Ukraine exceeds average of countries such as Poland and Germany. It determines significant prospects for use of solar panels in Ukraine. Also, one of the most promising and investment-attractive areas in Ukrainian alternative energy is production of solid biofuels. Characteristic feature of solid biofuel market is the significant demand for products in the European Union, which made the industry export-oriented [27].

However, process of development of renewable energy in Ukraine is very slow despite significant potential. Share of energy produced from renewable sources in total energy at the end of 2017 was only about 2% [24].

Fig. 3 shows energy consumption by source in Ukraine [37]. Primary energy consumption is measured in terawatt-hours (TWh). An inefficiency factor (the 'substitution' method) has been applied for fossil fuels, meaning the shares by each energy source give a better approximation of final energy consumption.

This situation requires urgent measures of state stimulation of "green energy" sector development in Ukraine. Among such measures O. Cherniak names:

• exemption from profits taxation of companies that produce electricity only from RES;

• introduction of "green" tariff;

• land tax reduction for enterprises using renewable energy;

• exemption from import duties when importing certain types of equipment for renewable energy;

• exemption from taxation of operations on import of certain types of equipment for renewable energy [36].

K. Lehka also offers at state level:

• to increase attractiveness of those RES development that have high probability of economic payback in future and are the most promising in terms of production in Ukraine;

• to support development and implementation of competitive technologies;

• to stimulate localization of production and the necessary equipment [30].

In turn, O. Trofimenko groups tools for implementing of state regulation mechanism of strategic development of renewable energy into three main parts:

• fiscal (preferential tariffs, government spending, income tax, financial instruments for the regulation of renewable energy);

• organizational (rules, organizational, legal norms and standards that determine state regulation of renewable energy, duties, rights and responsibilities of state regulators, organization of their activities, including organization of fiscal tools to implement the mechanism of state regulation of strategic development of renewable energy);

• methodical (set of measures to improve methodology of selection of renewable energy projects, methodological approaches to assessing the level of development of renewable energy, energy saving potential, study of the status and ranking of regions and industries by energy security, system of measures for renewable energy development at the methodological level) [35].

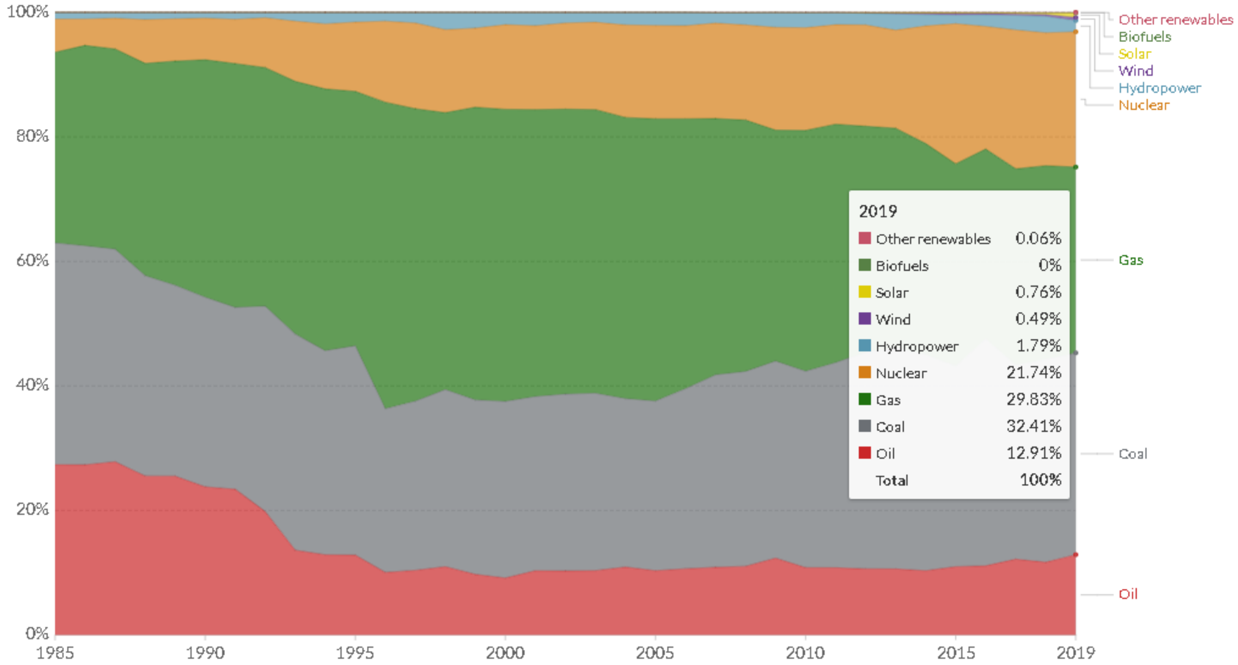

Fig. 3. Energy consumption by source, Ukraine [37].

According to V. Tkachuk, O. Rechun and O. Pryadko following measures can provide prospects for renewable energy development in Ukraine:

• energy safety level increasing of Ukraine by diversifying and depoliticizing supply of energy resources;

• burden reducing on the environment;

• environmental awareness raising of Ukrainian citizens, because "green" energy is not only improving environment, but preserving human health and prolonging life on Earth [34].

Thus, in the course of our research we identified leading trends of interstate and state regulation of green energy as a key element of mankind energy safety in the transition to a globalized society. They are embedded in the global strategy of human civilization through abandonment of hydrocarbons in favor of renewable energy.

3 Conclusions

Thus, we can conclude that rapid depletion of natural traditional energy resources on the planet and their constant price rise in the face of growing human needs for electricity will inevitably lead to rapid replacement of hydrocarbon economy by "green economy" based on renewable energy sources [39]. The world's leading countries actively develops alternative energy as a factor in energy safety improving. It improves environment, increases standard and quality of life.

Ukraine should to develop and actively implement new energy strategy based on effective state regulators and aimed at diversifying energy dependence on Russia and a gradual transition to the dominance of renewable energy sources. Our state should provide comprehensive legal, fiscal, tax, financial, informational and organizational support for creation and use of energy power plants, grant and investment support for scientific and technological developments in this area.

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Principles of natural capital preservation in the context of strategy of state environmental safety

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Abstract. The article analyzes issue of strategy forming of state development through prism of state environmental safety, preservation of its natural capital in the process of formation and implementation of state environmental policy. Basic ecological, economic, social principles of natural capital preservation of Ukraine are considered. Possibilities of ecological network development of Ukraine are investigated. A comprehensive knowledge framework for the management of natural capital is shown.

1 Introduction

Consideration of state development strategy of modern countries is impossible without taking into account such important component as natural capital - the natural environment of mankind, our noosphere. It should be understood as a whole societal organism. People and products of their activities are in unity and interconnection. They perform simultaneously number of important functions of societal self-organization (e.g. biological - as a habitat for biological objects; physiological - as a source of physiological needs of all living beings on Earth; socio-economic - as means of production, basis for placement of various spheres of human activity, cognitive - as an object of scientific research and cognition, etc.).

It is no coincidence that the Sustainable Development Goals (SDGs) [1] approved at the United Nations Summit on Sustainable Development and the adoption of the Agenda for Development in September 2015 [1] and revised Sustainable Development Goals for Ukraine adopted in accordance with them in four key areas:

1. Fair social development;
2. Sustainable economic growth and employment;
3. Effective management;
4. Ecological balance and development of sustainability [2].

As we can see, one of these key areas directly reflects the content and purpose of the environmental function of the state. Moreover - 6 of the 17 main goals of sustainable development for Ukraine in one way or another relate to natural capital, environmental protection (Objective 6 - Clean water and sanitation; Objective 7 - affordable and clean energy; Objective 12 - responsible consumption and production; Objective 13 - climate change mitigation, Objective 14 - conservation of marine resources and Objective 15 - protection and restoration of terrestrial ecosystems). According to these goals the effective preservation of Ukraine's natural capital for present and future generations is possible only through clearly planned and organized measures for formation and implementation of modern state environmental policy including preservation of natural capital and development of ecological network. It seems possible based on development of clear methodology for conservation of natural capital based on system of principles, methods and tools.

One of the most important principles of sustainable development is to ensure safe environment for life and health. One of the main criteria in this direction is the preservation of natural capital taking into account given environmental problems, economic instability and number of other factors. All this necessitates further development of preservation methodology of natural capital.

The article aim is definition of methodological principles and methods of natural capital conservation on the basis of foreign experience. The object of this scientific research is main components of the natural capital of Ukraine. The subject of scientific research is process of forming the methodology of public administration for natural capital preservation.

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2 Results

The term 'natural capital' was proposed by David Pearce [3], as a way to underline the role of nature in supporting the economy and human well-being. It is now recognised that human well-being depends on different types of resources or assets, which can be categorised in relation to four broad types of capital. All of these capitals support the economy and human well-being [3-5]:

• Manufactured or 'man-made' capital: assets used to produce goods and services, such as machines, tools, buildings and infrastructure. Financial capital includes money and other financial assets, and is sometimes seen as a distinct additional category.

• Human capital: assets in the forms of knowledge, education, motivation and work skills, mental and physical health.

• Social capital: includes social trust, norms and networks that facilitate social and intellectual interactions and solutions to common problems, e.g. neighbourhood associations, civic organisations and cooperatives, and the political and legal structures of a society.

• Natural capital: comprises of the ecosystems and abiotic assets of the planet that provide people with exploitable resources, e.g. solar radiation, fossil fuels and minerals, and generate a flow of benefits via ecosystem services, e.g. food, climate regulation and recreation.

While all four types of capital are needed to support human well-being, natural capital is arguably the most important one because it supports and underpins the other forms of capital. For example, minerals, metals and energy are needed to build the components of manufactured capital. Human and social capitals are heavily dependent on the physical health of individuals who are dependent upon ecosystem services to maintain good health. These services range from food, freshwater, timber and fibres, regulating ecosystem services, e.g. water purification, nutrient cycling, mitigation of floods, and benefits from open landscapes and urban parks that support recreation and well-being.

Natural capital: includes biotic and abiotic elements and comprises of all natural resources that human society draws upon. A sound analysis of ecosystem processes, combined with the general principles of environmental accounting, is the foundation for developing a natural capital accounting approach. Fig. 1 illustrates the main components of natural capital as currently understood – this has been developed from the natural capital figure in the first EU MAES report on the 'Mapping and Assessment of Ecosystems and their Services' [6].

Fig. 1 makes a distinction between ecosystem capital and abiotic resources. In reality, there is no clear-cut boundary between biotic and abiotic components [9]. For example, water is an abiotic factor but is included under ecosystem capital as living organisms play a modulating role in its cycle and water plays a key role in all ecosystem processes [7, 8]. However, this distinction helps to identify and classify different types of natural capital, which is important in the context of developing a natural capital accounting approach. Another dimension in Fig. 1 is the relationship between the concepts of 'assets' and 'flows'. According to standard economic theory, natural capital is the sum of the different physical assets of nature, e.g. mineral deposits or tonnes of biomass, and benefit flows would not really be part of natural 'capital'. However, for ecosystem capital in particular, the same natural processes govern ecosystem assets and ecosystem services, so it is often difficult to draw a line between the two. Secondly, in the context of monetary accounting, the value of the asset stock is often derived from the flows it generates. Lastly, in many less-specialist discussions, flows are considered as part of natural 'capital'. For these reasons, Fig. 1 shows ecosystem and abiotic assets and flows in the same colour but with different background shading. The second key feature of assets and flows is their depletability. Some are, under current circumstances, unlimited, i.e. 'non-depletable' – for example, sun light and wind depend on solar radiation, which humans cannot influence. Most abiotic assets are, for obvious reasons, classified as 'depletable' because they do not renew themselves and their stock is therefore reduced over time by exploitation, e.g. fossil fuels and minerals. Ecosystems and associated service flows are also 'depletable' since over-exploitation can lead to the extinction of species or depletion, e.g. fish stocks. Outright habitat destruction, e.g. the conversion of forests or grassland to urban areas, ultimately destroys ecosystems and the regulation and maintenance, or other services, they generate. Ecosystem capital is particularly vulnerable because many species and habitats depend on specific conditions being maintained, and human society heavily exploits it via agriculture, forestry and other land uses. This part of natural capital can therefore be considered as a component for which society has a particular 'duty of care' – it is fragile, and human actions have already negatively impacted much of it. However, with suitable management and care ecosystems are capable of delivering a sustainable flow of flow of ecosystem service benefits into the foreseeable future [9].

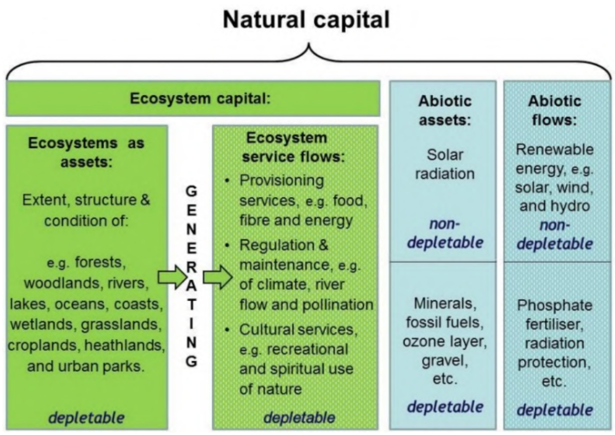

Fig. 1. Components of natural capital [9].

Strategy of natural capital preservation is defined by modern science as one of the most important functions of the state - fundamental component of the building process legal democratic state with developed market economy [10]. According to T.I. Pishenin, "Currently there are two approaches to solve the environmental problem. Globalist approach is based on the principle that developed countries with great potential can destroy the whole world, and therefore other countries to ensure environmental security. Most developed countries try to reap obvious globalization benefits. Current approach is based on recognizing of national safety priority reached through self-sufficiency through the by sustainable development of their own environmental safety of production. Existence of such approach is explained by the fact that in the modern world the main factor in making most important decisions are still nation-states. Therefore, acting on the world stage, each state cares primarily about their own interests" [11].

However, manifestations of Ukraine's conscious position on its environmental interests, clear strategy, and what is more importantly - appropriate actions since independence can not be traced as far as O. Palienko notes: "Ukraine is one of the most environmentally unreliable countries in Europe. The country's economy was formed without taking into account objective needs and interests of the population, while the protection of environmental measures was carried out on a residual basis. As a result, its economy is oversaturated with chemical, metallurgical and mining industries [10].

At the same time, it can not be said that our state did not have its own environmental policy at all. Thus, number of legislative and normative legal acts were adopted. The Law of Ukraine "On the Ecological Network of Ukraine" (2005) deserves special attention in the light of the chosen issues [12]. This Law regulates relations related to formation, preservation and rational, inexhaustible use of the ecological network. According to this law the ecological network is only territorial system formed to improve conditions for formation and restoration of environment, increase natural resource potential of Ukraine, preserve landscape and biological diversity, habitats and growth of valuable species of fauna and flora, genetic fund, ways of migration of animals through combination of territories and objects of the nature reserve fund. Also other territories with special value for environmental protection and are subject to special protection.

Development of science and technology due to formation and accumulation of intellectual capital allows more efficient use of natural capital- says O. Badrak. Along with emergence of new technologies that determine efficiency of natural resources in production processes there are previously unaccounted factors in the formation of gross national product. They still do not have a socio-economic status. Special role in this process belongs to economical use of natural resources in economic activity and environment protection from possible negative socio-environmental effects and risk prevention. It will contribute to collection of environmental rents and "green" taxes [13].

Concept of ecological network is manifestation of such environmental innovation aimed at more efficient use and preservation of natural capital. Structural elements of this network include:

• territories and objects of nature reserve fund;
• water fund lands, wetlands, water protection zones;
• forest lands;
• field protective forest strips and other protective plantings;
• health-improving lands;
• recreational lands;
• territories that are places of residence or growth of species of fauna and flora listed in the Red Book of Ukraine, etc. [12].

The legislator provided that inclusion of territories and objects in the list of territories and objects of ecological network does not lead to change in form of ownership and category of land for relevant land plots and other natural resources, their owner or user. At the same time the issue of ecological network management arises. Ukrainian researcher R. Miroshnichenko proposes to differentiate state regulation in the field of environmental safety on three levels. The first level according to researcher includes management of central public authorities of the state by a set of mechanisms. Their activities are aimed to monitor environmental situation in the country and nature of global impacts on it. Second are aimed at formation of socially adequate state policy on environmental safety management methods and ensuring effective functioning of mechanisms of public administration and state control over compliance by all authorities, institutions and organizations and individuals with current legislation [14].

In our opinion it is quite obvious to single out the third level - regional government; the fourth - level of local public authorities and self-governing institutions of territorial communities, civil society organizations and, finally, the fifth - level of specific economic entities and environmental facilities. It will comply with legal norms. It stipulates that public administration in the field of formation, preservation and use of the ecological network is carried out by:

• The Cabinet of Ministers of Ukraine;
• The Council of Ministers of the Autonomous Republic of Crimea,
• specially authorized central executive body for environmental protection, environmental safety, protected areas, as well as hydrometeorological activities and its territorial bodies;
• other central executive bodies;
• local executive bodies;
• local governments [13].

Numerous NGOs are also involved in this process. Formation, preservation and use of the eco-network is carried out according to the following basic principles:

a) ensuring of ecosystem functions integrity of components elements of ecological network;

b) conservation and environmentally sustainable use of natural resources on the territory of the ecological network;

c) stopping loss of natural and semi-natural areas (occupied by plant groups of natural origin and complexes changed in the process of human activity), expansion area of the ecological network;

d) state support providing, stimulating subjects of management when creating territories and objects on their lands nature reserve fund, other subject areas special protection, development of the ecological network;

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e) ensuring participation of citizens and their associations in the development of proposals and decisions on the formation, preservation and use of eco-network;

e) ensuring connection of the national eco-network with the eco-networks of neighboring countries that are members of the Pan-European Eco-network, comprehensive development of international cooperation in this field;

f) improving composition of the lands of Ukraine by providing scientific relationship between different categories of land;

g) systematic consideration of environmental, social and economic interests of society [12].

It should be noted that idea of the ecological network as an environmental technology arose in the 80s of last century. In 1993 Dutch experts proposed creation of European Ecological Network (EEN) at the international conference on the environment in Maastricht. The EEN program was a part of the Pan-European Strategy for the Conservation of Biological and Landscape Diversity, adopted in 1995 at the Conference of Ministers for the Environment of European countries in Sofia.

Structural elements of the EEM should be the so-called ecological nuclei, ecological corridors and buffer zones. Ecological nuclei are small, ecologically valuable and large in size. They usually have natural conservation status. Their main task is to preserve biological and landscape diversity in the reference natural areas, to help maintain the ecological balance in the region. Ecological cores should be interconnected by ecological corridors - strips or massifs of relatively unchanged, restored or artificially created natural landscapes. These can be river valleys, lakes, swamps, gullies, forests and strips, reclamation canals, etc. Buffer zones with regulated limited management are created in order to prevent negative impact of human economic activity on natural complexes.

Thus, from the above three structural components a kind of network is formed. It is more or less evenly covers the region. Such ecological network creates acceptable conditions for the preservation of biological and landscape diversity of a particular natural - territorial complex. The latest along with other environmental measures greatly contributes to maintaining sustainability of regional ecosystem. The ecological networks of individual states in particular the National Ecological Network of Ukraine are an integral part of the European ecological network. Its creation is provided by the Law of Ukraine "On the national program of formation of the ecological network of Ukraine for 2000-2015".

Scientists highlight following conditions for principles improving of state environmental policy and state regulation of environmental safety in Ukraine [14-29]:

• intensification of social factors use of environmental protection;

• formation of public opinion on building positive image of ecologically sustainable development of citizens in the state;

• carrying out measures to promote environmental activities among the population and positive attitude towards the environment;

• integration of regions and their ecological potential into single system with clear definition of development priorities;

• education of ecological thinking of citizens;

• application of the best international experience of developed countries of the world in combination with national features;

• creation of single methodological basis for the formation of normative indicators with their legislative consolidation;

• attraction of economic incentive instruments for preservation of natural capital (grants, bonuses, eco-grants, eco-credits, emissions trading, introduction of "green economy" instruments), etc.

Thus, concern for natural capital preservation of the Earth is increasingly coming to forefront of human civilization development of and its very existence. The first cosmonaut of Ukraine Leonid Kadenyuk was the most successful in this regard, noting: "It should finally be understood that environmental safety is an integral part of overall safety, prosperity and peace on Earth and prerequisite for sustainable development" [30].

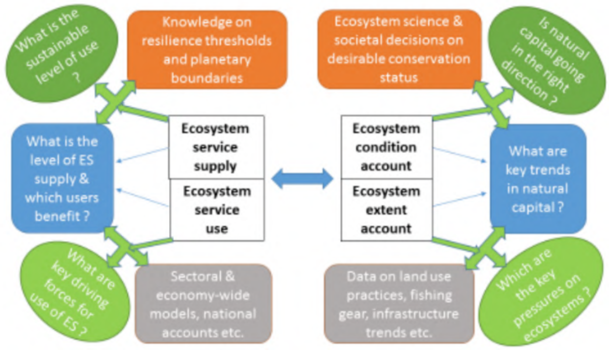

Fig. 2. A comprehensive knowledge framework for the management of natural capital [9].

Fig. 2 illustrates that various analytical tools need to be combined to enable the different analytical angles to manage natural capital in an integrated perspective via a range of policy instruments. Natural capital accounts remain central to the overall analytical approach but are complemented by other knowledge sources. A brief summary of the benefits and limitations of natural capital accounting brings up the following key points [9]:

Benefits of the ecosystem accounting developing:

• Better information flow on status and trends as for the ecosystems.

• More thorough approach to describe and to measure ecosystem services.

• More integrated support and perspective in understanding our links with natural capital.

• Underpins the analysis of environment with its links to economy.

• Helps in bringing consideration into ecosystem as a part of economic policy making.

Ecosystem accounting and its outputs are only positive as:

• Our ecological and modelling knowledge of ecosystem processes.

• Actual in-situ biodiversity monitoring data and other data input.

• Related tools and analysis that help translate it into policy decisions.

3 Conclusions

Conducted scientific research provides grounds for grouping principles of natural capital conservation by the following three components: biological (environmental), economic, organizational (managerial). Since the organic world on Earth consists of separate complex formations of different levels. Each formation has specific problems, so different levels of biological principles are identified. It is also proposed to include sustainability principle (ecological balance) anddevelopment of "green economy". Economic principles of natural capital conservation can be mandatory (licensing, taxation, payments) and incentives (grants, market assistance, bonuses, grants, insurance, etc.). Organizational principles are related to implementation of public administration mechanisms in the field of natural capital conservation.

Improving and applying methodology of natural capital conservation on the basis of the best foreign experience, taking into account national characteristics and the current regulatory framework will create an effective mechanism for natural capital conservation in Ukraine.

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Optimization of dose calculation of modified magnetite during sorption purification of water from copper ions to create environmentally friendly technology

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Abstract. Due to the growth of man-caused pollution, there is a need to use modern methods of water purification. It is advisable to use sorption methods for the extraction of heavy metals, which are considered to be particularly dangerous. It is established that sorbents based on magnetite are quite effective in the extraction of copper ions. It is shown that the sorption capacity of magnetite-based sorbents towards copper ions depends on the ratio of concentrations of Fe^{2+} and Fe^{3+} ions in the reaction mixture, and increases with increasing this indicator from 1/2 to 2. The sorption capacity of the sorbent towards copper ions increases by 4.4 times. It is shown that the efficiency of copper ions removal onto magnetite increases for sorbent modified with sodium sulfide. The proposed scheme provides the possibility of sorption treatment of large volumes of water from copper ions to the norms for the discharge of wastewater into fishery reservoirs. Post-productional magnetite is dehydrated and supplied to metallurgical enterprises for processing. The developed technology of water purification from copper ions is environmentally safe and energy efficient.

1 Introduction

The end of the XX and the beginning of the XXI century were marked by both scientific and technical achievements and a significant deterioration of the environment as a result of massive pollution. The state of the hydrosphere is becoming more and more worrying every year.

The problem of protection of hydro-ecosystems from pollution in Ukraine is especially acute, where, despite the decline in industrial production, the intensity of natural water pollution is growing [1–4].

The problem of pollution of water bodies with pollutants of various natures is now arising in many countries around the world. Heavy metals come to natural sources with effluents from various enterprises (galvanic, instrument-making and chemical industries, mining and processing plants and thermal power plants). A significant increase in the allowable discharges of heavy metal ions is observed in the discharges of nuclear power plants [5–9].

When discharging untreated or insufficiently treated galvanic effluents into rivers, lakes and other surface water bodies that contain a significant amount of heavy metals in their composition, enormous damage is caused to the environment: significant damage is caused to aquatic organisms and the ability of reservoirs to self-clean [10–17]. Some heavy metals are incapable of decomposition and accumulate in food chains.

Greening of processes for the introduction of low-waste methods is one of the key trends in the development of modern technologies. They are aimed at obtaining new highly selective, multifunctional materials to ensure environmental safety. Despite the presence of a large number of already known methods and techniques of synthesis, most of them occur with the participation of toxic reagents and are ineffective and dangerous to the environment. Traditional methods allow obtaining materials with the limited functional properties. This problem is becoming more important not only for Ukraine, but for the whole world [18–21].

The latest alternative types of multifunctional materials include nanomaterials and composite materials based on them, namely sorbents for water purification from organic impurities and heavy metals [22, 23].

Therefore, the development of methods for obtaining highly efficient sorbents, in order to ensure the rational use of natural resources in the application of new technologies, the progressive organization of low-waste and non-waste industries is extremely important.

Since heavy metals are priority contaminants, there is a need for modern methods that can provide high efficiency of purification from heavy metal ions [24–27].

When choosing a method of water purification, data on the volume of effluents, composition and content of impurities in them and technical and economic analysis were used [28, 29].

2 Analysis of previous studies

Extraction of copper ions from water with a high degree of purification, as well as the water purification from other heavy metals is quite difficult. Known methods of water purification from heavy metal ions are accompanied by the formation of toxic sludge, which is difficult to dispose of, or liquid waste, the processing of which requires significant costs. In addition, most of the known methods of water purification from heavy metal ions do not possess the necessary extraction efficiency. It is known that in fishery reservoirs, the maximum allowable concentration of copper ions reaches 1 μg/dm^3. Therefore, even when discharging relatively clean wastewater from power plants, where the content of copper ions reaches ~ 50 μg/dm^3, there is a risk of exceeding the maximum concentration limit in such reservoirs. However, most of the known methods of water purification from copper ions do not provide the required efficiency of water purification. The problem is complicated by large volumes of wastewater containing copper ions [30, 31].

Electrochemical methods are characterized as effective and advanced water purification technologies. Installations are quite compact and high-performative, while control and operation processes are simply automated. Electrochemical methods allow one to extract valuable components from effluents with a relatively simple automated technological scheme of treatment, often without the use of chemical reagents. The main disadvantage of these methods is the high cost of electricity [32–42].

Among the advantages of baromembrane methods are: low energy consumption, simplicity of construction of devices and installations, as well as their small size. The devices are easy to operate and consumed energy is mainly spent on creating high pressure over the solution. Disadvantages include the occurrence of the phenomenon of concentration polarization, which leads to a deterioration in the characteristics of membrane devices and the need for preliminary preparation of solutions [43–53].

Purification methods based on ion exchange using natural and synthetic materials are widely used. However, the main disadvantage of the ion exchange method is the need to supply to ion exchange units wastewater, pre-treated from suspended solids, cyanides, iron ions, petroleum products and other organic substances [54–57].

Sorption methods of wastewater treatment are highly efficient and are among the most environmentally friendly methods. The main criterion when choosing a material for wastewater treatment is its sorption properties, porous structure and efficiency. Therefore, the presented work is aimed at developing and improving methods of sorption purification of water from the heavy metals [58–62].

3 Results of the study

The aim of the work was to study the processes of copper ions extraction from water using sorbents based on magnetite, in order to determine the optimal conditions for modification of sorbents to achieve effective purification of water from copper ions to the maximum allowable concentration.

It is known that magnetite-based sorbents provide efficient extraction of heavy metal ions from water. They are quite effective in removing heavy metal ions in the presence of hardness ions [63]. Typically, magnetite obtained at a ratio of iron (II) and iron (III) ions in the reaction mixture of 1 : 2 is used, although it is known that with increasing iron (II) content, magnetite has a more amorphous structure, which should affect its sorption capacity. Therefore, magnetite was used in this work, at a ratio of Fe (II) / Fe (III) 1 : 2; 1 : 1 and 2 : 1. To increase the sorption capacity of magnetite, sodium sulfide was added at a concentration of 1 and 2 %.

When purifying water from copper ions when using sorbents based on magnetite, the sorption capacity of magnetite (K = 1 : 1) for copper is almost 10 % greater than when using magnetite obtained at K = 1 : 2.

The sorption capacity of magnetite increases with increasing ratio K = [Fe^{2+}] / [Fe^{3+}] in the range 1 : 2; 1 : 1 and 2 : 1. Thus, at K = 1 : 2 the sorption capacity of magnetite did not exceed 100 mg/g in the entire range of selected concentrations.

At K = 1 : 1, the sorption capacity of magnetite reached 108 mg/g for sorption from distilled water and 134 mg/g for sorption from tap water.

At K = 2, the sorption capacity of magnetite in both distilled and tap water exceeded 200 mg/g. This suggests that with increasing ratio K, magnetite has more amorphous structure, which causes an increase in its sorption capacity. In addition, it is obvious from the above data that calcium and magnesium ions are practically not sorbed on magnetite and therefore do not affect the sorption of copper ions. This is very important because with such properties of the sorbent it can be used to extract heavy metal ions from both natural and wastewater containing hardness ions. When using magnetite, only heavy metal ions are sorbed without removing hardness ions. When using cation exchange resins, hardness ions and heavy metal ions are sorbed together, and the ratio of the capacity of the cation exchange resin to hardness ions and heavy metal ions is close to the ratio of the concentrations of these cations in solution. And if we take into account that the concentrations of hardness ions in water are often tens of times higher than the concentrations of heavy metal ions, then it becomes clear that the use of ion exchange resins is appropriate only with deep softening of water. This approach is inappropriate when it comes to wastewater treatment.

To implement the method of sorption water purification, it is necessary to have detailed relationships between the main parameters of the process in optimal conditions. Therefore, the regression equations were calculated to illustrate the dependence of the sorption capacity of magnetite on the ratio of Fe (II) / Fe (III) and the equilibrium concentration of copper ions.

The calculation was based on a complete factor plan (CFP) type 2^2. The plan-matrix CFP 2^2 and the results of the experiment of the sorption capacity of magnetite from the ratio of Fe (II) / Fe (III) and the equilibrium concentration of copper ions in distilled water are shown in table 1.

Table 1. Plan-matrix CFP 2^2 and the results of the study of the extraction of sorption extraction of copper ions from distilled water.

Planning matrix		Natural value of factors		Value of parameters
x_1	x_2	Ce, mg/m^3	К	a, mg/g
−1	−1	2.0	0.5	34.23
+1	−1	104.0	0.5	66.89
−1	+1	2.0	2.0	23.98
+1	+1	104.0	2.0	210.00

As a result of appropriate calculations and after checking the conformity of the study results, assessing the significance of the obtained coefficients and checking the regression equation for adequacy, the unknown dependence is as follows:

$$Y = 83.775 + 54.670 \cdot X_1 + 33.215 \cdot X_2 + 38.340 \cdot X_1 \cdot X_2 \quad (1)$$

After replacing the code values in the obtained equation with natural ones,

$$X_1 = (C_e - 53)/51 \quad (2)$$

$$X_2 = (K - 1.25)/0.75 \quad (3)$$

we obtained the following regression equation:

$$Y = 38.009 - 0.181 \cdot C_e - 8.808 \cdot K + 1.024 \cdot C_e \cdot K \quad (4)$$

The obtained dependence is presented in Fig. 1 in the form of a plane on which lies the solution of the given equation. The figure shows the dependence of the sorption capacity of magnetite on the ratio of Fe (II) / Fe (III) and the initial concentration of copper ions in distilled water.

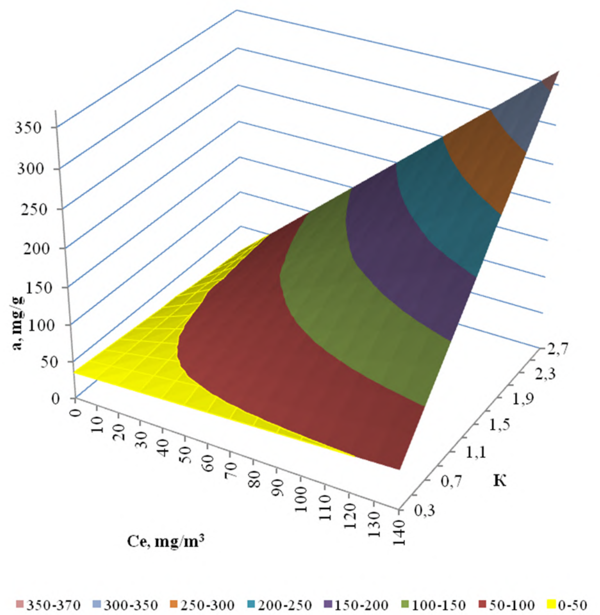

Fig. 1. Graphical representation of the results of CFP type 2^2 dependence of the sorption capacity of magnetite on the ratio of Fe (II) / Fe (III) and the equilibrium concentration of copper ions in distilled water.

The analysis of the presented graphs shows that the experimental points that were used in the calculation of the regression equation are on the constructed plane of solutions, which indicates the adequacy of the equation used. Using the data of the regression equation, it is quite easy to calculate the optimal ratio of Fe (II) / Fe (III) for effective purification of the solution from copper ions.

If we look at Fig. 1, we can say that in this case the mechanism of activated adsorption takes place. The reason for this is that the copper ions are included in the crystal lattice of magnetite. At low concentrations of copper at K = 1: 1 and 2: 1, almost complete extraction of copper is observed, which can be explained by this mechanism of sorption. In this case, heavy metal ions are practically not desorbed from magnetite without acid treatment and destruction of the structure of the sorbent.

Regression equations were calculated for the dependence of the sorption capacity of magnetite on the ratio of Fe (II) / Fe (III) and the equilibrium concentration of copper ions in tap water.

Plan-matrix CFP 2^2 and the results of the experiment of sorption capacity of magnetite from the ratio of Fe (II) / Fe (III) and the equilibrium concentration of copper ions in tap water are shown in table 2.

Table 2. Plan-matrix CFP 2^2 and the results of the study of sorption extraction of copper from tap water.

Planning matrix		Natural value of factors		Value of parameters
x_1	x_2	Ce, mg/m^3	К	a, mg/g
−1	−1	2.0	0.5	44.1
+1	−1	104.0	0.5	70.0
−1	+1	2.0	2.0	36.0
+1	+1	104.0	2.0	219.0

As a result of appropriate calculations and after checking the conformity of the study results, assessing the significance of the obtained coefficients and checking the regression equation for adequacy, the unknown dependence is as follows:

$$Y = 92{,}275 + 52{,}225 \cdot X_1 + 35{,}225 \cdot X_2 + 39{,}275 \cdot X_1 \cdot X_2 \quad (5)$$

After replacing the code values in the obtained equation with natural ones,

$$X_1 = (C_e - 53)/51 \quad (6)$$

$$X_2 = (K - 1.25)/0.75 \quad (7)$$

we obtained the following regression equation:

$$Y = 47.319 - 0.2595 \cdot C_e - 7.4536 \cdot K + 1.0268 \cdot C_e \cdot K \quad (8)$$

The obtained dependence is presented in Fig. 2 in the form of a plane on which lies the solution of the given equation. The figure shows the dependence of the sorption capacity of magnetite on the ratio of Fe (II) / Fe (III) and the equilibrium concentration of copper ions in tap water.

Increasing the sorption capacity of magnetite towards copper with increasing the ratio of K from 1 : 2 to 2 : 1 in addition to the positive value has significant disadvantages. First of all, magnetite obtained at K = 1 : 2 has the highest magnetic characteristics, which simplifies its separation from water, has the highest sludge density and the highest chemical resistance, because it has a

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crystalline structure. As the value of K increases, the contribution of amorphous elements to magnetite increases, which impairs its magnetic properties, reduces chemical resistance and leads to an increase in the volume of sediment due to a decrease in its density. Therefore, to increase the sorption capacity of magnetite obtained at a ratio of K = 1 : 2 in the process of its synthesis was modified with sodium sulfide. These substance, which is partially included in the structure of magnetite, contain functional groups Me = S, which are able to form complex bonds with heavy metal ions (with d-metals), do not interact with hardness ions and are able to increase the sorption capacity of magnetite. The results shown in Fig. 3 confirm this assumption. Modified forms of magnetite are dominated by unmodified magnetite, when copper ions are sorbed from tap water. Similar results are observed in the extraction of copper from distilled water. The equilibrium adsorption increases during the transition from unmodified magnetite to magnetite modified with sodium sulfide. Sodium sulfide provides the value of the limiting adsorption at the range of 332–388 mg/g, and is also a very affordable and cheap reagent and quite resistant to hydrolysis in alkali solutions.

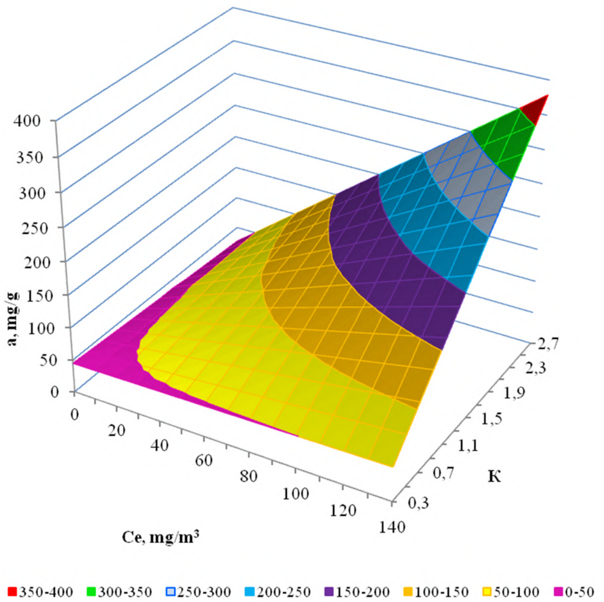

Fig. 2. Graphical representation of the results of CFP type 2^2 sorption capacity of magnetite from the ratio of Fe (II) / Fe (III) and the equilibrium concentration of copper ions in tap water.

Regression equations for the dependence of the sorption capacity of magnetite on the equilibrium concentration of copper ions in tap water and the concentration of sodium sulfide were calculated.

Plan-matrix CFP 2^2 and the results of the experiment of the sorption capacity of magnetite from the equilibrium concentration of copper ions in tap water and the concentration of sodium sulfide are shown in table 3.

As a result of appropriate calculations and after checking the conformity of the study results, assessing the significance of the obtained coefficients and checking the regression equation for adequacy, the unknown dependence is as follows:

$$Y = 164.5525 + 98.6475 \cdot X_1 + 24.9475 \cdot X_2 + 43.852 \cdot X_1 \cdot X_2 \quad (9)$$

Table 3. Plan-matrix CFP 2^2 and the results of the study of the extraction of copper from tap water using magnetite modified with sodium sulfide.

Planning matrix		**Natural value of factors**		**Value of parameters**
x_1	x_2	**Ce, mg/m³**	**C (Na_2S)**	**a, mg/g**
−1	−1	1.0	1.0	84.81
+1	−1	250.0	1.0	194.4
−1	+1	1.0	2.0	47.0
+1	+1	250.	2.0	332.0

After replacing the code values in the obtained equation with natural ones,

$$X_1 = (C_e - 125.5)/124.5 \quad (10)$$

$$X_2 = (C\ (Na_2S) - 1.5)/0.5 \quad (11)$$

we obtained the following regression equation:

$$Y = 122.884 - 0.26434 \cdot C_e - 38.5145 \cdot C\ (Na_2S) + 0.70446 \cdot C_e \cdot C\ (Na_2S) \quad (12)$$

The obtained dependence is presented in Fig. 3 in the form of a plane on which lies the solution of the given equation. The figure shows the dependence of the sorption capacity of magnetite on the equilibrium concentration of copper ions in tap water and the concentration of sodium sulfide used to modify the sorbent.

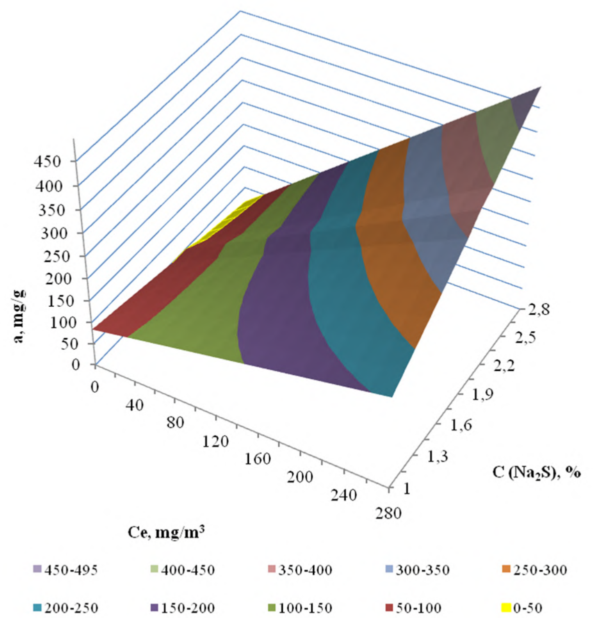

Fig. 3. Graphical representation of the results of CFP type 2^2 sorption capacity of magnetite from the equilibrium concentration of copper ions in tap water and the concentration of sodium sulfide used to modify the sorbent.

The research was conducted to determine the effectiveness of the developed sorbents depending on the ratio of the amount of sorbent and the volume of the solution. It was taken into account that the main problem is the extraction of copper ions from dilute solutions. Therefore, sorption was performed at doses of magnetite

500–10000 mg/dm^3. When sorbing copper from solutions with copper concentrations of 10 and 50 mg/dm^3, the sorption capacity of the sorbent increases with increasing dose of adsorbent. Higher values of adsorption were observed for magnetite at K = 2. Sorption increases during the transition from unmodified magnetite to magnetite modified with sodium sulfide. In the case of using magnetite modified with sodium sulfide, the sorption capacity only slightly depends on the ratio of K.

Modification of magnetite with sodium sulfide significantly affects the equilibrium concentrations of copper in purified water. When using unmodified magnetite at K = 1/2, the equilibrium concentrations of copper reach values of 2.0 – 6.7 mg/dm^3 and only at a dose of magnetite 10 g/dm^3 the equilibrium concentration decreased to 0.55 mg/dm^3. At a ratio of K = 2 at doses of magnetite 2.5 – 10.0 g/dm^3 at an initial copper concentration of 10 mg/dm^3, the equilibrium concentrations were in the range of 0.00 – 0.75 mg/dm^3. But at lower doses of magnetite, they still increased to 2 – 5mg/dm^3. When using magnetite modified Na_2S at K = 1/2 equilibrium concentrations of copper at an initial concentration of 10 mg/dm^3 decreased to 0.08 – 0.28 mg/dm^3 at all used doses of magnetite, and at K = 2 they were generally at the level of 0.0 – 0.1 mg/dm^3. Even at an initial copper concentration of 50 mg/dm^3 using modified magnetite (K = 2) at doses from 1.25 to 10 mg/dm^3, the equilibrium concentrations were at the level of 0.00 – 0.12 mg/dm^3.

4 Economic justification

In this case, we can say that modified with sodium sulfide magnetite is a fairly affordable synthetic inorganic sorbent with high efficiency for copper ions.

Given the high quality requirements for water purification from heavy metal ions, especially when discharging them into fishery reservoirs or when preparing drinking water, it was interesting to determine the minimum concentrations that can be achieved when using magnetite-based sorbents. When using magnetite modified with sodium sulfide, the concentration of copper was reduced to 5.44 μg / dm^3 at K = 1 : 2 (table 4, 5).

Table 4. Dependence of the efficiency of extraction of copper ions from tap water on the ratio [Fe^{2+} / Fe^{3+}] in magnetite, without modification with sodium sulfide.

Fe^{2+}/ Fe^{3+}	C Cu^{2+}, mg/dm^3		a, mg/g	Degree of extraction
	initial	Equilibrium		
1:2	10.00	0.7500	6.3000	92.50
1:1	10.00	0.1500	7.3888	98.50
2:1	2.00	0.0166	1.4875	99.17

When using sulfide-modified magnetite obtained at K = 2, and the copper concentration was reduced to 1.2 μg / dm^3.

Waste should be disposed of as part of building materials. Dehydrated waste of spent magnetite can be used as a thermal additive in the manufacturing of various heat-resistant materials.

Table 5. Dependence of the efficiency of extraction of copper ions from tap water on the ratio [Fe^{2+} / Fe^{3+}] in magnetite when modified with sodium sulfide

Fe^{2+} / Fe^{3+}	Na_2S, %	C Cu^{2+}, mg/dm^3		a, mg/g	Degree of extraction
		Initial	Equilibrium		
1:2	1	1.63	0.00540	1.0292	99.67
1:2	2	1.63	0.04688	0.9960	97.12
1:1	2	10.0	0.05600	7.4580	99.44
2:1	2	2.0	0.00120	1.4991	99.94

5 Conclusions

The application of modified sorbent based on magnetite for water purification from copper ions is the promising direction of sorption technologies, which allows to increase the efficiency of the process. When using modified sorbents based on magnetite, it is possible to reduce the concentration of copper to μg dm^3. Given the high capacity of the sorbent on copper ions, it will be possible to implement low-waste technology of water purification from heavy metals during its use.

The use of modified magnetite is a cost-effective way to purify water from heavy metals. The spent sorbent is utilized at the metallurgical enterprises.

Based on the complete factor plan, a regression equation is obtained, it has a linear character, which allows to optimize the calculation of the magnetite dose for efficient extraction of copper ions from aqueous solutions.

Given the constant increase in the concentration of hazardous pollutants in water bodies, the next step will be the development and implementation of methods for extracting a mixture of heavy metals from water and developing a mathematical model of the process to find optimal desalination parameters.

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Monitoring the water quality of Jiu River in Dolj County

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Abstract. Water is a renewable natural resource, but vulnerable and limited in terms of quantity and quality, which is why its exploitation must be done rationally, so as to ensure a complex recovery and a balanced distribution, depending on needs. The water management activity, which has as object the establishment and application of measures for rational use and control of water resources, quantitative and qualitative, is closely related to meeting the requirements of current legislation on exploitation and protection of water and aquatic ecosystems. In this context, the present paper presents a study carried out during 2019, having as the main objective the qualitative characterization of the Jiu River on the administrative territory of Dolj County (Romania). For this purpose, several water sampling campaigns (12, one for each month) from three control sections, established in partnership with the Jiu - Craiova Water Basin Administration, were carried out. The collected samples were analyzed in the analytical laboratory of the same institution and, on the basis of the obtained results, also considering the main existing sources of pollution, conclusions were drawn regarding the Jiu River water quality in the analyzed sector. Also, we applied an alternative control method whose purpose was to validate the initial conclusions.

1 Introduction

The central objective of the European Water Framework Directive is to achieve a "good status" for all bodies of water, both surface and underground, with the exception of heavily modified and artificial bodies, for which the goal is to achieve a "good ecological potential" [1]. Based on the principles contained in this directive, at the level of the Jiu - Craiova Water Basin Administration, a management plan is under development, a plan that has to solve the main problems related to water management, both quantitatively and qualitatively. Water management must provide solutions to ensure the current and future water needs of the population and the economy, starting from the renewable but limiting nature of freshwater resources [2].

For the sustainable management of water resources, the international community recommends that governments apply the following principles [3-5]:

1. The basin principle. Water resources are formed and managed on river basins. Rational management of water resources requires a global approach, combining social issues and economic development with the protection of natural ecosystems. Sustainable management of water resources can only be achieved at the level of the entire river basin, by taking into account all water users.
2. The principle of unitary quantity-quality management. The two sides of water management being in a close connection, it appears necessary a unitary approach, leading to optimal technical and economic solutions for both aspects.
3. The principle of solidarity. Planning and development of water resources requires the collaboration of all factors involved in the water sector: the state, local communities, users, water households, etc.
4. The "polluter pays" principle. All expenses related to water and environmental pollution, implicitly those of removing the effects and restoring the previous conditions, are borne by the one who produced the pollution.
5. The economic principle “the beneficiary pays”. Water has an economic value in all its forms of uses and must be recognized as an economic good. Managing water as an economic good is an important way to achieve efficient and equitable exploitation and to preserve and protect water resources.

These principles underpin the concept of integrated water management, which combines the problems of water use with those of protection of natural ecosystems [5].

Sustainable management of water resources, especially from a qualitative point of view, takes into account a number of objectives [3, 4], among which we mention:

- Ensuring the continuous supply of water with adequate quality of uses and, in particular, of the population requirements;
- Refurbishment of production processes by using clean, non-polluting technologies;
- Construction of new treatment plants and modernization of existing ones, in order to reduce pollutants discharged into surface waters and/or groundwater;

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- Elaboration of a normative framework necessary for the creation of hydrological and hydrogeological reserves, in order to protect vulnerable basins and aquifers;
- Implementation of methods and means to prevent, limit and reduce the effects of accidental pollution;
- Improving education for a clean aquatic environment;
- Improvement and creation of habitats corresponding to biodiversity conservation;
- Ensuring appropriate flows on watercourses, in order to protect aquatic ecosystems;
- Ensuring the continuity of the flow on the watercourses, in order to facilitate the migration of the fish species.

2 Description of the studied area

Jiu H.B. (hydrographic basin) has a length of approx. 260 km and an average width at the top of approx. 60 km and approx. 20 km at the bottom (figure 1).

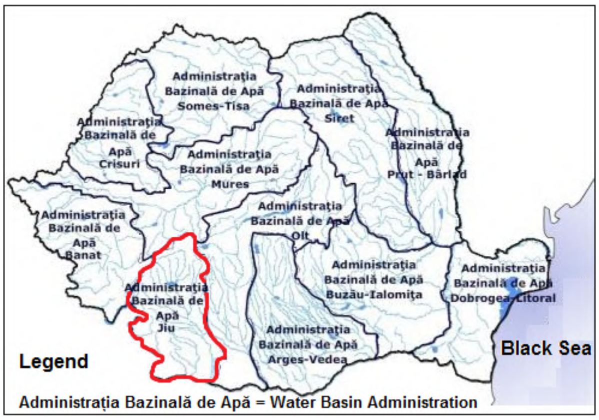

Fig. 1. Delimitation of hydrographic basins in Romania [6].

A feature of Jiu H.B. is the elongated form. The hydrographic network has a length of 3,876 km and a density of 0.34 km/km^2 [7].

The average altitude of the Jiu H.B. varies between 1,649 m in the northern area and 24.1 m in the confluence area. The average slope of the basin is of 5‰ [8].

On the right side, Jiu River, receives 31 tributaries (of which the most important: Tismana, Jilț, Motru and Raznic), while from the left side it receives 21 tributaries (of which the most important: Sadu, Cioiana, Gilort and Amaradia) [9].

The complex geological composition and the differentiated action of the climatic factors contributed to the formation of a wide variety of relief forms: mountains, hills, plains and swamps. These units are distributed in broad areas whose altitude declines from north to south (figure 2).

In relation to the altitude, more than 21% of the area, namely the northern and the northwestern parts, are occupied by mountain areas. The hills, belonging to the Getic Plateau and the Mehedinţi Plateau, occupy about 47%, the plain area being of over 32% [2].

The mountainous region has different characters due to the complex geological and lithological structure and determines a proper distribution of all elements of the natural environment (climate, vegetation, soils, etc.)

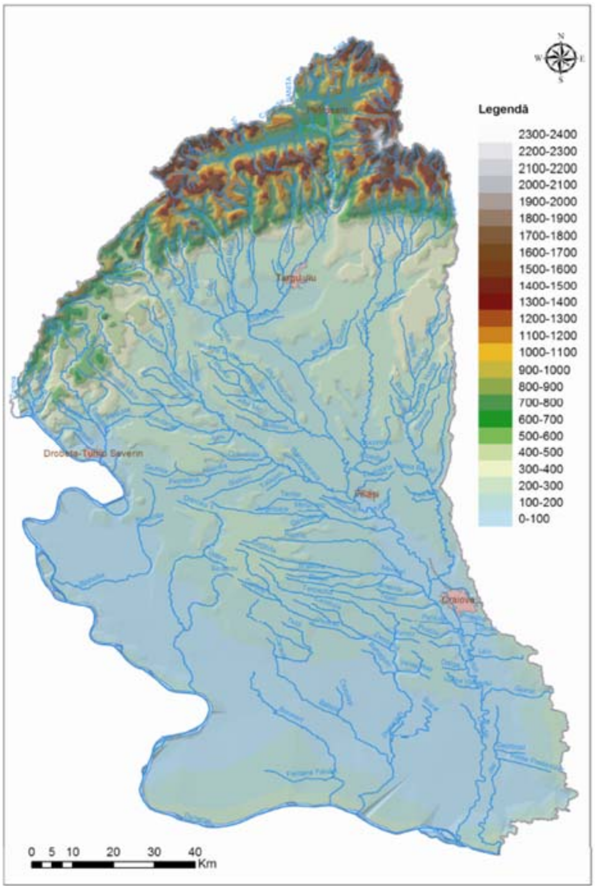

Fig. 2. Morphology of Jiu H.B. [7].

Subcarpathian depression includes:
- The depression of Celei - Novaci;
- Subcarpathian hills;
- Intercolinary depression Câlnic - Tg. Jiu - Câmpu Mare - Tg. Cărbuneşti;
- The piedmont hills in the south.

The piedmont area is represented by the Mehedinţi Plateau, located immediately in the south-east of Mehedinţi Mountains and represents a geographical individuality, although it is an organic continuation of the respective mountains.

The Getic Plateau is a large morphological unit extending south of the sub-Carpathian area up to the northern limit of the plain.

Oltenia Plain as a morphological subunit of the Romanian Plain is located in the south and southwest of the analyzed area, being delimited by the Danube and Olt rivers. As genesis and evolution, the Oltenia Plain is exclusively a creation of the Danube, the predominant forms of the relief being represented by the Danube meadow and terraces, the Jiu valley, to which the plain is added and, as a specific note, the relief of dunes.

The geological deposits that appear at the surface are of Miocene, Pliocene and Quaternary age, predominant being the siliceous type of rocks. The limestone rocks appear on limited areas, in the mountainous area, as well as in the northern part of the Bahna and Topolnița sub-basins.

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3 Material and methods

3.1 Pollution sources

In line with the Water Framework Directive, significant pressures are considered to be those that result in the failure to meet environmental objectives for the studied water body. Depending on how the body of water is operating, we can know if a pressure can cause an impact [10, 11]. Thus, in the present study, 4 major categories of problems were identified: pollution with organic substances, pollution with nutrients, pollution with priority and/or dangerous substances and hydromorphological alterations, described below:

Point sources of significant pollution

1. Urban pollution sources/human agglomerations

Urban wastewater contains, in particular, suspended matter, organic substances, nutrients, but also other pollutants such as heavy metals, detergents, petroleum hydrocarbons, organic micropollutants, etc. [2].

The industrial wastewaters similar to those from urban sources, contains the same pollutants but in different proportions, depending on the types of industry, as well as the pre-treatment level of the industrial waters collected in the sewer system (figure 3).

In terms of pollutants releases into surface water resources, table 1 show the monitored average quantities.

The organic substances are expressed as CCO - Cr and CBO_5, while the nutrients as total nitrogen and total phosphorus (data between 2014 and 2017 per categories of agglomerations).

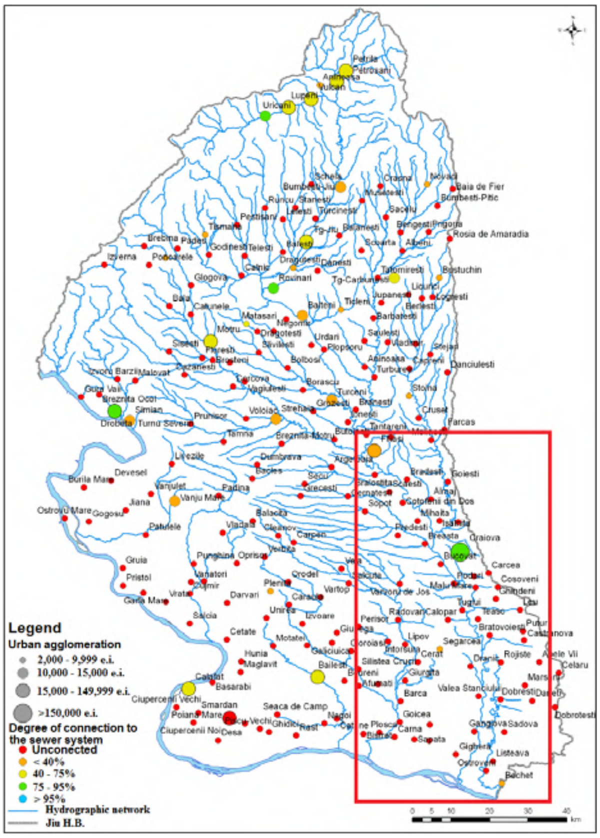

Fig. 3. Urban point sources of pollution (domestic and similar wastewaters) [7] (modified).

Table 1. Average discharges of organic substances and nutrients from human agglomerations into Jiu River [7].

Number of inhabitants (equivalent inhabitants)	Organic substances (CCO-Cr)	Organic substances (CBO_5)	N total	P total
	t/year	t/year	t/year	t/year
>100.000	8061.424	3428.233	1836.405	868.688
10.000 – 100.000	1166.029	569.761	217.800	18.318
2.000 – 10.000	63.298	38.247	14.801	1.494
<2.000	-	-	-	-
Total	9290.751	4036.241	2069.006	888.500

2. Sources of industrial and agricultural pollution

Sources of industrial and agricultural pollution contribute to the degradation of water resources by evacuating pollutants specific to the type of activity carried out (organic substances and nutrients: food industry, chemical industry, fertilizer industry, pulp and paper, livestock farms, etc.; heavy metals: extractive and processing industries, chemical industry, etc.; dangerous organic micropollutants: organic chemical industry, petroleum industry, etc.) [7] (figure 4).

The most important and significant point sources of industrial and agricultural pollution identified in the studied area are:

- C.S. Craiova Energetic Complex - Işalniţa Electric Power Plant;
- C.S. Craiova Energetic Complex - Craiova II Electrocentrale Branch;
- C.S. Automotive Subassemblies Craiova S.A.;
- C.S. Eco Sud Ltd.;
- C.S. Zahărul S.A. Podari;
- Petrom S.A. - Member of OMV Group. Petrom Craiova - DOLJCHIM Craiova;
- Leamna Pneumoftiziology Hospital;
- C.S. FELVIO Ltd. Bucovăţ (chicken intensive growth);
- A.N.P.- Pelendava Craiova Penitentiary (agriculture, zootechny, meat and milk processing);
- C.S. GIM CO Ltd. (chicken intensive growth);
- Sadova Socio – medical Facility;

In terms of releases of pollutants into surface water resources, table 2 shows the monitored average quantities of organic substances (expressed as CCO-Cr and CBO_5) and nutrients (total nitrogen and total phosphorus) between 2014 and 2017 per categories of pollution sources. Table 3 also shows the same situation, given the quantities of heavy metals measured and monitored.

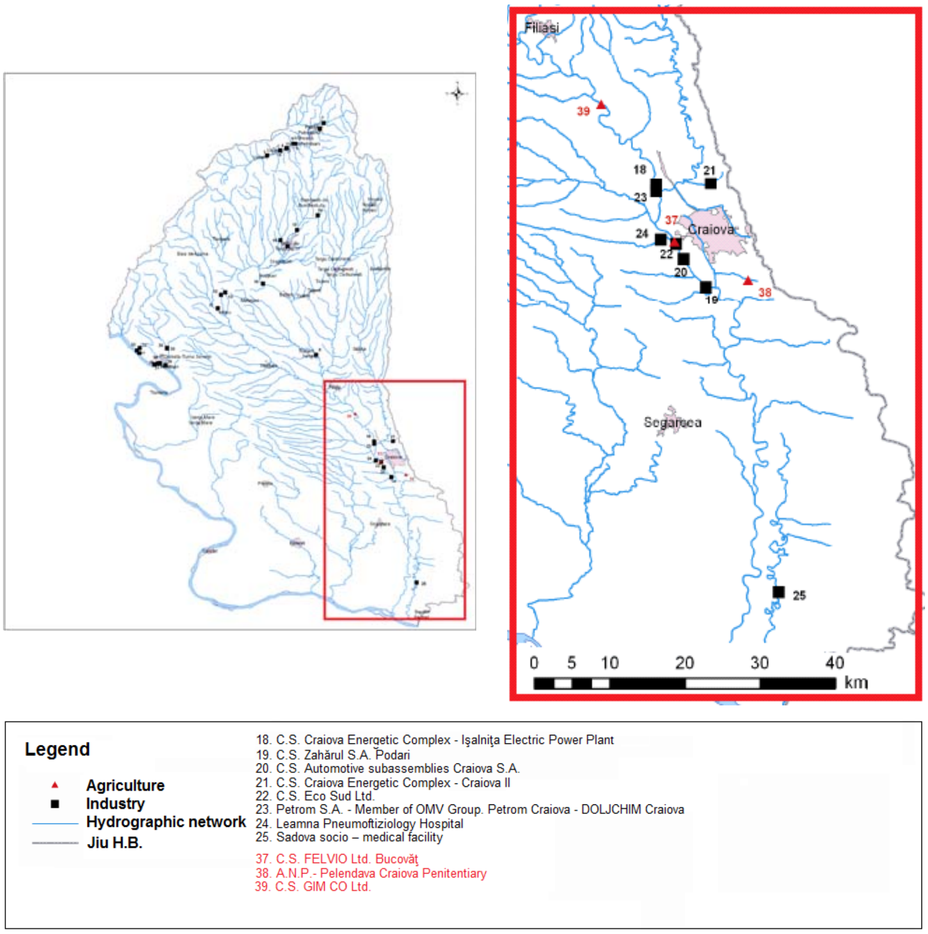

Fig. 4. Industrial and agricultural point sources of pollution [7] (modified).

Table 2. Average discharges of organic substances and nutrients from industrial and agricultural point sources into Jiu River [7].

Type of industry	Organic substances (CCO-Cr)	Organic substances (CBO$_5$)	N total	P total
	t/year	t/year	t/year	t/year
*IPPC Industry	12933.143	1904.359	31.389	12.831
Non *IPPC Industry	1313.617	321.987	16.295	26.009
Total Industry	14246.760	2226.346	47.684	38.84
Other Sources	170.997	8.606	8.509	0.056

Table 3. Average discharges of heavy metals from industrial and agricultural point sources into Jiu River [7].

Type of industry	Cu	Zn	Cd	Ni	Pb	Hg	Cr
	kg/year	kg/year	kg/year	kg/year	kg/year	kg/year	kg/year
*IPPC Industry	-	-	-	-	-	-	-
Non *IPPC Industry	0.9	1.9	-	-	0.1	-	0.1
Total Industry	0.9	1.9	-	-	0.1	-	0.1
Other Sources	0.1	0.1	-	-	-	-	1.0

*IPPC – Industrial activities as defined by the Integrated Pollution Prevention and Control Directive [12]

Significant diffuse sources of pollution

The way of using the land within the hydrographic space afferent to the Jiu Waters Administration is influenced by the physical-geographical conditions, as well as by the anthropic factors (figure 5) and, in turn, it influences the types and quantities of diffuse pollutants that reach the Jiu River waters.

Predominant in Jiu H.B. are arable lands (48.96%), the forests being representative for 28.74% of the surface of the river basin [8]. Agricultural lands are predominant in the river basins of the most important direct tributaries (54.12%). Perennial crops have a relatively uniform development, occupying 5.16%. The other areas occupy much smaller areas. Thus the water tables occupy only 1.0% [7].

The main categories of sources of diffuse pollution are represented by [2]:

1. Human agglomerations/localities that do not have wastewater collection systems or adequate systems for collecting and removing sludge from sewage treatment plants as well as localities with non-compliant household waste dumps.

2. Agriculture - agrozootechnical farms that do not have adequate manure storage/utilization systems, communes identified as vulnerable or potentially vulnerable to pollution by nitrates from agricultural sources, pesticide units that do not comply with the legislation in force, other units/agricultural activities that can lead to significant diffuse emissions.

The specific quantities of chemical fertilizers (expressed in active substance) used in 2016 were about 10% higher than the situation in 2012, when at the level of Jiu hydrographic basin there were used average quantities of approx. 6.910 kg N/ha of agricultural land, respectively 1.410 kg P/ha of agricultural land. In contrast, in 2016, compared with 2012, the specific quantities of natural fertilizers used decreased by approx. 10% [7].

3. Industry - warehouses of raw materials, finished products, auxiliary products, non-compliant waste storage, units producing diffuse accidental pollution, abandoned industrial sites.

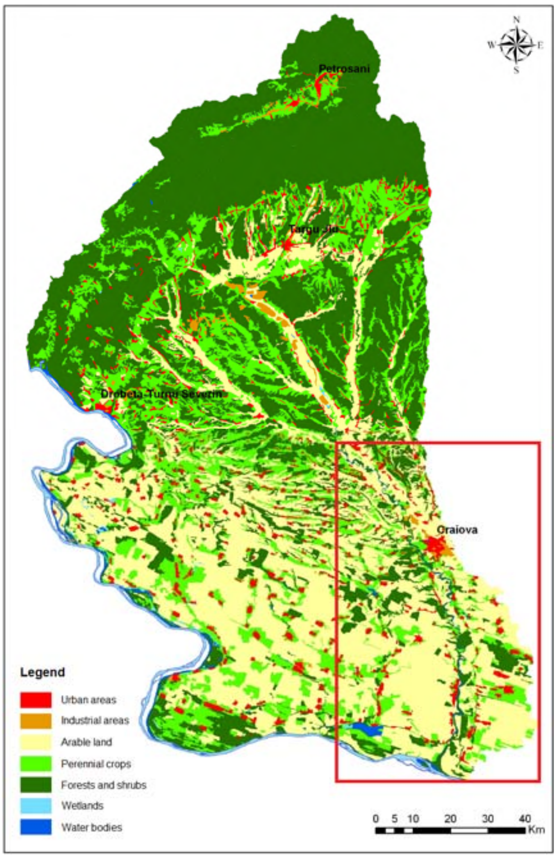

Fig. 5. Diffuse sources of pollution depending on the type of land use [7] (modified).

3.2 Establishing the control and sampling sections

Water samples were collected between January and December 2019, according to SR ISO 5667-6/2014 Water quality. Sampling Part 6: Guide for sampling of rivers and streams [13] (figure 6).

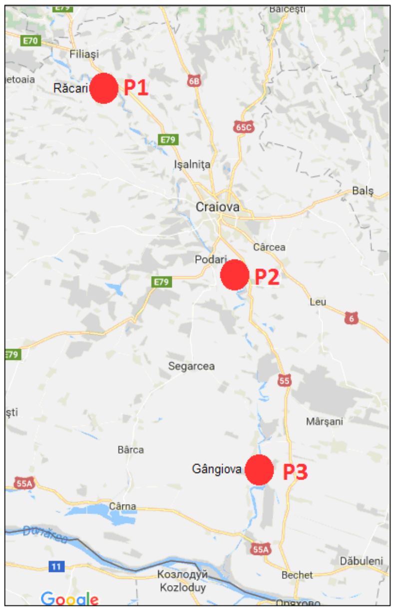

Fig. 6. Location of the sampling sections [15] (modified).

Establishing sampling locations has been done to allow for a comparative analysis. Sampling points can be located using fixed landmarks or GPS. Sampling points were clearly marked to avoid any confusion [2].

In establishing the sampling points the legal methodology was considered [14], as well as the location of the most important points in which untreated waste waters are discharged into the Jiu River on the territory of Dolj County.

For the collected of samples to be analyzed, in order to determine the quality of Jiu River in Dolj County, three control sections were established together with the Romanian Waters Administration (figure 6):

P1 - in Răcari de Jos village - downstream of Filiaşi, at the entrance to Dolj County;

P2 - in Podari village - downstream of Craiova City;

P3 - in Gângiova village - approx. 15 km upstream of the confluence with the Danube.

The collected water samples were transported to the authorized laboratory of the Romanian Water Administration - Craiova where the analyses were carried out according to the norms in force, the results of which are presented in the following paragraph.

3.3 Quality classes of surface waters

The surface water classification is based on the results of water quality monitoring and provides for a surface water classification a system divided in five quality classes defined by Order 161/2006 [16]:

Class I (very good) - surface waters where there are no (or very low) alterations in the physical-chemical and biological quality values. Concentrations of synthetic pollutants do not affect the functioning of aquatic ecosystems and do not harm human health. Surface waters corresponding to Class I can be designed for all types of use. Graphic representation uses blue color [16].

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Class II (good) - surface waters that have been affected to some extent by human activity, but nevertheless ensure all uses in an appropriate manner. The functioning of aquatic ecosystems is not affected. Simple methods of treatment are sufficient to prepare drinking water. Graphic representation uses green color [16].

Class III (polluted) - surface waters whose high quality physical-chemical and biological values deviate moderately from the natural water quality background due to human activities. There are moderate signs of disturbance of the functioning of the ecosystem. The necessary conditions for the *Salmonidae* family can no longer be ensured. Simple treatment is not sufficient for the use of drinking water for normal treatment methods. Graphical representation uses yellow color [16].

Class IV (polluted) - surface waters that show evidence of major alterations in physical-chemical and biological quality values from the natural water quality background due to human activities. The conditions for the *Cyprinidae* family can no longer be assured and do not meet the requirements for drinking water without applying advanced treatment methods. Graphic representation uses orange color [16].

Class V (very polluted) - surface waters that show evidence of major alterations in physical-chemical and biological values from the natural water quality fund due to human activities. Biological components, especially fish, are damaged and water can not be used for drinking purposes. Graphic representation uses red color [16].

From the ecological point of view, the five qualities are the following:

- Class I quality - very good ecological status;
- Class II quality - good ecological status;
- Class III quality - moderate ecological status;
- Class IV quality - poor ecological status;
- Class V – very poor ecological status.

Table 4 presents the maximum admitted concentrations (M.A.C.) of pollutants and the quality class in which surface waters fall into according to these concentrations [16].

Table 4. Quality classes according to Order 161/2006 (extract).

No.	Group	Parameter	MU	M.A.C. Class of quality cf. Ord. 161/2006				
				I	II	III	IV	V
1	Phisical indicators	Temperature	ºC	ns	ns	ns	ns	ns
2		pH	pH unit	6.5-8.5				
3		Suspensions	mg/l	ns	ns	ns	ns	ns
4	Oxygen regime	Dissolved oxygen	mgO_2/l	7	6	5	4	<4
5		CBO_5	mgO_2/l	3	5	10	25	>25
6		CCO - Cr	mgO_2/l	10	25	50	125	>125
7	Nutrients	NH_4^-	mg/l	<0.2	0.2	0.3	0.6	>1.5
8		NO_2^-	mg/l	0.01	0.06	0.12	0.3	>0.3
9		NO_3^-	mg/l	1	3	6	15	>15
10		N total	mg/l	1.5	4	8	20	>20
11		PO_4^{-3}	mg/l	0.05	0.1	0.2	0.5	>0.5
12		P total	mg/l	0.1	0.2	0.4	1	>1
13	General ions. salinity	Filtrate residue at 105ºC	mg/l	background	500	1000	1300	>1300
14		Ca^{+2}	mg/l	75	150	200	300	>300
15		Cl^- (chlorine)	mg/l	background	100	250	300	>300
16		SO_4^{-2}	mg/l	80	150	250	300	>300
17	Organic substances	Phenols	µg/l	background	1	20	50	250
18		Detergents	µg/l	background	500	750	1000	>1000
19		Fecal Coliforms	col./100 ml	100	2000	ns	ns	ns

MU – measuring unit; ns - not standardized.

4 Results and discussions

4.1 Water quality of Jiu River in 2019

In order to assess the Jiu River water quality in Dolj County, we have performed a comparative analysis of the characteristic quality parameters for the three sampling points (P1, P2 and P3) presented in tables 5 - 7.

The analyses regarding the water quality of the Jiu River were performed by the qualified personnel of Jiu – Craiova Water Basin Administration.

In a previous study, conducted in May 2017 [2], it was found that the quality of Jiu River in Dolj County is medium (moderate ecological status).

Analyzing the data presented in tables 5 – 7, several conclusions can be drawn:

- The dissolved oxygen shows values which are consistent to the first class of quality except for two determinations made in P2 and P3 in July. Thus, the degree of saturation in P1 is of 82.45%, which also qualifies Jiu River in the first quality class. This parameter is affected, by a decrease in value, so at point P3 the value reaches only 75.96%. This evolution is due to the organic pollutant load added between the sampling sections;
- CBO_5 is a parameter in correlation with dissolved oxygen (its evolution is in the opposite direction). At sampling section P1 we have low average oxygen biochemical consumption (5.73 mg/l), which increases in P2 to 6.14 mg/l and in P3 to 6.34 mg/l. The determined values place Jiu River in the third class of quality, a moderate ecological state;

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Table 5. Central table on Jiu River water quality at P1 (Răcari) monitoring point (2019).

No.	Parameter	MU	P1 - RĂCARI											
			Month											
			I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1	Temperature water/air	°C	4/6	3/5	7/14	11/15	18/19	19/24	20/26	20/26	17/19	14/16	8/10	4/5
2	pH (22.0°C)	UpH	7.96	7.76	7.67	7.76	7.96	7.98	8.06	7.68	7.87	7.88	7.78	7.77
3	Total suspensions	mg/l	6	3.4	8.5	4.4	6	3.9	4	4.9	8	5.6	4	3.9
4	Conductivity	µS/cm	356	334	387	324	356	298	296	287	301	312	293	267
5	Filtrated residue at 105ºC	mg/l	214	212	245	167	214	155	277	176	299	187	224	143
6	Dissolved oxygen	mg/l	8.6	7.6	7.6	8.6	8.6	7.7	8.6	8.7	8.6	7.7	8.6	8.9
7	Saturation	%	82.45	78.45	80.45	85.35	82.45	78.45	79.41	80.45	86.56	78.44	67.41	85.34
8	CBO_5	mg/l	5.5	5.2	6.5	4.2	5.5	5.4	7.5	6.4	5.5	6.2	5.5	5.4
9	CCO - Cr	mg/l	19.21	18.31	20.23	18.22	19.21	19.54	20.15	19.89	23.25	19.23	20.46	18.81
10	Alkalinity	mmol/l	2.369	2.249	2.322	2.209	2.369	2.104	2.143	2.213	2.082	2.201	2.087	2.201
11	Bicarbonates	mg/l	144.51	134.31	146.76	133.34	144.51	144.32	139.51	156.56	150.67	145.57	149.52	156.34
12	Chlorine	mg/l	15.521	14.641	16.523	15.612	15.521	15.224	17.343	17.284	16.357	18.222	19.356	19.244
13	Sulphate	mg/l	73.228	70.228	69.224	65.218	73.228	69.763	72.234	68.763	73.466	71.398	71.221	69.162
14	Ammonium - N- NH_4	mgN/l	0.0250	0.0245	0.0258	0.0199	0.0250	0.0255	0.0265	0.0245	0.0235	0.0256	0.0235	0.0235
15	Nitrates - N-NO_3	mgN/l	0.7525	0.6578	0.8534	0.5571	0.7525	0.5589	0.7432	0.5454	0.6739	0.4954	0.5632	0.4954
16	Nitrites - N-NO_2	mgN/l	0.0088	0.0072	0.0078	0.0062	0.0088	0.0098	0.0089	0.0089	0.0079	0.0090	0.0071	0.0067
17	Total nitrate -N	mg/l	0.9578	0.9235	1.0078	0.9125	0.9578	0.8735	1.0078	0.8567	1.0009	0.8589	1.0009	0.7367
18	O-phosphate – P-PO_4	mgP/l	0.0454	0.0514	0.0456	0.0494	0.0454	0.0598	0.0453	0.0498	0.0465	0.0478	0.0451	0.0399
19	Total phosphorus – PT	mg/l	0.0610	0.0614	0.0614	0.0611	0.0610	0.0615	0.0615	0.0598	0.0622	0.0566	0.0605	0.0578
20	Calcium	mg/l	55.132	55.342	52.145	55.278	55.132	52.321	56.032	55.367	54.109	52.289	55.125	58.564
21	Detergents ANA	mg/l	0.105	0.123	0.124	0.117	0.105	0.144	0.144	0.167	0.150	0.130	0.151	0.122
22	Phenols	mg/l	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
23	Hardness	mg/l $CaCO_3$	263.63	264.61	243.63	266.65	263.63	245.62	277.61	251.87	256.64	249.45	281.63	254.37

Table 6. Central table on Jiu River water quality at P2 (Podari) monitoring point (2019).

No.	Parameter	MU	P2 - PODARI											
			Month											
			I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1	Temperature water/air	°C	4/6	3/5	7/15	11/16	18/20	20/25	20/27	20/26	17/20	14/16	8/10	5/6
2	pH (22.0°C)	UpH	8.03	7.83	7.73	7.87	8.03	8.03	8.01	7.86	7.86	7.89	7.72	7.86
3	Total suspensions	mg/l	4.2	4.3	9.2	4.9	4.2	4.2	3.8	4.2	7.8	7.6	3.9	4.1
4	Conductivity	µS/cm	457	445	477	395	457	378	388	298	346	356	356	268
5	Filtrated residue at 105ºC	mg/l	274	254	298	193	274	209	293	211	331	213	267	178
6	Dissolved oxygen	mg/l	9.0	8.0	8.0	8.0	9.0	8.1	6.4	7.9	8.4	8.9	9.1	9.5
7	Saturation	%	83.41	82.41	83.41	80.38	83.41	83.42	78.43	83.55	84.76	87.53	78.43	88.57
8	CBO_5	mg/l	5.6	5.6	7.6	5.5	5.6	5.7	7.6	6.7	5.7	6.6	5.6	5.9
9	CCO - Cr	mg/l	23.49	22.34	27.45	23.31	23.49	22.78	23.41	21.98	23.67	22.56	23.44	22.34
10	Alkalinity	mmol/l	2.848	2.788	2.746	2.691	2.848	2.548	2.762	2.468	2.456	2.208	2.482	2.412
11	Bicarbonates	mg/l	173.73	165.76	177.73	155.71	173.73	165.76	156.31	164.74	157.463	161.71	154.67	162.72
12	Chlorine	mg/l	23.030	21.134	22.033	21.245	23.030	20.143	21.132	21.003	20.367	20.023	20.765	21.155
13	Sulphate	mg/l	78.428	68.658	74.435	68.158	78.428	68.674	75.433	69.677	75.187	70.387	75.167	69.689
14	Ammonium - N- NH_4	mgN/l	0.0605	0.0565	0.0703	0.0369	0.0605	0.0462	0.0613	0.0362	0.0489	0.0312	0.0432	0.0262
15	Nitrates - N-NO_3	mgN/l	1.1200	1.0100	1.2346	1.0092	1.1200	0.8965	1.1376	0.8778	1.0897	0.7893	0.9376	0.7989
16	Nitrites - N-NO_2	mgN/l	0.0154	0.0134	0.0145	0.0109	0.0154	0.0146	0.0157	0.0133	0.0187	0.0118	0.0123	0.0121
17	Total nitrate -N	mg/l	1.4530	1.4240	1.4678	1.3221	1.4530	1.0940	1.5033	1.0678	1.3890	1.0871	1.4067	1.0008
18	O-phosphate – P-PO_4	mgP/l	0.0804	0.0804	0.0224	0.0794	0.0204	0.0946	0.0215	0.0879	0.0783	0.0799	0.0234	0.0768
19	Total phosphorus – PT	mg/l	0.0268	0.0938	0.0298	0.1229	0.0268	0.1238	0.0289	0.1157	0.0879	0.1076	0.0276	0.1001
20	Calcium	mg/l	75.878	76.658	73.357	69.644	75.878	66.244	74.575	63.233	64.480	61.209	73.445	65.453
21	Detergents ANA	mg/l	0.150	0.147	0.146	0.143	0.150	0.179	0.153	0.188	0.153	0.158	0.158	0.167
22	Phenols	mg/l	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
23	Hardness	mg/l $CaCO_3$	282.51	284.46	265.31	280.51	282.51	276.59	275.53	278.55	276.98	255.25	271.45	278.43

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Table 7. Central table on Jiu River water quality at P3 (Gângiova) monitoring point (2019).

No.	Parameter	MU	P3 - GÂNGIOVA											
			Month											
			I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1	Temperature water/air	°C	4/7	4/5	8/15	11/16	19/20	21/25	21/27	20/26	17/20	14/17	8/10	6/6
2	pH (22.0°C)	UpH	7.62	7.84	7.82	7.94	7.62	7.94	7.99	7.91	7.91	7.93	7.81	7.95
3	Total suspensions	mg/l	8	7.5	9.8	6.5	8	6.5	4.2	6.5	8.2	8.5	4.1	6.3
4	Conductivity	µS/cm	489	487	499	436	489	417	492	349	387	388	397	290
5	Filtrated residue at 105°C	mg/l	293	287	302	237	293	267	313	258	334	243	287	208
6	Dissolved oxygen	mg/l	8.5	8.1	7.5	8.4	8.5	8.1	6.1	7.2	8.9	8.0	7.9	8.7
7	Saturation	%	80.96	82.96	80.16	83.96	80.96	82.96	81.92	82.65	88.32	82.45	81.92	82.65
8	CBO_5	mg/l	5.7	5.7	7.7	5.7	5.7	5.9	7.7	6.9	6.1	7.2	5.9	5.9
9	CCO - Cr	mg/l	22.41	22.56	27.67	23.59	22.41	23.06	23.51	23.15	24.19	23.76	23.98	23.56
10	Alkalinity	mmol/l	3.210	3.010	3.119	3.014	3.210	2.903	3.101	2.877	2.795	2.571	2.908	2.578
11	Bicarbonates	mg/l	195.81	194.31	189.89	184.48	195.81	187.86	194.65	189.22	189.16	182.16	184.59	187.65
12	Chlorine	mg/l	26.989	25.567	24.186	25.217	26.989	25.282	24.934	24.282	23.798	23.109	23.905	23.233
13	Sulphate	mg/l	78.724	76.454	78.356	69.434	78.724	73.503	78.083	73.233	76.389	73.193	78.003	72.543
14	Ammonium - N- NH_4	mgN/l	0.5964	0.4964	0.5863	0.3924	0.5964	0.3990	0.4984	0.4093	0.3984	0.3907	0.3875	0.3488
15	Nitrates - N-NO_3	mgN/l	1.1650	1.1230	1.3460	1.1145	1.1650	1.1009	1.1852	1.1106	1.1289	1.1209	1.1156	1.1078
16	Nitrites - N-NO_2	mgN/l	0.0325	0.0255	0.0305	0.0225	0.0325	0.0242	0.0334	0.0245	0.0278	0.0221	0.0278	0.0215
17	Total nitrate -N	mg/l	2.3180	2.2140	2.3421	2.2067	2.3180	1.2271	2.3420	1.2167	1.9087	1.2188	2.0098	1.1156
18	O-phosphate – P-PO_4	mgP/l	0.1895	0.1675	0.1769	0.1573	0.1895	0.1572	0.1785	0.1438	0.1309	0.1391	0.1567	0.1249
19	Total phosphorus – PT	mg/l	0.2574	0.2273	0.2464	0.2189	0.2574	0.2273	0.2400	0.2154	0.1984	0.1997	0.2162	0.1989
20	Calcium	mg/l	62.962	66.921	69.462	67.965	62.962	66.956	62.764	65.678	65.387	63.571	68.712	66.429
21	Detergents ANA	mg/l	0.132	0.149	0.156	0.155	0.132	0.209	0.161	0.212	0.176	0.199	0.176	0.189
22	Phenols	mg/l	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
23	Hardness	mg/l $CaCO_3$	266.36	256.39	256.37	266.31	266.36	266.31	267.65	267.18	268.49	261.68	288.34	279.19

- The chemical oxygen consumption puts Jiu River in the second category of quality, except for March when, in P2 and P3, it falls into the third category;
- The pH value falls within the range of variations characteristic to natural water courses, with a slightly basic character that can be explained by the intake of waters rich in carbonates;
- The temperature of Jiu River varies between 3 and 21ºC (lowest in February at P1, Răcari and P2, Podari, respectively, highest in June and July at P3, Gângiova). This variation is normal, and it is attributed to the influence of air temperature as can be seen from the tables. We do not consider that the discharge of waters with slightly higher temperature from the two power plants (Ișalnița and Craiova II Electric Power Plants) have a significant influence on the overall temperature of the river. We can also observe a small increase in temperature for each individual month from P1 towards P3. However this increase is also attributed to the increase of air temperature in between sampling;
- The nitrates concentration suffers a negative change (the average concentration rising from 0.63 mg/l in P1 to 1.14 mg/l in P3), suggesting that sewage discharges occur between the analysis sections (or wastewaters from zootechnical farms);
- The nitrites concentration suffers a negative change. The average concentration places Jiu River in the first quality class in P1 and in the second class in P2 and P3 (it increases from 0.008 mg/l in P1, to 0.014 mg/l, reaching 0.027 mg/l in P3). This evolution confirms that discharges of sewage and zootechnical wastewaters occur between the sampling sections;
- The evolution of the total nitrite concentration follows the same pattern as the concentrations of nitrates and nitrites (from an average of 0.92 mg/l in P1, corresponding to the first quality class, up to 1.87 mg/l in P3, corresponding to the second quality class);
- The average phosphate concentration increases between P1 (from 0.047 mg/l – first quality class) and the next two sampling sections (up to 0.062 mg/l in P2 and 0.159 mg/l in P3), corresponding to the second class of quality;
- The average total phosphorus content also increases from P1 towards P3. In the first two sampling sections the average concentrations (of 0.060 mg/l in P1 and 0.074 mg/l in P2) places Jiu River in the first quality class, while for the third sampling section, with a average concentration of 0.225 mg/l, Jiu River falls into the third quality class.
- Turbidity evolution is influenced in turn by domestic wastewater spillage and due to the high hydraulic stability of the suspended particles, favored by the predominantly laminar flow regime.
- The concentration of total dissolved salts (determined by the conductivity) is similar in evolution (increases in P3 compared to P1), appreciating that this is achieved mainly by the intake of wastewaters with higher content of salts.
- From the point of view of fecal coliforms, Jiu River falls into the second category of quality, having a good ecological status;

- For the rest of the analyzed parameters Jiu River falls into the first quality class.

As a general conclusion, considering the water quality of Jiu River in the analyzed sections, in terms of the determined values of the selected parameters compared with those listed in Order 161/2006, and taking into account the recommendations from it, we can say that the wastewater generated by industrial, agricultural and household activities and which are discharged directly into it, have a negative influence. However, the quality of Jiu River does not suffer a significant worsening, falling into the third category in all three control sections.

4.2 Control method

Another way of assessing the quality of Jiu River water for the three control sections is based on the calculation of the Water Quality Index (WQI).

The WQI was conceptually defined in the early 1970's by the US National Sanitation Foundation (NSF) to compare water quality from different water sources and to monitor water quality variations over time. For this purpose, 142 experts carried out 25 different tests and selected 9 indicators, with the main objective of aggregating individual indicators (expressed in physical units) into a single water quality index (on a conventional scale 0 - 100) [17]. The steps to achieve the set goal were as follows:

- Translating each of the 9 indicators into a quality index;
- Performing a weighted average of the obtained values.

This method involves the interpolation of the result of the water quality parameters analysis with a series of predefined curves (shown in the literature) to obtain the value of Q indicators, after which to the Qi values will be assigned a given weight Wi, and the quality index is calculated by the formula WQI = ΣQiWi [18, 19].

For each sample a table is produced with all the results for the water quality parameters, and then using the scale of quality (table 8) we determine the quality of the water according to the calculated score [20, 21].

Table 8. Quality scale for WQI [17] (modified).

Points	Quality	Category	Correspondence with Ord. 161/2006
91 - 100	excellent	A	I
71 - 90	good	B	II
51 - 70	medium	C	III
26 - 50	poor	D	IV
0 - 25	very poor	E	V

Table 9 presents the data which are at the base on the calculation of the water quality index for the three control sections considered on the Jiu River, and table 10 presents the values determined for Q in order to characterize its quality in Dolj County (for the three control sections). As can be seen, for the calculation of the water quality index additional analyzes were performed for the determination of fecal coliforms, turbidity and dissolved solids.

Table 9. Indicators required for WQI calculation (average values)

No.	Indicator	UM	Sampling section		
			Răcari	Podari	Gângiova
1	Dissolved oxygen	%	82.45	82.41	75.96
2	Fecal coliforms	colonies/100ml	180	268	280
3	CBO_5	mg/l	5.73	6.14	6.34
4	pH		7.84	7.89	7.85
5	Nitrates	mg/l	0.63	1.00	1.14
6	Temperature	ºC	17	17	17
7	Total phosphates	mg/l	0.047	0.062	0.159
8	Turbidity	NTU	28	58	61
9	TDS	mg/l	0.35	0.71	0.79

Table 10. Calculated values for determination of WQI.

No.	Indicator	P1 Răcari			P2 Podari			P3 Gângiova		
		Value Q_i	Proportion W_i	Total	Value Q_i	Proportion W_i	Total	Value Q_i	Proportion W_i	Total
1	Dissolved oxygen	90	0.17	15.3	90	0.17	15.3	80	0.17	13.6
2	Fecal coliforms	50	0.11	5.5	42	0.11	4.62	41	0.11	4.51
3	CBO_5	52	0.11	5.72	51	0.11	5.61	52	0.11	5.72
4	pH	89	0.11	9.79	89	0.11	9.79	89	0.11	9.79
5	Nitrates	97	0.1	9.7	95	0.1	9.5	90	0.1	9
6	Temperature	25	0.1	2.5	25	0.1	2.5	25	0.1	2.5
7	Total phosphates	99	0.1	9.9	98	0.1	9.8	95	0.1	9.5
8	Turbidity	52	0.08	4.16	34	0.08	2.72	33	0.08	2.64
9	TDS	80	0.07	5.6	80	0.07	5.6	80	0.07	5.6
10	**TOTAL (WQI)**	-	-	**68.17**	-	-	**65.44**	-	-	**62.86**

Using the three values calculated for the WQI, the chart in figure 7 was constructed, which allows us to observe how the Jiu River water quality evolves on the section investigated in Dolj County.

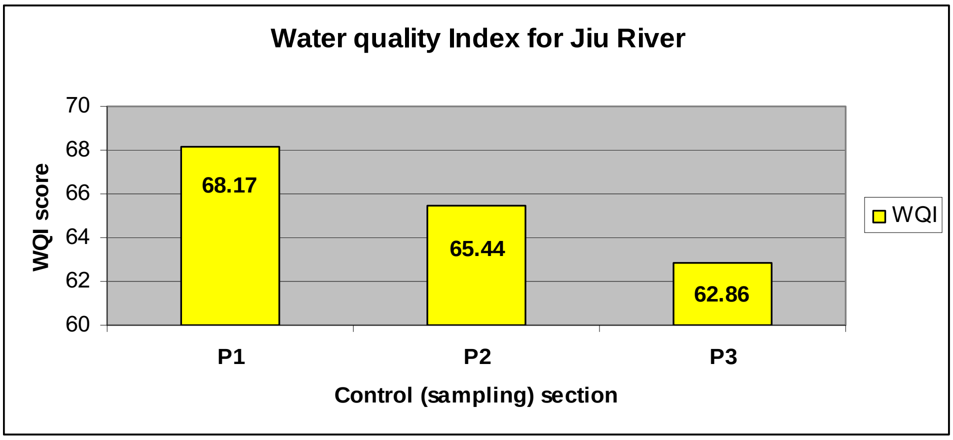

Fig. 7. Values of the Water Quality Index in the three control sections.

Although the value of the Water Quality Index falls slightly from P1 to P3, from the point of view of classification, the water of the Jiu River remains of medium quality (class C or IIIrd of quality) according with the methodology.

5 Conclusions

In the context of sustainable development, the protection of surface water quality occupies a major place, considering that water, which has long been considered an inexhaustible and renewable resource, is becoming increasingly obvious as one of the limiting factors in the socio-economic development of the modern society. As a major environmental factor and major vector of local and cross-border pollution propagation, as a vital resource of life support, water quality monitoring has gone through many stages in terms of organization and implementation.

The main anthropogenic sources of pollution from the monitored sections of Jiu River were identified and their impact on the quality of the water was analyzed. As shown in the present study, the main sources of pollution are industrial and agricultural activities, followed by wastewater discharged into the Jiu River without proper treatment.

From the present study, carried out on the Jiu River, the water quality in Dolj County on the Răcari - Gângiova sector, a series of general conclusions with theoretical and practical significance can be revealed:

1. Considering the total phosphate concentrations and the biochemical oxygen demand, it falls within the third quality class - moderate ecological status.
2. Depending on the concentration of nitrates and coliforms, it falls in the second quality class - good ecological conditions.
3. Depending on the temperature, pH and dissolved oxygen it falls into the first quality class - very good environmental status.
4. Based on the importance of the analyzed quality parameters, we believe that Jiu River should be classified in the **third quality class (or C according to the WQI methodology)**.

Analyzing through the Water Quality Index, all three points show that the water has a medium quality, and therefore the overall quality of Jiu River on the analyzed sector is medium.

In other words, both methods used to determine the quality of the Jiu River in Dolj County led to the same result, namely medium-quality water.

This highlights that it is absolutely necessary to implement urgent measures to bring the Jiu River to a higher quality level, in line with the European objectives in the field, namely to ensure at least a good ecological potential. In order to achieve this goal, the authors recommend:

- Connection of households to sewage and treatment systems to prevent river pollution by domestic wastewater drainage, directly into the river and pollution of the groundwater through infiltration into the soil;
- Ensuring efficient systems for evacuation of rainwater and waste water;
- Increase the efficiency of operation of sewage systems and wastewater treatment plants;
- Apply less polluting and/or more water-efficient technological processes, save water through recycling, and in some cases - extract useful substances from waste water and sediments and avoid waste and/or losses of water;
- Progressively reduce discharges of priority substances and priority hazardous substances (including the total exclusion of priority hazardous waste discharges).

The authors would like to thank the Jiu – Craiova Water Basin Administration for performing the instrumental and chemical analyses and providing the data regarding the quality parameters of Jiu River during 2019.

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Application of superheated water as a soil remediation media: a review

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Abstract. Water is a unique solvent cause its highly hydrogen-bonded structure, and at room temperature it has a high boiling point for its mass, a high dielectric constant and high polarity. At the higher temperatures, its permittivity, viscosity and surface tension decreases, but diffusion rate increases. Superheated water is a general term to denote the region of the condensed phase between 100 ˚C and the critical point. Liquid water at elevated temperatures above its boiling point has been used for many years as an industrial solvent and cleaning agent in applications ranging from enhancing the extraction of oil shale, the extraction of sulphur from ore bodies in the Frasch process, to degreasing. In recent years, there has been an interest in using superheated water for soil remediation. In this paper, a review on this area of application has been performed.

1 Introduction

Unfortunately, one of the inseparable outcomes of rapid population growth are environmental pollutions. In many cases ignoring the polluted areas or regions at risk of pollution, will have irreparable effects on the environment and subsequently on the health of the human beings. In different areas in the country, especially the oil-rich ones, the local and sometimes wide-area pollutions due to the oil spill or carelessness in oil compounds transfer can be seen. Chemical industries, despite having so many benefits for providing welfare and comfort for the life of modern man can cause different diseases, including cancer, by entering the food cycle of humans; As in different studies, the carcinogenicity and mutagenetic effects of various hydrocarbon compounds have been proven. Soil, as the basis for producing needed foodstuffs for humans, is of great importance, and sometimes is ignored by this much. Entering various pollutants directly and indirectly (through the water and air) can cause some changes in this medium, and just like other elements of nature, the soil is always acting against these changes; But sometimes, the balance of the soil is disrupted, and we face the challenge of soil pollution. In these situations, human interventions in order to help the natural clearing processes and accelerating them seem necessary [1]. Diseases including cancer, by entering the food cycle of humans; As in different studies, the carcinogenicity and mutagenetic effects of various hydrocarbon compounds have been proven. Soil, as the basis for producing needed foodstuffs for humans, is of great importance, and sometimes is ignored by this much. Entering various pollutants directly and indirectly (through the water and air) can cause some changes in this medium, and just like other elements of nature, the soil is always acting against these changes; But sometimes, the balance of the soil is disrupted, and we face the challenge of soil pollution. In these situations, human interventions in order to help the natural clearing processes and accelerating them seem necessary [1]. In other words, soils are considered as the refiners for nature. In addition to being a food supplier, soils also have purifying properties. These properties are originated from their physical properties (water diffusion through pores), chemical properties (adsorption and evaporation), and bio-based properties (decomposition and spoilage of organic matter). Contamination of soil with different chemical wastes is one of the most important environmental issues in various areas, which, due to the toxicity, carcinogenicity, and causing mutagenetic changes, there are vast concerns regarding their presence in nature [2]. These pollutants can be adsorbed on the surface of the soil or organic particles existing in it, which can enhance their concentration and subsequently cause their entrance to the surface waters along with the surface streams. On the other hand, these compounds may enter the groundwater and consequently lead to disorder in the food cycle of plants, humans, and animals, so they must be removed from the environment in some way [3]. Soil pollution factors include four major parts:

1- Agricultural factors
2- Oil contaminants
3- Industrial activities
4- Trash

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Regarding the soil pollution in Iran, according to the statistics, a few percent of industrial and domestic effluents are refined, and the major part of industrial and domestic effluents are discharged to the environment untreated. This manner can cause soil and groundwater pollutions, which increasing the nitrate content in well waters is a clear example for such consequences. One of the soil pollutions factors, which fortunately is not common in our country is acid rain. One of the actions of the department of environment to prevent acid rain is strong opposition to the establishment of a coke factory in the Savadkuh region. The atlas of soil pollution in Iran is being prepared, which provides accurate statistics on the amount of soil pollution in the country. Up now, the following regions are reported to be the most polluted regions in Iran: Isfahan province, south of Tehran, Asaluyeh in Bushehr, lands in the vicinity of the Mes-e Sarcheshmeh, Sistan and Baluchestan province, and Khuzestan province [4].

2 Modeling

The mass transfer mechanism of the extraction of soluble component is as follows: The soluble component attached to the solid network (by physical and chemical forces), have to be transferred to the solvent phase via liquidation or desorption. Then, the soluble component/solvent mixture diffuses to the solid surface and finally passes the static layer adjacent to the solid particles to reach the solvent phase.
Since the contents of the solid particles vary with distance and time, the diffusion coefficients of the soluble component existing in the solid particles can be determined by observing the changes of concentration in the vicinity liquid with time. There are four mass transfer steps in general, which the diffusion of the soluble component in the solid particles toward the solvent is usually the determinative step of mass transfer [36].

Initially, there is a rapid extraction period with a constant intensity, which is stable in the mass transfer and controls the resistance intensity of the mass transfer film. Then, an unstable descending step with a very lower extraction intensity occurs. In this stage, the diffusion in the solid particles controls the intensity of the extraction process [36]. In industrial operating units such as extraction, a specific component in one phase diffuses to the contact point of two phases and then enters into the other phase. Transfer of one phase to the other phase continues until the two phases reach equilibrium point [37]. The results obtained by Fick's second law were analyzed as a mathematical model. Since the modeling is performed in fluid phase, the following assumptions are considered:
1- Fluid moves with uz velocity.
2- Solid-phase is static.
3- There is no reaction.

In the fluid phase, movement is in z-direction, so the system is differentially modeled in this direction. According to the fluid stream, the diffusion term is ignored in this direction, and the convection term is considered as the determinative factor and described as follows:

$$u_z \frac{\delta c_{i,l}}{\delta z}$$

However, in radial direction, there is no movement, and lumped method is used for modeling, which only contains mass transfer flux:

$$u_z \frac{\delta c_{i,l}}{\delta z}$$

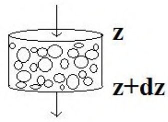
Now, the general relation of mass balance (input–output=accumulation) is shown below:

$$ka(c_i{}^* - c_{i,l}) + u_z \frac{\delta c_{i,l}}{\delta z} + \frac{dc_{i,l}}{dt} = 0$$

The initial and boundary conditions are as follows:

$$c_{i,l}(0,t) = 0$$
$$c_{i,l}(z,0) = 0$$
$$c_{i,s}(0) = c_{i,s,0}$$

Changes are considered only in the z-direction, and concentration variations in other directions are neglected. The following image is showing the considered system for mass balance schematically.



By considering a cylindrical shape element with a base area equals to the tower base area and with a height equals to dz, the mass balance is written. At the element input, we have:

$$N_{i,z}.A$$

Where $N_{i,z}$, and A are the i element flux in z-direction and tower base area, respectively. At the element output, we have:

$$N_{i,z+dz}.A$$

On the other hand, the mass transfer flux from the solid phase to gas phase is described as follows:

$$(dz.A)ka(c_i{}^* - c_i)$$

Where k is the mass transfer coefficient, a is the specific surface area, and c_i and c_i^* are the i component concentrations in the liquid phase and solid phase surface, respectively. By substituting the mentioned equations on this base that the total mass transfer from the gas phase to the liquid phase is equal to output rate minus input rate plus accumulation rate, we have:

$$\frac{\partial N_i}{\partial z} + \frac{\partial c_i}{\partial t} = ka(c_i^* - c_i)$$

By dividing both sides of the above equation by dz.A, the following relationship is obtained:

$$N_{i,z+dz}.A - N_{i,z}.A + dz.A\frac{\partial c_i}{\partial t} = (dz.A)ka(c_i^* - c_i)$$

By considering the below equation:

$$N_i = u_z c_i + J_i$$

Furthermore, by defining J_j as follows:

$$J_i = -D_l \frac{\partial c_i}{\partial z}$$

In the above equations, u_z and D_l are the fluid velocity in the z-direction and the axial distribution coefficient. By substituting the above equations, we will have:

$$\frac{\partial(u_z c_i)}{\partial z} - \frac{\partial}{\partial z}(D_l \frac{\partial c_i}{\partial z}) + \frac{\partial c_i}{\partial t} = ka(c_i^* - c_i)$$

By assuming that the axial distribution coefficient does not depend on z-direction, we will have:

$$c_i \frac{\partial u_z}{\partial z} + u_z \frac{\partial c_i}{\partial z} - D_l \frac{\partial^2 c_i}{\partial z^2} + \frac{\partial c_i}{\partial t} = ka(c_i^* - c_i)$$

By considering the continuity equation and assuming that the fluid density is constant:

$$\frac{\partial u_x}{\partial x} + \frac{\partial u_y}{\partial y} + \frac{\partial u_z}{\partial z} = 0$$

Since the velocity in x and y directions are zero, the above equation turns into the following equation:

$$\frac{\partial u_z}{\partial z} = 0$$

Finally, we have:

$$\frac{\partial c_i}{\partial t} = D_l \frac{\partial^2 c_i}{\partial z^2} - u_z \frac{\partial c_i}{\partial z} + ka(c_i^* - c_i)$$

The above equation is the one to be solved. To solve such an equation, two boundary conditions and one initial condition are needed.

The boundary conditions are described as follows:

$$c_i(0,t) = 0$$
$$\frac{\partial c_i(z,t)}{\partial z} = 0$$

The initial condition is determined as follows:

$$c_i(z,0) = 0$$

In this study, the mass transfers of naphthalene, phenanthrene, fluoranthene, and pyrene from soil to the super-hot water were investigated. The information about molecular weight and solubility of these compounds are illustrated in the Table 1 [38].

c_i^* is the solubility of *i* component in groundwater. Therefore, given that the solubilities at 25 ºC can be found in literature, the solubilities at 100, 150, 200, 250, and 300 ºC should be calculated. To calculate the solubilities, the following equation is used [36]:

$$ln\, x_2\,(T) = \frac{T_0}{T} ln\, x_2\,(T_0) + 15(\frac{T}{T_0} - 1)^3$$

Where $x_2(T)$ is the solubility at the temperature of T in the form of molar fraction and $x_2(T_0)$ is the solubility at the specified temperature of T_0, and the temperature unit is Kelvin. To calculate the D_l, the following equation is used:

$$D_l = \frac{ud_p}{\varepsilon Pe}$$

Table 1. The information of the compounds used in this study.

Compound	Molecular weight	Solubility in water at 25 ºC (mg/L)	Molecular volume (m^3/kmol)
Naphthalene	2.128	32	407.0
Phenanthrene	2.178	3.1	554.0
Fluoranthene	3.202	2.0	6195.0
Pyrene	1.202	1.0	626.0

Where d_p is the particle diameter, which is considered 2 mm in this study, the bed height is considered 10 mm, which is consistent with the empirical data, ε is the porosity coefficient (due to the presence of particles in soil), which is considered 0.4 in this work, and "u" is the entering velocity of the fluid. Four different flow rates, including 0.5, 1, 1.5, and 2 cm^3/min, are considered in this work. Moreover, Pe is the dimensionless number of Peclet and can be calculated using the following equation [24]:

$$Pe = 1.634\, Re^{0.265}\, S\, c^{-0.919}$$

According to the following equations:

$$\mathrm{Re} = \frac{\rho u d_p}{\mu}$$

$$Sc = \frac{\mu}{\rho D_{AB}}$$

It is needed to know the viscosity and density at the specified temperatures. In order to determine these values, we use the equations below:

$$\rho = 858.03 + 1.2128T - 0.0025T^2$$

$$\mu = \exp(-10.2 + \frac{290970}{T^2})$$

The units of temperature, density, and viscosity in the above equations, are Kelvin, kg/m^3, and Pa.S, respectively.

To calculate the diffusion coefficient (D_{AB}), the following equation can be used:

$$D_{AB} = \frac{(117.3 \times 10^{-18})(\varphi M_B)^{0.5} T}{\mu v_A{}^{0.6}}$$

Where M_B is the molecular weight of solvent (water in this case), φ is the correlation coefficient of solvent, which is equal to 2.26, and V_A is the molar volume of the soluble, which can be obtained from v_c and can be seen in the Table 1.

$$v_A = 0.285(v_c)^{1.048}$$

To calculate the mass transfer coefficient (k), the dimensionless number of Sherwood (Sh) is used:

$$k = \frac{Sh\,.D_{AB}}{d_p}$$

Where the Sherwood number can be obtained from [24]:

$$Sh = 0.38\,\mathrm{Re}^{0.83}\, Sc^{1/3}$$

3 Results and discussion

3.1 Time effect

The extraction time in the method of extraction with super-hot water is short. To extract compounds from plant samples or investigate the environmental samples, in 5 min to 2 hr in a dynamic state and 5-10 min in a static state, suitable efficiency can be achieved [3]. By increasing the extraction time, the efficiency will increase up to a constant value. The extraction time depends on the kinetics of the process and the time needed to reach the equilibrium. It is expected that by increasing the extraction time, the efficiency increases. The effect of time on the extraction of hydrocarbons or multiple-ring aromatic is shown in Figures (1,2).

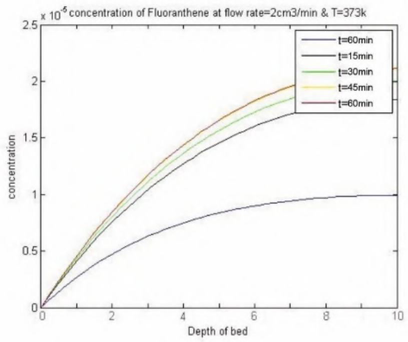


Fig. 1. Changes of fluoranthene concentration along the tower at different times at 373 K.

As it is obvious, by increasing the extraction time, the concentrations of hydrocarbons in the liquid phase are increased. In fact, from a specific time to further, there is no change in the curve by increasing the time, which means it reached equilibrium. Also, it can be concluded that by increasing the time, the change rate of concentration increases, which can be ascribed to the contact time of two phases. In other words, the sufficient time needed for mass transfer is provided by further increasing the extraction time.

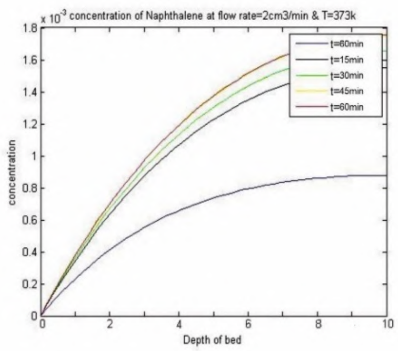


Fig. 2. Changes of pyrene concentration along the tower at different times at 373 K.

3.2 Flow rate effect

The intensity of extraction enhances by increasing the flow rate. It is expected that a more flow rate can mitigate the resistance of the fluid phase. Thus, the amount of mass transfer from the solid phase to the fluid phase increases. In the following figures (Figures (3-6)), the effect of changes in flow rate in the range of 0.5-2 cm^3/min is shown for the four mentioned compounds.

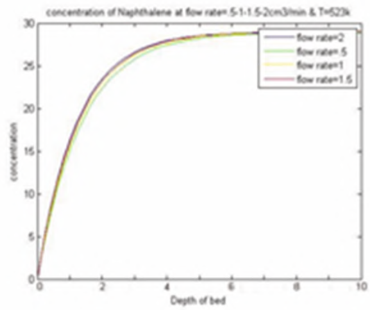


Fig. 3. The effect of flow rate on the concentration of phenanthrene.

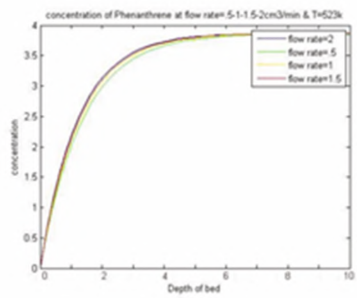


Fig. 4. The effect of flow rate on the concentration of fluoranthene.

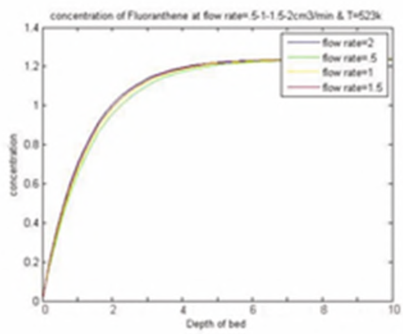


Fig. 5. The effect of flow rate on the concentration of naphthalene.

As can be seen in Figures, the variation of flow rate is not determinative on the amount of concentration. Also, for various compounds, there is no significant change in concentration, which can be concluded that the main resistance against mass transfer is the internal resistance, no the external one. In other words, the diffusion in the solid phase and reaching to surface, feel the most resistance. Overall, the resistance of the liquid phase is negligible.

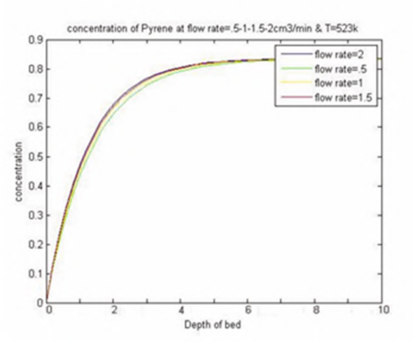


Fig. 6. The effect of flow rate on the concentration of pyrene.

3.3 Temperature effect

The most important parameter that affects the super-hot water system is temperature because by changing the temperature of the solvent (water), its properties will change [11, 39, 40]. By increasing the temperature, the surface tension and viscosity decrease, whereas the diffusion of the soluble compounds in the water enhances. In other words, more sufficient mass transfer will be provided by increasing the temperature, which can improve the extraction efficiency. This phenomenon is even more important in weak-polar or non-polar compounds because their solubility in water is negligible in low temperatures. Temperature can affect the solubility in water, axial distribution coefficient, and diffusion coefficient. So, significant changes in concentration are expected by varying the temperature. At the 25 ^{o}C temperature, as can be seen in the previous section, water has a weak capability to dissolve these kinds of hydrocarbons. As the temperature increases, the dielectric constant decreases, and consequently, the solubility increases. Therefore, it is expected that by increasing the temperature, the solubility of this group of hydrocarbons in the liquid phase enhances.

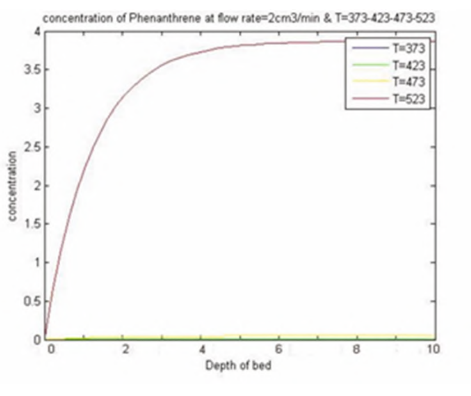


Fig. 7. The effect of temperature on the concentration of phenanthrene.

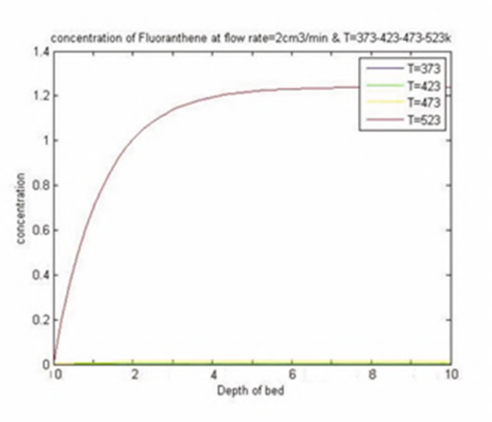


Fig. 8. The effect of temperature on the concentration of fluoranthene.

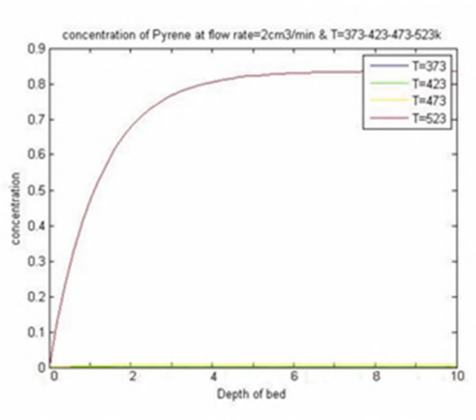


Fig. 9. The effect of temperature on the concentration of pyrene.

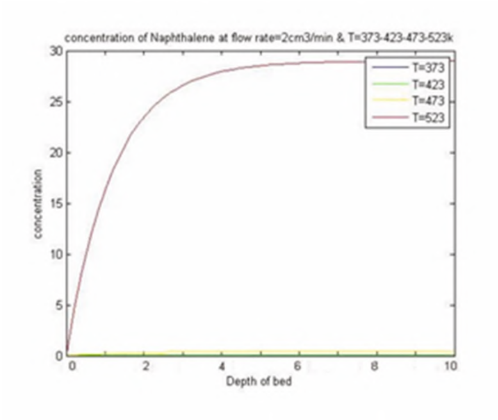


Fig. 10. The effect of temperature on the concentration of naphthalene.

As shown in Figures, by increasing the temperature ranging from 200 to 250, the concentration variations were significantly affected. This phenomenon can be assigned to the effect of these compound's solubility, which by increasing the temperature, the solubility enhances significantly, and this is obvious in Figures.

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The following figure provides a comparison between the concentration changes of the four compounds at 2 cm^3/min flow rate and 150 °C temperature. As can be seen in Figure, the concentration changes of naphthalene are more than others, and phenanthrene, fluoranthene, and pyrene come next, respectively. This order exactly originates from their solubility which is in the order of naphthalene, phenanthrene, fluoranthene, and pyrene, from higher to lower. On the other hand, the molecular weight of naphthalene is lower than others, which influences on its diffusivity in the liquid phase.

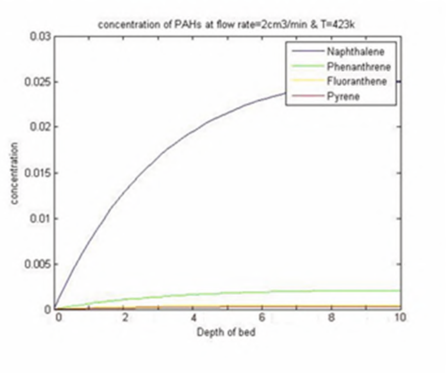

Fig. 11. A comparison between the concentration changes of the four compounds.

3.3.1 Review of experimental studies

This review is done for the compounds of naphthalene and phenanthrene [41].

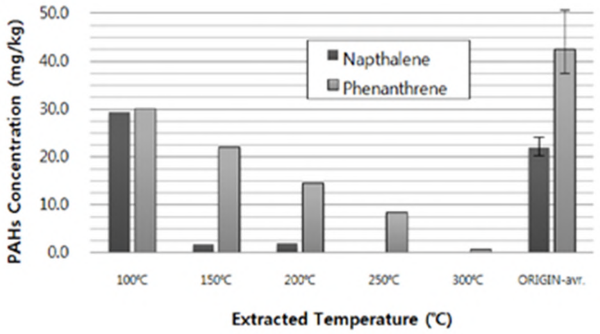

Fig. 12. Comparing the concentration of naphthalene and phenanthrene in the initial soil and the treated soil.

The concentrations of remaining naphthalene were 29, 1.8, 1.9, 0, and 0 ppm, at 100, 150, 200, 250, and 300, respectively. This means that the concentration of remaining naphthalene at 100 degrees, is slightly more than its concentration in the initial soil, and at 150 degrees, is significantly decreased to a value of 2 ppm. This evidences that the extracted naphthalene does not separate from soil in 100 °C. But, over 150 °C, it will be easily separated from the soil. There are some other reasons that why naphthalene does not separate from the soil at 100 °C. One of them is that the physical properties of soil up to 100 °C temperature and 100 atm pressure will change, and this variation can cause a change in the separation fraction of methanol from the soil and subsequently will affect the separation of remaining naphthalene from the soil. As another reason, the lack of homogeneity in the concentration of initial soil, which is heated up to 100n °C, can be mentioned. The concentration of remaining naphthalene was also decreased from 30 ppm at 100 °C, to 0.74 ppm at 300 °C. As can be seen in Figure 2, the separation of phenanthrene from the soil needs more heat than the value needed for naphthalene, which originates from the properties of phenanthrene that, in comparison with naphthalene, has a lower solubility in water and higher molecular weight and melting point.

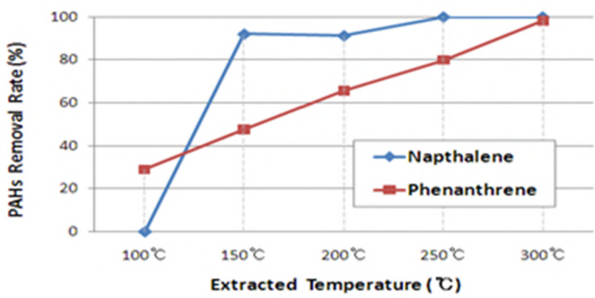

Fig. 13. The percentage of clearing soil from pollutants in different temperatures.

To clear a naphthalene-contaminated soil, 150 °C is sufficient. To clear a soil polluted with PAHs such as phenanthrene, anthracene, etc.

4 Conclusions

No need for organic solvent or negligible assumption of organic solvent is the most prominent characteristic of extraction with super-hot water. Accessibility, low-cost, and non-toxicity of water as the main solvent, and no need for drying the wet samples are other characteristics of this method. In many cases, this method in comparison with other methods, is more clear, cheaper, and faster. Extraction with super-hot water has showed lots of benefits in term of no need for organic solvents in environmental extractions. The equipment needed for this method is relatively simple and there is no need for applying high pressures, as the extraction with supercritical fluid. In this study, a simple mathematical model was presented for the fluid phase, which evaluated the extraction efficiency in terms of temperature, time, and flow rate. Also, the amount of concentration changes for naphthalene, phenanthrene, fluoranthene, and pyrene were measured with the parameters of temperature, flow rate, and time. Among these parameters, temperature was the most determinative one, and the amount of extraction is increased by increasing the temperature. It can be mentioned that almost 95% naphthalene was extracted at 100 bar. Because naphthalene was resistant in soil at 100 ºC and does not separate from the soil, but at 150 ºC and higher temperatures, due to its physical properties, which is changed in this condition, it can be easily separated from soil. As in this study, significant changes in concentration were observed in the temperatures of 200 and 250 ºC, which is ascribed to the effect of solubility of these compounds that increases by increasing the temperature. Also, the variation of flow rate has a negligible effect on the concentration for all compounds, which means that the internal resistance is determinative, comparing with the external one. In other words, the diffusion in the solid phase and reaching to the surface feel the most resistance. Overall, the resistance of the liquid phase is negligible. By increasing the extraction time, the rate of concentration changes increases, which can be assigned to the contact time between two phases. By a meaning, sufficient time for mass transfer can be provided by increasing the time. Short extraction time, high-quality extract, low cost of indicators needed for extraction, and compatibility with the environment are other prominent characteristics of this method.

5 Limits and suggestions

According to this fact that the solvent used in the extraction with super-hot water is water, the more assumption of water comparing with other methods can be mentioned as one of the disadvantages of this method, which is suggested that to overcome this issue in future studies, this should be included in the technical and economical calculations.

Also, as one of the limits of this method, high temperature and pressure can be mentioned, which can be a serious drawback regarding utilizing this method in more wide applications, so it is needed to be studied more.

Corrosion is also another important factor that should be considered. For example, stainless steel, as one of the most applicable material that is usually used in the equipment of super-hot water is corroded. So, for dealing with super-hot water, utilizing special materials is needed, which are more expensive than common materials in the industry. According to the discussed contents, it is hoped that the existing problems to be solved or mitigate in future studies, to facilitate the more application of this technology in industry.

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Morphometric parameters based prioritization of a Mid-Himalayan watershed using fuzzy analytic hierarchy process

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Abstract. Watershed prioritization has become increasingly crucial for managing natural resources, especially the watersheds. A useful decision support tool to provide appropriate weights to different morphological attributes with lineage with soil erosion is required to identify environmentally stressed areas for the watershed resources. This study examines the Western Nayar watershed delineation and further examination of the watershed's morphometric parameters. The morphometric parameters were quantified under the linear, areal, and relief heads for the watershed. The prioritization of sub-watersheds was done by the fuzzy analytic hierarchy process (FAHP). The study included nine morphometric parameters for forming a pairwise comparison matrix. The fuzzy analytic hierarchy process was employed for assigning the suitable weights to morphometric parameters, and further, these weights are normalized to assign the final ranks to the sub-watershed. In Western Nayar, SW9 got the highest priority, and SW1 was categorized as the least priority. The results were validated by the consistency ratio index, which depends on the matrix consistency index's size that should be less than 10%. The consistency index of the present study was found to be 2%.

1 Introduction

The morphological and climatic characteristics of a basin govern its hydrological response to a considerable extent. The morphological characteristics of watershed represent its measurable attributes, which are useful for synthesizing hydrological response. The importance of the morphological factors cannot be overlooked as an accurate prediction of runoff in concerned. Hence, linking the morphological parameter with the basin's hydrological characteristics can lead to a useful and straightforward procedure to simulate the hydrological behavior of the various basins, particularly the ungauged ones. Quantitative and rendition of various drainage parameters enable qualitative evaluation of surface runoff, infiltration, and susceptibility to erosion within the basin [7].

Morphometric science is the measurement, quantitation, and mathematical reckoning of the earth's surface layout, shape, and the dimension of its landforms. [8]. The analysis of morphometry of a watershed provides a quantitative description of the drainage system, which is an essential aspect for the characterization of watersheds [16]. Morphometric analysis requires measurement of linear features, areal aspects, the gradient of channel network, and contributing ground slopes of drainage basin [17]. The remote sensing technique is a convenient method for morphometric analysis. Large areas of synoptic view are easily procured through satellite imagery, and these are very useful in analyzing drainage basin morphometry. Pioneering work on the drainage basin morphometry has been carried out by Horton [10; 13], Miller [12], Strahler [16]. Some recent studies on morphometric analysis using remote sensing techniques have been carried out [1; 3; 4; 5; 9; 15; 17]. Geomorphological parameters such as stream order, stream length, stream frequency, drainage density, texture ratio, farm factor, circulatory ratio, elongation ratio, bifurcation ratio, and compactness ratio have been widely used for the prioritization of subwatersheds in a watershed [1].

Watersheds prioritization is the ranking of different sub-watersheds for varying levels of conservation treatments to be given to such watersheds. Once the watersheds are prioritized, the quantitative assessment of hydrological parameters of the watershed, such as peak flow and runoff volume, serves as necessary information for adopting suitable soil and water conservation measures in the watershed. The basin lies land use/land cover's physical characteristics influence these hydrologic parameters broadly, which are dynamic. The latest advances in remote sensing technology have provided handy tools for surveying, identifying, classifying forms of earth resources.

GIS-based multi-criteria decision analysis (GIS-MCDA) is a process of decision making in which geographical data and value judgments are brought together to obtain more information for the decision-makers [15; 17]. The fuzzy analytic hierarchy process (AHP) has proved to be an advantageous method in multiple criteria decision-making in fuzzy and has found various applications in recent years. Its applications use a crisp point estimate method, which includes fuzzy preference programming (FPP) based nonlinear method

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for fuzzy AHP priority derivation. The present study attempted to study different morphometric characteristics and implement GIS techniques through Fuzzy analytical hierarchy process (FAHP) techniques to identify critical sub-watershed in the Nayar River watershed. The morphological parameters were ranked according to the value and weights, which is evaluated by deriving the relationship between morphological parameters obtained by classification of all the sub-watershed by associating the strength of fuzzy. FHAP approach for identifying sensitive zones is found useful for implementing land and water resource conservation practices for sustainable development [2; 18].

This study explores the application of fuzzy AHP approach to prioritize the Western Nayar watershed sub-watersheds situated in the fragile Mid-Himalayan ecosystem using open source GIS tools and remote sensed DEM data. The results were validated by the consistency ratio index for a matrix of nine morphometric parameters.

2 Materials and Methods

2.1 Study area and data procurement

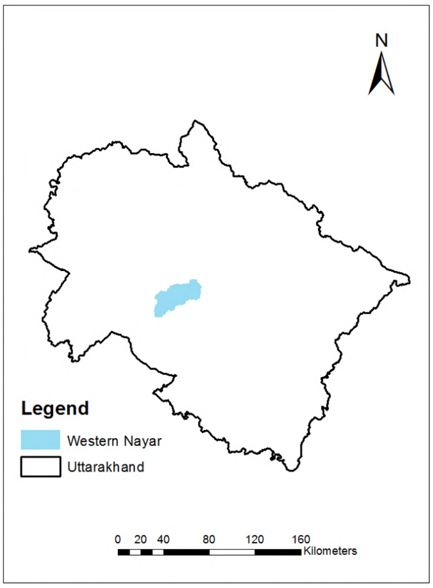

Fig. 1. Location map of study area.

The analysis has been practiced in the Western tributary of Nayar River, a non-glacial river in the Uttarakhand state of India. Nayar East and Nayar West are the two tributaries of the Nayar river. The Western Nayar lies between 29054’40’’N-30012’80’’N latitude and 78043’40’’E-7909’0’’ E (Fig. 1). The source comprises Nayar East, which is at an elevation of 2900 m, and the second source, which is Nayar West, has an elevation of 2800 m. Eastern Nayar's length is about 94 km, whereas Western Nayar's length is about 91 km. Eastern Nayar meets Western Nayar at Satpuli. Both of these tributaries join the Ramganga river in the lower Himalayan mountains for around 100 km further. Remote Sensing data used in this study are google maps of the study area, and Digital Elevation Model (DEM) obtained from Shuttle Radar Topography Mission (SRTM). QGIS 2.16, open-source software, is used for geospatial analysis.

2.2 Morphometric analysis

The formulas used to estimate morphometric parameters viz Stream frequency, Mean bifurcation ratio, Texture ratio, Length of overland flow, Elongation ratio, Circulatory ratio, Form factor and drainage density are presented in Table 1.

Table 1. Description of morphometric parameters used for FAHP prioritization/

Sl. No.	Parameter	Definition/Formula	Reference
1	Mean bifurcation ratio	$R_b = \frac{N_u}{N_{u+1}}$ where, N_u = complete number of stream order u, N_{u+1} = complete number of stream segment of next higher order	Schumm, 1956
2	Texture ratio	$T = \frac{N_1}{P}$ where, N_1 is complete number of first order stream and P = watershed perimeter (km)	Horton, 1945
3	Stream frequency	N_f = It is the number of streams per unit area of the watershed	Horton, 1945
4	Length of overland flow	$L_o = 0.5\frac{A}{L_b}$ where, A = watershed area (km^2) and L_b is length of watershed	Horton, 1945
5	Elongation ratio	$R_e = \frac{2}{L_b}\sqrt{\frac{A}{\pi}}$ where, A = watershed area (km^2) and L_b is length of watershed	Schumm, 1956
6	Circulatory ratio	$R_c = 12.57\frac{A}{P^2}$ where, P = watershed perimeter (km), A = watershed area (km^2)	Miller, 1953
7	Form factor	$R_f = \frac{A}{L_b^2}$ where, A = watershed area (km^2) and L_b is length of watershed	Horton, 1932
8	Drainage density	$D_d = \frac{L_u}{A}$ where, A = Basin area (km^2), L_u = complete stream length of all order	Horton, 1945
9	Relief	vertical distance between the lowest and highest points of a watershed (H)	Schumm, 1956

2.3 Prioritization of sub-watershed using FAHP

Present study focuses on the use of Fuzzy analytical hierarchical process (FAHP) along with the extent analysis method to prioritize the watershed. Fuzzy AHP is believed to obtain a crisp priority vector from a triangular fuzzy comparison matrix. Linear parameters such as bifurcation ratio, texture ratio, have a positive correlation with erodibility, higher value, more soil erodibility. Areal aspects parameter such as circularity ratio, form factor and compactness coefficient have an inverse relationship with erodibility.

The hierarchy process, by the method of extent analysis, each criteria is taken and extent analysis for each criterion, gi; is performed respectively. The M extent analysis values to each criterion evaluated by full notation

$$\dot{F}_{gi}^{1}, \dot{F}_{gi}^{2}, \dot{F}_{gi}^{3}, \dot{F}_{gi}^{4}, \dots \dots \dots \dots \dots \dots \ \dot{F}_{gi}^{n} \qquad (1)$$

where, g_i is the goal set (i=1,2,3,4…..n) and $\dot{F}_{gi}^{j}$ (j= 1,2,3,4,….m) are the members of triangular fuzzy number system (TFNs).

Keeping this in view, the preference values for each morphometric parameter are designated according to the FAHP rating scale, which determines the relative strength of each parameter over other parameters (Saaty 1980). By estimating the consistency ratio (CR), which can be calculated by the following equation, the consistency of judgment can be checked:

$$CR = \frac{CI}{RI} \times 100 \qquad (2)$$

Where the consistency index is a CI, and the random consistency index is a RI. The consistency index is a unit less number, which can be calculated using following equation, depending on the matrix's size (number of parameters).

$$CI = \frac{\lambda_{max} - n}{n-1} \qquad (3)$$

Where, λ_{max} is the principal eigen value obtained from priority matrix and n is the size of comparison matrix.

3 Result and discussion

3.1 Quantification of morphometric parameters

The morphometric parameters estimated for each of the sub-watersheds are given in Table 2. These values were acquired as defined in the section on materials and methods and were used in FAHP to construct a pairwise comparison matrix. In the form of a hierarchical tree, nine morphometric assessment indices were used for prioritizing sub-watersheds. Fuzzy analytical hierarchy process (FAHP) was used to evaluate the relative weights of parameters' character traits to prioritize sub-watersheds. The Western Nayar watershed is delineated The Western Nayar watershed is delineated into 11 sub-watersheds using QGIS 2.6.0 software(Fig.2). The Western Nayar watershed was found to be of fourth-order(Fig. 3). The analysis of the drainage network map reveals that there are 163 first-order streams having a total stream length of 219.72 km, 39 second-order streams with 129.80 km stream length, 11 third-order streams having 97.05 km stream length, and 1 fourth-order stream with 48.33 km stream length.

The perimeter of Western Nayar is estimated as 46.25 km. The sub watershed-wise basin length varies from 6.44 km to 20.88 km. As per Strahler's approach, the total numbers of streams for watershed are 216, out of which 163 belongs to first order, 39 are of second-order, 11 are of the third order, 1 is of fourth-order. It revealed that the highest number of streams are found in SW 7 (41), and the lowest number of streams is found in SW 4 (9). The stream frequency of the Western Nayar watershed sub-watersheds varies from 0.20 to 0.54; the highest stream frequency is observed in SW 4 (0.54/km^2), which indicated that it has the least infiltration capacity and thus highest erosion susceptibility in terms of N_f. Stream frequency is observed the lowest in SW 9 (0.20/km^2), which indicated it possesses the least erosion susceptibility. The mean bifurcation ratio of all the sub-watersheds is high, which indicates that all the sub-watersheds are structurally complex and have low permeability. Among the SWs, the highest mean bifurcation ratio is observed in SW 2 (5.642), which indicated that it is structurally complex and has low permeability and thus the highest erosion susceptibility in terms of R_{bm}. R_{bm} is observed the lowest in SW 4 (2.5), which indicated that it has the least erosion susceptibility. In the Western Nayar watershed, the lowest texture ratio is observed in SW 4 (0.14/km), which indicated that it has the highest infiltration capacity among the other SWs or conversely, it has the least susceptibility to erosion if the T is taken as a criterion for erosion susceptibility.

Table 2. Sub-watershed wise morphometric parameters for Western Nayar watershed.

Basin	A	P	L_u	R_{bm}	D_d	N_f	R_c	R_f	C_c	R_e	R	L_o	T
SW1	93.55	68.98	20.88	4.62	0.65	0.28	0.25	0.21	2.01	0.52	1.75	0.77	0.30
SW2	118.65	68.20	19.68	5.64	0.60	0.32	0.41	0.31	1.56	0.62	1.68	0.82	0.50
SW3	50.15	42.76	9.50	4.62	0.75	0.52	0.34	0.56	1.70	0.84	1.31	0.66	0.49
SW4	42.37	41.53	12.97	2.50	0.64	0.54	0.31	0.25	1.80	0.57	1.58	0.77	0.14
SW5	37.88	46.45	13.23	2.75	0.62	0.26	0.22	0.22	2.13	0.53	1.58	0.80	0.15
SW6	30.74	32.03	6.44	2.75	0.57	0.33	0.38	0.74	1.63	0.97	1.17	0.87	0.22
SW7	134.62	79.99	18.34	3.87	0.77	0.30	0.26	0.40	1.94	0.71	1.70	0.64	0.38
SW8	31.63	32.75	10.60	2.75	0.65	0.32	0.37	0.28	1.64	0.60	1.69	0.77	0.21
SW9	60.94	51.59	17.45	3.25	0.68	0.2	0.29	0.20	1.86	0.50	0.78	0.73	0.17
SW10	48.51	44.38	12.42	3.25	0.56	0.25	0.31	0.31	1.80	0.63	1.24	0.89	0.20
SW11	100.61	8.144	16.54	4.00	0.64	0.21	0.27	0.37	1.92	0.68	1.34	0.78	0.23

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The highest texture ratio was observed in SW2 (0.50/km), which indicated that it has the lowest infiltration capacity and thus highest erosion susceptibility in terms of T. L_o is less for steeper slopes and high for gentle slopes and thus

directly related to the slope of the channel. In the study area, the highest length of overland flow is observed in SW 10 (0.89km^2), which indicated that it has the highest potential to erode the land in a single stretch. L_o is observed the lowest in SW7 (0.64 km^2), making it the least susceptible to erosion as far as L_o is concerned.

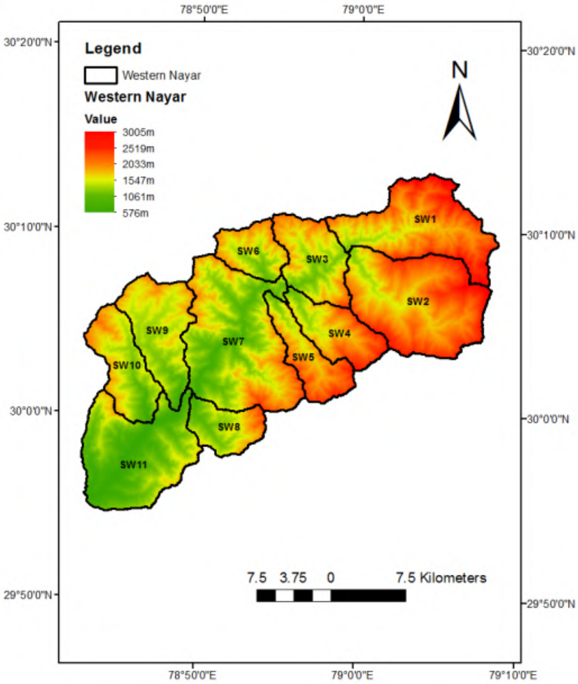

Fig. 2. Digital Elevation Model (DEM) map of western Nayar watershed.

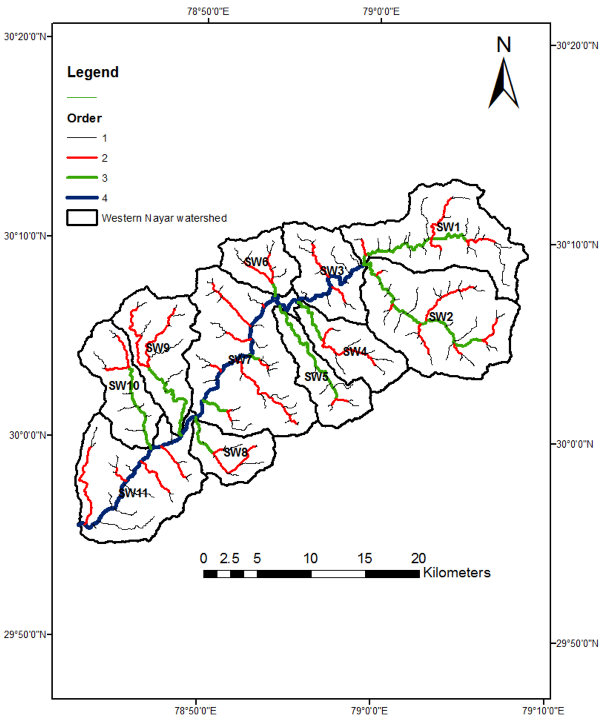

Fig. 3. Drainage network map of Western Nayar watershed.

Areal aspects of the morphological study of watershed include the description of the arrangement of areal elements. The total area of the Western Nayar watershed is estimated as 749.65 km^2 . The area of SWs varies from 30.74 km^2 to 134.62 km^2 (Table 2). In the Western Nayar highest elongation ratio is observed in SW6 (0.97), indicating that it has the least susceptibility to erosion in terms of R_e. R_e is observed the lowest in SW 9 (0.50), indicating the highest susceptibility. Among the SWs of the Western Nayar watershed highest Circulatory ratio is observed in SW2 (0.41), indicating low infiltration capacity and more erosion susceptibility in R_c terms. R_c is observed the lowest in SW 5 (0.22) indicates that it possesses low relief and higher infiltration capacity and resulting in lower susceptibility. The basins with high form factors have peak flows of shorter duration, whereas an elongated watershed with low form factors has a longer duration peak flow. Among the SWs of the Western Nayar watershed, the highest form factor is observed in SW 6 (0.74), indicating that it has peak flows of shorter duration and is least susceptible to erosion in terms of R_f. R_f is observed the lowest in SW 9 (0.20), indicating the highest susceptibility. Among the SWs of the Western Nayar river, the highest Compactness coefficient was observed in SW5 (2.13), indicating it's least susceptible to erosion in terms of C_c. C_c is observed the lowest in SW 2 (1.56), indicating the highest susceptibility to erosion.

The relief aspect is a three-dimensional characteristic of a watershed that is expressed in terms of the area, volume, and altitude of watershed landforms. The values of Stream frequency, mean bifurcation ratio, Texture ratio, Length of overland flow, Elongation ratio, Circulatory Ratio, form factor, drainage density and watershed relief are presents in Table 2. Linear parameters such as drainage density, stream frequency, bifurcation ratio, texture of drainage, have a positive correlation with erodibility, higher value, more erodibility. Areal parameters have negative correlation with erodibility, higher value, lower erodibility (Agarwal 1998; Srivastava et al. 2004, Bhattacharya et al 2020).

3.2 Prioritization of sub-watersheds using fuzzy analytical hierarchy process (FAHP)

The size of the comparison matrix as presented in Table 3 in Saaty's FAHP is equal to the number of parameters (n) and is in the form of a square matrix. The relative importance between the two factors can be scaled qualitatively between 1 and 9. Weightage 1 indicates the equal importance to both factors, while 9 indicates that one factor is more important than others. The comparison of each parameter with others is made to complete the comparison matrix of size (n × n) and the total no. of comparison comes out to be ${}_nC^2$. For filling the upper triangle of the matrix, each time two parameters were considered one by one, and considering the relative importance, a value between 1 and 9 is assigned. The lower triangle of the matrix was filled by reciprocal values of upper triangles.

The degree of importance between two factors in the matrix is filled based on field experience. When

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elongation ratio and form factor are used in a pair-wise comparison and it is decided that elongation ratio is important than form factor, a number 2 will be used to fill the element in the upper part of comparison matrix. The elements in the lower part of the matrix can be filled by taking the reciprocal of corresponding elements in the upper matrix. Having the weightage assigned to nine morphometric parameters using FAHP which are 0.238 for Relief (H), 0.184 for the length of overland flow, 0.189 for drainage density, 0.126 for mean bifurcation ratio, 0.080 for stream frequency, 0.054 for texture ratio, 0.049 for elongation ratio, 0.045 for circulatory ratio and 0.030 for form factor as presented in Table 4. The final priority of each sub-watershed is computed using normalized values of morphometric parameters and their respective weightage.

Table 3. Pairwise comparison matrix.

	R	**L_o**	**D_d**	**R_{bm}**	**N_f**	**T**	**R_e**	**R_c**	**R_f**
R	1	2	2	2	3.03	4	4	4	5
L_o	0.5	1	1	2	3.03	3.03	4	4	5
D_d	0.5	1	1	2	3.03	4	4	4	5
R_{bm}	0.5	0.5	0.5	1	2	3.03	3.03	3.03	4
N_f	0.33	0.33	0.33	0.5	1	2	2	2	3.03
T	0.25	0.33	0.25	0.33	0.5	1	1	2	2
R_e	0.25	0.25	0.25	0.33	0.5	1	1	1	2
R_c	0.25	0.25	0.25	0.33	0.5	0.5	1	1	2
R_f	0.20	0.20	0.20	0.20	0.33	0.5	0.5	0.5	1

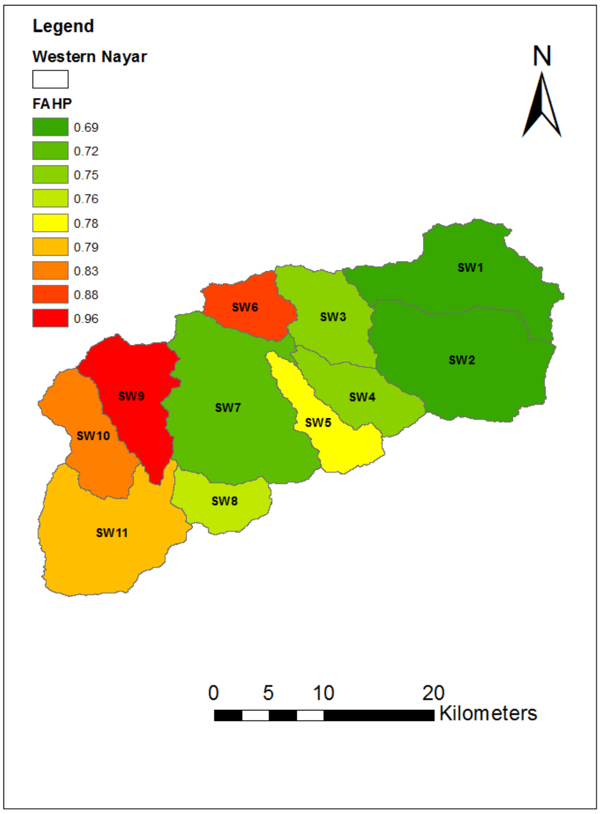

Fig. 4. The prioritized map of sub watersheds of eastern Nayar watershed.

Table 4. Weightage values for nine morphometric parameters.

Morphometric parameters	**R**	**L_o**	**D_d**	**R_{bm}**	**N_f**	**T**	**R_e**	**R_c**	**R_f**
Weight (X_i)	0.238	0.184	0.189	0.126	0.080	0.054	0.049	0.045	0.030

Table 5. Normalization of morphometric parameters and priority assessment (Western Nayar).

Basin	**R 0.238**	**L_o 0.184**	**D_d 0.189**	**R_{bm} 0.126**	**N_f 0.0806**	**T 0.0548**	**R_e 0.0492**	**R_c 0.0455**	**R_f 0.030**	**Final priority**
SW1	0.668	0.844	0.861	0.539	0.714	0.466	0.53	0.609	0.28	0.690
SW2	0.697	0.783	0.933	0.413	0.625	0.28	0.639	1	0.418	0.692
SW3	0.893	0.984	0.746	0.539	0.389	0.285	0.865	0.829	0.756	0.752
SW4	0.743	0.833	0.875	1	0.370	1	0.587	0.756	0.337	0.751
SW5	0.740	0.812	0.903	0.909	0.769	0.933	0.546	0.536	0.297	0.784
SW6	1	0.747	0.982	0.909	0.606	0.636	1	0.926	1	0.881
SW7	0.690	1	0.727	0.670	0.666	0.368	0.731	0.634	0.540	0.725
SW8	0.691	0.844	0.861	0.909	0.625	0.666	0.618	0.902	0.378	0.767
SW9	1.51	0.878	0.823	0.8	1	0.823	0.515	0.707	0.370	0.969
SW10	0.946	0.730	1	0.8	0.8	0.7	0.649	0.756	0.418	0.831
SW11	0.872	0.822	0.875	0.625	0.952	0.608	0.701	0.658	0.5	0.792

The normalization of morphometric parameters for the prioritization of subwatersheds of Western Nayar using FAHP revealed final prioritization ranks (Table 5). The final priority map of the Western Nayar after calculating the final ranks is presented in Fig. 4. The decreasing order of priority of subwatersheds are SW-9(0.969), SW-6(0.881), SW-10(0.831), SW-11(0.792), SW-5(0.784), SW-8(0.767), SW-3(0.752), SW-4(0.751), SW-7(0.725), SW-2(0.692), and SW-1(0.690).

4 Conclusions

The present study shows the Geographical Information System (GIS) feasibility and Fuzzy Analytical Hieratical Process (FAHP) approaches in morphometric-based sub-watershed prioritization Mid-Himalayan watershed. Prioritization centered on FAHP assessment was investigated systematically, which plays a significant role in explaining the issue by integrating environmental resources-causing risk assessment parameters. This assortment could be a suitable and effective strategy for developing efficient, sustainable development and management practices, particularly in the conventional watershed prioritization approach. It has been identified in this study that the subwatershed, SW9, and SW6 fall into the top priority category; therefore, these sub-watersheds should be given preeminence for conservation by policymakers.

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Surface water quality of small rivers in the Ukrainian regions of right-bank Polissia

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Abstract. The quality of surface waters of small rivers of the Ukrainian regions of right-bank Polissia, belonging to the basin of the river Pripyat, was estimated. The study was conducted via systematic observations based on the ecological classification of surface water quality of land and estuaries of Ukraine, which includes a set of hydrophysical, hydrochemical, hydrobiological and other indicators, which were grouped into three blocks of indicators: salt composition of water; tropho-saprobiological (ecological-sanitary) block; specific substances of toxic action. The integrated (ecological) index was determined, by which the class and category of surface water quality were established. The results of observations on the quality of surface waters of the rivers of the Ukrainian regions of right-bank Polissia indicate their satisfactory condition. Surface waters, on average, correspond to the II class of water quality, and the worst - to the III class. Water protection measures have been proposed to improve the ecological condition of small river basins in specified region.

Introduction

Deteriorating ecological conditions of river systems in Ukraine, as a result of irrational use of water resources and technogenic impact, are an ever-present problem, a problem for present and future generations. The main sources of pollution of river basins are industrial and municipal waste waters, agricultural runoff, surface runoff and atmospheric precipitation [1; 2].

The growing anthropogenic impact on the environment, its pollution by industrial waste, leads a significant deterioration of the ecological conditions of all riplatter, the most vulnerable being small rivers, which are used primarily for communal, agricultural purposes and industrial purposes, while also being points of wastewater discharge. This leads to continuous deterioration of natural environment, especially that of river basins, as they undergo constant changes. This is primarily due to their intensive, irrational use. The quality of surface waters in both large and small rivers depends on the degree of their contamination by industrial waste and utilities, as well as surface runoff from settlements, industrial facilities, agricultural lands, etc. After all, small rivers create the preconditions for the zonal regularity of the formation of water resources of large rivers. Thus, the problem of pollution of small rivers and their hydroecological analysis are quite relevant today [3; 4].

The urgency of assessing the surface water quality of small rivers in the Ukrainian regions of right-bank Polissia stems from the high anthropogenic (industrial and agricultural) load on these ecosystems and continuous deterioration of surface waters quality there. In the basins of small rivers, the resilience of natural landscapes has decreased, and in most cases there is an ongoing decline of water quality from class I to class III. The current regulatory framework is not able to stop these processes; furthermore, when compared with similar regulatory framework of advanced European countries, it can be considered obsolete. In this regard, there is an urgent need to develop a new regulatory framework and, above all, to conduct immediate environmental assessment and establish new environmental standards for water quality of rivers belonging to the Ukrainian regions of right-bank Polissia. Creation of new framework will concentrate efforts of all subjects related to water management on development and implementation of new environmental measures addressing ecological status of rivers in the regions, while also establishing new scientifically based indicators of surface water quality, representative of river’s natural state [5; 6].

Monitoring environmental conditions of surface waters is one of the key tasks of the state’s environmental activities, calling for joint efforts and resources of neighboring states, aiming to preserve, rationalize use of surface waters, as well as facilitate mutual “integration” of national and international laws, standards, and allow for continuous international environmental cooperation. Therefore, it is necessary to conduct timely observations of the qualitative condition of the surface water of the river basins and to analyze and summarize information about the condition of water bodies and predict its changes [2; 7-9].

The purpose of this paper is to give assessment of the surface water quality of small rivers of the Ukrainian regions of right-bank Polissia (Vyzhivka, Turiya, Tsyr, Stokhid, Styr, Lypa, Prudnyk, Serna, Chornoguzka, Horyn, Putylivka, Sluch, Ubort, Uzh, Noryn).

Methods

The evaluation of ecological condition of water quality of rivers belonging to the Ukrainian regions of right-bank Polissia was carried out according to the «Methodology of ecological assessment of surface water quality by relevant categories» [10], that allows to compare water quality in individual bodies of water and in bodies of water situated of different regions, on the basis of uniform ecological criteria. It includes three blocks of indicators: block of salt composition (I_1), block of tropho-saprobiological (ecological-sanitary) indicators (I_2), block of indicators for specific toxic substances (I_3). Block indicators for salt composition (I_1) includes chlorides, sulfates, mineralization value. Block of trophic and saprobiological (ecological and sanitary) indicators (I_2) includes: suspended matter, nitrates, nitrites, ammonium nitrogen, phosphates, dissolved oxygen, hydrogen index – pH, chemical oxygen consumption, biochemical oxygen consumption for 5 days. Block of indicators of content of specific toxic substances (I_3), which has one (general iron) to eight components (general iron, copper, zinc, manganese, total chromium, phenols, petroleum products, synthetic surface active substances).

The average values for the three block water quality indices are determined by calculating the average number of categories for all indicators of specific block, the three worst values for the block are determined by the relatively worst indicator among all indicators of this block. The results of the environmental assessment are presented in the form of a combined value, which is based on the final figures in the three blocks. Conducting a combined water quality assessment for a particular water body as a whole, or for its individual parts, is a prerequisite to determine an integrated environmental index (I_E) of said body.

An integral (ecological) index (I_E) is calculated using values of block indices to determine the class and water quality category. The procedure for determining the categories of water quality according to the ecological classification for each hydrochemical indicator by average values allowed the absolute quantitative values to be converted into unified, integral indicators of water quality (indices, categories, subcategories, classes), which reflect the essence of the process. This one the changes in the conditions for the formation of water quality under the influence of anthropogenic factors were fixed by the indices, and were defined boundaries of fluctuations of ecological indices of water objects which have important for the decision of issues of water management, implemetation of environmental protection and restoration measures (Fig. 1).

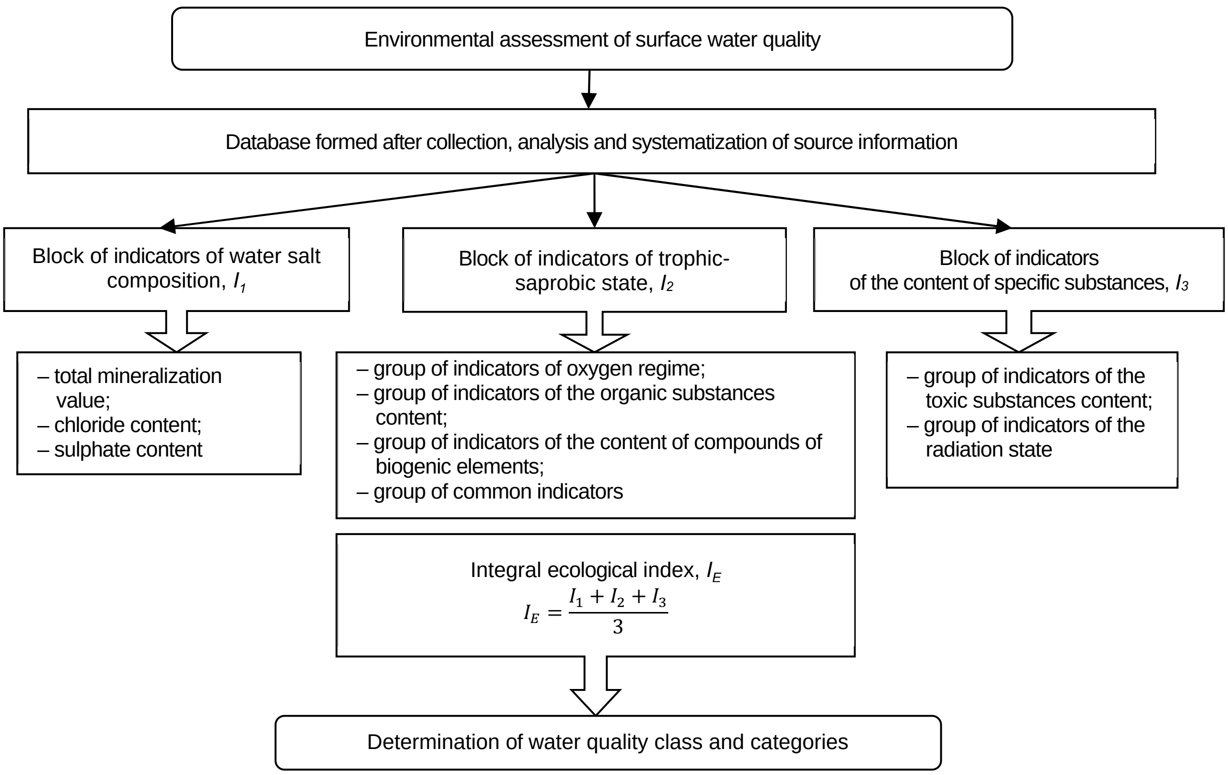

Fig. 1. Flowchart of the environmental assessment of the surface of small rivers belonging to the Ukrainian regions of right-bank Polissia.

The condition of small rivers belonging to the Ukrainian regions of right-bank Polissia was studied by us during 20-year period, from 1999 to 2019. Resulting materials include statistical and cartographic data on the ecological condition, use of land and water resources in small river basins.

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Assessment of water quality by salt composition (I_1) in selected sections of rivers of the studied basins included evaluation of river water quality by examination of their levels of mineralization, chlorides, sulfates and determination of ionic composition of river waters. For this purpose, according to «Methodology…» [10], a list of the following classifications was used: classification of surface water quality according to mineralization criteria, surface water quality classification according to ionic composition criteria, fresh hypo- and oligogaline water quality classification according to salt composition pollution criteria.

Assessment of water quality of the tropho-saprobiological block (I_2) was conducted using hydrophysical, hydrochemical parameters and saprobity indices. The end result of the assessment is the determination of trophic and saprobity zones of waters according to the ecological classification of surface water quality according to tropho-saprobiological criteria [10].

In «Methodology…» [10] when testing the water for specific toxic substances, the quantitative characteristics of 10 metals, as well as fluorides, cyanides, petroleum products, volatile phenols and synthetic surfactants, a total of 18 elements was screened for. However, the available information does not allow to give a sufficiently objective evaluation of the water quality of the Ukrainian regions of right-bank Polissia according to the criteria for toxic substances. Therefore, the following materials should be considered as indicative, and need further supplementation and clarification.

Calculated values of integral ecological indices (I_E) were compared against the environmental classification, with qualitative condition of water and the class and category of its quality being determined. In general, water quality is divided into five classes, which are accepted in many European countries. These classes have certain characteristics and a corresponding colour of the designation, which allows to clearly illustrate the ecological condition of the reservoir (table 1).

Table 1. Classes and categories of surface water quality according to the ecological classification [13].

Value of indicator I_E		1.0–1.50	1.51–2.50	2.51–3.50	3.51–4.50	4.51–5.50	5.51–6.50	6.51–7.00
Water quality classes and categories by their natural condition	class	I	II		III		IV	V
		excellent	good		satisfactory		bad	very bad
	category	1	2	3	4	5	6	7
		excellent	very good	good	satisfactory	mediocre	bad	very bad
Classes and categories of water quality by the degree of its cleanness (pollution)	class	I	II		III		IV	V
		very clean	clean		polluted		dirty	very dirty
	category	1	2	3	4	5	6	7
		very clean	clean	fairly clean	slightly polluted	moderately polluted	dirty	very dirty

Results

Rivers, together with their catchment areas, are complex interconnected systems. Any changes in the catchment area will inevitably lead to change in the river itself. As a result, all the main factors influencing catchment area of a small river (forest cover, wetlands area, humidity, percentage of arable land, presence of pollution, reclamation works, etc.) make it possible not only to evaluate the state of its ecosystem, but also to predict major trends in its development and determine the set of necessary measures that can improve water quality, environmental conditions of rivers and the state of coastal areas. Significant factors influencing small rivers are: presence of municipal, industrial and agricultural runoff. Their impact is rather dangerous, as in some cases the volume of runoff may be the same or even greater than that of a small river [9; 11].

The main ecological problems of small rivers of the Ukrainian regions of right-bank Polissia are: inflow of pollutants into rivers from the territories of settlements, industrial facilities and agricultural lands; soil erosion in the catchment areas; discharge of untreated and insufficiently treated wastewater into water bodies [3; 12].

Water quality assessment by indicators of salt composition (I_1). The formation of the chemical composition of the riverbeds of the rivers of the Ukrainian regions of right-bank Polissia takes place in conditions of excessive moisture, prevalence of carbonate-enriched Upper Cretaceous rocks and groundwater present in them, draining into riverbeds. This predetermines the hydrocarbonate-calcium composition of their waters: the relative concentration of HCO_3^- varies between 27-40% eq., And Ca^{2+} - 33-45% eq.

The salt composition of the water of small rivers of the Ukrainian regions of right-bank Polissia is formed in conditions of high humidity and presence of carbonate and gypsum rocks that form the basis of the catchment area. Therefore, the water of most rivers under natural conditions corresponds, according to the classification of O.O. Alokin, to hydrocarbonate class, calcium group oftype II-III, $C^{Ca}_{II\text{-}III}$.

The waters of the right tributaries of the Pripyat have an average mineralization (in the amount of ions) of 156-350 mg/dm3. In the waters of the main riverbed of the Pripyat and its tributaries, the content of chlorides is up to 30 mg/ m^3, sulfates - up to 50 mg/dm^3. On average, the waters of most rivers have low (200 mg/dm^3) and moderate mineralization (200-500 mg/dm^3). The increase in the amount of ions was observed only in places of discharge of insufficiently treated and untreated wastewater from municipal, industrial and agricultural facilities (Turiya, Kovel 424 and 514 mg/dm^3; Styr, Lutsk 400 and 480 mg/dm^3; Horyn River, below the discharge of WTP«Prolisok» 410-440 mg/dm^3; Ustya River, Rivne 702 mg/dm^3; Ubort River, Yemilchyne urban-type settlement 510 mg/dm^3).

On average, the water of the of small rivers of the Ukrainian regions of right-bank Polissia in terms of average and worst values of the sum of ions, belongs to category 1 "excellent" in class, "very clean" in degree of purity. It should be noted, that in areas where the highest values of the worst values of mineral content of water belong to category 2, which is caused by the anthropogenic activity.

The content of chlorides and sulfates depends on the natural conditions under which the chemical composition of water forms, as well as on the degree of intensity of anthropogenic activity in the catchment area. On average, in the Pripyat basin, the chlorides levels range from category 1 «excellent», «very clean», starting at the sources, to category 3 –«good», «fairly clean» in the middle reaches. With the exception of the waters of the rivers Ubort (Yemilchyne) and Noryn' (Ovruch), with average and worst chlorine ion content (97.2-143.0 and 79.8-104.5 mg/dm^3, respectively) classified as category 4 («satisfactory», «slightly polluted» waters), which is caused by the discharge of insufficiently treated wastewater from municipal enterprises of the urban-type settlement of Yemilchyne and city of Ovruch.

As for sulfates, according to the average and worst values of this indicator, the waters of the rivers of the Ukrainian regions of right-bank Polissia are in between 1 and 2 quality categories and varies from «excellent», «very clean» to «very good», «clean».

Evaluation of situation in the water bodies of the Ukrainian regions of right-bank Polissia by the criteria of pollution by components of the salt composition indicates that situation is quite good. The calculated indices of salt composition (I_1) indicate that the water of the main riverbed of the Pripyat on the average and worst values of I_1 is characterized as «excellent», «very clean» ($1{,}0 \leq I_1 \leq 1{,}3$), «very good», «clean» water ($1{,}7 \leq I_1 \leq 2{,}0$). There is only some deterioration in the water quality of the Ubort and Noryn' rivers, where the indices are in the 1,7-3,0 and 2,0-2,7 ranges respectively. That is, water quality varies from «very good», «clean» to «good», «fairly clean» (table 2).

Table 2. Water quality assessment of small rivers of the Ukrainian regions of right-bank Polissia according to the worst and average values of block indices (I_1, I_2, I_3)

№	River*	The value of indices					
		I_1		I_2		I_3	
		avg.	max.	avg.	max.	avg.	max.
1	Pripyat	1,0	1,3	4,6	5,3	3,5	4,5
2	Vyzhivka	1,0	1,7	4,8	5,5	3,4	4,6
3	Turiya	1,0	1,3	4,8	5,2	3,9	5,0
4	Tsyr	1,7	1,7	4,8	5,3	3,3	4,6
5	Stokhid	1,3	1,3	4,1	4,9	3,0	4,7
6	Styr	1,3	1,3	4,7	5,2	3,9	5,0
7	Lypa	1,3	1,7	4,6	4,9	2,2	3,5
8	Prudnyk	1,0	1,0	4,9	5,2	3,5	4,8
9	Serna	1,0	1,0	3,8	3,9	2,2	3,0
10	Chornoguzka	1,3	1,3	4,0	4,0	2,1	2,5
11	Horyn	1,3	1,3	4,6	4,8	2,2	3,9
12	Putylivka	1,3	1,7	4,4	4,9	2,7	3,6
13	Sluch	1,3	1,7	4,1	4,7	3,3	3,4
14	Ubort	2,0	2,3	4,4	4,8	-	-
15	Uzh	1,7	2,0	3,7	4,3	4,6	5,0
17	Noryn	2,0	2,7	4,8	5,0	3,0	3,2
On average in the river basin		1,3	2,0	4,4	4,8	3,1	4,1

Note: * - on average along the river. I_1 – block index of salt composition; I_2 – block tropho-saprobiological index; I_3 – block index of specific toxic substances; I_E – ecological water quality index.

Water quality assessment by tropho-saprobiological (sanitary and hygienic) indicators (I_2). The water quality of small rivers of the Ukrainian regions of right-bank Polissia, assessed by the worst values of tropho-saprobiological indicators, belonged to category 5, subcategory 5(6), i.e. eupolytrophic waters with slant to polytrophic waters of ά'-mesosaprobic and ά''-mesosaprobic zones. The water quality evaluated by the average values of the same indicators, belonged to subcategory 4-5, i.e. in the transitional state from eutrophic to eupolytrophicwaters of the transitional β''-mesosaprobic to ά'-mesosaprobic zone.

The waters of small rivers of the Ukrainian regions of right-bank Polissia as a whole are also assigned quality category 5 «mediocre», «moderately polluted», but if they are evaluated by the worst values of the indicators they would unconditionally belong to the eupolytrophic waters of the ά'-mesosaprobic zone, while judging by the average values of these indicators - to the eupolytrophic waters with a slope to eutrophic waters of the ά'-mesosaprobic zone with a slant to β''-mesosaprobic zone. That is, within the 5th category of water quality, these rivers vary only by some differences in the worst and average values, expressed at the subcategory level.

Overall, the water quality in the rivers of small rivers of the Ukrainian regions of right-bank Polissia, assessed according to tropho-saprobiological criteria, corresponds to class III («satisfactory», «polluted»). The main reason for the current state of the rivers is the excessive content of nitrogen and phosphorus compounds in the water, i.e. intensive eutrophication (table 2).

Water quality assessment by indicators of specific toxic substances (I_3). The index of specific toxic substances (I_3) indicate a considerably high levels of pollution of the waters of the rivers of small rivers of the Ukrainian regions of right-bank Polissia by specific toxic substances. The value of I_3 for the Pripyat River varies in the range of 4,4-5,2 by its worst value («satisfactory», «slightly polluted», - «mediocre», «moderately polluted» water), and the average - 3, 1-3.7 («good», «fairly clean» - «satisfactory», «slightly polluted»). According to the worst values of this index, the water of the Pripyat basin corresponds to the III class of quality «satisfactory», «polluted», and according to the average - II-III class and is assessed as «good», «fairly clean» - «satisfactory», «slightly polluted».

The waters of the rivers Vyzhivka, Turiya, Tsyr,Stokhid, Styr, Prudnyk, Uzh have the highest average and worst values of I_3: the worst values (I_3 = 4,6-5,0, category 5, subcategories 4-5 and 5) is graded as «mediocre», «moderately polluted», class III quality «satisfactory», «polluted» water, and its average value (I_3 = 3,0-3,9, categories 3 and 4) as «good», «fairly clean» - «satisfactory», «slightly polluted», II-III class «good», «clean» - «satisfactory», «polluted» (table 2).

The rivers Horyn and Putylivka have the same characteristics (average values I_3 = 2,2-2,7, the worst values I_3 = 3,6-3,9). The water quality of these rivers corresponds to 2 and 3 categories, subcategories 2 and 3(2) with average values of I_3 and 4th category, and subcategories 3-4 and 4, by the worst, II and III quality class, «good», «clean» and «satisfactory», «polluted».

The waters of the rivers Sluch, Noryn' (Ovruch) and Ubort (Perga) are in the categories«good», «fairly clean» (category 3) and «satisfactory», «slightly polluted» (category 4), and by class quality–«good», «clean» (class II) and «good-satisfactory», «clean-polluted» (class II-III).

The waters of Chornohuzka and Serna (I_{3avg} = 2,1 and 2,2, category 2, I_{3w} = 2,5 and 3,0, category 3, respectively) are graded (by the value of the index of specific toxic substances) as the cleanst.

At 17% of the study sites located in the Pripyat basin, the index of specific toxic substances (I_3) was calculated only by determining the total iron content in river waters. Therefore, it makes no sense to use such insignificant information to calculate the integrated index of specific toxic substances.

Limited data available from field experiments in the block of specific toxic substances made it possible to determine only an approximate grade for water quality. The results displayed a tendency to reduction of anthropogenic impact on water by such compounds as iron and chromium, although the nickel content of water deteriorated from categories 2 and 4 to category 5 by average and the worst indicators. On average, the quality of water in the region has improved, in regards to pollution with specific toxic substances, as according to the average and worst indicators it has «appreciated»from categories 4 and 5 to category 3, quality class II, water «good», «clean».

Integrated environmental assessment of surface water quality (I_E). The essence of determining the joint grade of water quality in the of small rivers of the Ukrainian regions of right-bank Polissia as a whole and at individual observation points is to calculate the integrated ecological index (I_E), according to which, an unambiguous assessment of river water quality is performed. It is calculated for the average and worst values of block indices for individual items and on average for rivers (table 3). The analysis of calculations indicates that the values of integrated indices (I_E), calculated using average and worst values of block indices are: on the rivers of Pripyat – 3,0/3,7; Turiya – 3,2/3,8; Tsyr– 3,3/3,9; Stokhid – 2,8/3,6; Styr – 3,3/3,8; this classifies the waters of these rivers as intermediate between categories 3 and 4 «fairly clean» and «slightly polluted».

According to the water quality class of the main riverbeds of Pripyat, Turiya, Tsyr, Stokhid, Styr, Horyn, Sluch, Uborta, Noryn are rated as «good», «clean» and «satisfactory», «polluted».

During the study period, the best quality of water from the tributaries of the Pripyat according to the I_E came from the rivers Chornohuzka ($2,5 \le I_E \le 2,6$), Serna ($2,3 \le I_E \le 2,6$), Sluch ($2,5 \le I_E \le 3,3$), and Pripyat ($2,3 \le I_E \le 2,5$), and the worst quality in terms of these indices - rivers Vyzhivka ($3,1 \le I_E \le 3,9$), Tsyr ($3,1 \le I_E \le 3,9$) and Uzh ($3,7 \le I_E \le 3,9$). The waters of these tributaries belong to the II class according to the average and to the III class - according to the worst characteristics of I_E.

Thus, condition of water bodies in the basin of the Pripyat River has improved according to the worst indicators from class III «satisfactory», «polluted» to class II water «good», «clean».

Proposals that will help improve the ecological condition of water resources: 1) reconstruction of existing and construction of new treatment facilities; 2) termination of untreated effluents discharges into rivers; 3) strict following of current water protection legislation by all water users.

Conclusion

The results of observations on the quality of surface waters of small rivers of the Ukrainian regions of right-bank Polissia indicate their satisfactory condition. Water corresponds to the II-III class of water quality. Exceeding the MPC (Maximum Allowable Concentration) in the surface waters of small rivers of the Right Bank Polissia was recorded by tropho-saprobiological indicators. This is due to the high anthropogenic load in river basins, in particular discharges of insufficiently treated wastewater.

Table 3. Combined water quality assessment of small rivers of the Ukrainian regions of right-bank Polissia according to the worst and average values of the integrated ecological index (I_E)

№	River*	I_E		Grage by class		Degree of purity	
		avg.	max.	avg.	max.	avg.	max.
1	Pripyat	3,0	3,7	good	satisfactory	pure	polluted
2	Vyzhivka	3,1	3,9	good	satisfactory	pure	polluted
3	Turiya	3,2	3,8	good	satisfactory	pure	polluted
4	Tsyr	3,3	3,9	good	satisfactory	pure	polluted
5	Stokhid	2,8	3,6	good	good -satisfactory	pure	pure - polluted
6	Styr	3,3	3,8	good	satisfactory	pure	polluted
7	Lypa	2,7	3,4	good	good	pure	pure
8	Prudnyk	3,1	3,7	good	satisfactory	pure	polluted
9	Serna	2,3	2,6	good	good	pure	pure
10	Chornoguzka	2,5	2,6	good	good	pure	pure
11	Horyn	2,7	3,3	good	good	pure	pure
12	Putylivka	2,8	3,4	good	good	pure	pure
13	Sluch	2,9	3,3	good	good	pure	pure
14	Ubort	3,2	3,5	good	good -satisfactory	pure	pure - polluted
15	Uzh	3,3	3,8	good	satisfactory	pure	polluted
17	Noryn	3,3	3,6	good	good -satisfactory	pure	pure - polluted
On average in the river basin		3,0	3,7	good	satisfactory	pure	polluted

Determining the water quality of small rivers is important for assessing the ecological situation of bodies of water of the Ukrainian regions of right-bank Polissia, and main areas of water protection activities to improve the ecological status of each water body, as well as establishing environmental standards for water quality. Environmental assessment of the river water quality is important for generalizing information on the ecological condition of water bodies, forecasting its changes and developing scientifically based water protection recommendations for approving appropriate management decisions in the field of use, protection and reproduction of water re-sources. All this determines the prospect of further studies on the quality of surface waterof of small rivers of the Ukrainian regions of right-bank Polissia.

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Intensifying agricultural crops production by means of thermal reclamation

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Abstract. The use of surface heating with heat exchangers significantly affects the temperature regime of the soil and the surface air layer. It is manifested in a change in the distribution of temperatures according to the soil horizon, in a considerable increase in the temperature of the soil and air, in a change of heat exchange between the soil and the surface layer of air. When using tunnel greenhouse, heating the soil with the coolant temperature of 25…30 ºC contributes to the creation of all necessary conditions in ground area equipped with a heat exchangers for shifting the vegetation period of ultra-early cultivation of agricultural crops, on average, by 1-2 months depending on the crop type. This allows for earlier sowing and planting of thermophilic crops and getting harvest earlier than usual, as well as increasing the amount of crop production and improving its quality. The thermal efficiency of soil heating with water-filled flexible sleeves was studied experimentally in a field model experiment performed in the climatic terms of the Ukrainian Polissya on sandy loam and chernozem soils. Strawberry of the "Festivalny" type was used as the main crop-indicator. The influence of soil heating with heat exchangers on the growth, development and yield of strawberries has been studied.

1 Introduction

The problem of getting early and permanent yields of agricultural crops, particularly vegetables and berries; flowers of saleable quality is one of the major socio-economic issue in agriculture of many countries. Climate change and weather conditions, which are becoming unpredictable, exacerbate the urgency of the problem. In the generally accepted tendency of global warming, experts also pay attention to the possibility of local temperature decreases in some areas, prolonged cold periods in spring, considerable fluctuations of weather conditions [1-4].

Studying the influence of possible climatic and weather changes on the development and productivity of agricultural crops production and developing measures to prevent the negative climatic and weather phenomena are becoming relevant in agriculture not only for researchers but also for professional practitioners

The role of climate in improving soil fertility is well-known, scientists have even introduced a concept "agricultural fertility of the climate" as the ability of the atmosphere and the underlying surface to provide a certain level of soil fertility and agricultural crops yield through climatic resources. It is thus emphasized that the soil properties, its natural and effective fertility are manifested only in the presence of certain amount of moisture in the soil and at a certain thermal regime [5-7].

Thermal resources play a significant role in yield formation. Each plant has its own strictly individual thermal-temporal structure of the development cycle from sowing to harvesting. The parameters of this cycle are strictly related to the corresponding level of temperatures in the soil and air. Therefore, purposeful control of plant ontogenesis can be possible by controlling the thermal regime of the microenvironment of its habitat. It is obvious that the thermal regime of the soil and the surface layer of air will be also decisive for the intensification of the processes of growth and early cultivation of crops.

The analysis of meteorological observations in the Ukrainian Polissya shows that the danger of low temperatures persists at night and in the early morning hours practically throughout the entire spring period. For instance, the frosts up to -10ºC took place daily until March, 25, the transition of minimum air temperatures to more than -10ºC took place on April, 10. During April, nighttime sub-zero temperatures of air persist. Even in April, the air temperature drops to -1 ºC [8, 9].

These features of temperature conditions of the Ukrainian Polissya do not allow the active vegetation to begin in March-April, especially for thermophilics crops, and force to postpone the active soils use to May. The task of heat supply for crop production in the early spring periods is traditionally solved by creating greenhouse facilities and by heating the soil. Thus, high-temperature sources of thermal energy are used for heating the soil and air in cultivation facilities, which are obtained by burning high-value fuels, primarily natural gas.

Significant increase in the price of natural fuels and thermal energy puts on the agenda the tasks of finding, justifying and developing alternative ways to regulate the thermal regime of the soil and air, sources of alternative

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energy with the purpose of getting early harvests of agricultural crops.

2 Materials and methods

One option for solving this problem can be creation of soil areas heated by special thermal reclamation facilities using thermal wastes from industry. Hot water (heat-exchange water) from industrial and power-generating facilities with the temperature of 20-40 ºC and geothermal water can be used as attractive free sources of thermal energy [6, 10-12]. Their attractiveness is that such temperatures are optimal for the development of most crops.

In the 80s of the last century in many developed countries of the world, in the USA, France, Germany, the former Soviet Union, and in particular at our National University of Water and Environmental Engineering, long-term researches of the efficient use of the charged hot water from nuclear power plants and thermal power plants for heating the soil by the pipeline systems were conducted [13-23]. The pipeline systems showed sufficient efficiency in increasing the productivity of separate agricultural crops and enabling earlier harvesting. However, their thermal efficiency in relation to the surface layer of air was low (0,5…1,5 ºC), which did not allow them to find wide application as an effective method of heating reclamation, except for some engineering problems (cooling of water in soil, accumulation of heat in the soil, heating of sports grounds, etc.).

One of the promising and effective methods of thermal reclamation of adjacent areas, in our view, can be the surface heating of soil with warm water with the temperature parameters within 25…35 ºC.

The working scientific hypothesis is that the maximum thermal effects when using water with such temperatures should be expected with directing the water flows to the area of plants habitat. The transfer of thermal resource in the amount of 15…20 ºC to the environment "soil – air" will theoretically allow shifting the transition through 10ºC to the end of February – beginning of March (fig. 1).

Technologically, this technique can be implemented by directing the water flow in a thin layer on the soil surface, and can be technically executed with the application of special sleeves – heat-exchangers of various designs and geometry, made of thin, long lasting, flexible polymeric materials – films (fig. 2).

The thermal efficiency of soil heating with water-filled flexible sleeves was studied experimentally in a field model experiment performed in the climatic terms of the Ukrainian Polissya on sandy loam and chernozem soils [24-25]. Strawberry of the "Festivalny" type was used as the main crop-indicator. The soil was heated with specially heated warm water, which circulated by gravity-flow under a small initial pressure (10...20 cm) (fig. 2). The temperature of water in the sleeves was automatically maintained within 24…26 ºC in March with a subsequent increase in April and May up to 27…30 ºC.

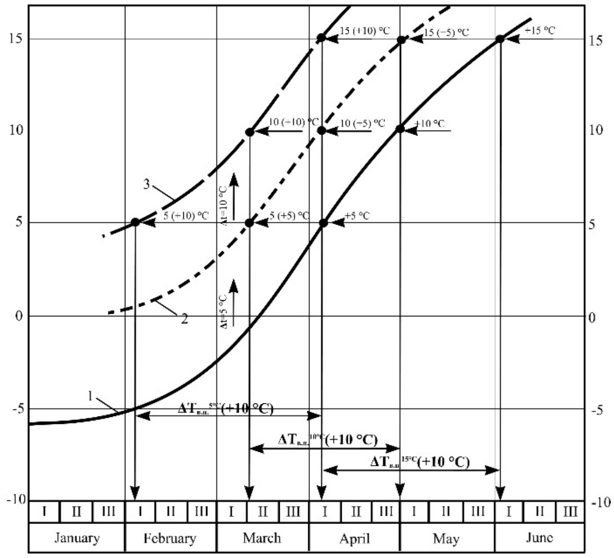

Fig. 1. Forecast of the efficiency of heat reclamation for the conditions of Ukrainian Polissya: 1 – average ten-day long-term temperatures of the surface air layer (Rivne); 2 – increased air temperatures by 5°C; 3 – increased air temperatures by 10°C.

Fig. 2. A general view of heat-exchanger with plants.

The temperature of the soil, air and water circulating in heat-exchangers was measured by precise laboratory meteorological mercury thermometers, by Savinov thermometers to the depth of 20 cm, by buried thermometers in depth, electric thermometers, and aspiration psychrometers. In the experiment, part of the heated adjacent areas was additionally protected by tunnel

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type film greenhouse (Fig. 2). For this purpose, polyethylene film with the thickness of 150 mkm was used. The water was heated by an automatic water heating device, the heated water supply was regulated by dampers and valves.

3 Results and discussion

The initial stage of soil heating by heat-exchangers was studied by us since March, 12, 2009 during two weeks. All parameters were measured twice a day at 7:00am and 7:00pm. The basic results of measuring the temperature of soil, water and air, are shown in Figure 3. An open heated ground in natural conditions was taken as a control option.

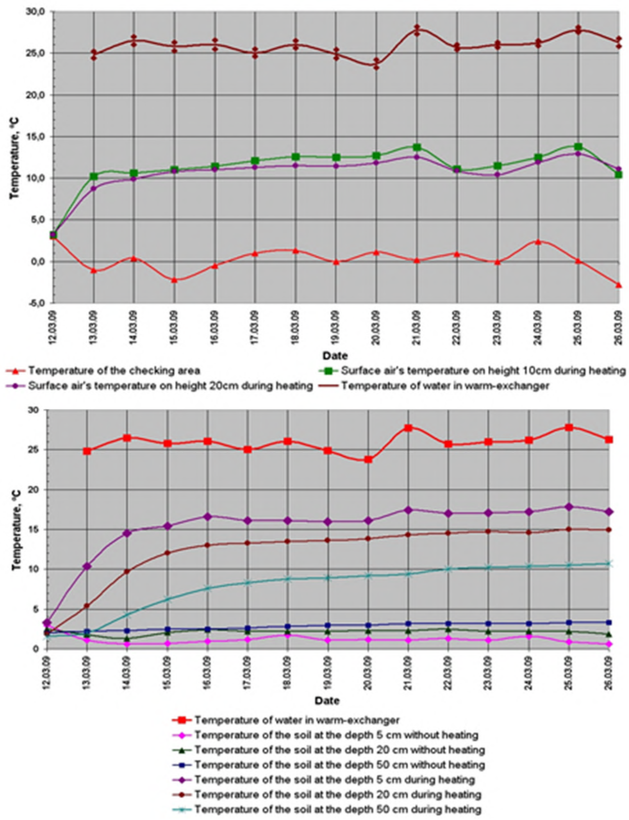

Fig. 3. The research results of surface air (A) and soil (B) temperature in March 2009.

The research results show that surface heating is an effective technical method of thermal reclamation of the plants habitat, which makes it possible to quickly and reliably increase the temperature of the soil and the surface air when using a film cover. On the third day of operation of heat exchangers, the temperature in the upper 20 cm soil layer rose to 10…14ºC. At the same time, due to the heat flow from the surface of heat exchangers upwards, the surface air layer warmed up to 8…11 ºC.

On the fourth-fifth day of the heating system operation, favorable temperature conditions were created at the level of 14…16 ºC in the upper 20 cm layer of soil and about 10…12 ºC in the surface layer of air, which were constantly preserved even on cloudy and frosty days. Therefore, heating with heat exchangers, which is very important, is guaranteed to maintain the positive air temperature at night and protect plants from frost.

The soils temperatures obtained as a result of constant heating (14…16 ºC) promote the germination and development of most vegetable and berry crops, even thermophilic ones. In this case, under natural conditions, soil and air temperature remain very low, varying from - 2 ºC to +3 ºC. The whole period of observations of the soil in natural conditions remained unprepared for agricultural use due to low temperatures. It should be noted that at this time there was precipitation in the form of snow and cold rain. The snow that fell remained on the surface of the control area, while on the surface of the film cover it melted and turned into water.

Heat-exchangers constantly consumed thermal energy, and consequently water cooled down. As a result of measurements and calculations of thermal energy, its consumption amounted to 700-800 Wt/h or 200-220 Wt/h per one square meter of soil which was heated, and water in the sleeves cooled down by 0,6...0,9 ºC.

Observations of the soil temperature have shown that the effect of heating extends to a considerable depth. Thus, according to the results of measurements in 2009, the soil temperature at a depth of 1 m under heat exchangers after two weeks of their operation rose to 6.4 ºC, while in the control area it amounted to 4 ºC (table 1).

Obviously, soil heating can be carried out at the depth of 2m and more. In this case, an array of heated soil is created under the heat exchanger, accumulating significant reserves of thermal energy. This reserve of thermal energy guarantees the protection of the upper root layer of the soil from penetration of negative temperatures from the lower soil layers.

Table 1. Temperature of the soil in the area that is heated and in the control area in different points of the soil profile, ºC (of March 26, 2009 at 7:00 am).

Depth, cm	Control area	Heated Soil
0.0	-0.3	15.4-22.8*
5.0	0.6	17.5
10.0	0.8	17.2
15.0	1.6	16.8
20.0	1.9	15.8
30.0	2.7	13.5
40.0	3.0	11.8
50.0	3.3	10.7
60.0	3.4	9.7
80.0	3.6	7.5
100.0	4.0	6.4

*Note: lower value corresponds to the soil temperature at input of the heat exchanger, higher one – to the temperature of the soil above the heat exchanger.

Great importance in assessing the temperature of the heated soil is attached to the peculiarities of its formation during the vegetation period (March-May), as well as during the day. According to the results of our research in 2004-2013, conducted on sandy loam soils of the Ukrainian Polissya, the influence of the surface heating is more noticeable in cold periods (March, April). The constant inflow of heat from the heating system prevents penetration of negative temperatures into the soil and maintains the temperature background in the habitat of plants at the levels close to optimal [6, 11, 26].

The temperature regime of the soil in the daily cycle, due to the frequency of receiving solar heat, is characterized by a slow change of temperature values from maximum to minimum, which changes with time and depth.

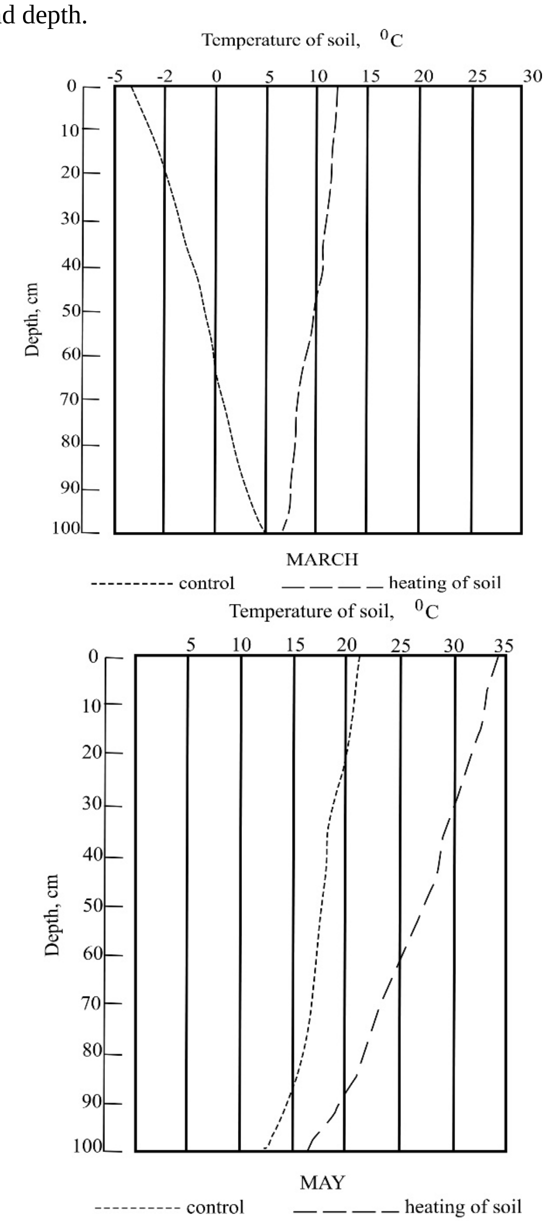

Fig. 4. Profile changes of average monthly soil temperatures in 2009.

In the course of our research it is found out that the general nature of temperature changes during the day, both in the heating section and in the control one it remained the same. For example, the maximum temperatures of soil at the depth of 5 cm for the heated area are reached at 4:00pm…6:00pm and are within 27…29 °C, while in the control area – at 5:00-6:00pm reaching the temperature 18…19°C. The minimum soil temperatures are observed in the heated area at 7:00-8:00am and are 19…20°C, and in the control area they reach 12…13°C at the same time. The process of heat exchange in the "soil-air" system and the direction of heat flows depend on the thermal gradient conditions in the soil. The heated soil is characterized by the presence of maximum temperatures in the area where heat exchangers are located (surface soil), therefore, the dynamics of merging gradients and their type of movement must be investigated for a considerable soil layer (fig. 4) [6, 27-28].

In March, 2009, soil temperature at the depth from 0 to 20 cm in the control area was below zero, while in the heated area it reached 11…13 ºC. In the layer from 20 to 80 cm, the temperature of control soil changed from 0,5ºC to 3.5 ºC, and in the heated area it ranged from 8ºC to 11ºC.

A completely different picture is observed in May. For example, in the soil layer ranging from 0 to 20 cm in the control area, the temperature is 20…21 ºC, and in the heating area – 31…34ºC. In the layer from 20 to 80 cm in the control area, the soil temperature is 16…20 ºC, and in the heating area – 26…32ºC.

Although heating with heat exchangers using warm water cannot create optimal temperatures in the upper soil layer immediately after starting the system, but in late March and early April contributes to its increase by 10°C and more, and in mid-April – by 15ºC and more. At the control site, the temperature reaches 10ºC in late April, and 15ºC in mid-May.

The increase in periods of soil heating and increase in absolute temperatures during these periods result in the increase in the sum of soil temperatures during vegetation period (table 2).

Table 2. The sum of soil temperatures more than 5, 10, 15 and 20 ºC at the depth of 20 cm, ºC

Temperature, °C	Heating with heat exchangers	Control
5	8125	6348
10	7240	5886
15	6430	4522
20	4055	1925

The obtained results demonstrate that from the point of view of positive temperatures accumulation, the option of soil heating with heat exchangers with the use of greenhouses provides very effective heat reclamation method.

The difference in sums of soil temperatures at the depth of 20 cm as compared to control area are more than 2000ºC.

As our research has shown for the heated soil, the relationship between its temperature (Y) at the depths of 5, 10, 20 cm, air temperature (X) and water temperature in heat exchanger (Z), can be described by the following empiric equations (for values of Z > 20 ºC):

$$Y_{0.05} = X + 0.14 \times Z - 0.48; R_{xyz} = 0.95 \quad (1)$$

$$Y_{0.1} = X + 0.15 \cdot Z - 1.76; R_{xyz} = 0.95 \quad (2)$$

$$Y_{0.2} = X + 0.12 \cdot Z - 2.4; R_{xyz} = 0.95 \quad (3)$$

When using tunnel type greenhouses, soil heating with heat exchangers with water temperature of 25…30 ºC helps create all the necessary temperature conditions for shifting the vegetation period and early growth of agricultural crops, on average, from one to two months depending on the type of crop.

The moment that determines the beginning and suspension of active vegetation of plants is the date of transition of air and soil temperature through 10 ºC. With the onset of the dates of temperature transition through 10ºC, the same patterns appear along with the beginning of active temperatures period. In the area of heating by heat exchangers, the date of temperature transition through 10ºC in the soil at the depth of 20cm in 2009 fell on April 1, and in the control area – on April 22, that is 21 days earlier.

It is known that the criterion for assessing the effectiveness of any measures, including heat reclamation is the yield of crops. As a result of application of surface heating in a root-containing layer, there is a change of a whole complex of processes which, in the end, influences the growth, development and formation of crops.

We studied the effect of surface heating on the growth and development of the “Festivalny” strawberry type. The results of observations during March-May 2009 showed that the first leaf on the strawberry appeared on March 19 and at the same time it increased the appearance of the second leaf, and the third one appeared on March 23. Strawberries beginning of stolon (runner) formation in the area of soil heating on April 3 (code 41 according to the BBCH-scale of strawberry) [29], and on April 6, 5 flowers appeared and mass flowering began on April 9 and lasted throughout the second decade of April. Mass bud forming of strawberries was observed on April 21, and the first crop of ripe berries was harvested on April 25.

The dynamics of the strawberry harvest during the study period is presented in Table 3.

Table 3. Dynamics of strawberry crop yield.

Date	**The mass of berries, g**	**The average weight of 1 berry, g**	**crop yield**	
			g / m^2	**g / meter of heat exchanger**
25.04.2009	145,41	13,10	22,37	5,59
01.05.2009	475,45	14,28	73,15	18,29
06.05.2009	4754,5	16,06	731,46	182,87
08.05.2009	3670,77	13,97	564,73	141,18
10.05.2009	5306,17	13,04	816,33	204,08
13.05.2009	6716,24	13,86	1033,27	258,32
15.05.2009	3571,61	12,38	549,48	137,37
19.05.2009	2096,42	11,80	322,53	80,63
21.05.2009	1001,22	11,28	154,03	38,51
25.05.2009	645,65	11,63	99,33	24,83
Sum	**28383**	**13,14**	**4366,68**	**1091,67**

4 Conclusion

Field research has shown that heating the soil with heat exchangers circulating hot water with the temperature of 25...30°C increases the temperature of the arable layer by 12...16°C in the soil, and by 7...12°C – in the air, which provides sufficient conditions for plant growth and development in early spring.

It is proved that heating with heat exchangers allows the period of active soil use to start earlier in the spring by 40-60 days for sheltered soil, and also increases the amount of positive temperatures in the arable soil layer during the spring period by 1500 ... 2000°C. Close linear relationships are established between the temperatures of soil, air and water in the sleeves.

It is established that the joint action of surface heating and solar radiation during the day leads to a rapid increase in air temperature and the need for ventilation of tunnel greenhouses. Intense ventilation leads to the loss of moisture that evaporates from the plants and drying of the upper 10-cm layer of soil, which causes the need to replenish moisture in the soil during the increase in strawberry yield. It is recommended to carry out two or three waterings in late April and early May at the rate of 150-200 m^3/ha.

The influence of soil heating with heat exchangers on the growth, development and yield of strawberries has been studied. Under the conditions of soil heating, ripening of strawberry berries occurs to about 40 days earlier than in the control area without heating, the total yield increases due to heating by 50% or more when compared to the control area.

Assessment of the introduction of surface heating technology for soil on the area of 1 hectare as an innovative project based on the methodology for assessing net discounted income gives a net discounted income of 32 thousand dollars when growing strawberries. The payback period for capital investments does not exceed 3 years.

At the same time, a number of scientific problems need further research, in particular the issues of rational designs of surface heating systems, heat exchangers, methods of soil protection and structures of greenhouses (translucent shelters), water supply and collection regimes, methods of soil water regulation [30], automation, control and management, operation of heating systems and ventilation systems of greenhouses, technologies of cultivation of agricultural crops, development of methods of thermotechnical and hydraulic calculation, methods of technical operation, etc.

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Principles of creating a system of sustainable water use in Ukraine

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Abstract. This research focuses on the problem of water supply, and its solution requires scientific and practical approaches in environmental, engineering, economic and other fields. Practical recommendations to create an integrated water use system in Ukraine are based on the delimitation of its target subsystems. Special attention is paid to an integrated approach to water resources management, identification of key issues, clear conceptual modeling, strategy development, and production of 'useful' scientific information. It is important to study the role of coordinating government bodies in the field of water space monitoring. In particular, this mechanism involves the development of national program for monitoring the aquatic environment, the formation of budgets of all bodies and institutions; search for additional sources of funding and organizational methods. An important tool for improving the state of water resources is the implementation of international environmental standards and conventions. These strategic decisions are entrusted to the Ministries of Environment and other governing bodies. The use of software products generate significant amounts of data accumulated in various information banks. The main direction of the study is the concentration of information data in one key database. It will provide clear assess to the data aquatic environment and make analytical studies.

The problem of interaction between society and nature is one of the most important issues of humanity. It has required a lot of effort of scientists and practitioners in the environmental, engineering, economic and other fields. The results of previous public research [1-3] are significant progress in this direction: the transfer of environmental information has become much better, environmental monitoring and special studies in various fields of ecology and water use, a number of changes in environmental legislation in accordance with international agreements and conventions. However, it should be noted that despite the desire to improve the environmental situation, society still suffers from anthropogenic pressure.

The problem of water supply needs special attention. Saving of water resources and rational water use is the key to further economic growth and social welfare. Growing freshwater shortages and changing climates are increasingly comprehended as a major risk to the global economy [4]. Scientists point out the need for transition to sustainable water use, which requires appropriate government regulation, business sector initiatives, consumer responsibility [5, 6]. Significant progress in solving water use problems has been the concept of integrated water resources management. It has a number of shortcomings, but it is the basis for many environmental policies, strategies and management systems.

Taking into account the existing scientific achievements, we have shaped the main tasks for building a system of sustainable water use in Ukraine.

In this study, the system of sustainable water use is considered as a complex system that includes a set of simpler, to some extent isolated from each other subsystems with a clear hierarchy of goals, principles and mechanisms of interaction. We consider it expedient to differentiate the development and substantiation of practical recommendations for the creation of a system of sustainable water use in Ukraine according to its five target subsystems. These include the following:

1. development and ensuring the effectiveness of the water source;
2. modernization and ensuring the reliability of water management;
3. rationalization and efficiency of water use in resource constraints;
4. improvement of information and methodological support of water management processes;
5. certification of industries and technologies, as well as regions for the effectiveness of water management.

Sustainable water use requires integrated management. At the same time, special attention should be paid to the definition of key issues, clear conceptual

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modeling, strategy development, scenario analysis, production of 'useful' scientific information [7].

To ensure the effectiveness of the first subsystem 'Development and effectiveness of the water resources' we have identified problems that need to be addressed and proposed appropriate measures. For example, there is a significant problem of cooperation between the Ministry of Environment and other ministries, state committees and parliamentary committees, as well as with regional and local authorities. Complex and lengthy procedures do not promote cooperation in the development of legislative projects. Therefore, in our opinion, the National Environmental Action Plan should be revised and refined to take into account the prospects of implementing a sustainable water use system in order to set clear priorities, goals and time frames in different sectors of environmental protection. This needs to be done in close cooperation with other ministries and stakeholders.

Despite the fact that the correlants of the Ministry of Environmental Protection of Ukraine are aware of the importance of international legislative instruments, the urgency of implementing the provisions and compliance with new norms and action plans, however, the latter is not a priority for this institution. A serious analysis of water use needs will clarify the objectives and ensure clear implementation of the obligations of related ministries and agencies. To improve the situation in this area, strategic plans for the implementation of agreements should be developed and agreed together with proposals for ratification, their implementation should follow the integration of international obligations into national law and include financial obligations to implement and comply with the provisions of Association Agreements of Ukraine with EU Member States. In addition, strategies and strategic plans need to focus on defining and justifying realistic goals, rather than developing unrealistic programs within the 'doctrinal foundations of sustainable development'.

The NGO sector includes not only independent organizations but also former state-supported research institutes. The current Public Council does not appear to be representative enough to be the Ministry's only partner for public consultation. Because of the Chernobyl accident, public environmental concerns and interest remain relatively, high compared to many other Central and Eastern European countries, although environmental protection does not seem to be a top priority given the problems of the economic crisis. Therefore, the Ministry of Environmental Protection of Ukraine should strengthen its coordination activities on environmental monitoring. Complete and coherent national monitoring systems need to be developed, which should be preceded by consistency of data systems and methodologies. Data needs to be systematized, integrated and prepared for management decisions. The European Environment Agency must be provided with aggregated data. Work on the development of an adequate information system should be accelerated in order to increase public and government concerns about environmental issues.

The Ministry can strengthen its position in public if it succeeds in meeting the high social interest in solving environmental problems. Although some laws provide for public participation, it is not significant in the environmental field, as adequate procedures are not developed. The expected ratification of the Aarhus Convention is the right step, which, however, cannot replace the procedural grounds for public participation. The Ministry of Environment should improve public access to environmental information in accordance with the Aarhus Convention and seek closer contacts with the entire NGO sector, including in the development of laws, policies and programs. Appropriate methods for enhancing public participation should be adopted in consultation with NGOs. Environmental impact assessment should be seen as one of the mechanisms to increase public participation in the decision-making process. The ministry must determine its contacts with the press. The public should be encouraged to exercise their environmental rights, and the development of procedures for public participation in environmental decision-making should be accelerated.

Although Ukraine is already a part of many international conventions, several have not yet been ratified, including the Convention on the Transboundary Effects of Industrial Accidents, the Convention on Cooperation for the Protection and Sustainable Use of the Danube River Basin and some protocols to the Convention on Long-range Air Pollution. Ratification of these agreements can be a tool for further development and strengthening of comprehensive environmental policy and legislation and international cooperation in these fields. Considering the ratification of these conventions as soon as possible, it should be borne in mind that a full and realistic assessment of their consequences is a prerequisite. The National Commission for Sustainable Development needs to intensify its activities. Meetings of the Commission should be regular so that it becomes an effective tool between sectoral coordination of environmental issues. Together with the world community, Ukraine should produce and consume ecosystem services [8].

Biogens and petroleum products, which come mainly from onshore local sources of pollution through rivers, undermine the environment of the Black and Azov Seas. Despite the significant number of water treatment facilities located in the coastal zone, a significant amount of untreated and incompletely treated industrial and domestic wastewater is still discharged into the sea. Largely, this pollution is a consequence of unsatisfactory technical condition and reduced efficiency of treatment facilities, as well as frequent accidents on sewerage networks and treatment plants. The reasons for this situation - mainly financial - stem from the general economic difficulties in the country. However, in the interests of marine water protection, sewerage networks and treatment facilities need to be repaired and upgraded immediately. Funding can be temporarily secured through mandatory contributions from profitable economic activities in the coastal zone.

The Ministry of Environmental Protection of Ukraine should build up its role as a coordinating governmental unit in the field of marine environmental monitoring. In particular, it should develop a mandatory overall national marine monitoring program and participate in the budgeting of all monitoring bodies and agencies; and ensure that other sources of funding and organizational arrangements are sought.

Ukraine has a significant number of water quality standards, which in some cases are very strict. This leads to a rather complex permitting system, which undermines the application and overloads the understaffed regulators. Therefore, the Ministry of Environmental Protection must ensure the coordination of monitoring programs, as provided for in Resolution № 391 (1998). The number of water quality standards needs to be lowered and they need to be implemented at true levels to enable their practical application.

Surprisingly, there are no formal consultations between national, regional and local authorities within the river basin. Such cooperation could help the overall cooperation between these bodies and would clearly contribute to a more coordinated management of water resources in the basin. These provisions should be taken into account when preparing the Ministry of Environmental Protection of Ukraine new proposals for the basin council for the implementation of the National Program for the restoration of the Dnieper basin and improving the quality of drinking water. The relevant draft resolution of the Cabinet of Ministers was sent for consideration to all interested national and regional authorities, scientific and environmental organizations. For each significant river basin, administrative bodies and committees should be established, and the principle of integrated water management should be implemented at the basin level. All national, regional and local authorities involved should be involved, if possible with international partners (e.g. the Republic of Moldova in the case of the Dniester). The institutional responsibility of the basin structure for water management should be supported by adequate financial funding so that water management objectives, particulary for wastewater, can be achieved at the local level. Financial revenues in the form of water payments collected in the basin should be used to improve water management in the same area.

It is known that in general, the quality of surface water is inappropriate for drinking, which is a consequence of pollution from municipal and industrial effluents, diffuse pollution from agriculture and the atmosphere. This problem cannot be solved in the nearest future. Groundwater is less vulnerable. Therefore, addressing the practice of using groundwater for drinking seems to be completed and balanced task; however, its solution requires modernization not only of the water complex, but also of the national economy in general.

Surface and underground hydrosphere is one of the important factors in the evolutionary development of the biosphere and man, its natural mechanisms and the preservation of their sustainable impact will contribute to the safe development of the economy and the state as a whole. A thorough analysis of the domestic structure of water use and its technical and economic indicators shows the low perfection of technological, environmental and existing regulatory mechanisms. There are 200 different regulations in this area, which are mainly of a recommended nature. In addition, a significant part of them is based on the use of different methodological principles and is not focused on the agreed levels of water-ecological assessments of surface and groundwater bodies, landscapes, natural and man-made systems, etc.

In order to arrange and implement a set of measures in the context of ensuring the effectiveness of the subsystem ‘Modernization and ensuring the reliability of water production’ we have proposed the following recommendations.

The responsibility for implementing international environmental standards and conventions lies primarily with the Ministry of the Environment. However, in many cases, ministries such as the Ministry of Finance, the Ministry of Economy, and the Ministry of Agriculture must also be involved. Ukraine does not properly analyze the effectiveness of international environmental assistance. A special center for environmental project management should become a tool at least for obtaining such valuable information, as well as for improved project management. Cooperation with the National Agency for Development and European Integration is essential in this regard. Implementation, compliance and application of environmental norms and action plans in relation to existing international obligations should be a priority of Ukraine’s environmental policy. Plans for ratification of new international environmental legislation should include an assessment of the cost of implementing them. Ukraine needs to continue working on ratifying all major international environmental conventions in line with national priorities. It should be borne in mind that some industries are special and need separate consideration. For example, the mining industry, which in Ukraine is almost not included in the system of sustainable water use. Instead, in the world this problem is raised [9].

In order to improve water management, the principle of river basin management needs to be further implemented. National action programs have already been developed for some river basins, such as the Dnieper. In developing the National Program for the Restoration of the Dnieper Basin and Improving the Quality of Drinking Water, the role of regional and local authorities was limited to providing information (suggestions) about the Dnieper to national authorities. Of course, measures taken (or not taken) from below will affect the measures proposed from above. The responsibility of water management bodies and the development of standards need to be streamlined. A clear responsibility for coordination should be defined and a mechanism for such coordination established. The establishment of a national body to unify standards and methods, i.e. the standardization body, needs to be considered.

Water consumption in Ukraine is quite high. At the same time, water prices for utilities and industry are relatively low. This is not surprising, as Ukrainian, law states that water is the exclusive property of the people of Ukraine, and water use is free. Only water supply, sewerage and wastewater treatment are paid moderately. However, this fee does not fully reimburse all costs, including investment. Significant efforts are needed to recoup the investment, maintenance and operation of water supply systems. Increasing tariffs for water use and discharges are important steps to ensure adequate funding for water infrastructure, such as the reconstruction of water treatment plants. Determining the price of water, which would fully reimburse the relevant costs, and the installation of water meters to detect the volume of its actual consumption would save significant amounts of water. At the same time, users' accounts are hardly affected by these measures, as they should pay a higher price but consume less. Such measures would help to improve the operation of treatment plants, as they would receive less water for processing. Therefore, the introduction of best available, low-cost technologies and / or technology-based emission standards should form the basis of pollution reduction strategies. For the construction and operation of sewerage networks and water treatment facilities, new financial support mechanisms adequate to real processes should be formed, with clearly defined responsibility of polluters.

To improve the efficiency of wastewater treatment, further training of personnel on the operation of facilities and equipment and process control is needed. Responsibility for urban wastewater management and sewage disposal should be clearly defined. Preference should be given to the use of silt in the form of fertilizers [10].

At the same time, the EU Directive on urban wastewater and the use of sludge in agriculture should be followed. In addition, trained personnel should manage treatment plants. Low professional level of staff is a common problem. Special training on the operation of facilities and equipment and process control could significantly improve the efficiency of treatment facilities. There is an urgent need for Ukraine to increase the level of professionalism and professional training of staff and management entities that take care of water use problems.

In order to improve the management of the marine environment, it is necessary to define clear environmental policy objectives and include them in the national program for the protection and restoration of the Black and Azov Seas. A wide network of administrative and scientific institutions has been formed to facilitate the management of the marine environment. At the same time, the developed institutional capacity at the regional and local levels cannot compensate for the lack of a specialized management structure at the national level. To improve the coordination of the efforts of numerous institutions aimed at improving the effectiveness of the protection of the marine environment, the Ministry of Environmental Protection of Ukraine should establish a special structural unit for the protection of the Black and Azov Seas.

Shipping and related activities are a major source of marine pollution, especially gasoline hydrocarbons. Another significant threat to the marine ecosystem is the penetration of exotic species, most often by removing ballast water. That is why it is necessary to develop special recommendations and implement appropriate measures.

Ecological optimization and sustainable development of the water management complex are and should be the main direction of improving the environmental parameters and safety of water bodies. The previous development of the water management complex of Ukraine on the principles of their maximum importance in economic circulation has led to destructive changes in water resources systems, deterioration of environmental parameters (hydrosphere, biosphere, lithosphere, atmosphere). To fundamentally improve the ecological level of water use within Ukraine, it is recommended to develop technological, regulatory and other documents based on the principles of maximum allowable water-ecological changes or loads.

In accordance with the provisions of the National Water Code, funds from the fee for water intake and discharge of wastewater into water bodies of local significance are paid to the local budget. Funds from the fee for water intake go to the national (80.0%) and regional budgets (20.0%). However, the majority of the population receives water from public facilities and most of the money goes to the state budget, while investment, operating costs and maintenance of water supply, sewerage and treatment systems must be provided at the local level. Therefore, a more balanced decentralization of responsibilities and budgets seems to be a prerequisite for more efficient water management.

In order to ensure the effectiveness of the subsystem "Rationalization and increase the efficiency of water use in resource constraints" we have made the following proposals.

There are a significant number of standards - in fact, thousands that cannot be tracked for both technical and economic reasons and compliance with which remains problematic. Therefore, from all points of view, it would be useful, taking practical expediency, to take appropriate legal and organizational measures to establish and apply standards. This requirement can be met relatively easily, as it requires virtually no funds. On the contrary, it would reduce costs. Therefore, it is necessary to identify effective economic tools for the introduction of the "polluter pays" principle. Research is needed to prepare for the transition to a clearly market-oriented fiscal and economic policy. It is important to find out what levels of environmental payments will be possible and effective and what time frames are needed to implement them.

The main problems exist in the field of financing environmental measures. The fundamental problem of creating a viable system of public revenues in Ukraine is the further complication of the situation with environmental expenditures, as there are more urgent priorities. Even more, the approach to solving the problem, which is to allocate certain categories of public revenues for environmental purposes, is not easy to apply, which creates limited transparency. Statistics on environmental expenditures, including funding sources, need to be improved.

The difficult financial situation is forcing more and more importance to be attached to foreign aid. The experience of other countries with weak economies shows that the management of environmental projects that have components of foreign aid often benefit much more from more specialized and effective administrative measures. The presence of a separate special center in the structure of environmental management, as a rule, contributes to the strengthening of environmental components in general assistance programs or projects. It also gives a better idea of all international environmental assistance and is therefore more useful for the process of setting national priorities in environmental policy. The activities of such a center should be coordinated with the National Agency for Reconstruction and European Integration. Among other things, the center transparently and efficiently should accumulate funds from environmental payments.

In modern conditions, it may be appropriate to consider the introduction of a national environmental fund and local environmental funds in order to manage both revenues and expenditures for environmental protection with the help of appropriate supervisory boards. Regional funds can be created by consolidating local funds, which should finance the costs of local environmental measures. Proceeds from such funds should come mainly in the form of environmental taxes, fees and penalties, as well as foreign aid.

Most cities and towns in Ukraine use treatment facilities for municipal and industrial wastewater. The quality and efficiency of wastewater treatment could be improved by increasing the capacity and technical condition of existing facilities. In particular, reducing water consumption would improve the operating conditions of treatment plants, as reducing the amount of wastewater would make it possible to process them more efficiently. This provision applies to both water treatment plants and treatment plants. In addition, the practice of sewage treatment is unsatisfactory and needs to be streamlined. These mules can never be returned to the rivers. The best option is to use them as fertilizers, provided that the metal content does not exceed the established limits. This means that some industrial wastewater must undergo a pre-treatment stage in order to remove toxic elements or not enter the treatment plant at all, but be treated in another way.

It should be noted that external water quality standards are currently used to calculate the maximum permissible discharges of pollutants from industry into water bodies, although technologies that do not require additional funds have not yet been defined and provided for by the National Water Code. The rational aspect of the standards required for Ukraine (focused on such technologies) is also to minimize, using existing technologies, discharges of used water. But, in contrast, the current practice in Ukraine is to bring industrial pollution to the level of certain standards for external sources instead of trying to constantly reduce emissions from industry. This practice in water management does not encourage a reduction in water consumption, as external targets can only be achieved by diluting wastewater. In addition, since a permit is issued for pollution of a particular environment, attempts are made to redirect pollution from the aquatic environment to another, such as the atmosphere, or to convert it into solid waste. That is why it is necessary to take into account the correlants and consider the introduction of an integrated permitting system, the introduction of which will significantly reduce financial costs. At the same time, the experience of wide implementation in Europe of emission standards based on advanced management technologies is useful for the environment and Ukraine.

Requires rationalization of pricing. The price of water should be transparent and realistic. It is necessary to introduce water meters for all water users, and the payment should be made in proportion to the amount of water used. The cost of water should correspond to the level of full reimbursement of all costs for investment, maintenance and operation of water infrastructure. Exceptions should be made for those who are unable to comply with these requirements.

When justifying the cost of water and the efficiency of its use, it is necessary to consider possible alternatives and reflect not only economic components, but also environmental and social factors.

Significant work has been done in recent years to develop new legislation. The new Water Code and special regulations for the protection of marine waters from pollution and clogging define the basic requirements for the protection of the marine environment. The lack of special norms and standards of sea water quality hinders control activities, permitting procedures and assessment of the state of the environment. At the same time the general specifications for surface waters are used. There is also a need to develop a common methodology for issuing permits for discharges into the sea, which could be used by regional authorities instead of giving specific tasks to research institutes. The new environmental legislation does not include funding mechanisms for environmental management.

National environmental authorities are fully aware of the need to integrate environmental policy development and management in coastal areas. Draft relevant documents on the implementation of the principle of integrated coastal zone management have been developed mainly within the framework of the Black Sea Environmental Program. The special needs of the marine environment should be reflected in special legislation on the protection of the marine environment. It should comply with relevant national and international norms and standards and include new mechanisms for the formation and replenishment of funds. Control over the operation, development and construction of new structures and facilities for the loading, transhipment and storage of petroleum products, chemicals and other hazardous substances needs to be strengthened. Ukrainian ports are equipped with water treatment plants for oil-contaminated waters and the necessary means to combat oil spills within its territory. The Ministry of Environmental Protection and Nuclear Safety and the Ministry of Transport have every opportunity to monitor activities in the coastal zone within the scope of their powers established by law. Improved management technologies and reporting on current, intermediate and final controls on the operation, development and construction of new structures and facilities for loading, transshipment and storage of petroleum products, chemicals and other hazardous substances need to be developed.

Increasing concerns about addressing both national and international environmental issues, conventions and strategies, and strengthening their links with many social and economic aspects of sustainable development must be given higher priority. This requires the improvement of information and methodological support, expansion of dialogue, development of communication channels. Achieving goals in this direction requires special programs and the use of adequate methodologies aimed at specific audiences, the integration of international environmental standards, reflected in many conventions ratified by Ukraine. Incorporation into national socio-political strategies will be significantly facilitated if the cognitive-informational aspects of the knowledge movement are streamlined.

To this we add that, as a rule, the monitoring of the marine environment is a by-product of the main activities of some agencies and research institutes, and these circumstances determine how it is carried out. According to national legislation, the Ministry of Environment of Ukraine is responsible for the overall coordination of monitoring processes that take place in the country at the national level, but, in practice, it can not participate in budget preparation to intensify all monitoring activities in the field of nature. The Ministry of Environment of Ukraine takes an active part in several international initiatives, such as the Black Sea Environmental Program, the Danube Program, and the Working Group on the Environment of the Black Sea Economic Cooperation. In addition, Ukraine has already signed some international agreements in this area, and the Ministry is now working to ensure their ratification and implementation. Therefore, applying the international agreements already signed by Ukraine and their existing structures, further management of the environment of the Black and Azov Seas should cover the entire catchment area. Ukraine should consider initiating a basin program and / or promoting closer cooperation between the Black Sea Environmental Program and all existing and planned programs for rivers flowing into the two seas, in order to ensure basin coordination of environmental management affecting the Black and Azov Seas. Adequate coordination mechanisms should also be developed for the Black Sea catchment area within the country.

In this regard, we have developed a set of measures for the implementation of the subsystem "Improvement of information and methodological support of water management processes."

The existing monitoring system is too fragmented: many institutions monitor a significant amount of pollutants, and outdated stations use incompatible methodologies. Often different institutions have to collect the same data because they cannot be exchanged due to data bank incompatibilities. Environmental audits of industrial enterprises should be used as a basis for the gradual development of an integrated permitting system covering water, air and waste permits. The organization of the various inspection services needs to be reviewed to improve their combined economic efficiency.

The amount of work required should not be underestimated, even taking into account all the experience of previous conferences, it should be used as an opportunity to involve many ministries, other government agencies, public and scientific institutions. In an economic depression, international environmental cooperation is certainly not a top national policy priority. In Ukraine, in addition, many managers, as well as the public, should pay more attention to environmental issues and international environmental cooperation, including their impact on other areas of activity, from the economy to health care. Coordination and cooperation between all institutions involved in the development and implementation of policy and management of international cooperation programs needs to be improved. Consideration should be given to establishing a special organizational structure for these purposes. An international task force should also be established, which will include, on a voluntary basis, representatives of partner countries wishing to assist Ukraine in its environmental activities. A clear focus on market measures and principles in the field of international cooperation is needed.

Groundwater monitoring needs to be improved. Individual monitoring networks, using different software products, generate significant amounts of data that accumulate in different information banks. As a result, the compatibility of monitoring data from different networks is very complicated. In addition, most monitoring data is not aimed at regulation, and in some cases it cannot even be used by regulators. Monitoring data are often collected and collected by regional authorities and are not available for decision-making at the state level. The Ministry of Environment of Ukraine is authorized to be responsible for the coordination of these monitoring activities in order to ensure better integration and control of water quality. The implementation of these provisions will not only save significant funds and harmonize the monitoring data obtained from different programs, but will also allow the full use of monitoring results for decision-making at all levels. The system and scale of monitoring networks in the field of water use need to be improved. Although various ministries and state committees have already set up several monitoring systems, their activities are aimed at achieving certain local goals. There is duplication of work, especially in the monitoring of chemical and bacterial parameters.

Providing the population with adequate drinking water that meets hygienic standards should be considered a priority. Therefore, public access to information on drinking water quality must be ensured. The use of water from relevant groundwater sources must increase significantly, and the protection of drinking water resources must be properly ensured.

Environmental certification plays an important role in strengthening the information and methodological support of water use management processes. Its implementation requires certain costs, so it must be objective, complete and useful for the business environment [11]. In Europe, there is a positive experience of voluntary environmental certification, implemented, for example, in Tuscany [12]. This helped to discuss policy measures aimed at environmental safety and increase the soundness of investment decisions.

The significant factor for decision-making is the value of information. Ukraine has a wide network of environmental monitoring, and it covers various executive bodies and scientific institutions. They are on the edge of surviving. Primarily because of broken ties with former Soviet partners and disintegrated monitoring system. It has also lost some methodological support, and suffers from severe budgetary constraints, while the activity of its various structural units is often duplicated. In order to reduce the cost of the monitoring system, it needs optimization. In the country, there are no procedures of self-controlling. The Ministry of Environmental Protection of Ukraine together with all executive bodies and the participation of all stakeholders should clearly create integrated coastline zone organization as an independent part of its new policy. It requires the creation of suitable tools for institutional cooperation and the involvement of academic staff, local business and the public to ensure integrated coastal zone management. A positive example of monitoring is the EMAS Regulation (Reg. 761/01 EC). It is an EU scheme implemented by the European Commission since 1993 and intended to integrate the Environmental Management System (EMS) [13]. There is a close connection between the implementation of the environmental management system and indicators of the ecological condition of the territory.

Given the semi-enclosed nature of the Black Sea, the high anthropogenic pressures and the vulnerability of its ecosystem, it is clear that only regionally coordinated action can actually improve its condition. In order to use new effective tools for managing the marine environment, Ukraine should participate in the development and implementation of a harmonized system of state port control in the Black Sea region (together with neighboring countries and entities) and, accordingly, in the development of a regional emergency plan.

Preferably, the environmental criteria of existing water regulatory or regulatory documents are based on the use of maximum permissible concentrations or levels of pollutants. Practically, until recently, these norms as regulatory criteria - are the only ones approved at the state level, which have scientific, methodological and analytical justification. Therefore, this requires the development of a new system of relative indicators to assess and forecast the effectiveness of water management, some of it should be introduced into the system of national accounts.

Regarding the implementation of the subsystem "Certification of industries and technologies, as well as regions by the factor of effectiveness of water management", in our opinion need to develop a universal application toolkit, reporting documentation forms, etc., which are recommended for different levels of government. At the same time it is necessary to provide reflection of a water trace and production of [14].

At present, there are questions about the possibility (or impossibility) of increasing and rationalizing the development of the strategic potential of Ukraine's economy, in general. It should be noted that currently the main source of information is the data of the State Statistics Service of Ukraine, Ministries of Economic and Regional Development of Ukraine, Ministry of Infrastructure, etc. and, as is known, the results of a comprehensive survey of state water farms, providing evidence in generalized form. The importance of primary data is determined by a system of indicators that should be used to assess the effectiveness of integrated water resources management [15]. Therefore, the development of passports is the subject of a separate scientific study.

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Features of forming the salt balance in rice fields with various parameters and designs of the Danube rice irrigation systems

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Abstract. Ecological-reclamation state of rice irrigation systems harvest of cultivated crops determined by a number of factors, including natural (soil, topographical, hydrogeological, climatic factors) and technological (irrigation norm, designs and parameters of irrigation and drainage networks, etc.) factors. One of the main factors influencing the formation of rice yield which is traditionally grown by flooding technology is the efficiency of the rice irrigation system's design. Construction features of irrigation fields and their parameters (distances between the drains, depth of the drainage network) affect the intensity of the processes of salinization of soils and groundwater. Analysis of the components of salt balances of rice fields with different parameters and designs on example of the Danube rice irrigation systems showed that fields with the distances between the drains from 200 to 250 m have significant advantages over Krasnodar-type fields with the same parameters and over fields with 500 m distance between the drains creating optimal salt regime for rice and, accordingly, obtaining higher yields of rice. As on the card-checks with drainage with the distances between the drains 500 m uniform desalinization of soils on all area cannot be reached and yield of rice on them is close to 20 c/ha such card-checks with drainage must be converted into card-checks with drainage with the distances between the drains 250 m.

1 Introduction

The concept of the stable development of national economy envisages rational ecological and economic nature use guaranteeing the business operation without worsening environment and its preservation for generations to come. In this connection problems arising in the sphere of rice sowing in Ukraine are becoming of late especially urgent and call for speedy positive solutions.

In its time the main aim for creating native branch of rice sowing had been not only the satisfaction of the need for own rice but also the introduction in agricultural production of low efficient saline and bogged land in the Crimea, the Danube delta and areas adjoining the Black sea.

Industrial experiments have shown that such lands may be successfully used for rice irrigation systems (RIS) with obligatory application on them reasonable constructive decisions on ensuring a favorable ecological and reclamation condition on irrigated lands.

The construction of engineering rice irrigation systems in Ukraine began in the 70-s of the last century and at present their area amounts to about 62 thousand hectares (Crimea – 30.8 thousand hectares, Kherson region – 18 thousand hectares, Odessa region – 14 thousand hectares).

Modern RIS is a complex set of water supply, drainage, regulative and other elements connected by a single technological process in combination with the rice fields, where the leading crop of rice crop rotation - flooded rice and related overland crops are grown. The main element of any engineering rice system is a rice irrigation field. How well the design of the field is chosen and its parameters are selected depends on how successfully it will perform its functions, which are to create the optimal salt and water-air regime for rice and related crops.

The long-term studies have determined that drainage on saline lands RIS must meet the following basic requirements:

- ensure, for 2-3 years, the salinization of the upper layer of soil 1.0-1.5 m to create favorable conditions for growing rice and related crops of rice crop rotation;
- provide after drainage of the water from the checks the required norm of drainage not less than critical depth (1.5-1.8 m) at the beginning of the new irrigation season;
- exclude the possibility of secondary salinization of soils in the fields occupied by related crops;
- create and maintain in the rice field optimal filtration rates for removal of salts from the active layer of soil.

Research by a number of authors [1, 2, 3, 4, 5] showed that the desalination effect of the drainage network on the rice field cannot be estimated only by the amount of salts carried through it. In [6, 7, 8, 9, 10] the unreasonableness of the study of soil salinization without taking into account the change of salt reserves in groundwater, especially at their close occurrence, is emphasized.

Based on these provisions, the most reliable and complete idea of the direction of salt processes in soils and groundwater, and hence an objective assessment of the drainage network can be obtained by drawing up a salt balance, which would take into account changes in salt reserves in soils, groundwater, inflows of salts with irrigation water and their removal with drainage water, other components of both income and expendable parts of such balance.

2 Materials and methods

The studies were performed according to standard methods [5]. The salt balances were compiled for a 3-meter layer of soil and groundwater of each of the fields during the period of rice cultivation on them and based on water balance data.

The weighted average reserves of salts in soils and groundwater were determined on experimental fields also the period of related crops cultivation. In order to obtain comparable data, the thickness of the aeration zone was assumed to be 1.2 m, and the thickness of the groundwater layer in the balance layer - 1.8 m.

Studies of salt balance were conducted by us for 5 years in order to assess the effectiveness of rice fields with various parameters and designs on the Danube RIS located in the Odessa region (Fig. 1).

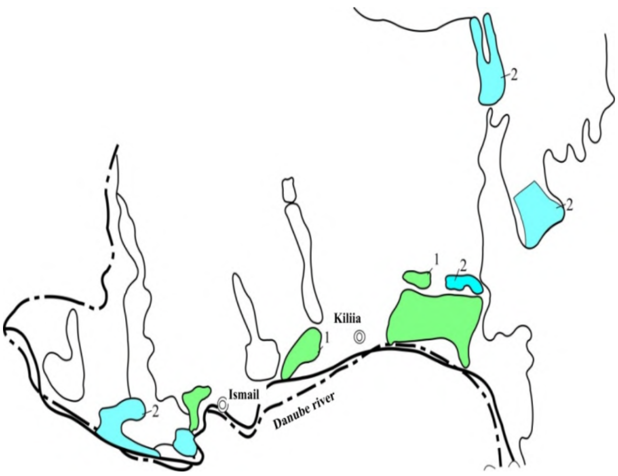

Fig. 2.1. Location of rice systems in Odessa region: 1 - existing; 2 - planned for the future

To solve the problems as the object of research was selected the Kiliia RIS with the total area of 3.45 thousand hectares, which is located on the territory of saline East-Kiliia floods of the Danube delta.

Soils are represented mainly by sandy loam falling to the first regional water confining layer.

Before the construction of the Kiliia RIS the depth of occurrence of groundwater level was in the range from 0.0 to 2.5 m and their overall slope is directed towards the Danube River.

The content of salts in groundwater was in the range of 10-30 g/l, reaching 70 g/l in individual cases. The mineralization of groundwater increased from swampy part of the floodplain to its central part.

During the long period of growing rice on the Kiliia RIS occurred desalination of groundwater. Their mineralization decreased to 1.5-15.0 g/l, which is explained by the relatively intense washing regime, which was created as the result of watering rice by flooding and drainage work. Only in small areas there was a desalinization of ground water up to 30 g/l.

The Kiliia RIS was built according to the well-known scheme of irrigation cards of the Krasnodar-type (KTC) and card-checks with drainage (CCD) with one-side and two-side command.

The distance between the channels, depending on the soil-hydrogeological conditions, was 200-500 m and the depth of the card drains – 1.5-1.7 m. The KTC is the most common type of irrigation cards in the RIS of Ukraine.

Schemes of CCD and KTC are given in Fig.2.

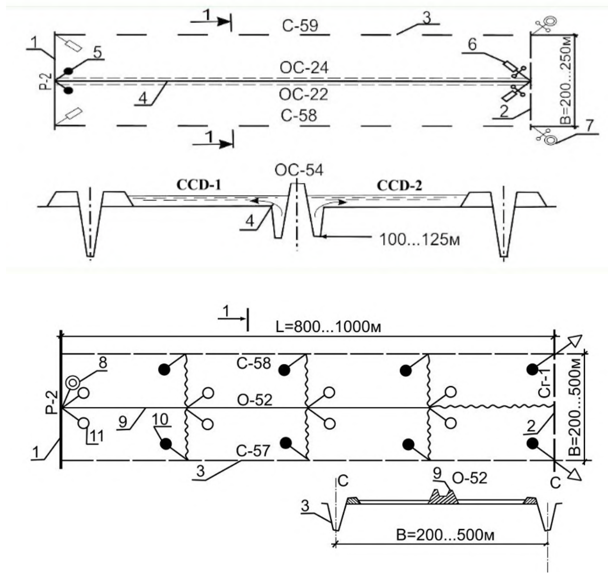

Fig. 2. Schemes of experimental card-check with drainage (CCD) and Krasnodar-type card (KTC) on the Danube rice systems: 1 - distribution channel; 2 - discharge channel; 3 – card-drain (CCD), or drain-discharge (KTC); 4 - irrigator-discharge of unilateral command; 5 - water outlet from the distribution channel to the irrigator-discharge; 6 - water outlet from the irrigator-discharge to the discharge channel; 7– water outlet from the card-drain to the discharge channel; 8 - water outlet from the distribution channel to the card-irrigator; 9 - card-irrigator; 10 - water outlet from the check to the discharge channel; 11 - water outlet from the card-irrigator to the KTC.

The research was conducted on three experimental sites. Shortened flooding was maintained in all areas during rice cultivation.

The first site consisted of two CCD with a one-way command irrigators-discharge, average depth of which was 0.7 m, and distance between the drains - 200 m. As a control, there was KTC with the card-irrigators of bilateral command and distance between the drains 200 m.

The second site also consisted of two CCD and KTC, but the distance between the drains was 250 m.

The third site consisted of two CCD with irrigators-discharge of unilateral command and the distance between the drains for the first CCD was 250 m, and for the second - 500 m.

Field studies conducted by us and other scientists [11, 12, 13, 14] on the rice systems of the Danube delta showed that features of motion of filtration streams on irrigation cards during the maintenance of the water layer is that in the part of their area formed a zone of groundwater lifting (along the irrigation channels) and a stagnant zone – in the center of the check, active movement of groundwater occurs only on the part of the area that adjoins directly to the drainage channel (Fig. 3).

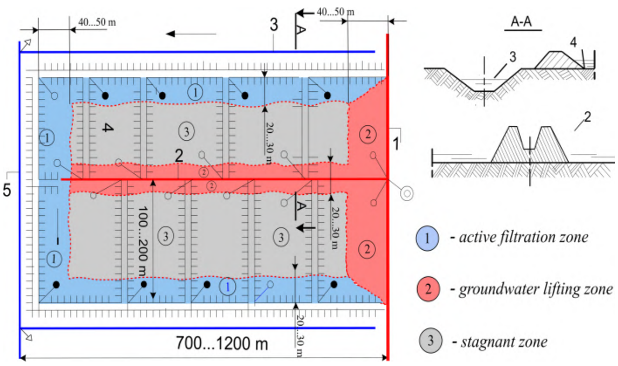

Fig. 3. Scheme of formation of characteristic zones of filtration on the rice check: 1 - distribution channel; 2 - card irrigator of bilateral command; 3 - card drainage and discharge channel; 4 - check; 5 - sectional drainage and discharge channel.

The dimensions of these zones are determined by the hypsometric characteristics of the irrigation channels, depth of drains and water levels in them, and by size of the irrigation card.

The presence of such zones indicates irregular drainage on the area of the irrigation card. The total area that is practically doesn't drained is more than 60% of the area of the irrigation card. Calculations of filtration losses from the drainage zone, according to the schedule of rates, indicated that their volume from the drained strip is about 70% of their total volume.

3 Results and discussions

On the basis of annual salt balances were compiled averaged salt balances for fields of various parameters and designs (Table 1, 2, 3). The analysis of salt balances was carried out by assessing the structure and dynamics of their main components.

Comparing the change in salt reserves in the 1.2 m layer of soils on CCD and KTC with distances between the drains 200 m (site № I), we can note a higher intensity of soil desalinization. In general, for the entire period of observations and for each of the irrigation seasons with treatment of rice with herbicides, it was higher than on KTC by an average of 4% (Table 1). In the site № 2 (distances between the drains 250 m) also recorded the removal of salts at 8% higher on CCD than on KTC on average for each of the seasons of rice cultivation (Table 2).

Table 1. Salt balance of CCD and KTC with distances between the drains 200 m (five-years observation period).

Elements of salt balance	**B = 200 m**			
	CCD		**KTC**	
	t/ha	**%**	**t/ha**	**%**
income part				
Reserves of salts in the soil in April in the layer 1.2 m	31.60	32.2	41.91	33.0
Reserves of salts in groundwater in April in the layer 1.8 m	55.53	56.5	74.70	58.8
Receipt of salts with irrigation water	9.63	9.8	8.91	7.0
Receipt of salts with fertilizers	1.50	1.5	1.50	1.2
Total salts in the balance layer (3m)	98.26	100.0	127.0	100.0
expendable part				
Reserves of salts in November in the layer 1.2 m	24.36	24.8	37.03	29.2
Reserves of salts in groundwater in November in the layer 1.8 m	40.25	40.9	61.21	48.2
Removal of salts with drainage water	34.07	34.6	24.35	19.2
Removal of salts with waste water	1.83	1.8	2.90	2.3
Removal of salts with the harvest	1.24	1.3	1.19	0.9
Salt exchange with the lower horizons	-3.49	-3.5	0.34	0.3
Total salts in the balance layer (3 m)	98.26	100.0	127.02	100.0

Comparison of the intensity of the reduction of salt reserves in the card- checks with distances between the drains 200 m, 250 m and 500 m can be carried out only in relative terms, because the initial salt reserves in these areas differed significantly. On average, during the rice growing season with flooding the salt reserves decreased on 7-9% for CCD, regardless of, practically, the value of distances between the drains. Although in the first years after the reconstruction of rice systems, during which there was a deepening of drainage network, the reduction of salt reserves was more intense.

At the same time, more intensive salt accumulation was observed the period of related crops cultivation on CCD with distances between the drains 500 m than on CCD with - 250 m and 200 m, which further negatively affected on the rice yield.

Observation of changes in salt reserves in groundwater of all experimental site showed that they are as well as changes in salt reserves in soils are characterized by a number of features caused by the deepening of the drainage network, namely: the highest intensity of salt removal in the first year of rice cultivation after reconstruction; significant reduction of salt reserves compared to the original. During the period of crop rotation cultivation there was some increase in salt reserves in groundwater.

Table 2. Salt balance of CCD and KTC with distances between the drains 250 m (five-years observation period).

Elements of salt balance	B = 250 m			
	CCD		KTC	
	t/ha	%	t/ha	%
income part				
Reserves of salts in the soil in April in the layer 1.2 m	41.49	41.2	38.42	38.5
Reserves of salts in groundwater in April in the layer 1.8 m	48.58	48.3	51.04	51.2
Receipt of salts with irrigation water	9.09	9.0	8.80	8.8
Receipt of salts with fertilizers	1.46	1.5	1.43	1.4
Total salts in the balance layer (3m)	100.62	100.0	99.69	100.0
expendable part				
Reserves of salts in November in the layer 1.2 m	32.33	32.1	37.65	37.8
Reserves of salts in groundwater in November in the layer 1.8 m	34.82	34.6	37.76	37.9
Removal of salts with drainage water	27.76	27.6	21.90	21.9
Removal of salts with waste water	1.77	1.8	2.20	2.2
Removal of salts with the harvest	1.25	1.2	1.15	1.1
Salt exchange with the lower horizons	2.69	2.7	-0.97	-0.9
Total salts in the balance layer (3 m)	100.62	100.0	99.69	100.0

Table 3. Salt balance of CCD with distances between the drains 500 m (five-years observation period)

Elements of salt balance	B = 500 m	
	CCD	
	t/ha	%
income part		
Reserves of salts in the soil in April in the layer 1.2 m	98.86	38.5
Reserves of salts in groundwater in April in the layer 1.8 m	147.54	57.5
Receipt of salts with irrigation water	8.55	3.3
Receipt of salts with fertilizers	1.50	0.5
Total salts in the balance layer (3 m)	256.45	100.0
expendable part		
Reserves of salts in November in the layer 1.2 m	79.02	30.8
Reserves of salts in groundwater in November in the layer 1.8 m	127.90	49.8
Removal of salts with drainage water	41.16	16.0
Removal of salts with waste water	2.14	0.8
Removal of salts with the harvest	0.88	0.3
Salt exchange with the lower horizons	5.35	2.0
Total salts in the balance layer (3 m)	256.45	100.0

Comparison of changes in salt reserves on CCD and KTC with distances between the drains 200 m showed that seasonal removal of salts from groundwater during the period of rice cultivation was higher on CCD on the average for all period of observation by 6.94% in comparison with KTC, and in separate years exceeded 10%. And although even if on KTC was a significant desalinization, but at the end of the study the salt reserves were higher than on CCD. This advantage of CCD is explained by its higher drainage during drying.

A similar situation with regard to the reduction of the amount of salts in groundwater was observed in the site № 2 (distances between the drains 250 m) where the CCD also showed a higher intensity of desalinization in comparison with KTC.

Comparison of the intensity of reduction of salt reserves for CCD with different distances between the drains 200 m and 250 m showed that it practically not differ and made 19.08-24.81% from the original salt reserves and in 2 times exceeding this indicator for distances between the drains 500 m, where it averaged only 11.41% of the original salt reserves. Given such a low rate of groundwater desalination at CCD with distances between the drains 500 m as well as the fact that at the end of the study the salt supply in the groundwater remained significant, we can conclude that under such circumstances it’s not possible to achieve the desired groundwater desalination even in the near future.

Annually, the experimental sites received an average of 8.55 to 9.69 t/ha of salts with irrigation water, which was up to 9.8% of the income part of the salt balance (Table 1, 2, 3) and, in practice it does not significantly depend on the parameters and designs of rice fields.

The receipt of salts with fertilizers on the experimental sites varied from 1.43 to 1.50 t/ha, which averaged up to 1.53% of the income part of the salt balance (Table 1, 2, 3) and has no significant effect on the formation of salt balance.

Removed salts from soils and groundwater of the balance layer of the experimental sites with drainage runoff varied during the observation period in a wide range, averaged up to 34.67% of the expendable part of the salt balance and was the main factor influencing the intensity of salt reduction in soils and groundwater.

Comparison of the amount of salts removed with the drainage runoff on the CCD and KTC with distances between the drains 200 m and 250 m showed the significant advantage of CCD. The average seasonal removal of salts on CCD with distances between the drains 200 m was higher by 13.9%, and with 250 m - by 2.4% higher than on KTC with the same parameters (Table 1, 2).

Comparison of the removal of salts with the drainage runoff on the CCD with different distances between the drains showed that with increasing the distances between the drains it decreases significantly. The main reason for the greater removal of salts with drainage runoff on CCD in comparison with KTC with distances between the drains 200 m and 250 m is the presence on the CCD the irrigator-discharge, which plays the role of shallow drainage during the part of the irrigation season. The amount of salts removed by the irrigator-discharge was up to 14.36% of the total amount of salts removed from the

CCD by the whole drainage network (Table 4).

If on the CCD along the irrigator-discharge there was desalinization of soils and groundwater, then on KTC in the central part there was contrary process - salinization. These facts indicate that there is a significant advantage of CCD over KTC in terms of ensuring optimal salt regime.

Removal of salts from the experimental sites with waste water there were in ten times less than removal of salts from drainage water. This averaged only 1.77-1.90 t/ha during the season and did not exceed 2.28% of the expendable part of the salt balance (Table 1, 2, 3). This indicator of the salt balance did not depend much on the parameters and designs of rice fields, but depended mainly on the original salinity of the upper soil horizon.

Removal of salts with the rice harvest over the years of research was 0.91-1.25 t/ha and did not exceed an average of 1.3% of the expendable part of the salt balance.

Table 4. Removal of salts from CCD on the experimental sites through irrigators-discharge during the season (April – November).

№ experimental site	№ CCD	Distances between the drains, m	Removed salts from CCD with the drainage runoff		
			total, t/ha	irrigator-discharge	
				t/ha	%
1	CCD-1	200	35.61	1.80	5.06
	CCD-2	200	32.53	1.58	4.85
2	CCD-1	250	28.65	3.70	12.94
	CCD-2	250	26.88	3.86	14.36
3	CCD-1	250	54.26	5.87	10.82
	CCD-2	500	41.15	4.41	10.72

Actual production data on ecological and reclamation condition on irrigated lands of the Danube RIS are given in Table 5.

Table 5. Ecological and reclamation condition on irrigated lands of the Danube RIS (at the beginning of the growing season of 2016).

Irrigation system		Area under control	Ecological and reclamation condition on irrigated lands, ha		
			Favorable	Satisfactory	Unfavorable
Kiliia region					
Kiliia RIS-1		3317	-	2894	423
Kiliia RIS-2		1515	605	910	-
Liskovska RIS		3859	-	3091	768
Kiliisko-Maiakska RIS		1026	-	1026	-
Michurinska RIS		1016	356	587	73
Rice area		135	-	135	-
Total	ha	10868	961	8643	1264
	%	100	9	80	12
Ismail region					
Kyslytska RIS		2810	638	1815	357
Total	ha	2810	638	1815	357
	%	100	23	65	12

Production data showed that according to assessment criteria of actual ecological and reclamation stability of irrigated lands (depth and mineralization of groundwater, their hydrochemical composition, degree of salinity of soils), a significant part of the Danube RIS area is unstable.

4 Conclusions

1. With the distances between the drains 200 m and 250 m on CCD there is a more intensive desalination of soils and ground waters, than on KTC with the same parameters. The intensity of desalination at CCD with distances between the drains 200 m and 250 m differs insignificantly. With the distances between the drains 500 m it is impossible to achieve high rates of desalinization of soils and ground waters even in the conditions of CCD.

2. The fact that the desalination of soils and groundwater in all years of observations in sites with the distances between the drains 200 m and 250 m was more significant on CCD than on KTC indicates the advantage of CCD in terms of creating more favorable reclamation situation. This advantage of CCD is explained by the fact that during part of the irrigation season and part of the not irrigation season it is drained around the perimeter, thanks to the irrigator-discharge arranged on it, which acts as a shallow (up to 0.7 m) drain.

3. Due to the fact that at CCD with the distances between the drains 200 m and 250 m desalination of soils occurred more intensively than on KTC the rice yield on them was on average 6 c/ha higher.

4. As on the CCD with the distances between the drains 500 m uniform desalinization of soils on all area cannot be reached and yield of rice on them is close to 20 c/ha such CCD must be converted into CCD with the distances between the drains 250 m.

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Theoretical research of friction factor in hydraulically smooth pipes

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Abstract. The paper presents the disclosure of the problem of calculating the friction factor. This problem exists in the calculations of head losses for a given flow discharge and the geometric parameters of the pipes. The analysis of the formulas recommended by known scientists is described. The article also presents the shortcomings of the formulas and the variance of the adequacy of the experimental data. These research data were obtained by J. Nikuradze for smooth pipes. We obtained a formula based on the method of dimensional analysis. This formula characterizes the inner surface of the pipes. Also, this formula describes the change in the friction factor from the Reynolds number. The accuracy of calculating the obtained formula is higher than the accuracy of existing formulas.

1 Introduction

To solve hydrodynamic problems, it is necessary to improve the hydraulic calculation of pipes. Due to the difference in geodetic marks or due to the energy that is transferred to the fluid when passing through the pumps, the fluid moves in the pipes. Hydraulic calculation of pipes is necessary to determine the head loss for the geometric dimensions of the pipes and a given of the flow discharge.

In 1752, Leonard Euler mathematically derived the Bernoulli equation for an elementary stream of real fluid

$$z_1 + \frac{p_1}{\rho g} + \frac{u_1^2}{2g} = z_2 + \frac{p_2}{\rho g} + \frac{u_2^2}{2g} + h_w, \qquad (1)$$

where, respectively, in sections 1 and 2 z_1 and z_2 - the position of the elementary stream relative to the plane of comparison, m; p_1 and p_2 - the value of pressure, Pa; u_1 and u_2 – flow velocity, m/s; ρ – density of liquid, kg/m^3; g – density of liquid, $g = 9{,}81$ kg/m^3; - acceleration of gravity, m/s^2. The equation includes the head loss h_w that occurs when the fluid moves due to friction forces.

In 1845 J. Weisbach and in 1857 A. Darcy proposed a formula for calculating the head loss [1]

$$h_w = \lambda \frac{l}{d} \frac{\bar{u}^2}{2g}, \qquad (2)$$

where λ – friction factor; $\bar{u}$ – average flow velocity, m/s, $\bar{u}^2/(2g)$ – velocity head, m.

Different types of flow are different forms of movement of flow particles. Flow types were experimentally studied by O. Reynolds. He identified the existence of two forms of flow. At low flow velocities, a layered flow is observed, and at high velocities in the form of small vortices with stirring. The first form of flow is called laminar flow, and the second form of flow is turbulent flow.

Classical experiments of O. Reynolds in 1868 and other scientists have shown that with a gradual increase in velocity, the laminar flow is maintained up to a certain flow velocity. After this velocity, the flow turned into a turbulent flow. When conducting experiments in reverse order, ie with decreasing velocity, the turbulent flow was also maintained up to a certain velocity, after which it passed into a laminar flow. O. Reynolds called this velocity critical, at which there is a change in flow. There are two critical velocities: the lower velocity $\bar{u}_{l.v}$, at which the turbulent flow turns into laminar, and the upper velocity $\bar{u}_{u.v}$, at which the laminar flow turns into turbulent. There is always inequality $\bar{u}_{l.v} < \bar{u}_{u.v}$.

For different types of flow, there are different dependencies between head losses h_w and average velocity $\bar{u}$. Figure 1 shows a graph of dependence $i = h_w/l = f(\bar{u})$ in logarithmic coordinates.

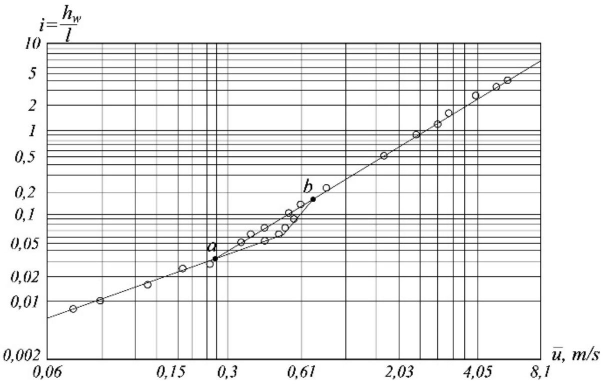

Fig. 1. Graphs of dependence $i = h_w/l = f(\bar{u})$.

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In laminar flow, the graph values of velocity less than $\bar{u}_{l.v}$ (point a) pressure loss along the length proportional to the first degree of velocity, and in turbulent, velocity values greater than $\bar{u}_{u.v}$ (point b) - flow velocities proportional to degree m, ranging from 1, 75 to 2. Between points a and b there is a transition zone within which there is a transition of a laminar stream to turbulent, or on the contrary.

Subsequent studies have shown that the presence of a laminar or turbulent flow depends not only on the flow velocity but also on the flow viscosity and on the geometric dimensions of the flow cross section. Therefore, the type of flow is characterized by the value of the dimensionless similarity criterion, which is called the Reynolds number

$$Re = \frac{\bar{u}d}{\nu}, \quad (3)$$

where d – pipe diameter, m; ν – kinematic viscosity of the flow, m^2/s.

In practice, the type of flow in the pressure pipes is determined by the lower critical Reynolds number ($Re_{н.к} = \bar{u}_{н.к}d/\nu = 2320$).

Extensive experimental studies of the dependence of the friction factor on the Reynolds number and the smoothness of the inner surface of the pipes in 1928-29 were performed by J. Nikuradze at the Kaiser-Wilhelm Institute under the direction of Dr. L. Prandtl [2,3].

J. Nikuradze investigated the influence of the Reynolds number on the friction factor in pipes with uniform granular roughness and in hydraulically smooth pipes on hydraulic installations [2, 3]. The results of his study of pipes with a uniform granular roughness are shown in Figure 2 in the form of graphs in coordinates $lg(100\lambda) = f(lgRe,\ r_0/\varepsilon)$.

The importance of this figure 2, which is called the Nikuradze graph, is that it shows the boundaries of laminar and turbulent flows and regions of hydraulically smooth, prequadratic and quadratic turbulence and the change in friction factor for each region.

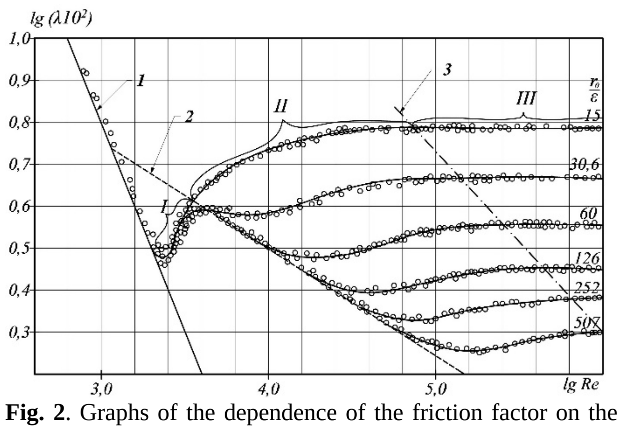

Fig. 2. Graphs of the dependence of the friction factor on the Reynolds number and the inner surface of the pipes (according to J. Nikuradze): 1 - laminar flow; 2 - region of hydraulically smooth turbulence (G. Blasius); 3 - the boundary between the regions of prequadratic and quadratic turbulence; I - transition region between the laminar flow and the region of hydraulically smooth turbulence; II - region of prequadratic turbulence; III - region of quadratic turbulence.

In the laminar flow, the fluid moves slowly and calmly. It flows around the roughness of the inner surface of the pipe. The values of local friction drag are small, so they can be neglected.

The friction factor of the laminar flow in the coordinates $lg(100\lambda) = f(lgRe)$ is described by a graph of a straight line (Fig. 2).

In 1838, Poiseuille studied currents in pipes of small diameter (capillaries) with distilled water at low flow discharges (Poiseuille flows). In 1846 he published a law determining the flow discharge of a steady stream of viscous incompressible fluid in a thin cylindrical tube of circular cross-section.

According to this law, the second volume flow discharge is proportional to the pressure drop $(p_1 - \mathrm{p}_2)$ per unit length of pipe l (pressure gradient in the pipe), the fourth degree of the pipe diameter d and inversely proportional to the dynamic viscosity of the flow

$$Q = K\frac{(p_1 - p_2)d^4}{\mu l}, \quad (4)$$

where K – coefficient of proportionality, $K = \pi/128$ – theoretically determined by D. Stokes in 1845; μ – dynamic viscosity, Pa·s.

It should be noted that in 1839 this law was first formulated by the G. Hagen. Therefore, equation (4) is called the Hagen – Poiseuille law. The flow discharge in the Hagen-Poiseuille formula was represented by the average velocity and diameter of the pipe, and the resulting expression was compared with the Darcy – Weisbach equation. The dependence on determining the friction factor was then obtained.

$$\lambda = \frac{64}{Re}. \quad (5)$$

If $Re \leq 2320$, then this formula is correct and describes the line of the laminar flow (Fig. 2). The graph of the given equation in ordinary coordinates has the form of a hyperbola, and in logarithmic coordinates is represented by a straight line.

Turbulent flow moves much faster than laminar flow. This leads to large velocity gradients between the flow layers of the turbulent core. As a result, a vortex flow is formed. All this leads to an increase in hydraulic friction, which in the laminar flow could be neglected.

The laminar layer is in the turbulent flow between the turbulent flow core and the inner surface of the pipe in the region of hydraulically smooth turbulence.

The thickness of the laminar layer of the total flow is greater than the height of the roughness. In this case, the roughness of the inner surface of the pipe has almost no effect on the turbulent core and the head loss does not depend on the roughness.

Many scientists have performed a large amount of experimental and theoretical research to determine the dependences of the influence of major factors on the value of the friction factor.

Currently, there is no general formula for determining the friction factor λ.

The topic of this article is the theoretical study of the dependence of the friction factor on the Reynolds number of turbulent flow in hydraulically smooth pipes.

Consider the basic formulas of the friction factor for the region of hydraulically smooth turbulence, which is in the range of values ($4000 \leq Re \leq 3 \cdot 10^6$).

G. Blasius in 1913 showed that the friction factor is determined by the dependence [1]

$$\lambda = \frac{0,3164}{Re^{0,25}}. \quad (6)$$

L. Prandtl in 1932 obtained the dependence on the logarithmic velocity profile and on the basis of the results of experimental studies [2]

$$\frac{1}{\sqrt{\lambda}} = 2\, lg\left(Re\sqrt{\lambda}\right) - 0,8. \quad (7)$$

In 1938, C. Colebrook proposed to determine the friction factor by the formula [3]

$$\lambda = \frac{1,63639}{(ln\, 0,142857Re()^2)}. \quad (8)$$

P.K. Konakov (1946) presented an empirical formula [4]

$$\lambda = \frac{1}{(1,8\, lgRe - 1,5)^2}. \quad (9)$$

G.K. Filonenko in 1948 recommended the following dependence [6].

$$\lambda = \left(\frac{0,55}{lg\frac{Re}{8}}()^2\right). \quad (10)$$

In 1962, M.Y. Ruzin proposed to determine the friction factor by the formula [5]

$$\lambda = \frac{0,246}{Re^{0,22}}. \quad (11)$$

F.A. Shevelyov in 1973 determined on the basis of experimental studies the dependence for steel pipes [6]

$$\lambda = \frac{0,25}{Re^{0,226}}. \quad (12)$$

Based on mathematical statistics, the Chinese scientist Guo Ningxiang proposed to determine the friction factor by a formula [7]

$$\frac{1}{\sqrt{\lambda}} = 1,689\, lgRe + \frac{0,35}{1 - 0,084Re}. \quad (13)$$

2 Problem statement

There are problems in calculating engineering hydraulic problems. When calculating the capacity of pipes, it is not enough to know the main factors: flow viscosity, pipe diameter, the roughness of the inner surface of the pipes. It is necessary to take into account the influence of the hydraulic regime on the value of the friction factor λ.

Analysis of the presented formulas, in addition to the formula of L. Prandtl (7), shows that in the region of hydraulically smooth turbulence the friction factor λ depends only on the Reynolds number, which is in the denominator and has a degree of about 0.25. The numerator of these formulas contains a coefficient, the physical meaning of which is not explained. The graphs of the above equations, in ordinary coordinates, have the form of a hyperbola, and in logarithmic coordinates are represented by a straight line.

In L. Prandtl's formula, the square root of the friction factor is described in an implicit form and is calculated, like the Reynolds number, under the sign of the logarithm. This form of the formula complicates the determination of the friction factor and does not show the influence of parameters on its value.

The formulas of the friction factor along the length of the pipe, which is included in equation (2) are the subject of our theoretical research.

3 Research results

To develop a general method of taking into account the head loss in the flow of real fluid, it is necessary to identify the dependence of friction forces on the main factors. These main factors are fluid density ρ, dynamic viscosity μ, hydraulic flow radius R, the complex of the linear dimensions that characterize the inner surface of the pipe wall (roughness height, the distance between roughness's and their shape) ε_i and average flow velocity $\bar{u}$.

Using the method of dimensional analysis, we have established a general view of the dependence of the friction forces on the inner wall of the pipe from these factors [1]

$$\tau_0 = k\rho^z\mu^m R^p\varepsilon^x\bar{u}^n. \quad (14)$$

In dimensional quantities, equation (14) has the form

$$\frac{Ml}{t^2}\frac{1}{l^2} = \frac{M^z}{l^{3z}}\frac{M^m}{l^m t^m}l^p l_i^x\frac{l^n}{t^n}, \quad (15)$$

where M – mass; l – linear dimensions; t – time.

Equated dimensionalities M, l, and t in the right and left parts of equation (15) have the form

$$\left.\begin{array}{c}\text{for the mass: } 1 = m + z \\ \text{for linear dimensions: } -1 = n + p - m - 3z + x \\ \text{for time: } -2 = -n - m\end{array}\right\}. \quad (16)$$

1 and 2 are known parameters and from the system (16), we will define other indicators of degrees

$$\left.\begin{array}{r}m = 2 - n \\ z = n - 1 \\ p = n - 2 - x\end{array}\right\}. \quad (17)$$

Substituting the found degrees through n and x in equation (14), we obtain the formula of tangential stresses on the inner wall of the pipe.

$$\tau_0 = k\rho\frac{\bar{u}^2}{Re^{2-n}}\left(\frac{\varepsilon}{R}\right)^x. \quad (18)$$

Based on experimental studies, it is known that in a turbulent flow, the value of degree $n = 2$. Then the tangential stresses on the pipe wall are

$$\tau_0 = k\left(\frac{\varepsilon}{R}\right)^x \rho \bar{u}^2 = 2k\left(\frac{\varepsilon}{R}\right)^x \rho g \frac{\bar{u}^2}{2g}, \qquad (19)$$

In order to simplify the calculations, A. Darcy proposed in equation (19) to replace the coefficient of friction $f = 2k\left(\frac{\varepsilon}{R}\right)^{x}$ by the coefficient of A. Darcy $f = \frac{\lambda}{4}$.

$$\tau_0 = \frac{\lambda}{4}\rho g \frac{\bar{u}^2}{2g}. \qquad (20)$$

The right-hand sides of equations (18) and (20) are the same and $x = 1$, $R = r_0/2$

$$\lambda = 8k \frac{2\varepsilon/r_0}{Re^{2-n}}. \qquad (21)$$

The obtained dependence (20) shows that the dimensionless coefficient in formulas (6) - (12), in addition to L. Prandtl's formula, characterizes the roughness of the inner surface of pipes with degree $n \approx 1{,}75$.

If in formula (20) take $k = 8$, $x = 0$, and $n = 1$, then we obtain the dependence (5) to determine the friction factor λ of the laminar flow

$$\lambda = \frac{64}{Re}.$$

Based on experimental studies, it is known that the degree takes its minimum value of $n = 1$ for laminar flow and the maximum value of $n = 2$ for turbulent flow in the region of quadratic turbulence. It is also known that the inner surface of the pipes affects the amount of friction factor.

We accept two hypotheses:

- degree n in the regions of hydraulically smooth and quadratic turbulence takes intermediate values in the range $1 < n < 2$;

- to characterize the inner surface of the pipe wall, namely: the average roughness height, the distance between the roughness and their shape is possible only using the relative parameters $2\varepsilon_i/r_0$.

Based on the accepted hypotheses, the dependence (20) will have the form

$$\lambda = 64\left(\frac{2\varepsilon_1/r_0}{Re^{0,75}} + \frac{2\varepsilon_2/r_0}{Re^{0,5}} + \frac{2\varepsilon_3/r_0}{Re^{0,25}} + \frac{2\varepsilon_4}{r_0}\right). \qquad (22)$$

Dependence (22) is obtained by the method of dimensional analysis and characterizes the inner surface of the pipes. This formula determines the friction factor depending on the Reynolds number.

The adequacy of equation (22) was verified by the experimental data obtained by J. Nikuradze and A.D. Altshul for the flow in smooth pipes.

J. Nikuradze performed experimental research on three experimental installations. These installations were built in the workshops of the Kaiser Wilhelm Institute.

For small Reynolds numbers from $3 \cdot 10^3$ to $60 \cdot 10^3$, the pressure in the pipe was created by an overflow tank. The water supply came from the general water supply system. The discharge of water consumption was determined by the volumetric method.

For Reynolds numbers up to $1400 \cdot 10^3$, the pressure in the pipe was created using a rotary pump.

To create an even larger Reynolds number (up to $2500 \cdot 10^3$), the pressure in the pipe was increased by compressed air in a closed pressure tank.

In the last two installations, the Reynolds number was further increased by increasing the water temperature.

When conducting experiments on such installations, J. Nikuradze expanded the range of research to large values of Reynolds numbers. The maximum possible value of the Reynolds number in the study was $Re = 3300 \cdot 10^3$.

The results of J. Nikuradze's experiments in the region of hydraulically smooth turbulence [2] are graphs in coordinates $lg(100\lambda) = f(lgRe())$ in Figure 3.

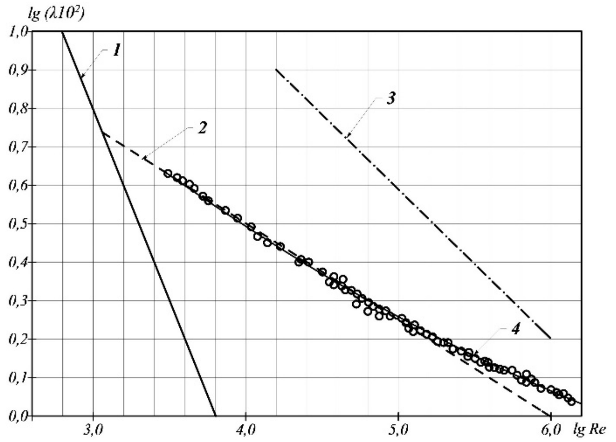

Fig. 3. Graphs of the dependence of the friction factor on the Reynolds number (according to J. Nikuradze): 1 - laminar flow; 2 - the region of hydraulically smooth turbulence (G. Blasius); 3 - the boundary between the regions of prequadratic and quadratic turbulence; 4 - according to the author's formula; ○ - experimental results of J. Nikuradze.

The figure 3 shows that the friction factor in coordinates $lg(100\lambda) = f(lgRe)$ depending on the main factors and the hydraulic regime within the regions takes different values.

Table 1 shows the diameters of the pipes and the Reynolds number, in the range of which hydraulic studies were performed by J. Nikuradze. The table also presents the dispersion of adequacy, which characterize the discrepancy of the experimental data relative to the theoretical formulas (6) - (12), (22).

The least squares method gave the values of the elements of the complex of relative parameters: $2\varepsilon_1/r_0 = 0$, $2\varepsilon_2/r_0 = 0{,}01034$, $2\varepsilon_3/r_0 = 0{,}003124$, $2\varepsilon_4/r_0 = 0{,}0000726$. Then equation (22) has the form

$$\lambda = 64\left(\frac{0{,}01034}{Re^{0,5}} + \frac{0{,}03124}{Re^{0,25}} + 0{,}0000726\right). \qquad (23)$$

The table 1 shows that the dispersion of adequacy of experimental data with the formula of G. Blasius increases with increasing Reynolds number. The dispersion of adequacy with the formulas of L. Prandtl, C. Colebrook, P.K. Konakov, G.K. Filonenko, F.A. Shevelyov and with the formula of the authors of this article decreases with increasing Reynolds number. The dispersion of adequacy of experimental data with the M.Y. Ruzin formula with increasing Reynolds numbers first increases and then decreases.

Table 1. The dispersion of adequacy of experimental data of hydraulic studies of smooth pipes obtained by J. Nikuradze, relative to the recommended formulas.

Author	Formula number	Dispersion of adequacy $D^2 \times 10^6$ for pipe diameters, mm and Reynolds numbers $\frac{Re\ \ mim \times 10^{-3}}{Re\ \ max \times 10^{-3}}$					
		10	20	30	50	100	10 – 100
		$\frac{3,07}{23}$	$\frac{17}{182}$	$\frac{106}{288}$	$\frac{37}{670}$	$\frac{318,9}{1364}$	$\frac{3,07}{1364}$
G. Blasius	(6)	0,167	0,251	0,293	0,433	2,835	1,348
L. Prandtl	(7)	0,336	0,210	0,050	0,082	0,023	0,112
C. Colebrook	(8)	0,401	0,203	0,046	0,103	0,026	0,123
P.K. Konakov	(9)	0,449	0,239	0,059	0,152	0,036	0,150
G.K. Filonen-ko	(10)	1,056	0,202	0,048	0,069	0,023	0,196
M.Y. Ruzin	(11)	0,877	3,310	1,732	2,210	0,244	1,417
F.A. Shevely-ov	(12)	1,572	0,694	0,160	0,342	0,573	0,645
Guo Ningxiang	(13)	0,358	0,134	0,053	0,090	0,021	0,116
Authors of the article	(23)	0,150	0,194	0,041	0,069	0,024	0,083

If we analyze the dispersion of the adequacy of experimental formulas in Table 1, then at Reynolds numbers from 3070 to 1364000 - minimal errors give the formula of the authors of the article and the formula of L. Prandtl, C. Colebrook and G.K. Filonenko. The biggest errors are given by the formulas of G. Blazius and M.Y. Ruzin.

A.D. Altshul performed experimental research on hydraulic and aerodynamic installations [8].

Aluminum pipes had a smooth inner surface and were coated with oil. Before the experiments, they were washed with solvent and thoroughly wiped with rags. Pipes with a diameter of 350 mm had a small roughness, formed by insufficiently clean broaching (during their manufacture) and coating of alumina oxide.

The tested sections of pipes were always made of solid pipe (there were no joints on the section). The inlet and outlet sections were made of the same aluminum pipes as the measuring section.

The study of an aluminum pipe with a diameter of 26 mm was performed on a hydraulic installation, and with a diameter of 109.8 and 350 mm – on an aerodynamic installation.

The results of experimental studies of A.D. Altshul in the region of hydraulically smooth turbulence [8] are shown in Figure 4 in coordinates $lg(100\lambda) = f(lgRe())$.

Table 2 shows the diameters of the pipes and the Reynolds number, in the range of which hydraulic studies were performed by A.D. Altshul. The table also presents the dispersion of adequacy, which characterizes the discrepancy of the experimental data relative to the theoretical formulas (6) - (12), (22).

If we analyze the dispersion of the adequacy of experimental data (table 2) relative to the formulas for Reynolds numbers from 2844 to 338844, the minimal errors give the formulas of the authors of this article, L. Prandtl, C. Colebrook, G.K. Filonenko, and F.A. Shevelev.

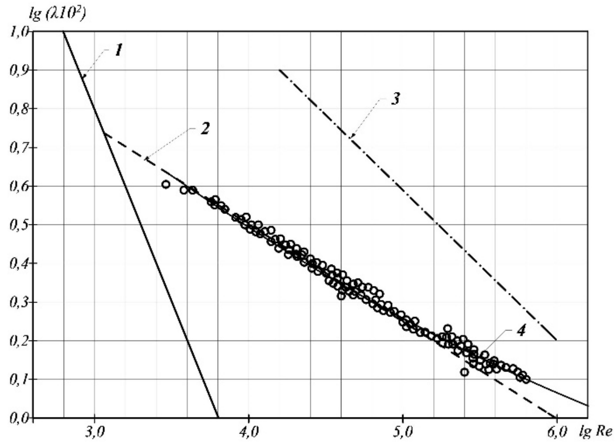

Fig. 4. Graphs of the dependence of the friction factor on the Reynolds number: 1 - laminar flow; 2 - the region of hydraulically smooth turbulence (G. Blasius); 3 - the boundary between the regions of prequadratic and quadratic turbulence; 4 - according to the author's formula; ○ - experimental results of A.D. Altshul.

Table 2. The dispersion of adequacy of experimental data of hydraulic studies of smooth pipes obtained by A.D. Altshul, relative to the recommended formulas

Author	For-mula num ber	Dispersion of adequacy $D^2 \times 10^6$ for pipe diameters, mm and Reynolds numbers $\frac{Re\ \ mim \times 10^{-3}}{Re\ \ max \times 10^{-3}}$					
		18,45	26	26	109,8	350	18,45 – 350
		$\frac{2884}{38905}$	$\frac{19486}{33113}$	$\frac{9550}{25119}$	$\frac{141254}{285102}$	$\frac{251189}{338844}$	$\frac{2884}{338844}$
G. Bla-sius	(6)	0,509	0,286	1,128	0,324	1,239	0,690
L. Pran dtl	(7)	1,420	0,249	2,207	0,078	0,192	0,571
C. Co-lebrook	(8)	1,879	0,265	2,373	0,050	0,204	0,651
P.K. Kona-kov	(9)	1,995	0,371	2,794	0,044	0,226	0,763
G.K. Filo-nenko	(10)	1,279	0,187	1,602	0,083	0,192	0,559
M.Y. Ruzin	(11)	0,866	2,675	0,353	2,176	0,874	1,595
F.A. Sheve-lyov	(12)	0,292	0,516	0,588	0,341	0,213	0,389
Guo Ning-xiang	(13)	1,609	0,264	2,234	0,078	0,192	0,612
Aut-hors of the ar-ticle	(23)	1,167	0,199	1,713	0,066	0,199	0,477

The biggest errors are given by the formula M.Y. Ruzin.

Table 2 shows that the dispersion of the adequacy of experimental data for the formula of G. Blasius with increasing Reynolds number increases. For the formulas of L. Prandtl, C. Colebrook, P.K. Konakov, G.K. Filonenko, F.A. Shevelyov, and the formulas of the

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authors of the article with increasing Reynolds number, the dispersion of adequacy decreases.

The good results of L. Prandtl's formula can be explained by the fact that this dependence is obtained theoretically from the logarithmic velocity profile.

All other formulas are obtained by statistical methods, so the determined results differ significantly from the experimental data.

The given experimental researches of J. Nikuradze and A.D. Altshul were performed for pipes of different material and diameter, on hydraulic and aerodynamic installations with the use of different measuring equipment.

The experimental data of A.D. Altshul (Figs. 3, 4) have a greater dispersion of adequacy. This can be explained by the fact that the experiments were performed using water and air. But all studies have a wide range of Reynolds numbers.

It should be noted that the determination of pipe diameters, pipe lengths between piezometric pressure sampling points, pressure drops, and water discharges were determined by calibrated equipment.

The accuracy of all experiments is high because there are no systematic errors. All experimental data are grouped only near one theoretical line by dependence (23). There are random errors, and they are greater in the experiments of A.D. Altshul.

We can conclude that the described experiments of J. Nikuradze and A.D. Altshul are sufficient for theoretical research.

The formula of the authors of the article gives good results because it is obtained on the basis of the method of dimensional analysis, characterizes the roughness of the inner surface of the pipes. This formula also takes into account the influence of Reynolds numbers on the friction factor.

4 Conclusions and prospects for future research

The article presents the results of theoretical studies of the flow friction factor in hydraulically smooth pipes. The dependence for the calculation of the friction factor based on the method of dimensional analysis is obtained. The adequacy of the author's equation and experimental data of J. Nikuradze and A.D. Altshul in the study of water flow in smooth pipes is determined.

It is shown that in almost all cases, formula (23) gives the best results. This formula is obtained on the basis of the method of dimensional analysis, which characterizes the roughness of the inner surface of the pipes. It also takes into account the influence of Reynolds numbers on the friction factor.

Therefore, formula (23) can be recommended to determine the friction factor of turbulent flow in the region of hydraulically smooth turbulence.

Future articles will present the results of theoretical studies of the friction factor for the regions of prequadratic and quadratic turbulence in steel and aluminum pipes.

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The dam slope stability under the transient condition during an extreme flood

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Abstract. Mountain Flood Control Reservoir (MFC Reservoir) is used to reduce the flood level in the mountainous area and protect settlements downstream. The special feature of this MFC Reservoir is the fast filling during 1-2 days, short storage time at the maximum level and speed falling of the water level. Simulation of the MFC Reservoir operation was carried out on the software Midas GTS NX. Two rockfill dam models were developed: with the core and with the screen. The fluctuation of the water level in the MFC Reservoir was taken as the transformed flood from 1% to 10% probability. The fast water level change in the MCF Reservoir creates the transient seepage condition during the flood. During the water level rising in the MFC Reservoir, the upstream slope stability gradually increases because of hydrostatic pressure. After the water level begins to fall with rate of 0.7 m/hour, the slope stability decreases. The core or screen location significantly affects the stability of the upstream dam slope. The simulation showed that the upstream slope of the dam with the core was more stable. Due to the high hydraulic conductivity, the upstream dam prism with the berm significantly dampens the pore pressure in the dam and increases the stability of the upstream slope.

1 Introduction

The floods take place both in winter and in the warm period, but cold floods have the higher flow rates in the Transcarpathian region. Due to the unstable temperature regime in winter, the frequent thaws are observed in the Tisza river basin, during which extreme cold floods are formed. In the mountainous part of the Tisza river basin floods have the high flow rate and short lag time, due to steep floodplain slopes and riverbed slope, the duration of flood does not exceed 3-5 days.

One of the active flood protection measure to lower water levels is using Mountain Flood Control Reservoir, which transforms the extreme flood flow of 1% probability to safe one. The safe flood flow which provides the sustainability of the river ecological system is estimated as Channel-forming flow of 5% - 35% probability for Tisza River basin according researchers in the work [1].

Mountain Flood Control Reservoir is created by dam with the bottom spillway. The spillway is designed for discharge of Channel-forming flow which passes without changing downstream. In the case of the extreme flood, the part of the river runoff that exceeded the Channel-forming flow is temporarily accumulated in the MFC Reservoir formed by the dam [2]. To save vegetation diversity inside the MFC Reservoir area, the duration of the water storage in the MFC Reservoir should not exceed 8-10 days, during which the water gradually flows downstream.

During the period of flooding the water level rises rapidly and the same rapid falls. During the rapid water rising in the MFC Reservoir, the pore pressure increases in the dam prism and the seepage is directed to the downstream slope. As the water level falls in the MFC Reservoir, the direction of seepage changes to the upstream slope with the gradual decrease in pore pressure. The rapid change of the water level in the Reservoir does not enable to stabilize the seepage, as the water penetration into the dam body is partial and transient [3, 4]. The depth of water penetration into the dam body affects the slope stability.

The calculations of authors [5-10] showed that the slope Safety Factor decreasing during the intense water level falling under the steady state seepage condition at the initial time, and if the water level was getting higher the Safety Factor increased in the water reservoir [11]. Decrease in slope stability is noted also under the transient seepage conditions as water penetrates into unsaturated soil during the rain that leads to increase of the phreatic surface [7, 12, 13]. In the article [14] is noted that Safety Factor of the clay slope during the rapid rising and falling (transient condition) decreases less than the Safety Factor calculated during the water falling from steady high level in the water reservoir. Therefore, it should be expected that Safety Factor of the upstream slope will decrease but the dam stability will be higher during the Mountain Flood Control Reservoir operation than when the water level falls suddenly after prolonged standing at a high level as in the typical water reservoir.

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The transient analysis requires additional parameters of unsaturated soil, such as volumetric water content function, hydraulic conductivity function, residual water content [15]. Not all unsaturated parameters have a significant impact on the results of calculations, in the works [4, 16] were noted that saturated hydraulic conductivity had greater impact on the slope stability, than the volumetric water content function, which could be determined by theoretical methods. In the article [17] Safety Factors for slope at the different hydraulic conductivity and water falling rate were studied and established that the slope stability was not depend on the water falling rate if the saturated hydraulic conductivity of the slope was 0.2 m/hour and above.

To reduce construction cost, the dam of the Mountain Flood Control Reservoir is made of local materials, the quarries of which are located nearby. The most common building material in the mountainous part of the Carpathians is the gravel-pebble soil, the mechanical properties of which meet the requirements of the dam construction regulations. This material has the high saturated hydraulic conductivity of 30-50 m/day, which requires the use of the impermeable layer.

There are enough clay materials with low hydraulic conductivity of 0.01-0.07 m/day in Carpathians region, so two types of dam, the dam with the core and with the screen were considered in this article. The dam with screen simplifies the process of construction and operation of the dam, at the same time the dam with the clay core is more stable during seismic activity. Therefore, it is necessary to investigate whether the presence of the clay screen will affect the upstream slope stability and which of the impermeable structures will be more reliable for MFC Reservoir.

Mountain Flood Control Reservoir leads to the temporary intensive water level rising and falling during the extreme flood, which may reduce the upstream dam slope stability. This problem can be solved by simulating transient seepage by means of finite element method. Assessment of the slope stability under transient conditions is an urgent task that will ensure the reliability of flood protection. The stability of the upstream dam slope and transient seepage analysis were carried out by the Stress Analysis Method (SAM) and the Stress Reduction Method (SRM) using the software Midas GTS NX (version 2.1).

The purpose of the work is to simulate the possibility of dangerous landslide processes of the upstream dam slope during the MFC Reservoir operation under the transient seepage condition of unsaturated soil and to determine the optimal design of the impermeable structure of the rockfill dam.

2 Methods

2.1 Mountain Flood Control Reservoir

Expected location of the Mountain Flood Control Reservoir is the Irshava River of the mountainous part of the Tisza river basin. The main function of the MFC Reservoir to protect settlements of Brid, Zagattya, Irshava against floods and to lower flood water level in the river. The catchment area of the MFC Reservoir is 71.4 km^2. The height of the dam is 19.6 m. The upstream slope is 1:2.5, and the downstream slope is 1:2.25. Dam structure is shown on the fig. 1. The berms of 3.0 m wide are formed on the upstream and downstream slopes to increase the slope stability, and are used as cofferdam during construction period. The upstream slope is covered with the riprap. The base of the dam is strong dark grey Basaltic andesite, which is cracked near the surface with saturated hydraulic conductivity of 0.01-0.1 m/day.

The modern alluvial deposits of boulder-gravel-pebble materials on loamy aggregate which covers mountain base, should be removed out of the dam pit.

2.2 Extreme floods

Floods occur several times a year in Transcarpathian region, and extreme floods occur periodically: 1947, 1957, 1968, 1970, 1992, 1998, 2001, 2008, 2010, 2019. The flood of November 1998 is one of the most catastrophic in the recent years. It covered all the rivers of Tisza basin and it was formed by prolonged rains. Intense and prolonged rains led to the water levels rise up to 2.5-6 m in the rivers on the 4th of November, 2020.

To simulate the Mountain Flood Control Reservoir operation hydrograph of the flood of 1% probability was taken that was equal to 181m^3/s for the Irshava River. The flood water level raising to the maximum flow occurs in 12.4 hours, the level falls slower during 43.3 hours. The transformed flood flow, which flows through the bottom spillway to the downstream, is shown in fig. 2 (red line) and equal to 103m^3/s. The storage of the flood in the MFC Reservoir enables to reduce the flood flow twice due to stretching of the maximum flow in time. The water storage continues for the short time of 15 hours, then water level falls along 30 hours. The transformed flood hydrograph was converted into the relationship between water level and time by means of the flow rate and total head function.

This relationship between water total head and time was used to simulate MFC Reservoir operation during flood event.

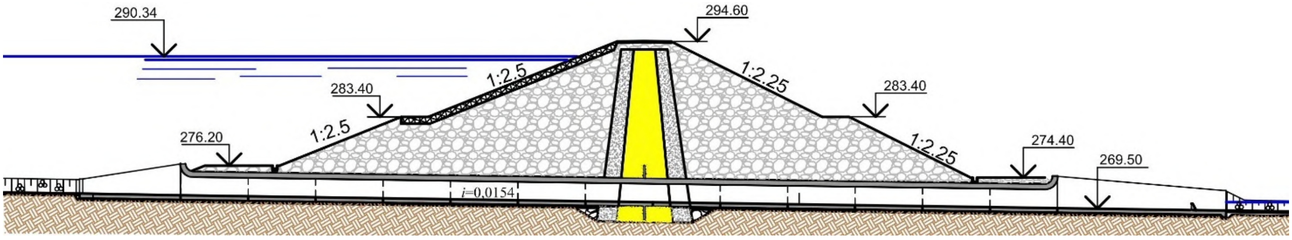

Fig. 1. Mountain Flood Control Reservoir dam with core.

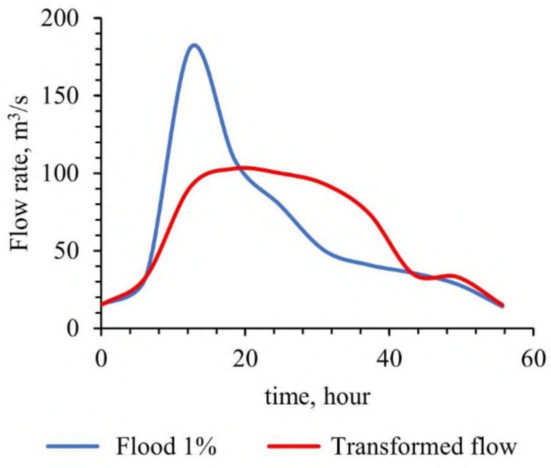

Fig. 2. The flood hydrographs of 1% and transformed flow downstream.

2.3 Soil properties of the dam and the base

The soil of the gravel-pebble with loamy aggregate for the dam prisms is classified as GM, the core and screen of heavy loam is classified as SC according to the Unified Soil Classification System. The base is Basaltic andesite cracked on the top and water saturated.

The mechanical properties of the soils of the dam and the base were obtained as a result of field surveys and laboratory processing of the samples. The soil property which were taken into account during simulation are shown in table 1.

Table 1. The soil properties of the dam and the base.

Propertied	Prism (GM)	Core, screen (SC)	Bedrock
Elastic Modulus, MPa	25	22	150
Unit Weight, kN/m^3	21.3	19.6	21
Cohesion, kPa	1	16	30
Internal friction angle, º	30	23	36
Hydraulic conductivity, m/day	19.9	0.067	0.001
Porosity, m^3/m^3	0.46	0.58	0.3

2.4 Transient seepage analysis of the Mountain Flood Control Reservoir

Simulations of the transient seepage in the dam during water level increasing and falling were made using the semi-coupled Seepage-Stress-Slope Analysis by the Midas GTS NX software. The Darcy`s equation is solved by the finite element method:

$$\frac{\partial}{\partial x}\left(k_x\frac{\partial H}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_y\frac{\partial H}{\partial y}\right)+Q=\frac{\partial\theta}{\partial t}, \quad (1)$$

where H is total head; k_x, k_y are the hydraulic conductivity in the horizontal and vertical directions, respectively; Q is boundary discharge; θ is the volumetric water content; t is the time.

The volumetric water content functions and the hydraulic conductivity functions of unsaturated soils for the prism GM, core (SC) and screen (SC) were set to simulate transient seepage analyses. The base was taken as saturated with the hydraulic conductivity according to table 1. It was assumed that the dam had already built and initial deformation was finished, for which the stage of zero initial deformations was entered during the calculations. The initial water level was set at the level of 1.0 m above the base of the dam which corresponded to the water level in the river before the flood, the initial stage of steady state seepage analysis was made to simulate water in the river. The influence of the rain and the possible evaporation from the surface of the dam were not simulated.

2.5 The upstream slope stability analysis

The Stress Analysis Method (SAM) is the limit equilibrium method, in which the Safety Factor is determined for the several circular sliding surfaces using the results of the stress calculation by the finite element method. The Safety Factor is calculated by equation:

$$SF=\frac{\int_s \tau_f d\Gamma}{\int_s \tau_m d\Gamma}, \quad (2)$$

where τ_m is shear stress, which determined as a result of calculation; τ_f is shear stress, which for the Mohr-Coulomb criterion is calculated by equation:

$$\tau_f = c+\sigma_n tg\varphi, \quad (3)$$

$$\tau_m = 0.5(\sigma_y-\sigma_x)sin2\theta+\tau_{xy}cos2\theta, \quad (4)$$

$$\sigma_n=\sigma_x sin^2\theta+\sigma_y cos^2\theta-\tau_{xy}sin2\theta, \quad (5)$$

where c is cohesion; φ is internal friction angle; θ is the angle between the sliding surface and horizon; σ_n is the total normal stress; σ_x, σ_y are normal stress in the horizontal and vertical directions, respectively; τ_{xy} – shear stress in x- and y-directions at the base centre.

The Stress Reduction Method (SRM) is based on the gradual decrease in shear stress until the slope reaches limit equilibrium state, the minimum value of the Safety Factor using the Mohr-Coulomb criterion is determined by the equation:

$$SF=\frac{c+\sigma_n tg\varphi}{\frac{c}{SRF}+\sigma_n tg\varphi_f}, \quad (6)$$

$$\varphi_f = tg^{-1}\left(\frac{tg\varphi}{SRF}\right), \quad (7)$$

where SRM – Stress Reduction Factor.

The Stress Reduction Method enables to simulate the sliding surface which is close to the real form of sliding surface without preliminary adopted potential sliding surfaces that is the great advantage over the other methods in which it is necessary to set sliding surfaces [18, 19].

The two-dimensional model was used to simulate the Mountain Flood Control Reservoir operation. Since the size of the mesh affects the calculations accuracy before the simulation, the optimal mesh size was accepted by gradually reducing the mesh size from 2.0 m to 0.5 m. The simulation was carried out for dam with core. The mesh size of 1.0 x 1.0 m was set for dam, and the variable mesh

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from 1.0 m to 2.0 m for the base as further mesh reduction significantly increases the calculation time and practically does not increase the Safety Factor accuracy, the similar result was obtained in the work [20].

The Mohr-Coulomb model was used for the soil simulation. Two dam construction were simulated: the location of the impermeable layer in the middle of the dam (dam with core) and the impermeable layer location near the upstream prism (dam with screen). The flood hydrograph was divided by regular intervals every 5 hours. The following assumptions were made during the simulation:

- the parts of the model (prism, core, screen, base) were accepted as homogeneous and isotropic;
- the mechanical soil properties in saturated and unsaturated condition were assumed to be the same;
- the hydraulic conductivities are isotropic;
- the maximum hydraulic conductivity is equal to the water permeability;
- the seepage inside the dam is transient;
- the initial water level is set at the level of 1.0 m above the base.

3 Results and discussion

The phreatic surface location inside the dam during the rise of water level at first 30 hours of the flood is shown in figs. 3A and 4A. The high-water level keeps for 10 hours from 25 to 35 hours, during which the phreatic surface does not reach the steady state position (the steady state phreatic surface is shown in figs 3 and 4 in dark red). The water rise rate of 0.7 m/hour does not enable to establish steady state seepage in the prism of the dam with the core (fig. 3A), so the water saturation of the soil in the core is less than in the screen soil, which is located closer to the upstream slope. The screen is saturated with water more intensely even at the first 20 hours of the flood.

After the short period of high water, the water level begins to decrease, the falling rate reaches of 0.78 m/hour at the time period from 35 hours to 55 hours (figs. 3B and 4B). The direction of water movement changes: part of the water continues to seep through the downstream slope, as evidenced by the gradual increase in water level inside downstream prism and approaching the steady state position, the second part changes direction to the upstream slope. The figs. 3 B and 4 B show that the reduction of pore pressure in the dam prism occurs almost simultaneously with the water level decrease in the MFC Reservoir, and the lag time of the phreatic surface is formed due to the low hydraulic conductivity of the core and screen. The location of the impermeable layer (screen) near the upstream slope significantly affects the pressure gradient during the water level falling.

Therefore, from the point of view of reliable operation of the MFC Reservoir, the impermeable layer should be moved away from the upstream slope to decrease the pressure gradient and fast the pore pressure damping in the dam prism.

The fig. 5 presents the results of upstream slope stability calculations by the SAM for the dam models with core and screen and the change of water levels in the MFC Reservoir, which corresponds to the transformed flood hydrograph. The zero time corresponds to the upstream slope stability at the steady state water level of 1.0 m above the dam base. The Safety Factor of the upstream slope of the dam is 1.5 at the zero time, which is lower than the SF of the MFC Reservoir filled with water due to the stabilizing effect of hydrostatic pressure. At the begin of the flood (from 0 to 10 hours) during the slow water raising, the SF of the upstream slope decreases slightly due to increasing pore pressure in the dam prism, the next time period with increasing water level the stability of the slope increases to 1.57 for the dam with core and to 1.5 for the dam with screen.

After 35 hours of the flood, the water level begins to fall, the water level in the MFC Reservoir falls faster than the phreatic surface in the dam body and the slope stability decreases, reaching a minimum value at the 50th hour of flood, which corresponds to the highest gradient of phreatic surface (figs. 3B, 4B). The upstream slope of the dam with the screen loses stability faster than the dam with the core and Safety Factor reaches the limit value at which the slope is kept stable at 50th hour. At the same time, the dam with the core has the safety margin.

Dam stability simulation by the SRM demonstrates the similar trend of Safety Factor change with the maximum value at the highest water level in the MFC Reservoir during the flood and the minimum value of the upstream slope stability at the 50th hour (the end of the flood). At the end of the flood, the upstream slope is stabilized with the gradual restoration of the initial Safety Factor. The results of calculations are shown in the fig. 6.

Calculated sliding surfaces by SRM and SAM had circular shapes. The location of the critical sliding surfaces determined by the SRM and SAM were situated on the upstream berm. The sliding surface determent by SRM is located deeper and has bigger radius than surface designed by SAM. The sliding area created by SRM is bigger.

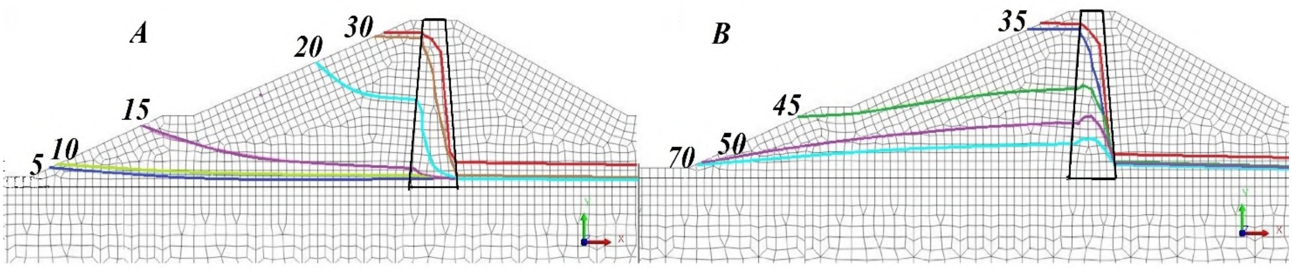

Fig. 3. The phreatic surface location at the 5, 10, 15, 20, 30, 35, 45, 55 and 70 hours of the flood inside the dam with the core.

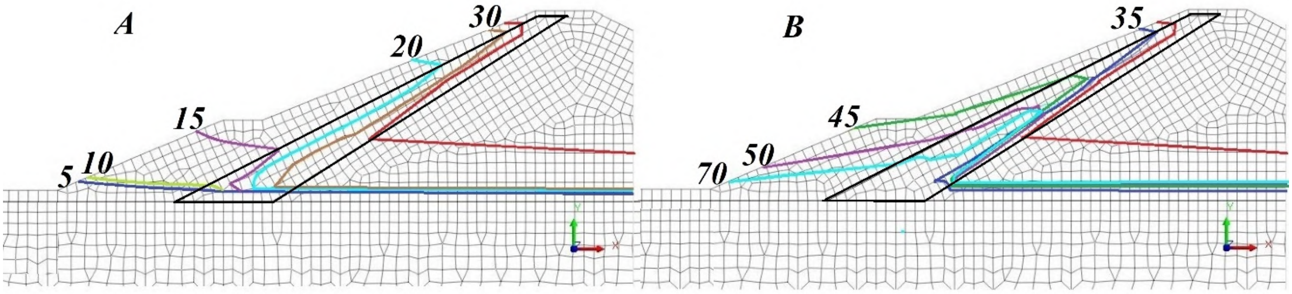

Fig.4. The phreatic surface location at the 5, 10, 15, 20, 30, 35, 45, 55 and 70 hours of the flood inside the dam with the screen.

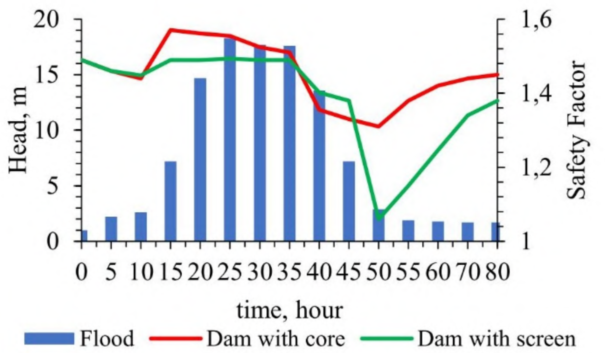

Fig. 5. The Safety Factor of the upstream slope of the dam with core and screen calculated by the SAM.

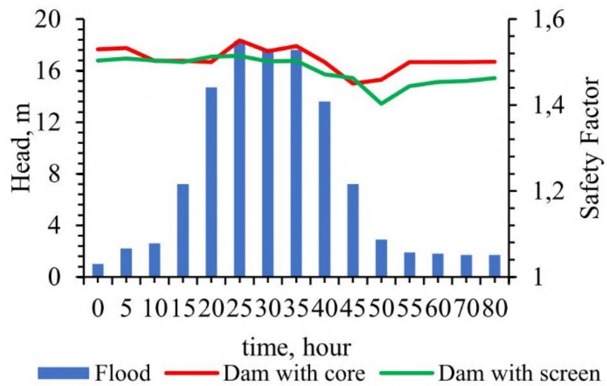

Fig. 6. The Safety Factor of the upstream slope of the dam with core and screen calculated by SRM.

4 Conclusions

Floods in mountainous areas have a sudden nature and the short period of 2-3 days, with a significant water rise in short time and the same rapid water level falling. Construction of the Mountain Flood Control Reservoir requires rockfill dam. Two different type of the impermeable layer of the dam were used for simulation: the dam with core and the dam with screen.

When the water level rises to the maximum value and then falls, there is the water lag time in the impermeable layer, especially great seepage gradient takes place in the dam with the screen.

The dam prism with the hydraulic conductivity of 20 m/day leads to pore pressure damping, so in a dam with the core phreatic surface are gentler, and the seepage point almost coincides with the water level in the MFC Reservoir. In the dam with screen, the water lag in the screen soil leads to the larger values of pore pressure near the upstream slope, and the seepage point is situated above the water level in the MFC Reservoir.

The Safety Factor of the upstream slope of the dam is 1.5 for initial position, when the MFC Reservoir is empty and the initial river water level is 1.0 m above the base.

Seepage analysis of the rockfill dam with impermeable layer showed that the maximum values of the Safety Factor is achieved by setting the high-water level in the MFC Reservoir. The flood condition does not enable to form of steady state seepage due to the low hydraulic conductivity (0.067 m/day) of the impermeable layer and the high-water level changing rate in the MFC Reservoir. Therefore, simulation of the MFC Reservoir operation must be carried out using transient seepage analysis, taking into account the unsaturated properties of the soil.

Simulations of the dam with core under transient condition of water level rising and falling showed that the upstream slope stability significantly depends on the position of the phreatic surface in dam prism. On the example of the dam with core on the Irshava River, the simulation using SAM showed that the water level falling at the end of the flood reduces the slope stability, the Safety Factor was 1.31 when the minimum water level is reached.

The water level falling under transient condition in the unsaturated soils by SRM also leads to the decrease of the upstream slope stability, but the minimum value of the Safety Factor was 1.48 for the dam with core.

The dam with screen as impermeable layer has operational advantages, but in the case of transient seepage condition, the screen saturation leads to the significant increase in the phreatic surface gradient that reduce the slope stability to unacceptable Safety Factor values of 1.06. Therefore, the rockfill dam with the clay core significantly increases the reliability and safety of the structure and ensures the upstream slope stability. The dam prisms should have high hydraulic conductivity and the slopes should be divided with berms of 3.0 m width.

Calculations of slope stability by SAM and SRM show the circular sliding surface and not the same location of the critical sliding surface. The values of the Safety Factor under the same conditions differ due to the different radius of the sliding surface and location. The values of the Safety Factor calculated using the SAM are lower than the value determined by SRM under similar conditions.

The overestimated Safety Factor by SRM were obtained in the works [20 - 24], that explained sensitive to the nonlinear solution algorithm and its incapable of determining other failure surfaces near critical value.

Since the Safety Factor values defined by SAM lower, they were taken to assess the upstream slope stability.

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Sexual dimorphism in shell morphology of mollusks of the genus *Viviparus* – important objects of water resources of Ukraine

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Abstract. Bioindication assessment of water bodies of Ukraine can be carried out using the ratio of males and females of mollusks of the genus *Viviparus*. In practice, it is very convenient to determine the sex of mollusks by the differences in their shell. Male and female freshwater snails *Viviparus viviparus* (Linnaeus, 1758) and *V. contectus* (Millet, 1813) are shown to have reliable differences in shell morphology depending on their age. There is almost no sexual dimorphism by shell morphometrics and indices in Viviparus snails aged one to three years. After three years of life, mature females have significantly larger shell width, higher body whorl, and size of the aperture. Females of *V. viviparus* at the age of two to five years may be differentiated from males by the relationship of mean shell width and shell height, which is statistically significant higher than in males. This difference is explained by the different size of the mantle section genital organs of mature male and female. The obtained results should be taken into consideration in establishing the sex of viviparid snails.

1 Introduction

Mollusks of the genus *Viviparus* Montfort, 1810, namely *V. viviparus* (Linnaeus, 1758) and *V. contectus* (Millet, 1813) are quite common in the rivers, floodplain lakes and large ponds of Ukraine, in which they can accumulate significant numbers and biomass [1]. The freshwater pond snails are essential in the maintenance of water ecosystems, as part of various trophic chains, particularly as intermediate hosts of many bird parasites [2]. Also, these prosobranch gastropods with filtration and sedimentation cleanse water bodies from suspended matter, depositing it on the bottom [3, 4].

Viviparid snails were found useful for bioindication of water bodies of Ukraine [5]. For that, the ratio of males to females in the mollusk population is used. The sex structure of freshwater pond snails in water bodies with an increased organic matter content (alphamesosaprobic and polysaprobic zones) is characterized by an increase in the number of females, less often young (1–3-year-olds individuals) males [1]. In practice, it is important to clearly distinguish between male and female freshwater pond snails when conducting bioindication studies.

The representatives of the genus *Viviparus* are dioecious freshwater snails with exact sexual dimorphism: in males, the right tentacle is shorter, thickened and blunt (transformed into copulatory organ), while in females the right and left tentacles were of the same shape and size. Sex chromosomes in both species were not identified, but there are statistically significant differences in dimensions of homological chromosomes of *V. viviparus* and *V. contectus* males and females [6, 7].

The studies about sexual dimorphism in the shell morphology of *Viviparus* are contradictory. For example, sexual dimorphism was not found in the shell sizes of *V. sphaeridius* (Bourguignat, 1880) and *V. viviparus*, collected in the Southern Buh river [8, 9]. However, statistically significant sex differences in the conchological characters of these species in the Bucha river were noted in that study. Examination of five species of the genus *Viviparus* (*V. viviparus, V. contectus, V. acerosus* (Bourguignat, 1862), *V. ater* (Christofori et Jan, 1832), and *V. hellenicus* (Clessin, 1879)) revealed no dimorphism between male and female snails in the shell shape [10].

At the same time, a number of studies point out the presence of such differences. In particular, females of *Viviparus* are usually larger than males, with more convex whorls, and wider aperture [11–13]. T. A. Andriychuk [6] revealed sex differences in the shells of *Viviparus* using discriminant analysis and dispersion statistical analysis.

Geometric morphometric analyses of three shell characters (ventral/aperture, dorsal, and top/whorl portion) indicated sexual dimorphism in the shape in *V. angularis* (O. F. Müller, 1774) [14]. Sexual dimorphism in the shell sizes was also noted for the

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American endemic species *V. subpurpureus* (Say, 1829) [13]. Females of this species have relatively lower shell spire, more convex whorls and larger size of the aperture compared with males. In *V. viviparus* [15] and *V. contectus* [16], there were marked sexual differences by the allometric coefficients of the relationship between shell height, shell diameter (width) and aperture height.

However, there also are reports [such as 17], according to which male snails are larger than females and these differences are statistically significant.

Taking into account the discrepancies in the literature about sexual dimorphism in the shell morphology, we decided to carry out our own study.

The purpose of our work was to study sexual dimorphism in the shell morphology of *V. viviparus* and *V. contectus,* taking into account the age of mollusks.

2 Material and methods

The materials for the study were the samples of *V. viviparus* (Fig. 1a) from the Irsha river (city of Khoroshiv, Zhytomyr region, Ukraine; 50°60'31" N, 28°45'42" E) and *V. contectus* (Fig. 1b) from the floodplain of the Tnya river (village of Nesolon, Zhytomyr region, Ukraine, 50°56'08" N, 27°92'81"E) collected in August, 2016. The mollusks were collected at a depth of 1 m. At each station, at least three samples were taken [18].

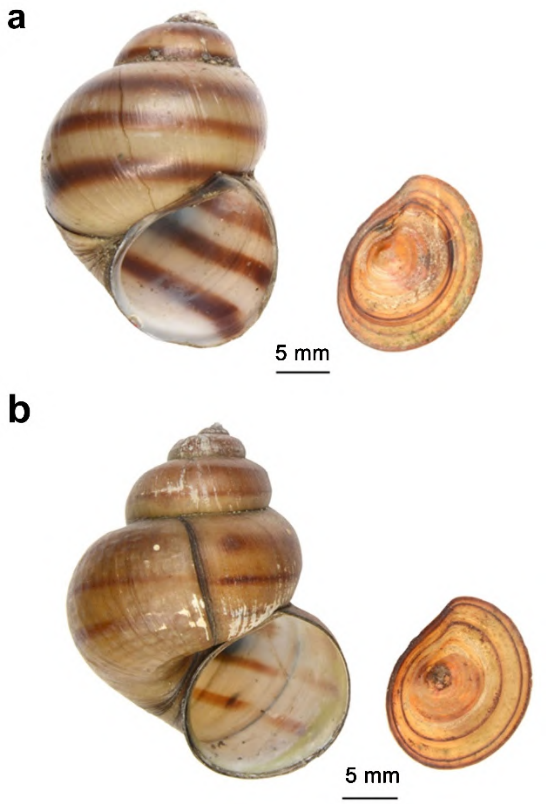

Fig. 1. Shell and operculum of *Viviparus viviparus* (Linnaeus, 1758) (a) and *V. contectus* (Millet, 1813) (b).

Snail species were identified according to P. Glöer [19] and F.W. Welter-Schules [20].

We studied males and females of viviparid snails with different the shell size and age. The age of the mollusks was determined by the number of concentric dark structure on the operculum, which marks the slower snail growth in winter [1]. The snail sex was determined by the shape of the right tentacle [21].

The shells were measured using a caliper with the accuracy of 0.1 mm. Five shell morphometric parameters were analyzed: shell height (SH), shell width (SW), aperture height (AH), aperture width (AW) and body whorl height (BWH) (Fig. 2) [15]. According to these measurements, the following indices were calculated: SW/SH, BWH/SH, AH/SH, AW/SH.

The received digital data are processed using standard methods of variation statistics [22]. Descriptive statistics was conducted using the program STATISTICA 6.0. Significant differences between the values were assessed by the Student's *t*-test.

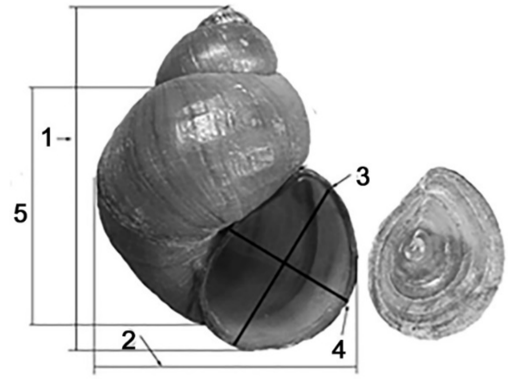

Fig. 2. Measurements on shell morphometric parameters of viviparid snails: 1 – shell height, 2 – shell width, 3 – aperture height, 4 – aperture width, 5 – body whorl height [15].

3 Results and discussion

At adverse conditions (prolonged colder winter temperature), the growth of viviparid snails is inhibited. As a result, the ion exchange and sedimentation of CaCO3 decrease or even completely cease, which leads to the formation of a clear dark concentric structure on the operculum and spiral bands on the shell that are more visible than other formations of different origin.

The river snails under a year in age (0+ age) do not have specific sculpture elements on their shells and dark structure on the opercula, because they have not experienced a winter period of slowed growth (Figs. 3, 4). At the same time, the operculum of shell of all age classes, including the one-year-old snails, bear the so-called embryonic mark (Figs. 3e, 4e). It is more or less pigmented and formed during the embryonic development in the body of parent female in winter.

Snails with one spiral band on their shells and one-year-old concentric structure on the operculum are here designated as 1+; accordingly, 2–6-year-olds are designated as 2+, 3+, 4+, 5+ and 6+. Figures 3 and 4 depict the operculum of the *V. viviparus* snails (age from 0+ to 5 years) and *V. contectus* (age from 0+ to 6 years) from different populations to visualize their variations in pigmentation, clarity and thickness of annual concentric structure.

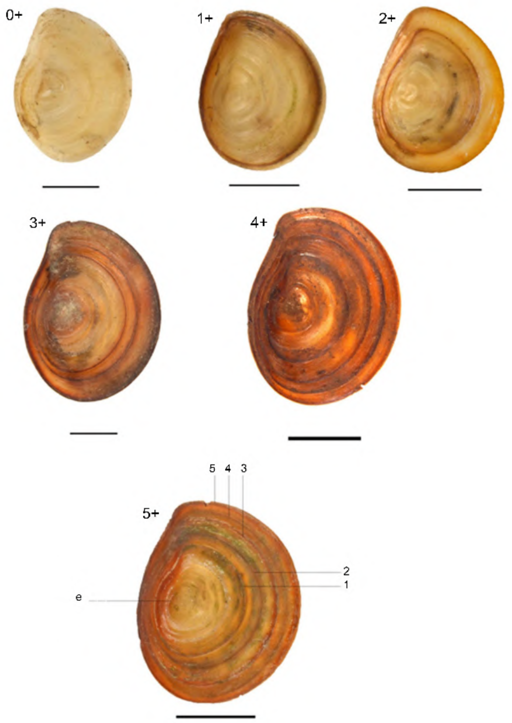

Fig. 3. Winter marks on the operculum of *V. viviparus:* 0+, 1+, 2+, 3+, 4+, 5+ − the 1, 2, 3, 4 and 5 year old specimens, respectively*;* 1−5 – post-embryonic marks; e – embryonic mark. Scale is 5 mm.

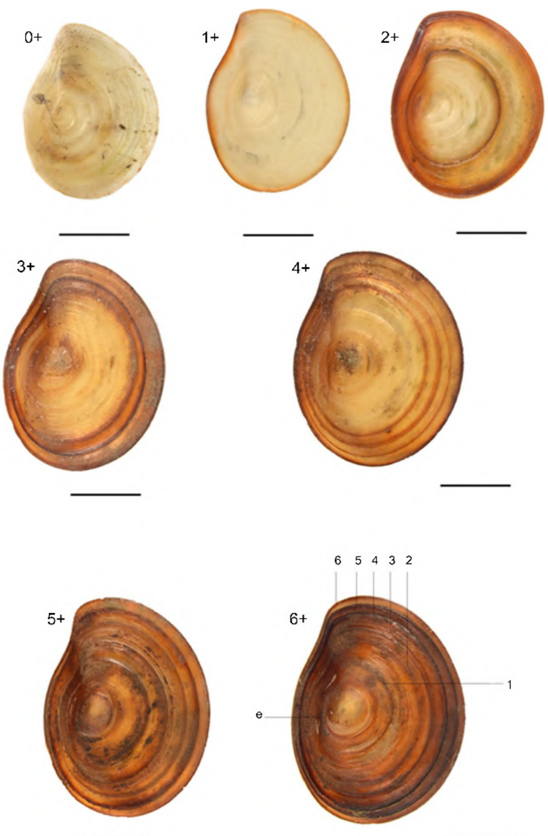

Fig. 4. Winter marks on the operculum of *V. contectus:*0+, 1+, 2+, 3+, 4+, 5+, 6+ − the 1, 2, 3, 4, 5 and 6 year old specimens, respectively; 1−6 – post-embryonic marks; e – embryonic mark. Scale is 5 mm.

In the water bodies of Ukraine, the maximum age of *V. viviparus* mollusks was 5 years and that of *V. contectus* snails was 6 years [1].

We analyzed the representative samples of *V. viviparus* males and females of each age class from one population (Irsha river). When comparing the average values of the shell height, it was found that young (0–2-year-olds individuals) have no sex differences in this parameter, at the age of 3, the males were larger than females, and at the age of 4-5 years, the females were larger than males (p >0.05) (Table 1).

Table 1. Sex differences in shell morphometrics and indices ($x \pm m_x$) of *V. viviparus* of different age collected in August, 2016 in the Irsha river (city of Khoroshiv, Zhytomyr region).

Age class, years	*n*	**Shell morphometrics [1], mm**				
		SH	***SW***	***BWH***	***AH***	***AW***
0+	20	14.9±0.1	10,8±0,1	8.7±0.2	10.0±0.1	8.7±0.1
	20	15.1±0.1	11,0±0,1	8.8±0.1	9.9±0.2	8.8±0.1
1+	20	18.1±0.1	14,0±0,2	8.9±0.1	11.1±0.2	9.1±0.1
	20	18.2±0.2	14,2±0,3	9.0±0.1	11.0±0.2	9.2±0.1
2+	20	20.8±0.3	15,2±0,1	9.2±0.2	12.1±0.1	10.0±0.1
	20	20.5±0.2	16,4±0,2	10.0±0.1	12.4±0.1	11.2±0.1
3+	15	23.0±0.2	17,5±0,1*	10.8±0.2*	12.9±0.2	12.8±0.3*
	15	22.2±0.3	19.6±0.3	11.9±0.3	13,0 ±0,3	13,9±0,2
4+	10	25.1±0.3	18.1±0.2*	11.3±0.2*	13,3±0,3	14,8±0,2*
	10	26.5±0.2	20.8±0.3	12.8±0.2	13,8±0,2	15,9±0,3
5+	5	28.7±0.2	19.2±0.3*	16.0±0.2*	14,0±0,3	15,8±0,2*
	5	30.1±0.4	22.5±0.4	17.2±0,3	14,2±0,3	17,0±0,4
Age class, years	*n*	**Shell indices**				
		SW/SH	***BWH/ SH***	***AH/SH***	***AW/SH***	–
0+	20	0.72±0.01	0.58±0.01	0.67±0.02	0.58±0.01	–
	20	0.72±0.01	0.58±0.01	0.66±0.02	0.58±0.01	
1+	20	0.76±0.01	0.49±0.02	0.61±0.02	0.50±0.01	–
	20	0.78±0.02	0.49±0.01	0.60±0.01	0.50±0.01	
2+	20	0.75±0.01*	0.44±0.02	0.58±0.01	0.48±0.01	–
	20	0.81±0.03	0.48±0.01	0.60±0.02	0.54±0.01	
3+	15	0.76±0.02*	0.46±0.03*	0.56±0.02	0.55±0.02*	–
	15	0,83±0,02	0,53±0,01	0,58±0,04	0,62±0,01	
4+	10	0,72±0,03*	0,45±0,02	0,52±0,04	0,58±0,02	–
	10	0,78±0,02	0,48±0,03	0,52±0,03	0,60±0,03	
5+	5	0,66±0,03*	0,55±0,02	0,48±0,02	0,55±0,02	–
	5	0,71±0,04	0,57±0,03	0,47±0,03	0,56±0,04	

Notes: 1 − conchological parameters are described in “Material and methods”; the numerator presents the measurements for males, the denominator for females; *n* — quantity of studied specimens; * — statistically significant difference between sexes (p<0.05).

The average values of the shell width in young individuals (0+ to 1 year old) of both sexes are almost the same. These parameter tend to increase in the females since the age of both when they become mature. At the age of three to five years, this difference is statistically significant (p = 0.05).

We analyzed the limits of variability of the shell width for *V. viviparus* males and females of different age (Fig. 5a). The minimum and maximum values of this trait parameter for both sexes often overlapped.

The body whorl height is higher in older females than in males, with statistically significant difference (p = 0.05) in 3−5 year old snails. There was no statistically significant difference in the aperture height between sexes of viviparid snails. As for the aperture width, in older (3–

5-year-olds) females this parameter is significantly (p = 0.05) higher than in males.

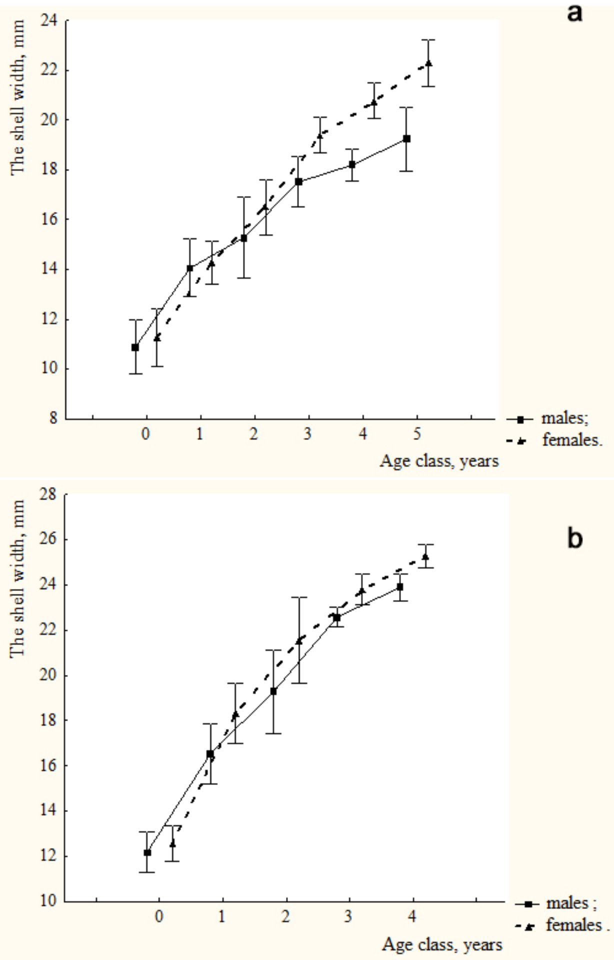

Fig. 5. Relationships of age and shell width in males and females of *V. viviparus* from the Irsha river (city of Khoroshiv, Zhytomyr region) (a), and *V. contectus* from the floodplain of the Tnya river (village of Nesolon, Zhytomyr region) (b) in August 2016.

As for the relative values of the conchological character of *V. viviparus* males and females, starting at the age of 2 years, the most reliable for sex differentiation is the SW/SH index. Only at the age of 3 years, the indices of BWH/SH and AW/SH are significantly (p = 0.05) higher in females compared with males.

During the morphological study of the conchological parameters of *V. contectus* in the population from the floodplain of the Tnya river, only one 5-year-old male was found, and 6 years-old snails were not recorded at all. Therefore, we did not statistically analyze the age class of 5−6 years.

It should be noted that in other populations of *V. contectus*, as well as *V. viviparus*, males of this age are also very rare. The reasons for the number of males decreasing with age in the populations of Viviparus remain unclear. Possibly, one of the causes are trematode infections. After all, higher infection rates are noted for older males than females of the same age. There is an evidences that males are less resistant to parasitism in general and to trematodes in particular [23]. Lower ratio of males in the freshwater snail populations may also be associated with less favourable conditions for their existence in the modernized transformed water bodies of the Ukraine, where females exhibit greater viability. V. A. Geodakyan [24] considers that male individuals of many animals in the populations have less sustainability to influence of unfavorable environment factors. The revealed changes in the sexual structure of the viviparid populations can be considered an adaptive strategy for reproduction in a transformed environment.

No significant sexual differences were noted in the shell height of *V. contectus* snails (Table 2). Shell width from the age of one year, and body whorl height from the age of three years were significantly higher (p = 0.05) in females than in males. We also analysed the variability range of shell width for *V. contectus* males and females with different ages (Fig. 5b), and noted that the minimum and maximum values of that character often overlapped in both sexes.

Table 2. Sex differences in shell morphometrics and indices ($x \pm m_x$) of *V. contectus* of different ages collected in August 2016 at the floodplain of the Tnya river (village of Nesolon, Zhytomyr region).

Age class, years	*n*	Shell morphometrics [1], mm				
		SH	***SW***	***BWH***	***AH***	***AW***
0+	20	16.4±0.1	12.2±0.1	10.1±01	10.2±0.1	8.2±0.1
	20	16.5±0.1	12.6±0.1	10.2±0.1	10.0±0.1	8.3±0.1
1+	20	21.1±0.2	16.4±0.1*	11.1±0.2	12.0±0.2	8.9±0.1
	20	22.2±0.1	18.1±0.2	12.8±0.1	13.1±0.1	10.0±0.2
2+	20	25.1±0.3	19.2±0.2*	12.7±0.3	14.0±0.3	9.5±0.1
	20	24.8±0.2	21.4±0.2	13.5±0.2	14.8±0.3	10.5±0.1
3+	15	26.0±0.4	22.7±0.3*	13.3±0.2*	14.8±0.2*	10.9±0.2*
	15	26.9±0.3	23.6±0.3	14.7±0.2	15.7±0.1	11.6±0.1
4+	5	29.2±0.4	24.0±0.3*	14.1±0.3*	15.2±0.3*	12.0±0.3*
	5	30.1±0.5	25.2±0.3	16.7±0.4	17.4±0.4	13.9±0.2
5+	1	32.1	24.9	15.2	17.2	13.1
	3	34.2±0.3	28.2±0.4	18.1±0.4	19.0±0.3	14.5±0.4
6+	–	–	–	–	–	–
	1	37.8	28.5	19.3	19.5	14.9
Age class, years	***n***	**Shell indices**				
		SW/SH	***BWH/SH***	***AH/SH***	***AW/SH***	–
0+	20	0.75±0.01	0.61±0.01	0.62±0.01	0.50±0.01	–
	20	0.76±0.01	0.61±0.01	0.61±0.01	0.50±0.01	
1+	20	0.76±0.01	0.50±0.01	0.57±0.01	0.38±0.01	–
	20	0.81±0.01	0.58±0.01	0.59±0.01	0.45±0.01	
2+	20	0.75±0.01*	0.50±0.01	0.55±0.01	0.40±0.01	–
	20	0.84±0.01	0.54±0.01	0.56±0.01	0.42±0.01	
3+	15	0.84±0.01	0.50±0.01	0.53±0.01	0.41±0.01	–
	15	0.85±0.01	0.54±0.01	0.55±0.01	0.43±0.01	
4+	5	0.82±0.01	0.48±0.01	0.51±0.01	0.41±0.01	–
	5	0.83±0.01	0.53±0.01	0.56±0.01	0.46±0.01	
5+	1	0.80	0.47	0.53	0.40	–
	3	0.82±0.01	0.53±0.01	0.55±0.01	0.42±0.01	
6+	–	–	–	–	–	–
	1	0.77	0.51	0.52	0.40	

Note: the designations as in Table 1; dash — no data available

In older (3−4-year-olds) females of *V. contectus*, the size (height and width) of aperture is larger than in males. As for the shell indices, a significant (p = 0.01) sex difference was found only for SW/SH index in 2-year-olds *V. contectus*.

Correct identification of sex is an important component of wildlife management because changes in sex ratios can affect population viability. Most malacologists, studying sexual morphological dimorphism of snails, take into account the absolute and relative indices of the shell and do not consider the age of individuals. For the first time, considering the age of *V. viviparus* and *V. contectus*, the analysis of the conchological parameters of their males and females was performed, and differences in adults were revealed.

Populations of *V. viviparus* from the Irsha river (Khoroshiv, Zhytomyr Region, Ukraine) are similar to populations of this species from other geographical areas – the Dnepr river (Smolensk, Russian Federation) and the Shokhonka river (Ples, Ivanovo region, The Russian Federation) [15].

The revealed pattern of sexual conchological characters in adult snails is noted by malacologists for other members of Caenogastropoda as well. Such a pattern has been found for *Melanoides tuberculatus* (Müller, 1774) from Israel [25], for *Buccinanops globulosus* (Kiener, 1834) from Argentina [26].

Differences in the shell morphology of *Viviparus* males and females are explained by different sizes of mantle section of the male and female reproductive system, located in the body whorl. Pregnant females have a large brood pouch, filled with egg capsules with embryos, which may be quite numerous [1, 27, 28]. The brood pouch is located in the upper part of the mantle cavity and occupies almost the entire volume of the body whorl. The ejaculatory chamber is located in the bottom of the male mantle cavity, and in the inactive state, it occupies a much smaller volume within the body whorl. Other researchers have the same opinion about Viviparidae and other Caenogastropoda [15, 26, 29, 30]. According to results, Viviparidae mollusks can be used as bioindicators in environmental assessment of water bodies. Average shell height of mature (2 to 3 year old) snails and sex ratio in populations of Viviparidae are the population characteristics which are the most informative in bioindication with this species (mostly by organic pollutants). Primary sexual structure (age class 0+) of *V. viviparus* expressed as 1 : 1. Reservoirs are characterized by the best conditions for hydrobionts and hydrochemical parameters of water within the limits of norm at equal correlation of mollusks sexes (secondary sexual structure). There is a rejection of this index toward the increase of number of females, rarer – young males in the conditions of environment, less favorable for the organisms. Such reservoirs are characterized by rejections in hydrochemical parameters (concentration oxygen, content of organic matter). Forming of greater amount of females at large anthropogenic influence on reservoirs is adaptive strategy of populations *V. viviparus* in the changing conditions of environment.

4 Conclusion

Therefore, the analysis of morphometric conchological characters of the two *Viviparus* species revealed sexual dimorphism for adult individuals (3−5 years old): females mostly have a wider shell and aperture, and more convex body whorl than males. Differences in the shell morphology of males and females are explained by different sizes of mantle section of the male and female reproductive system, located in the body whorl. However, these parameters often overlap in males and females and do not always permit to identify them reliably. This may be due to the different growth rates of individuals. Hence, we recommend taking into consideration not only the specifics of shells of male and female viviparid snails, but also their head tentacle in the course of bioindication assessments.

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Sorption characteristics studies of eco-friendly polymer composites

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Abstract. This paper presents the results of new composite materials based on polylactide and coffee grounds sorption characteristics study. New material, that include coffee grounds as additive material is cheaper than one of common polylactide. All types of dishes cam be made from new material and they also will be biodegradable, as made from polylactide. The sorption properties and characteristics were tested in different liquid medium. The last was chosen among the most wide spread mediums which are contact with dishes during its operational life. It was found, that optimal content of coffee grounds is 40 wt.% as for level of impact strength also for complex of sorption characteristics.

1 Introduction

The modern paradigm of global economy and industry is directly related to the concept of “Zero Waste”, based on minimum waste generation principle at each stage of material or product production, operation and disposal [1,2]. That is why today we are talking about the widespread use of so-called “eco-” or “biomaterials” that do not harm the environment. This trend can be found both in various branches of modern industry and in ordinary household spheres of human life: food, hygiene, entertainment industry and others. We faced with wastes every minute in our life. Even common phenomenon such as making coffee at home or in a restaurant leads to the generation of waste’s large amounts, that usually called coffee grounds.

Coffee consumption in Ukraine is more than 15,000 tons per year and continues to grow on average by 5% per year [10]. Today, coffee is a popular raw material for making broad range of beverages, as well as the provision of various additional services in hotel and restaurant industry. Its fruits contain a large number of substances that one of various chemical nature: proteins, carbohydrates, organic acids, fats, alkaloids, in particular caffeine.

High demand for this species marketable products, leads to the emergence of new production plants in our country instant coffee. And like any industry, coffee production cannot be waste-free. The main waste of this class of enterprises is coffee grounds or coffee cake. Coffee grounds is a product obtained from the industrial production of instant coffee or waste remaining after the preparation of a beverage from ground coffee. Coffee grounds is a valuable organic raw material and contains a large number of nutrients, primarily proteins. In the production of one ton of dry instant coffee, the yield of absolutely dry cake is 1.5 tons. Wet thicket molds quickly, so storage is required its additional drying. According to the generally accepted classification of waste, it is household organic waste [3]. In terms of the Zero Waste concept, most developed countries in the last 20 years have begun to actively use coffee grounds as a valuable resource that corresponds to the concept of sustainable development.

World trends analyze allowed to outline the main directions of coffee grounds:

– utilization in agriculture in the form of additives in fertilizers or soils. however, this direction of dry coffee grounds use is rather limited because it is not studied transformation of useful substances from a field to soil. That is why, you can find a lot of amateur information about the use of coffee grounds in some farms, but thorough research has not yet been conducted. You can also find information about the general harm of coffee grounds due to its acidic pH level, at the same time, it is generally studied to use wet coffee grounds as a basis for growing mushrooms, in particular champignons and coffee grounds using as fuel;

– use as an abrasive material in the manufacture of cosmetics, including creams, scrubs, soaps, etc. Manufacturers of so-called “green” or “eco” cosmetics prefer to use coffee grounds. However, this direction is able to dispose a limited amount of coffee grounds waste;

– use of coffee grounds in modern art, including for the production of jewelry, painting and various installations;

– use as an additive to polymeric materials to reduce the cost of the final product. The most forward-looking conception is to produce biodegradable polymer dishes,

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which is dominated by an organic additive - coffee grounds.

The last conception allows to utilizate a large volumes of coffee grounds the same time to achieve the principle of “Zero Waste” when using bioplastics. The concept of sustainable development implies the recycling of materials that were previously considered waste. The criterion for the expediency of using waste as a resource can be not only the economic component, but also a decrease environmental impact. At the same time, the life cycle of a new material object should not increase the environmental impact. Coffee grounds, getting to landfills for solid household waste, within three days become a breeding ground for mold, which quickly spreads to other elements of the landfill.

Using of coffee grounds waste as a filler, you can get a product that haven’t negative environmental impact with low price. That is why the development of biodegradable polymer composite materials based on bioplastic such as polylactide (PLA) and coffee grounds waste is very relevant.

2 Literature data analysis and problem statement

Today, there is a significant number of scientific studies of coffee grounds as a filler in polymer composite materials [4, 5, 6, 7]. At the same time, research in the field of using coffee grounds as filler for new biodegradable composite materials is rarely found [8, 9]. The objective of this research was to determine the effect of spent coffee grounds filler on the physical and mechanical properties of PLA bio-composite film. The bio-composite film was fabricated by a twin-screw and blow film extruder.

In researc [9] characterizes and compares coffee chaff and spent coffee grounds, the two most useful coffee waste products, and evaluates their performance as fillers and/or reinforcing agents in polymer composites.

We have previously studied [10] chemical, physical, mechanical and operational properties of new high-filler composite based on PLA. As shown, the highest performance indicators were characterized for compositions with a content of coffee grounds filler from 40% to 60% wt. It is also noticed, that using coffee grounds as fillers for polymer materials can decrease the total volume of it at landfills faster than any other method of coffee ground reuse. Further research the level of sorption stability for developed materials to the most characteristic environments of their operation is perspective.

3 Study purpose

The aim of the research was study sorption resistance of biodegradable polymer composite materials based on PLA and coffee grounds waste.

To achieve this aim in the work it was necessary to perform the following tasks:

- to study the effects of coffee grounds waste on the mechanical characteristics of biodegradable polymer composite materials based on PLA;
- to research the sorption characteristics of the developed materials to the most characteristic environments of their operation.

4 Materials and methods

The objects of study were:

- extrusion PLA of the Terramac TP-4000 brand;
- coffee grounds waste, gathered in 8 different coffee shops in Kharkiv and dried to moisture content 50% Coffee grounds waste have a polyfractional composition in the particle size limit from 0.5 to 1 mm. Using IR spectroscopy methods, it has been shown [10] that coffee grounds, in their chemical composition, are characterized by up to 6% or more content of caffeine, alkaloids and their companions, up to 1% of chlorogenic acids and their derivatives content.

Composites were obtained by extruding pre-prepared raw materials in a single-screw laboratory extruder at a temperature of 170–200 ° C and a roll rotation speed of 30–100 rpm. The L / D ratio of the extruder is 25, and in order to increase the uniformity of dispersed waste distribution in the finish compositions, 2 mass passes were used to obtain finished samples. It was made 20 parallel experiments for each composition, statistical processing was made by characteristics such as arithmetic mean, standard deviation and variation coefficient.

The study of impact strength and breaking stress during bending of the samples without notching at a temperature of 20 ° C was carried out on a pendulum head according to ISO 180 and ISO 178, respectively.

Microscopic studies were carried out using the electron microscope Digital Microscope HDcolor CMOS Sensor (China).

The chemical method for determining the porosity of the paint coating is to identify violations of its continuity in the formation of points of the turnbule salt in the reaction of the reagent - red blood salt K_3 [Fe (CN) $_6$] with Fe^{2+} (pH ≤ 7), which occur due to corrosion of steel and diffuse to the surface of the coating. To assess the destruction of the coating from the formation of bubbles, coating samples applied to a steel substrate measuring 10x15 cm and sealed at the edges are placed in the operating environment for 7 days at a temperature of 20 ºC.

The method of evaluation is to determine the surface area of the coating, which is destroyed by bubbles and the linear size of the bubbles (diameter and depth of the lesion). The degree of destruction of the coating due to the formation of bubbles is assessed on a five-point scale.

Sorption characteristic of the samples was determined as the amount of reagents absorbed by the sample (size 15x10x1.5–4.5 mm) as a result of its stay in the model liquid (water, drink Coca-Cola, 5% surfactant) for 30 days at room temperature (about 18–20 ° C).

5 Results

The first step was to investigate the physical and mechanical properties of the obtained biopolymer composite material: impact strength and breaking stress during bending (figure 1). It is well known, filled polymeric materials must have a higher impact strength than homopolymers. Our new materials has shown the same properties - the impact strength for coffee-filled composite (40 wt.% coffee grounds on 60 wt.% PLA) is 2.5 times more than for the sample without coffee grounds. the value of impact strength has tendency to increasing with increasing volume of coffee grounds.

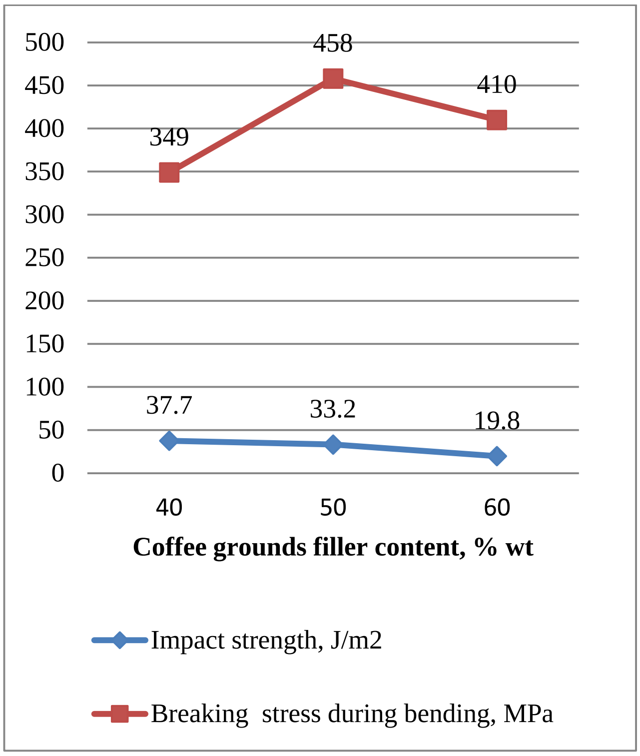


Fig. 1. Physical and mechanical properties of designed composite material based on PLA.

Level of impact strength influence the possibility for forming various products of composite material. As we see, for new composite material impact strength is within the required value [10].

The next step was sorption properties study of new composite material. Note that the samples with the lowest porosity were selected using a microscope, because in the laboratory a significant part of the samples have an uneven surface with large pores and cavities, which will distort the data on water (and any other liquid) absorption [11].

At the first stage of the sorption characteristics study for new composite material, its porosity was determined and the tendency to form pulp bubbles in two types of operating media - water (non-purified drinking water) and 5% surfactant solution (surfactant) was evaluated. It is in these types of media PLA-based dishes with coffee grounds will be immersed during operation (washing dishes, pouring into the dishes of coffee or other beverages) [11].

Table 1 shows the results of the study of compositions based on PLA with different content of coffee grounds on the porosity and tendency to making bubble. Data analysis of table 1 allows to choose as optimal for further operation a composition with a content of coffee grounds 40 wt. %, because it demonstrate the same properties as its original polymer without adding the condensate [11]. The increase in the content of coffee grounds leads to its uneven distribution in the surface layer of the composition and high porosity of the samples.

Table 1. Porosity study of compositions based on PLA with different content of coffee grounds.

№	Coffee grounds contents, wt.%	Porosity of the coating, score, in the environment		Destruction of the surface due to the formation of bubbles, A, in the liquid medium	
		water	5% surfactant solution	water	5% surfactant solution
1	40	1	1	A1,00	A1,00
2	50	2	2	A0,95	A0,93
3	60	3	3	A0,85	A0,79
4	0	1	1	A1,00	A1,00

A necessary and standard characteristic for all polymeric materials, which determines their performance properties, is to determine the diffusion coefficient of the liquid, for which long-term experiments are performed according to the method described in [11]. The samples were immersed in water and periodically measured changes in their mass and geometric shape. The results are shown in table 2.

Table 2. The resistance study results of compositions samples based on PLA with different content of coffee grounds to water at a temperature of 20 ° C.

Cycle		The increase in the mass of the samples by numbers,%			
	coffee grounds contents, wt.%	40	50	60	0
A day later					
- 1		1,35	2,74	3,77	0,01
- 3		1,50	2,75	3,85	0,74
- 7		1,55	2,77	3,95	0,75
-15		1,60	2,78	4,10	0,76
-30		1,65	2,79	4,20	0,77

As can be seen from table 2, the original polymer and composition with a content of 40 wt. % show a small weight gain, which after two months does not exceed 2%. With increasing content of coffee grounds, the increase in the mass of the samples, their water absorption, reaches 5%. But even such indicators are not critical for the manufacture of dishes. However, the composition containing 40 wt. % thick is the most resistant to operating loads [11].

Sorption characteristics study of the compositions to the action of aggressive environments was also performed. An analysis of the market for beverages found in coffee shops alongside natural coffee has clearly identified Coca Cola as the most common. The pH of this drink is 2.5, so it is an acidic environment. Table 3 shows the results of increasing the mass for composition after immersion in Coca Cola.

Table 3. The resistance study results of compositions samples based on PLA with different content of coffee grounds to Coca Cola at a temperature of 20 ° C.

Cycle		**The increase in the mass of the samples by numbers,%**			
	coffee grounds contents, wt.%	**40**	**50**	**60**	**0**
A day later					
- 1		4,0	6,8	5,2	0,22
- 3		10,1	11,3	18,2	1,1
- 7		15,2	20,2	24,4	1,8
-15		28,9	36,5	40,1	2,3
-30		62,5	71,2	82,5	3,0

All samples became very brittle after 30 days, and their surface became porous. The increase in the mass of all samples indicates an easier way for the middle of the samples to penetrate the aggressive medium after three days of exposure [36]. As expected, the original polymer has the lowest weight gain, and among the compositions, such properties are inherent in compositions with a coffee grounds content of 40 wt. %.

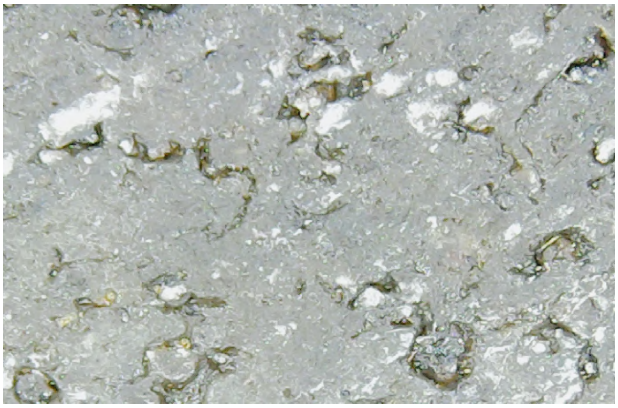
Sorption characteristics study of the compositions to the action of water and a temperature of 100 ° C was made. Table 4 shows the results of increasing the mass for composition after immersion in the water.

Table 4. Sorption characteristics study results of the compositions to the action of water and a temperature of 100 ° C.

Cycle		**The increase in the mass of the samples by numbers,%**			
	coffee grounds contents, wt. %	**40**	**50**	**60**	**0**
A day later					
-1		5,2	7,8	10,9	0,35
- 3		5,9	8,5	11,8	0,38
- 7		7,8	9,3	12,5	0,42
-15		15,2	24,3	30,8	0,55
-30		21,2	35,6	45,6	0,68
- 40		28,5	42,8	52,1	0,77

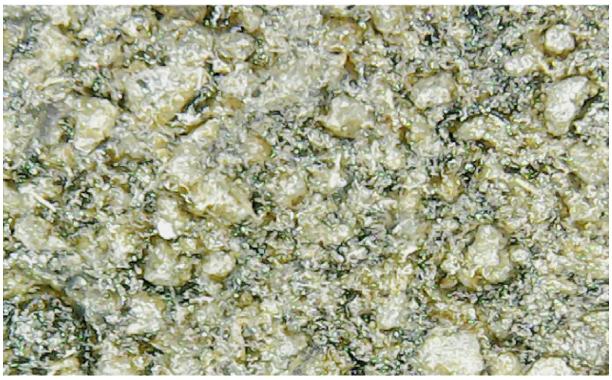
The composition, which contains 50 and 60 wt. % of coffee grounds compared to that containing 40 wt. % during 15 days of immersion in boiling water, shows an increase in weight of almost 2% more. This is not critical given this figure, but still should prefer a composition with a lower content of thick.

Sorption characteristics study of the compositions to the action of aggressive media in the form of anionic-type surfactants at a concentration of 5 % and a temperature of 75 ° C was made. Table 5 shows the results of increasing the mass for composition after immersion in the surfactant. As you can see from the results of the study, after 7 days the weight gain is slow and does not exceed the average for all samples with coffee grounds - samples with 40, 50 and 60% coffee grounds waste content of 0.09% per cycle.

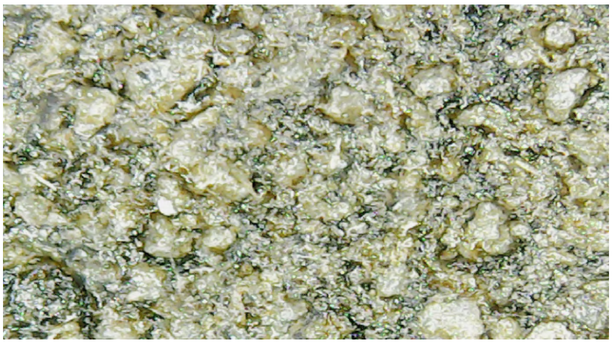


Before

After
A



After
B



After
C

Fig. 2. Surface's micrographs of new compositions with 40 wt. % coffee grounds waste content before and after the sorption characteristics study in different model environments: A - water at a temperature of 20 ° C; B - surfactant anionic type at a concentration of 5% and a temperature of 75 ° C; C - Coca Cola at a temperature of 20 ° C.

After
A

After
B

After
C

Fig. 3. Surface's micrographs of new compositions with 50 wt. % coffee grounds waste content before and after the sorption characteristics study in different model environments: A - water at a temperature of 20 ° C; B - surfactant anionic type at a concentration of 5% and a temperature of 75 ° C; C - Coca Cola at a temperature of 20 ° C

Starting from 8 days, the increase in weight can be up to 0.9% per cycle, constantly increasing to 40 days. For the original PLA polymer, there is also an increase in the rate of weight gain starting from 15 days. This behavior of the compositions and the original PLA is due to the ability to biodegrade products from them under the condition of creating a temperature greater than 65 ° C. That is, the results obtained prove, including the actual ability to biodegrade compositions with a thicker based on PLA.

Equilibrium, the end of the water absorption process during the study period was not reached, but the tests are ongoing. The equilibrium state will be characterized by a straight line on the graph or no increase in the mass of the samples. Based on experimental data according to the method described in [11], the diffusion coefficient for the samples was calculated (table 6).

Table 5. Sorption characteristics study results of the compositions to the action of aggressive media (surfactants of the anionic type at a concentration of 5 %) and a temperature of 75 ° C.

Cycle		**The increase in the mass of the samples by numbers,%**			
	coffee grounds contents, wt. %	**40**	**50**	**60**	**0**
A day later					
-1		6,3	8,9	11,2	0,89
- 3		7,1	10,2	13,4	0,92
- 7		7,9	11,1	15,1	0,99
-15		18,9	25,6	28,9	1,8
-30		24,6	34,5	39,3	2,6
- 40		32,6	44,5	58,2	3,9

Table 6. Water diffusion coefficient in samples of compositions based on PLA with different content of coffee grounds.

Samples number	**PLA content, wt. %**	**coffee grounds contents, wt. %**	**D·1010, sm^2/s**
1	60	40	0,72145
2	50	50	0,81526
3	40	60	0,86998
4	100	0	0,63085

The data in table 4 indicate the hydrophobic nature of the surface of both the source polymer material PLA and compositions based on them [11].

In fig. 2-4 shows surface's photomicrographs of new compositions before and after the sorption characteristics study in different model environments.

As can be seen from Figure 3-5, the smallest changes in the surface can be observed for compositions with a coffee grounds content of 40 wt.%, which, as shown above, have the best sorption characteristics in different model environments.

6 Conclusions

The designed and studied in article polymer composites on the basis of PLA and coffee grounds solve the problems of recycling food industry waste in the form of coffee grounds and expand the possibilities of its rational utilization for agriculture. The use of coffee grounds as a filler for biodegradable polymeric materials can significantly reduce its quantity at landfills and obtain a new material that will be biodegradable. Thus, as a result of the conducted researches the rather high level of sorption resistance of the developed eco-friendly polymer composites on the basis of PLA and coffee grounds is shown. It is founded that the optimal strength characteristics have compositions with a content of coffee grounds waste of 40 wt.%. The study of compositions based on PLA with different content of coffee grounds on the porosity and tendency to making bubble is presented.

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Sorption characteristics study of eco-friendly polymer composites based on PLA and coffee grounds waste are shown for different liquid media: water, surfactants and Coca-Cola. The obtained dates indicate the hydrophobic nature of the surface of both for PLA and compositions based on them. It is shown that the composition with a content of 40 wt.% is most resistant to operating loads in different model liquid mediums. According to their sorption characteristics, the studied composites can be recommended for the production of reusable tableware and kitchen utensils, food containers and packaging. The study of the developed eco-friendly polymer composites for their main performance indicators in the conditions of field tests looks prospective.

After
A

After
B

After
C

Fig. 4. Surface's micrographs of new compositions with 60 wt. % coffee grounds waste content before and after the sorption characteristics study in different model environments: A - water at a temperature of 20 ° C; B - surfactant anionic type at a concentration of 5% and a temperature of 75 ° C; C - Coca Cola at a temperature of 20 ° C

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Environmental and economic assessment of the possibilities to increase the land preservation level in terms of open-pit mining

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Abstract. Conditions of the planning of open-pit mining objects have been identified, making it possible to reduce the need in the allotted land area during mineral extraction. The research results have allowed proposing a methodological approach to determine economic expediency of the increase in the technogenic land reclamation level under conditions of open-pit mining, being the reserves to expand the technogenic land areas returned to the economic use.

1 General statement of the problem

In Ukraine, level of land reclamation in terms of the land area disturbed by open-pit mining is not more than 50%; the rest of the mining area is excluded from the economic use for decades or even for ever resulting in considerable losses for further land use in a mining region and leaving the unsolved problem of negative environmental impacts of mining activities. First of all, reclamation is topical for those mining areas requiring the lowest costs for their restoration. Due to the fact that a great share of the disturbed lands is not restored, a mining enterprise is to compensate the land owners their losses of land resources that form the grounds for conflicts related to the land allotment for mining purposes. Thus, current topical problem is to search for the possibilities to increase a specific land share to be restored in terms of a general area of mining allotment along with the substantiation of technological solutions to plan mining operations aimed at reducing the disturbed land area while mineral mining.

2 Analysis of recent studies and publications

Scientists, dealing with the problems of the reduction of mining-related environmental impacts, pay considerable attention to the development of ecological and economic criteria of administrative decision-making concerning mining object planning. Implementation of the measures for land reclamation after open-pit mining should favour the mining industry transfer into the sustainable mode. That is the sustainable development of the mining sector which should be determinant for the activities related to the mineral use for national economy [1]. Thus, the development of main mining processes should be in compliance with the measures for the negative mining effects compensation in both environmental and social terms since negligence of the environmental-saving requirements is the reason of sharpening economic and social problems in the mining sector.

Source [2] indicates that mining effects on the environment should be overcome partially by creating investment-attractive technogenic lands and partially by activating the processes of natural self-restoration of the disturbed terrains. Nevertheless, following problem is still unsolved: what share of mining allotment should be covered with the lands to be returned for the economic use. It is obvious that it requires the elaboration of certain criteria to evaluate the expediency of restoration of specific mining objects in terms of the land use purposes.

Litvinov [3] highlights the necessity of such planning of mining objects in terms of which it will be possible to restore as many disturbed land areas as possible. According to the researcher, it is the level of lands under reclamation that should be one of the main criteria to evaluate the efficiency of different technological schemes for deposit mining.

However, a problem, concerning the following, still lacks its solution: evaluation of possibilities to improve the land preservation level in terms of open-pit mining at the expense of both limited shares of disturbed lands for the construction of open-pit mining objects and search for the resources to improve economic attractiveness of

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disturbed land restoration according to the specific land use purposes.

Irrespective of the considerable scientific findings as for improving the efficiency of activities related to the restoration of environmental objects within the mining allotment area, insufficient attention has been paid to the identification of economically expedient reserves for the increase in mining-related land restoration according to the land disturbance. An issue concerning substantiation of technological schemes for planning mining objects in terms of land preservation criteria should be considered more as well.

The research objective is to substantiate theoretically the grounds and develop recommendations concerning the specification of technological trends in providing the limited disturbance of the mining allotment lands as well to assess economically expedient reserves of land reclamation for the areas disturbed while open-pit mining to reduce the land losses in terms of the land disturbance area.

3 Statement of the main research material

Mineral mining is still of high importance for the economic development of industrial countries. The mining sector is a factor for increasing a level of capital investment in tangible assets in all the technologically related industries; it favours overall economic growth of the countries with the developed mining sector [4].

However, planning of mining enterprises requires paying considerable attention to the development of measures to limit the mining impact on the environment. Those negative effects are inevitable; their amount depends on the demand for some specific products offered by the mining sector [5, p. 494].

Along with the economic effects from the deposit development, among other things, a society has environmental damages in the form of disturbed land resources. While accumulating at a certain level, the damages result in the necessary costs for their elimination, and the costs may exceed the effect of the mineral use [6].

Thus, legislation of the majority of mining countries obliges mining enterprises to restore the lands so that they will be of the same state before mining operations [7]. To do that, it is required to determine the factors stipulating the extent of mineral-mining land disturbance and identify the possibilities to implement economically expedient activities for technogenic land restoration.

Horizontal open-pit mining, resulting in more intense land disturbance in reliance on the mass unit of the extracted mineral, is of the highest loss for land resources and for the ecosystem in general. According to [8], constant tendency to open-pit operations is peculiar for current world mining development. There is about 73% of total mineral output extracted by open-pit mining worldwide. In its turn, surface mining development is accompanied by the increasing concentration of production, deepening open pits, and, correspondingly, volumes of the rock mass removal. Open-pit mining is mostly used to extract ore minerals, lignite, rock for construction materials, kaolin, rare earth metals etc. In terms of Ukraine, about 75% of mineral output is extracted by open-pit mining. As for the iron-ore industry, the figure is 85% [9, p. 1]. For instance, Dnipropetrovsk region encloses 100 open pits and mines. Total area of the disturbed land within the region is 27 thousand ha.

Generally, each million tons of the extracted manganese ore result in the disturbance of more than 600 ha of land. In case of iron ore, the figure is 640 ha; coal – up to 43 ha, and non-metallic minerals – up to 580 ha. If the open pit depth is down to 150…200 m, then about 100 ha are to be disturbed totally with the formation of the mined-out space. If the open pit depth is 450 m, more than 250 ha are to be disturbed [10]. To fill that space, about 80 mln m^3 of the overburden rock are required. Analysis of international practice shows that even in terms of the involved cutting-edge technologies, the most efficient land restoration is impossible if there is no economic motivation. In this context, Table 1 represents the balance of mining land use in Rhine lignite basin as of the late 2012.

Table 1. Balance of the land use areas in Rhine lignite basin [11, p. 41]

Area of allotment, ha	Area of restored lands, ha/%	Including the land area restored for agricultural purposes, ha/%	Area of disturbed land, ha
31512, 2	22248.4 / 70.6%	11839.2 / 53.2%	9265.8 / 29.4 %

Land losses in German are mostly tried to be cut by reducing the environmental hazard of land use and by developing environmentally non-exhausting types of land use. However, considerable share of technogenic terrains is still inaccessible for public. To reduce land losses due to mining objects, certain technological solutions should be approved and measures should be taken to create the most favourable conditions for further land reclamation for the lands which disturbance is inevitable right at the stages of open pit planning, stripping operations, and mining operations.

Technological objects, which location required natural land allotment, are demonstrated schematically in Fig. 1. Depending on the mineral type to be mined and the appropriate deposit mining scheme, different land areas are subject to disturbance (Table 2). Thus, it is possible to have certain effect on general land disturbance area in terms of mining allotment at the level of technological solutions as for the mining object planning (e.g. by internal waste dumping as opposite to external waste dumping, transfer of the transportation routes inside the open-pit field etc.).

Thus, while developing a manganese-ore deposit and depending on the occurrence depth of the ore deposit, it is required to have 163…228 ha of natural lands for stripping and dumping. According to the open pit objects, that area is distributed as follows: permanent trench – 3.5…4.5%; transport incline – 8.6…8.4%; working trench – 57.0…56.1%; and construction waste dump – 31.0%. Consequently, the majority of residual mine workings (about 90%) is accounted for the working trench and construction waste dump.

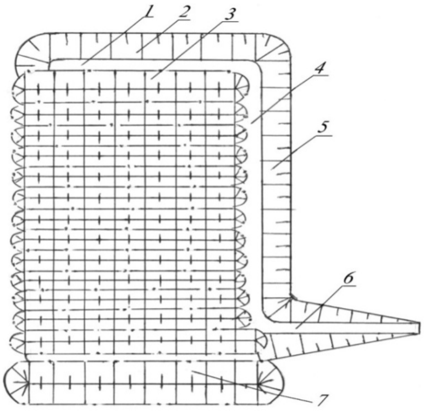

Fig. 1. Schematic of technological structure of open pits while developing a horizontal deposit: 1 – residual mined-out space; 2 – mining flank of an open pit; 3 – internal waste dump; 4 – transport incline; 5 – non-mining flank of an open pit; 6 – permanent trench; 7 – construction waste dump.

Reserves of the land area reduction should be determined by optimizing parameters of land allotment for the open-pit technogenic objects. In their turn, the parameters depend on the geometry of the open-pit field, system of its stripping and mining. Degree of the land resources use is defined by the ratio of the areas of lands being returned and lands being allotted for technological open pit objects during all the deposit mining stages. Such an approach makes it possible to determine the reserves of land resources preservation by reducing the area of land allotment to the scientifically substantiated standards and by increasing the areas of restored sites within each of the mentioned technological objects.

Losses of land resources $\Pi_з$ due to the open pit objects are the target function of the parameters $S_{нi}$, S_{pi}, $S_н$, being formed during all the stages of deposit development. In general, the function may be represented as follows:

$$\Pi_з = f\,(B, L, \Phi, \Gamma, \Pi, T, C, P) \qquad \min \quad (1)$$

where B, L, Φ is width, length, and shape of the open-pit field respectively; Γ is mining and geological conditions of the ore deposit occurrence; Π is technological parameters of the formation of an open-pit working zone; T is technical facilities for production processes; C is stripping and mining system for the deposit; and P is topography of the mining allotment area.

Table 2. Distribution of the land allotment area in terms of technogenic objects of a manganese open pit [12]

Open pit depth, m	Area of the permanent trench on top, ha	Area of the transport incline on top, ha	Area of the working trench on top, ha	Construction waste dump			Total allotment area, ha
				height, m	base width, m	waste dump area, ha	
50	5.6/3.4*	14.1/8.6	93.0/57.0	73	253	50.6/31.0	163.3
60	7.8/4.0	16.6/8.5	110.5/56.4	88	304	61.0/31.0	195.9
70	10.3/4.5	19.1/8.4	127.9/56.1	101.7	352	70.5/30.9	227.8

Note: numerator – total area of the mining allotment, ha; denominator – share in % within the total allotment area.

Identification of the land preservation reserves should rely on the development of mining technologies, rational selection of the striping and dumping parameters. It means that nowadays reserves of the reduction of land resource losses are connected first of all with reaching the parameters of open-pit technological objects. Development of current technologies and mining systems for certain deposits should be oriented to the rejection of a fixed transport incline along with the search for possibilities to form mostly internal waste dumps.

Basing on the expression (1), reserves for reducing losses of land resources are connected with the parameters of technological objects of a mining enterprise. Thus, the objects are to be designed taking into consideration their location on the earth's surface. In general, rational land use parameters are stipulated by certain ratio between the parameters of operating objects and their elements as well as other objects in the context of mining and concentration complex, when the lowest land capacity $З_e$ and the highest reclamation coefficient K_p are reached.

According to the rates of ore bed mining, the internal waste dumps are restored and returned for their further use; here, there are no technological problems. There are other solutions in case of using the residual mine workings and construction mine dump. They can be filled and reclaimed mostly when the deposit is mined out; that is due to a great volume of labour-intense and costly operations. The operating mining and concentration complexes use land resources at the level of theoretical land capacity. As for reclamation of the mined-out land, it is performed within the considerably smaller areas comparing to the potential ones; that is due to the necessity of significant costs for overburden removal for filling the working trench.

To specify the main parameters of technological objects to mine horizontal deposits that stipulate the losses of allotted land areas, the report data of mining and engineering reclamation of lands within the manganese open pits of Pokrovskyi mining and concentration complex (PGZK) have been analyzed. Effect of the area of open-pit field $S_{в.о}$, area of the residual mine workings $S_в$, coefficient of reclamation $K_р$, and land capacity $З_е$ upon the land losses $\Pi_з$ has been considered. The mentioned parameters have been taken into account in terms of each open pit and on average in terms of the complex (Table 3). Following equation of regression is obtained for the statistic data represented in Table 3:

$$\Pi_з = 26.4 + 0.0008\, S_к - 0.0026\, S_в - 33.8\, K_p + 0.21\, З_e, \text{ ha/mln t of ore.} \qquad (2)$$

Table 3. Land use in terms of open-pit fields of Pokrovskyi GZK.

Open pit	*S_к*, ha	*S_{в.о}*, Ha	*S_в*, ha	*K_p*, ha/ha	*З_е*, ha/mln t of ore	*П_з*, ha/mln t of ore
Alexandrovsky	904	735	169	0,81	44,10	8,25
Bogdanovsky	1335	765	570	0,57	27,53	11,76
Zaporizhzhya	1320	800	520	0,61	30,7	12,10
Shevchenkovsky	1637	1263	374	0,77	29,02	6,62
Pivnichnyi	1510	1050	460	0,70	31,92	9,47
Chkalovskyi-1	1182	771	411	0,65	34,36	11,96
Chkalovskyi -2	1796	976	820	0,54	30,13	13,77
Pokrovskyi	700	556	144	0,79	21,67	4,46
Average of PGZK	1298	864	433	0,68	31,18	9,80

The equation does not contain $S_{в.о}$; it shows that there is no connection between land loss and area of internal waste dumps. Such a conclusion can be explained by the fact that the internal waste dumps are formed throughout the whole open pit area, and its effect on the land loss is considered with the help of parameter $S_к$. Adequacy of each of equation regressors (2) has been defined with the help of Student statistic t. During the comparison with table values t = 3.18 for the number of degree of freedom n = 3, regressor $S_в$ has the lowest adequacy. It means that the area of residual mine workings has minor effect on the loss value $П_з$ in the mining allotment, and this parameter may be also excluded from the regression model. Thus, we obtain the equation:

$$П_з=26.4+0.0008S_к-33.8K_p+0.21З_е, \text{ ha/mln t of ore.} \quad (3)$$

If statistic value is t = 2.78, all the regressors of equation (3) are significant, and the resulting feature $П_з$ is closely connected with the factor features $S_к$, $K_р$, and $З_е$ (R^2 = 0.98), which, according to Fisher's ratio test, represent adequately their influence on the result (F = 61.1).

Thus, it can be concluded that the value of the land losses in terms of open-pit mining is stipulated first of all by the open-pit field area, coefficient of reclamation, and land capacity of the mining operations. Consequently, it is possible to reduce overall level of land losses for mining enterprises by increasing the level of land reclamation in terms of the area of land disturbance, by the development of mining technology towards the reduced external dumping, and by the creation of more favourable conditions to restore technogenic lands.

It is necessary to spend different sum of money for the reclamation of mining objects; correspondingly, that causes unequal motivation to the formation of certain-purpose lands within the territory of a specific mining object. Table 4 show classification of the open-pit mining objects according to the economic expediency of their reclamation for economic purposes.

Table 4. Classification of the open-pit mining objects according to economic expediency of their restoration for economic purposes

Object	Ratio in the mining allotment area, %	Location of the object	Characteristics*
Internal waste dumps	38...40	Surfaces of the internal waste dumps	The lands are subject to mining and engineering as well as biological reclamation
Construction waste dump	30.5...31.5	Surfaces of the external waste dumps	
		Surfaces of the washery refuse storage	
		Surfaces of the slopes of external waste dumps	The lands are irretrievably lost for agriculture
Transport incline on top	8...9	Sites for transportation communications (automobile and railway roads, electric networks)	The lands are subject to reclamations upon the condition that the mentioned objects are liquidated
Working trench on top	16...17	Surface of the residual working trench	The lands are not subject to reclamation for agricultural purposes
Permanent trench	3...4.5	Surfaces of the external transport (permanent) trenches	The lands can be restored in case of economic expediency by using fertile soil from other open pits

Note*: made up involving the data from source [13].

Thus, there are the surfaces of external waste dump slopes and partially the surfaces of external transport (permanent) trenches which are the territories being often left without any reclamation. However, expediency of land restoration should be determined by the ratio of costs for land reclamation according to certain economic purpose and market monetary estimation of the reclaimed lands, being represented by the following expression:

$$К_{ei} = \frac{Ц_{зi}}{В_{Гi}+В_{Рi}+В_{Бi}+В_{к.я}+В_{рем.i}}, \quad (4)$$

where $К_{ei}$ is coefficient of efficiency of costs for land reclamation in terms of ith reclamation purpose; $Ц_{зi}$ is market monetary estimation of a unit of the restored land in terms of ith reclamation purpose; $В_{Гi}$, $В_{Рi}$, $В_{бi}$ are losses for mining and engineering as well as biological reclamation and maintenance within the land area in terms of ith reclamation purpose respectively; $B_{к.я}$ is payment for the deteriorated quality of the land reclaimed in terms of ith reclamation purpose; and $B_{рем.i}$ is costs for repair operations due to land restoration.

The highest value $К_{ei}$ will stimulate for more complete restoration of the technogenically disturbed lands. However, if the degree of land surface disturbance requires growing costs for reclamation (first of all, for agricultural purposes), that will reduce motivation to reclaim corresponding mining objects. As a result, technogenic lands are of nonuniform structure, being the combination of reclaimed sites and the sites left without any reclamation due to their more serious disturbance. Generally, land reclamation for agricultural purposes is the most costly one, and market value of those lands in Ukraine is reduced (Fig. 2).

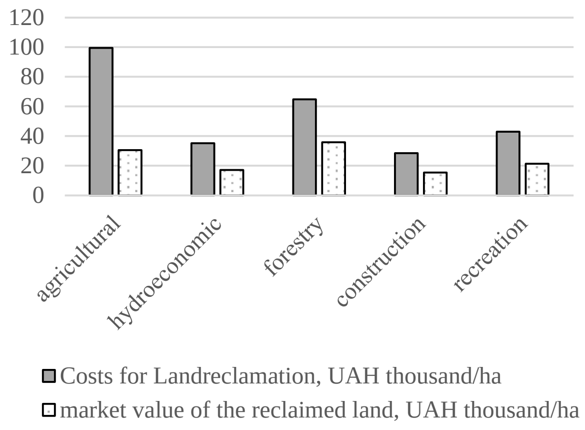

Fig. 2. Ratio of costs for reclamation and standard monetary estimates of technogenic lands in terms of land use purpose.

Market value of the land is defined by actual state of supply and demand for the land; it is specified upon consultation between the sales parties. At the same time, liquidation of different technological mining-related objects will require different costs per unit of the reclaimed area. From the viewpoint of cost cutting, a mining enterprise is interested in reclamation of nothing but the sites where the highest coefficient of efficiency of reclamation costs will be obtained. Only the changing land purpose will make it possible to consider the sites being unattractive for agricultural-purpose reclamation as the ones which reclamation may provide the appropriate degree of efficiency. Thus, depending on the land reclamation purpose, economically expedient reserves of land restoration throughout the disturbance area will experience certain changes (Table 5).

The lowest costs for land reclamation are meant for hydroeconomic and forestry purposes; in their case, the requirements concerning soil quality and land topography relative to technogenic terrains are not so strict. For instance, a depression in the land surface, being the result of mineral extraction, may be fit for a reservoir as that depression favours the accumulation of water resources. Combination of hydroeconomic and forestry purposes for land reclamation makes it possible to restore practically all area of mining allotment.

Correspondingly, combination of different land use types will help replace the purposes of land reclamation with one another, if some purpose turns to be inexpedient; thus, there will be possible to use land reclamation reserves to the maximum. The most disturbed sites should be allotted for natural process of self-restoration with the preliminary measures for their chemical purification. In the context of reclaimed lands, it is possible to use 10…15% of the mining area for that purpose. At the same time, land reclamation for the forestry purposes will make it possible to activate soil-forming processes and favour the preservation of nutrients in the soil thickness.

Land reclamation performed timely and properly will be the basis for further land use for the post-industrial purposes. However, it is more important to have such planning of mining operations which will allow reducing the need of a mining enterprise in the involvement of land resources in mineral mining. That will be possible owing to the selection of proper technological schemes of stripping, mining, and cleaning-up of an open-pit field from the viewpoint of total area of land disturbance by a mining enterprise.

Table 5. Economically expedient reserves of land reclamation in terms of open-pit mining.

Reclamation purpose	**Economically expedient reserves of land reclamation**	**Mining objects to be reclaimed**
Agricultural	60…70% of the disturbed area	Internal and construction waste dumps
Forestry	78...80% of the disturbed area	Internal and construction waste dumps, transport incline and permanent trenches on top
Construction	70…80% of the disturbed area	Internal and construction waste dumps, transport incline on top
Hydroeconomic	30% of the disturbed area	Working and permanent trenches, transport incline
Sanitary	60% of the disturbed area	Internal waste dumps, working trench, and transport incline on top
Recreation	90 % of the disturbed area	Internal and construction waste dumps, working and permanent trenches, transport incline
Succession	100% of the disturbed area	Internal waste dumps, construction waste dump, transport incline on top, working trench on top, permanent trench

Basing on the results of the carried out research [2], certain technological solutions to mine the PGZK operating open pits have been proposed. While analyzing land resources from the viewpoint of market conditions of the mining enterprise economy, following parameters are proposed to assess the efficiency of the technological solutions:

1) Economic expediency of land preservation that characterizes a level of value conservation (monetary value) of natural lands:

$$E_{з.с} = \frac{100 \cdot Ц_р \left(1 - П_{з.р}\right)}{Ц_{пр}}, \%, \qquad (5)$$

where $Ц_р$, $Ц_{пр}$ is monetary value of the reclaimed and natural (undisturbed) lands respectively, UAH/ha; and $П_{з.р}$ is losses of land resources in terms of the area, a unit share;

$$П_{з.р} = \frac{\left(1 - К_р\right) \cdot Б_{пр}}{Б_р}, \text{ unit share;} \qquad (6)$$

where $Б_{пр}$,$Б_р$ is bonitet (quality) of the natural and reclaimed lands respectively, %; and $К_р$ is coefficient of reclamation (a unit share);

2) Economic expediency of land reclamation as a payback parameter for the reclamation costs:

$$Е_р = \frac{100 \cdot Цр \cdot \left(Б_р\right) \cdot К_р}{В_р}, \%, \qquad (7)$$

where $Ц_р$ $(Б_р)$ is monetary estimation of the reclaimed lands according to their bonitet, UAH/ha; and $В_р$ is reclamation prime cost of the disturbed lands, UAH/ha;

Along with the use of those parameters, Table 6 represents technological approaches aimed at reduction of natural land areas being used and at the creation of favourable conditions for mining and engineering reclamation as well as increase in the land areas returned to the national economy. Firstly, that objective was reached by considering the possibility to locate stripping mine workings in the middle of an open-pit field; secondly, it was reached by changing the procedure of advance of the working front of stripping, extracting, and dumping benches along with the location of the stripping mine workings relative to one another.

Table 6. Conditions of the use of technological schemes while mining horizontal deposits.

Technological approach	**Conditions of the technological scheme application**	**Land-preservation efficiency**
Filling the gap between the edge of the working trench and slope of the external waste dump	Stage of open pit construction; depth of mineral seam occurrence is 10 … 40 m; seam thickness is compared to the stripping thickness. High-capacity transportation and dumping facilities.	The mining allotment area for construction waste dump is reduced by 12.8 ha; reclamation costs are cut by UAH 1034 thousand.
Using internal permanent trenches	Stage of construction; ramps are located along the working trench length. Open pit depth is down to 100 m. Low-capacity transportation means for cyclic mining operations.	The mining allotment area for open pit construction is reduced by 20 … 25 ha; that results in the compensation payments cut by UAH 4000 thousand.
Basing on changes in the procedure of open-pit field mining: - combining the mined-out space with the transport incline *- reclamation of mine workings in terms of the external transport incline* *- combination and reclamation of the residual mined-out space in terms of the external transport incline*	Stages of construction and operation. Mining of two adjacent open pit fields or one field by blocks. Stripping thickness is not more than 50 m. High-capacity transportation and dumping facilities. At all the operation stages. Mining of two adjacent open pit fields or one field by blocks. Open pit depth is 50 … 70 m. Stripping shovels – draglines, motor transport for mineral blocks. Construction and operation stages. Open pit depth is 50 … 70 m. Cyclic mining and transportation facilities.	Surface of the residual mine workings decreases by 45 … 103 ha. Costs to compensate agricultural losses are reduced by UAH 67200 ... 94200. Complete filling of the residual mine workings. Land disturbance decreases by 112 … 147 ha, costs to compensate agricultural losses are reduced by UAH 10048 thousand Land disturbance decreases by 112 … 157 ha. Costs to compensate agricultural losses are UAH 67.2 ... 94.2 thousand, costs for mining and technical reclamation are cut by UAH 7168 ... 10048 thousand. Economic efficiency of reclamation grows from 10.6% up to 13.1%.
Basing on the division of an open-pit field into two blocks (sites)	Stage of clearing-up. Depth of the open pit is 40 ... 60 m. Length of the working trench is 1.5 ... 2 km. Reduced open-pit mineral output. High-capacity transportation and dumping facilities.	The surface area of the residual mined-out space for reclamation experiences two-fold increase. In terms of Chkalovskyi open pit, the surface increases by 159.2 ha.

Thus, preservation of land resources is connected with the dimensions of stripping workings and waste dumps, places of their locations as well as the direction of front advancing of mining operations within the open-pit field. Consequently, selection of certain mining system determines the cutting method and limits the number of technologically possible and economically expedient technological systems of deposit mining.

3 Conclusions and prospects of the research development

1. Planning of the open-pit mining objects should involve the implementation of those technological schemes which make it possible to avoid additional land disturbance and preserve the planned output according to the demand for

mineral. It has been specified that it is the selected mining system and technological scheme of stripping operations (i.e. parameters of permanent, transport, and working trenches) of the open-pit field which are of essential effect on the amount of disturbed lands of mining allotment. According to that fact, technological approaches have been proposed concerning the change in parameters of technological objects within the open-pit field aimed at reduction of the disturbed land area.

2. A criterion has been offered to identify economic expediency of land reclamation in terms of economic purposes. It has been determined that economic expediency of the disturbed land reclamation will depend on the degree of land surface disturbance within the mining allotment and purpose of its restoration. Economically expedient reserves of technogenic land reclamation in terms of open-pit mining should be specified by the most favourable ratio between the expected market value of the reclaimed lands and total costs for their reclamation disturbed by open-pit mining, basing on the classification of technogenic mining objects as for their suitability for reclamation at the economically attractive level.

3. There is the following prospective issue for further research in terms of the outlined problem: quantitative estimation of the amounts of value losses reduction for land resources resulting from the implementation of technological schemes of deposit mining in the context of land preservation.

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Distribution of radionuclides in modern sediments of the rivers flowing into the Dnieper-Bug Estuary

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Abstract. The article presents the results of large-scale studies of the content and distribution of natural and man-made radionuclides in the sediments of the rivers flowing into the Dnieper-Bug estuary. The article also presents the results of the granulometric analysis of the surveyed water bodies. The data about natural radioactive elements in the sediments rivers flowing into the Dnieper-Bug estuary obtained in this research are demonstrated moderate specific activity, which, however, clearly correlates with the granulometric composition of sediments. The ^{137}Cs determined by us is contained in the sediments of all studied water bodies and the places of it greatest concentration coincide with the areas in which the sediment is represented mainly by the pelitic fraction. The data obtained in this research can serve as a baseline data in natural radionuclides concentration in sediments rivers flowing into the Dnieper-Bug estuary. The obtained data can also be used for further monitoring of the specific activity of man-made radionuclides, in particular ^{137}Cs.

1 Introduction

Aquatic ecosystems play an important role in the migration of both natural and artificial radionuclides, as well as in their redistribution. On the one hand, they play the role of transport arteries for migration radionuclides within the reservoir and adjacent ecosystems, on the other hand, they are natural barriers to the deposition of a certain amount of radionuclides [1].

The barrier role of hydroecosystems is determined by the nature of the reservoir, the quality and intensity of the processes that take place in it. The main ones are the volume and depth of the water column, the flow rate, biological productivity, the composition of sediments, the intensity of sedimentation, the presence of geochemical barriers, as well as the amount of biomass and species composition of aquatic organisms. Equally important for the value of the barrier function of aquatic ecosystems are the physicochemical and biogeochemical properties, the mobility of the radionuclides themselves, the intensity of their sorption and accumulation by the abiogenic and biogenic components of aquatic ecosystems [2].

Bottom sediments of reservoirs and watercourses, to a large extent, fulfill the mission of depositing substances entering the water from catchment areas during coastal erosion and runoff from adjacent areas. Thus, composition of sediments reflects the ecological state of rivers and their catchment areas. Natural radionuclides in bottom sediments reflect the geochemical features of the region. Man-made radionuclides, which include ^{137}Cs and ^{90}Sr, are of artificial origin, the pollution by them is carried out mainly by air way, to a lesser extent, waterways.

The relevance of the presented studies is determined by the decision to build the E-40 channel [3, 4]. The E-40 waterway is a transnational initiative aiming to link the Baltic and Black Seas by an approximately 2,000 km long navigable connection running from Gdansk in Poland to Kherson in Ukraine. This proposes that the route would go through the river systems of Vistula, Bug, Pina, Pripyat and Dnieper. Several parts of planned route would need to be straightened, dammed, dredged, or drained.

Analysis of radioactivity in Polesia has been carried out by experts from «Association pour le Contrôle de la Radioactivité dans l'Ouest» (ACRO) [4, 5]. More than 35 years after Chernobyl accident, residual radioactive contamination is such that people are prohibited to live in an extensive exclusion zone. At the present time, contamination is dominated by cesium-137, strontium-90 and various isotopes of the highly toxic plutonium. Cesium-137 binds to clay sediments (pelitic fraction), while strontium-90 is more mobile.

The whole Pripyat-Dnieper watershed was contaminated by nuclear fallout. Dominating contaminants are cesium-137 and strontium-90. First one has tend to be fixed in bottom sediments, unlike second is continuously transported down to the Black Sea through the Dnieper cascade. Sediments contaminated by cesium-137 have been slowly covered by less contaminated and clean sediments, offering a natural shield to this pollutant. The International Atomic Energy Agency (IAEA)

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recommends leaving these sediments in place and avoiding processes that will lead to their resuspension.

Downstream of the Chernobyl exclusion zone, the Dnieper river serves as a water source for approximately 8 million Ukrainians and its waters are used to irrigate crops consumed by as many as 20 million people.

The section of the E-40 waterway running from the Kiev reservoir to the Black Sea would require regular dredging work. However, the feasibility study on the proposed E-40 waterway failed to consider some of the major dangers posed by radiation. Experts provided an initial evaluation of the impact of the construction and maintenance of the E40 waterway on the distribution of radioactive material. Among other things, they point to, that E-40 waterway risks disturbing several radiation hotspots. International Atomic Energy Agency recommends leaving contaminated sediment undisturbed [4, 5].

Thus, ***the aim of our researches*** were determination of specific radioactivity and distribution of natural and man-made radionuclides in modern sediments of the rivers flowing into the Dnieper-Bug estuary. The data obtained in this study may serve as a baseline data of radionuclide concentration in modern sediments of the researched rivers and water reservoirs.

2 Literature review

Determination of specific radioactivity and total β-activity of sediments allows to establish the intensity of anthropogenic impact, identify areas with high content of natural or man-made radionuclides, monitor the level of contamination of areas - i.e. is a widely used method of environmental research.

River sediment depositions on the bottom of rivers most frequently consist of sand and gravel particles with different grain sizes, which make them particularly valuable for the building construction. Knowledge of radioactivity present in building material enables one to assess any possible radiological hazard to mankind by the use of such materials. In the review [6], the natural radionuclide (^{238}U, ^{232}Th and ^{40}K) contents have been analyzed for the sediment samples of Ponnaiyar River. In the presented study, the dose rate was calculated, as well as the mineralogical characteristics of the sediment were investigated. The results obtained in the study suggest that the level of natural radioactivity of the present sediments mainly depends upon the amount of kaolinite (clay). Mineral characterization of various grain sized sediments show clay and magnetic minerals are rich in lower grain sized ($\leq$120 μm) samples.

The effect of sediment grain size, mineralogy, composition of the acid-extractable materials on the distribution of ^{7}Be, ^{10}Be, ^{137}Cs, and unsupported ^{210}Pb in detrital sediment samples collected from rivers in China and the United States were examined by authors in the presented research [7]. Acid-extractable materials (made up predominately of Fe, Mn, Al, and Ca from secondary minerals and grain coatings produced during pedogenesis) are positively related to the abundance of fallout radionuclides in sediment samples. Grain-size dependency of fallout radionuclide concentrations was significant in detrital sediment samples. Authors conclude that time-dependent geochemical, pedogenic, and sedimentary processes together result in the observed differences in nuclide distribution between different grain sizes and substrate compositions. These findings likely explain variability of measured nuclide activities in river networks as well as spatial and temporal differences in erosion rates and processes.

Discharges from the Krasnoyarsk Mining and Chemical Industrial Complex near Krasnoyarsk resulted in radioactive contamination of sediments of the River Yenisei. Between 1999 and 2006, 16 sediment cores were collected at different positions 15-1500 km downstream from the discharge point. Contamination levels of artificial radionuclides were decreasing with increasing distance downstream the Krasnoyarsk Mining and Chemical Industrial Complex: the fastest decrease of average activity by a factor of 10 over a distance of 300 km was observed for ^{241}Am, whereas for ^{137}Cs this decrease occurred over a distance of 1100 km. Sequential extraction experiments revealed that in all depths and at all distances the studied radionuclides were tightly bound to the sediment [8].

The results of a radioecological study of six small rivers located in the impact zone of the Beloyarsk Nuclear Power Plant (BNPP) and the cooling reservoir of the BNPP are presented [9]. The activity of 21 radionuclides was determined, as well as the total α- and β-activity in the main components of aquatic ecosystems. It is shown that after the decommissioning of blocks I and II of the BNPP, the content of ^{137}Cs in water, bottom sediments, ichthyofauna and macrophytes of the Beloyarsk reservoir decreased by tens and hundreds of times. The fundamental significance of this phenomena lies in the fact that in a large time range two mechanisms work: self-purification of the aquatic ecosystem from radionuclides due to the decay of radioactive substances and mechanism of redistribution of radionuclides from water to other components, primarily into bottom sediments.

The report [10] is devoted to the study of the activity of the natural radionuclides ^{40}K, ^{232}Th, ^{226}Ra and technogenic ^{137}Cs radionuclide in the river sediments of watercourses around the Lomonosov diamond deposit (northwestern Russia). Samples of river sediments and surface waters were taken from the Zolotitsa River and its tributaries in the area of the diamond deposit. The average activity of ^{137}Cs, ^{226}Ra, ^{232}Th and ^{40}K were 5,4; 9,0; 11,2; 318.8 Bq/kg, respectively. Several patterns of radionuclide accumulation have been found depending on the physicochemical parameters of river sediments. These patterns are due to the technogenic influence of the mining and beneficiation complex. The performed studies present the evaluation of the impact of diamond mining on natural radionuclides' distribution and accumulation in the river sediments within the adjacent territories.

The report on the concentrations of radionuclides ^{40}K, ^{137}Cs ^{232}Th and ^{226}Ra in river sediments along the Arvand river of Iran for future environmental monitoring was shown. Sediments were collected from 20 sites. The mean concentration activity for ^{40}K, ^{137}Cs ^{232}Th and ^{226}Ra, were

280,91; 5,96; 16,47 and 16,10 Bq/kg dry weight, respectively. The values of radiation hazard parameters were comparable to the world averages and below the recommended values. The data obtained in this study will serve as a baseline data in natural radionuclide concentration in sediments along the Arvand river [11].

In the paper [12] authors present distribution of natural gamma-active nuclides (^{40}K), elements of uranium ^{238}U rows (^{214}Pb, ^{214}Bi, ^{226}Ra), elements of thorium ^{232}Th rows (^{212}Pb, ^{212}Bi, ^{228}Ac, ^{208}Tl), and technogenic ^{137}Cs in the bottom sediments of the small rivers of the National natural park «Zacharovannij kraj». It is shown that content of these elements in the bottom sediments is relatively stable and can be examined as base-line, it is proportional to the siltation level of the small rivers and largely depends on their morphology. Total specific activity of natural gamma-active nuclides (without taking into account ^{40}K) in the bottom sedimentations is within of 126-184 Bq/kg. Averaged data of heavy metals content and specific activity of radionuclides in the bottom sediments of the small rivers are used for mapping of this protected territory and for the prediction of migration. Also these data apply for identification of the investigated areas of the rivers taking into account the geochemical features of the region.

The Rhone River is one of the most nuclearized river in the world. Radionuclide concentrations in water and suspended sediments transferred to the marine environment were intensively monitored in this river over the last decades (2002–2018). While >60% of plutonium, americium, cesium, cobalt, silver, beryllium and actinium radioisotopes are carried by sedimentary particles, sodium, tritium, antimony and strontium are mainly exported as dissolved species (>90%) due to their low affinity with particles. The concentrations of numerous anthropogenic radionuclides originating from nuclear industries significantly have declined since the beginning of the 2000s were shown [13]. If no change of the current anthropogenic and climatic pressures, the time required for a reduction by half the concentrations in the downstream part of the Rhône River, would be close to 6 years for most artificial radionuclides. The exception is for tritium and other artificial radionuclides conveyed to the river by soil leaching and erosion (^{90}Sr, ^{241}Am, plutonium isotopes), their half-life would be far longer.

Vertical profiles of environmental radionuclides (^{210}Pb, ^{137}Cs, ^{238}U, ^{232}Th, ^{226}Ra and ^{40}K) in a sediment core (Y1) of the Yellow River Estuary wetland were investigated to assess whether environmental evolutions in the coastal wetland could be recorded by the distributions of radionuclides. Based on ^{210}Pb and ^{137}Cs dating, the average sedimentation rate of core Y1 was estimated to be 1.0 cm y^{-1}. Vertical distributions of natural radionuclides (^{238}U, ^{232}Th, ^{226}Ra and ^{40}K) changed dramatically, reflecting great changes in sediment input. Concentrations of ^{238}U, ^{232}Th, ^{226}Ra and ^{40}K all had significant positive relationships with organic matter and clay content, but their distributions were determined by different factors. Environmental changes such as river channel migrations and sediment discharge variations could always cause changes in the concentrations of radionuclides. Frequent seawater intrusion decreased the concentration of ^{226}Ra significantly. The value of ^{238}U/^{226}Ra tended to be higher when the sedimentation rate was low and tide intrusion was frequent. In summary, environmental evolutions in the estuary coastal wetland could be recorded by the vertical profiles of natural radionuclides [14].

Thus, it can be noted that the determination of the specific activity of natural and man-made radionuclides in sediments is used to solve various scientific and applied problems.

A study which determined the activity concentration of ^{137}Cs in sediments contaminated by effluents from the Chernobyl accident which had collected along the coast of the Eastern Black Sea region in Turkey was carried out in 1993. Marine sediment samples were collected in 2015 from the same fifteen sampling points, and the activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs were determined for the sediment samples. The activity concentrations ranged from 10,94–25,95, 12,14–33,05, 265,74–459,89 and 2,08–37,45 Bq/kg for ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs respectively. The results showed that there was a steep decline in ^{137}Cs within the sediment at most of the sampling sites from the Eastern Black Sea region during the 22-year period [15].

A recent study along the northern Black Sea coast with combined using of artificial (^{137}Cs, $^{238,239+240,241}$Pu, ^{241}Am) and naturally occurring (^{210}Pb/^{226}Ra, ^{40}K) radionuclides as tracers for dating has allowed to reveal in sediment increase radioactive contamination of this basin with 137Cs after the Chernobyl accident. This is presumably caused by the prolonged input of the man-made radionuclides that showed a rise in the late 1990s – early 2000s, and by a possible post-deposition remobilization of ^{137}Cs from the seabed [16].

Radiation contamination sediments of the rivers flowing into the Dnieper-Bug estuary occurred due to aerosol falls on the water area, as well as a result of partial removal of radionuclides by the Dnieper and Southern Bug and due to leakage from polluted watersheds. Thus, according to the National Report on the state of man-made and natural safety in Ukraine [17], the radiation status of water bodies in the Dnieper basin in 2016, as in other years after the Chernobyl accident, was determined mainly by man-made radionuclides.

The main route for the entry of radionuclides into the Kyiv Reservoir with subsequent migration along the Dnieper River is the waters of the Pripyat River. Along the length of the Dnieper cascade of reservoirs due to the processes of sedimentation and dilution of the Dnieper water with cleaner waters of the side tributaries, the content of radionuclides decreases. In the water of the Kakhovka Reservoir near the town of Nova Kakhovka, the average concentration of ^{90}Sr in 2016 was 21 Bq/m^3, which is 4,2 times less than in the water of the Pripyat River. The average concentration of ^{137}Cs was 0,72 Bq/m^3, which is 47 times less than in Pripyat water. In the Dnieper-Bug estuary near the town of Ochakiv, the average ^{90}Sr content per year was 10,4 Bq/m^3, and ^{137}Cs – 4,8 Bq/m^3. The average concentration of ^{90}Sr in the water of the Southern Bug near Mykolayiv was 6,7 Bq/m^3, ^{137}Cs – 2,7 Bq/m^3.

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As a result of sedimentation of water-suspended particles, radionuclides migrating from the Pripyat River along the Dnieper are deposited and accumulate in sediments. Thus, the research presented below reflects the content of radionuclides in the sediments of the lower reaches of the rivers of the Dnieper-Bug estuary basin.

3 Objects and methods

Large-scale studies of modern sediments lower reaches of the Dnieper and the Southern Bug, as well as their lower tributaries − Inhulets and Inhul, respectively, have been carried out. The sediments of the Dnieper-Bug estuary and two reservoirs also were studied: Karachunivsky reservoir on the Inhulets River and Sofiyivsky reservoir on the Inhul River. The choice of the researched area was due to large anthropogenic pressure on hydroecosystems, owing to the location of significant industrial and agricultural capacities in this region (Figure 1).

The sampling points were located along profiles that crossed the investigation objects. The Dnieper river research area was the lower reaches, below the Kakhovka hydroelectric station; 36 samples were selected. The research area of the Southern Bug was from 143 km above the delta (below the Voznesensk city) and before falling into the Dnieper-Bug estuary; 30 samples were selected. The Inhulets River and the Inhul River both were surveyed from the top to the mouth; 52 and 48 samples were selected, respectively. In the Karachunivsky reservoir 3 profiles were laid and 35 samples were selected; 3 profiles were laid and 29 samples were selected in the Sofiyivsky reservoir. Samples of sediments from the Dnieper-Bug estuary were selected along its perimeter in the section of the coast and Kinburn Peninsula with Kinburn Spit; 32 samples were selected. Overall analyzed 262 samples of sediments.

Samples of sediments were taken with the special cylindrical equipment. Samples with intact structure were taken by soil tube, samples along the shores were taken by drilling. The thickness of the sediment layer selected for analysis was 0,1-0,35 m. The selected samples after drying were subjected to averaging at the points of selection.

The determination of granulometric composition of bottom sediments was carried out on the basis of standard technique by a sieve method. The particle size distribution is the main indicator of the type of bottom sediments, which characterizes the influence of hydrodynamic processes on the structural framework of the samples.

After sieving with the laundering, 12 fractions were allocated, which in the process of analyzing the data were grouped into 4 fractions: psephite, psammite, silts and pelity.

The specific activity of natural (^{238}U, ^{235}U and ^{232}Th, as well as ^{40}K) and artificial (^{137}Cs) γ-emitters was determined by means of a gamma-ray spectroscopy system SEG-50 with Ge (Li) detector DGDK-110. Spectroscopy measurements were carried out in the geometry of a "Marinelli conteiner" with a volume of 1 dm^3, which provided the maximum sensitivity of the analysis. The specific activity of ^{90}Sr was determined by means a selective β-radiometer RUB-91. The total β-activity of bottom sediment samples was determined using a UMF-1500M device (in thin layers with a SBT-13 counter). Since the research required a large amount of starting material, data on specific radioactivity were not obtained for some of the research sites.

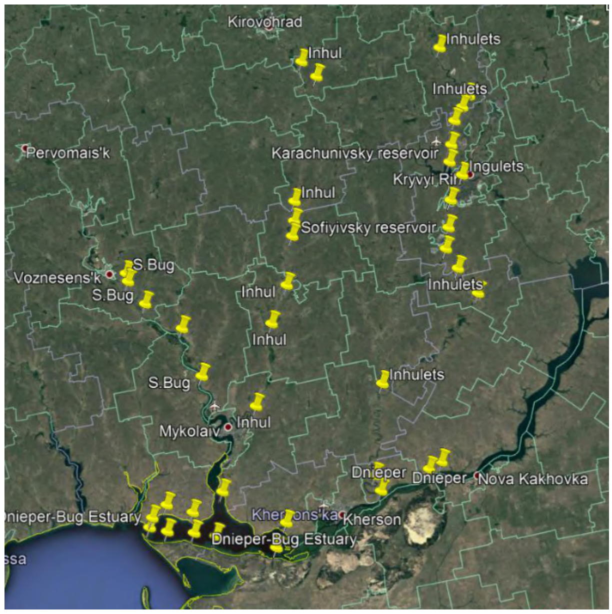

Fig. 1. The research area.

4 Results and analysis

The Southern Bug River is the largest river, the basin of which is completely located on the territory of Ukraine. The Southern Bug River originates in the Podillia Upland, then flows along the Black Sea lowlands and flows into the Black Sea, forming the Dnieper-Bug estuary with the Dnieper. A feature of the Southern Bug is the almost complete absence of significant tributaries. The Southern Bug River in the lower reaches has a wide channel and minor meanders. The research area is located in the Bug-Dnieper region of the Black Sea lowland of the Black Sea southern steppe province. On this section of the river 3 transverse profiles were laid. The sediments of the selected samples are dominated by pelity fraction (Figure 2).

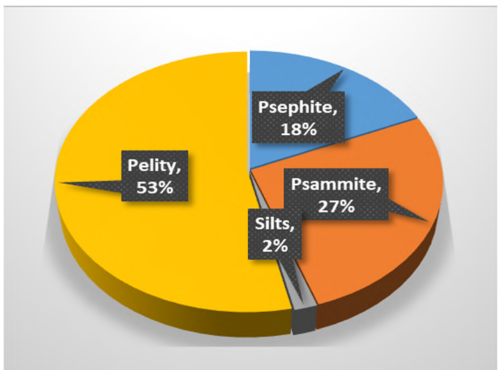

Fig. 2. Granulometric composition of the Southern Buh River sediments.

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The generalized results of determining the specific radioactivity of sediments (by individual radionuclides) of the lower reaches of the Southern Bug River are presented on the diagrams (figures 6-11). The specific activity of natural radioactive elements in sediments of the Southern Bug River occupies an intermediate position between the Dnieper River and the Inhulets and Inhul Rivers. Whereas the content of artificial strontium-137 in the Southern Bug River is the lowest among all surveyed objects. The total β-activity and isotopic ratios of radionuclides of the sediment samples are presented in table 1.

Table 1. Total β-activity (Bq · kg^{-1}c^{-1}) and isotopic ratios radionuclides of the sediment samples.

Object of study	The researched indicators, M±m				
	Σ_β	^{238}U / ^{226}Ra	^{232}Th / ^{238}U	^{212}Pb / ^{214}Pb	^{40}K / ^{238}U
The Southern Bug	38,0±5,0	4,3±1,0	0,5±0,1	2,3±0,5	4,6±0,9
The Inhul River	45,0±6,5	2,9±0,5	0,4±0,1	-	3,7±0,7
The Sofiyivsky reservoir	50,5±7,0	3,6±0,8	0,4±0,1	1,6±0,3	3,3±0,7
The Dnieper River	27,5±5,0	1,6±0,6	0,8±0,2	0,9±0,3	18,2±5,1
The Inhulets River	40,0±7,0	3,6±1,1	0,4±0,1	1,4±0,3	4,3±0,9
The Karachuniv-sky reservoir	51,2±8,0	4,8±1,7	0,3±0,1	1,3±0,3	2,1±0,4
The Dnieper-Bug Estuary	47,8±5,2	3,1±0,9	0,6±0,1	1,5±0,3	6,2±2,5

The Inhul River is the largest left tributary of the Southern Bug, which originates on the southern slope of the Ukrainian Shield. The Inhul River flows into the Bug estuary within the city of Mykolaiv. The territory through which the Inhul River flows belongs to the Dnieper and Kirovohrad metallogenic provinces, within which a considerable number of uranium deposits and manifestations are concentrated [18]. During the works, three sections of the river were investigated. The first of the researched areas, approximately 12 km long, was located at a distance of 80 km from the source of the Inhul River, i.e. in the upper reaches. This river section is characterized by a narrow channel with numerous rapids and a fairly fast flow, despite the over-regulation. Upstream the first researched area, on the southern outskirts of Kropyvnytskyi (earlier Kirovohrad), there are dumps of uranium mine of the Michurinsk deposit [19]. The second river section, about 15 km long (in the middle course of the river), is characterized by an expanded watercourse, slower flow, no rapids. The third, the longest studied area (in the lower reaches of the river) is located outside the Ukrainian Shield. The Sofiyivsky Reservoir, which is built on the Inhul River, was studied separately. The sediments of the first and second sections of Inhul River are represented mainly by psammite, which are replaced by pelity sediments within the Sofiyivsky Reservoir. Pelity fraction of sediments also dominates in the mouth of the Inhul River.

The share of large fractions naturally decreases from the top to the mouth and, accordingly, the share of fine fractions increases. Although on some profiles of the third section are deviations from this pattern, probably due to the features of the relief. The results of determining the particle size distribution of the Inhul River sediments and the Sofiyivsky Reservoir are shown in the Figure 3.

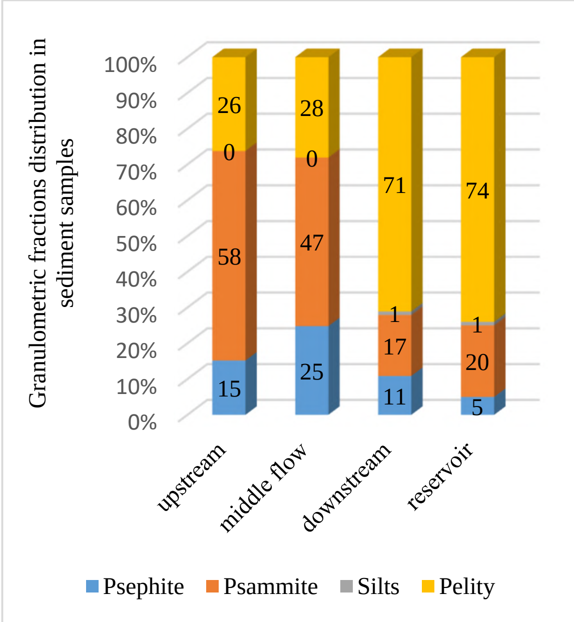

Fig. 3. Granulometric composition of the Inhul River and the Sofiyivsky reservoir sediments.

The results of determining the radionuclides content in the sediments samples of the Inhul River researched areas are presented in table 2.

Table 2. Specific radioactivity of the Inhul River sediments, Bq/kg dry matter.

Nuclide	Upstream		Middle flow		Downstream	
	Min* / max	M	Min / max	M	Min / max	M
^{238}U	61 / 107	79,0	87 / 150	117,0	47 / 182	107,0
^{226}Ra	47 / 53	50,0	24 / 40	29,0	23 / 34	27,5
^{232}Th	29 / 35	31,7	34 / 78	54,0	33 / 96	46,0
^{235}U	5,1 / 6,6	5,6	2,3 / 5,4	3,1	1,8 / 5,0	3,5
^{40}K	191 / 355	285,0	402 / 528	423,0	345 / 475	420,0
^{137}Cs	2,5 / 4,4	3,4	1,7 / 6,0	3,7	0,8 / 4,1	2,5

*the numerator of the pseudo-fraction is the minimum values of the indicator, the denominator is the maximum

Specific activity of ^{238}U in the sediments gradually increases along the Inhul river flow, as is shown by the results. Similarly, ^{232}Th is distributed, while the content of ^{226}Ra decreases almost twice along the river flow. Other radionuclides demonstrate a multidirectional nature of distribution in the bottom sediment.

The Sofiyivsky Reservoir was built on the Inhul River in the Novobuzhsky District of the Mykolaiv Region in 1968. The channel type reservoir is the largest in volume and closes a cascade of reservoirs on the Inhul River. The

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reservoir is used for drinking water supply. The Sofiyivsky Reservoir sediments are presented by the pelity fraction, the latter is characterized by adsorbing properties, including adsorption of radionuclides (see Figure 6-11).

The Dnieper River is a typical plain river with a slow and calm flow. A powerful anthropogenic offensive significantly changed the configuration of the banks of the Dnieper in the twentieth century. In a large section, this river has turned from clear watercourse with fast stream into a polluted lake-type reservoir, which is gradually but relentlessly silt up (Figure 4). Regulation of the Dnieper River runoff by a cascade of reservoirs has significantly changed the conditions of functioning of the lower river ecosystem.

The spring flood became less expressed, but the unstable runoff regime due to the uneven operation of the Kakhovka hydroelectric power station during the day acquired ecological significance. As a result, even in the main watercourse of the lower reaches of the Dnieper River there are short-term fluctuations in water levels. The negative changes were shown by researches of the ecosystem of the lower Dnieper River in recent years [20, 21]. Eutrophication of watercourse, siltation, overgrowing with aquatic vegetation are determined.

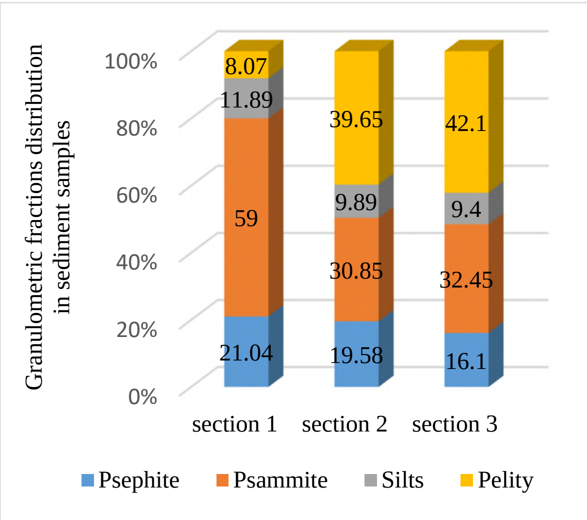

Fig. 4. Granulometric composition of the Dnieper River sediments.

The data of the performed radiological analysis of the Dnieper River are presented in figure 6-11. It should be noted that the profiles were laid down by us were below the entire cascade of Dnieper reservoirs, which in total retain more than 96% of all terrigenous runoff of the Dnieper. That is why, in our opinion, the specific activity in the bottom sediments of the research section of Dnieper River is the lowest among all the studied objects.

The highest concentrations of ^{137}Cs, most likely of Chernobyl origin, however, as well as concentrations of ^{238}U and ^{226}Ra tend to the right less flowing bank of the Dnieper. The equilibrium state in a chain of uranium is characterized by some lack of ^{226}Ra. However, given the rather high measurement errors of extremely inactive samples, it can be assumed that these nuclides are in equilibrium. The greatest variability is shown by the ratio $^{40}K/^{238}U$, which is explained by the diversity of the lithological composition of the studied samples. After all, practically "clean" quartz sands border on sandy loams, dark-colored sands, shells, etc. Total β-radioactivity and isotopic ratios of samples of bottom sediments of the Dnieper River; lower right tributary − the Inhulets River and Karachunivsky reservoir are presented in table 1.

The Inhulets River is a lower right tributary of the Dnieper River, originating on the southern slope of the Ukrainian Shield. Analysis of previous researches [22] allowed to conditionally divide the river valley by zones with different ratio of natural and man-made components in the sediments, which in turn is due to different degrees of anthropogenic presser.

The first zone is the upper reaches of the river, where it flows through metamorphic and ultrametamorphic rocks of the Ukrainian Shield. This area is represented mainly by agricultural areas. The second zone of the Inhulets River is located parallel to the elongated in the meridional direction of the Kryvyi Rih iron ore basin. In this area, the Inhulets River basin is exposed to strong man-made impact from numerous mining and processing enterprises. In the second zone, the Inhulets River receives a tributary − the Zhovta River, which drains the dumps of mines and tailings of hydrometallurgical production of Zhovti Vody [21]. Also in this area is a powerful mining complex of the Kryvyi Rih. The third zone is located below the Kryvyi Rih. The Inhulets River here is characterized by a plain slow-moving current.

The granulometric composition distribution of the researched areas sediments reflects changes in the hydrodynamic regime of the Inhulets River. In the area of the reservoir is a change in the hydrodynamic regime from lotic to lentic, which is recognised in more than 75% of the pelitic fraction of the sediment (Figure 5).

The minimum and medium particle size recorded for the upper and lower reaches of the river, where the content of man-made material in the sediments is low. Psammite fraction in sediments dominates in the second zone, which is due to the man-made impact of mining and processing enterprises. Our previous studies [22] have determined that this is caused by the presence of a man-made component (tails of ore benefication) in the sediments.

When interpreting the results of radiological analysis of the sediments of the Inhulets River, it should be taken into account that the basin of this river is located within the uranium-bearing province of the south of the Ukrainian Shield. Radiological analysis was performed for bottom sediments of the second (middle flow) and third (downstream) zones [23]. The results of radionuclide content study in samples of the Inhulets River sediments are presented in Table 3. Data analysis shows that the specific activity of all natural radionuclides is higher in the second zone, except for ^{238}U.

The results of gamma-spectrometric studies of the Inhulets River sediments demonstrate significant variability in the specific activity of natural radioactive elements. As for technogenic radionuclides in the samples, ^{137}Cs was determined in the second technogenic zone of Inhulets River and Karachunivsky reservoir.

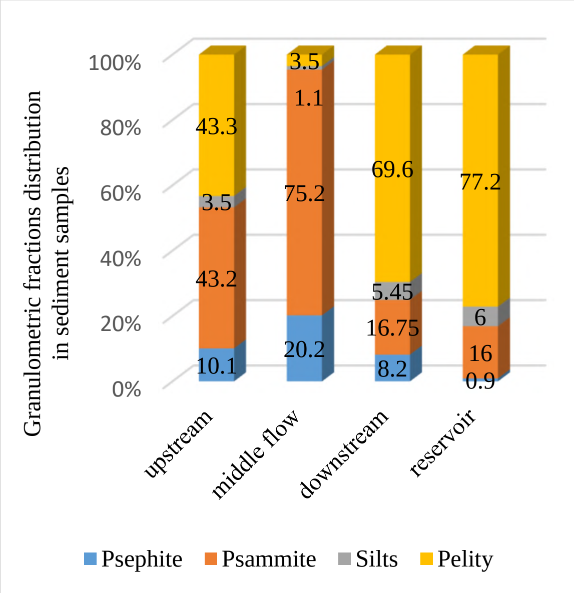

Fig. 5. Granulometric composition of the Inhulets River and Karachunivsky reservoir sediments.

Table 3. Specific radioactivity of the Inhulets River and Karachunivsky reservoir sediments, Bq/kg dry matter.

Nuclide	Average value of specific activity, M±m		
	Middle flow (second zone)	**Down-stream (third zone)**	**Karachunivsky reservoir**
^{238}U	58,0±22,0	68,0±10,1	129,0±15,2
^{226}Ra	19,1±2,2	16,0±2,2	27,0±3,1
^{232}Th	28,0±3,2	21,0±2,1	37,4±3,9
^{235}U	1,7±0,4	1,4±0,4	3,4±0,8
^{214}Pb	19,2±11,8	16,3±8,1	15,0±9,0
^{214}Bi	21,3±10,5	17,0±10,4	14,0±12,0
^{228}Ac	30,1±17,8	21,3±9,2	19,0±11,0
^{212}Pb	28,0±9,9	21,0±12,0	20,0±9,7
^{212}Bi	46,4±17,2	24,1±15,4	*bml
^{40}K	297,5±37,0	241,0±31,7	268,5±14,0
^{137}Cs	4,6±0,7	*bml	42,5±9,2

*bml – below the measurement limit

The Karachunivsky reservoir is the closing reservoir in the cascade on the Inhulets River and due to its largest volume serves as the main regulator of river flow. The reservoir is used for drinking water supply, as well as irrigation of adjacent lands. Construction of the Karachunivsky reservoir on the Inhulets River began in 1932 and commissioned in 1939. It is located in the zone of influence of technogenic factors of the mining complex of Kryvyi Rih. During 1950-1958 years, the reservoir received its modern shape. The reservoir is very silted up. Thus, the age of sediments of the most stagnant part reservoir exceeds 50 years. In the studied samples, the uranium content usually significantly exceeded the radium content. It is known that the mobility of the latter in the zone of hypergenesis is somewhat limited, except for environments with low pH values.

The specific activity of ^{137}Cs of Chernobyl origin varies widely. Since caesium-137 migrates mainly in the form of a suspension (adsorbed on clay pelitic particles), its accumulation sites in bottom sediments coincide with stagnant zones, where the flow is minimal and suspended particles fall out of the water. The specific activity of ^{137}Cs in the Karachunivsky reservoir exceeds similar values in other researched rivers on an average in ten times (Figure 11). Also, ^{90}Sr of Chernobyl genesis was determined in single samples of precipitation from the Karachunivsky reservoir. In contrast, natural ^{226}Ra is somewhat chemically similar to calcium and strontium. It is known that molluscs build their shells from calcium compounds and are also able to capture strontium and radium from solutions of compounds. Thus, radium-226 can be eliminated from the solution and bound in the shell material. Compounds of uranium and thorium are not usually used by living organisms to build a skeleton. The accumulation of the above-mentioned elements in biogenic sediments is mostly associated with later stages of lithogenesis and occurs due to purely chemical processes.

The Dnieper-Bug estuary is the largest estuary of the north-western Black Sea coast and at the same time it`s a complex natural open type hydroecosystem. In the estuary, as in the water area with limited water exchange, changes occur in hydrological, hydrochemical and hydrobiological conditions of sedimentation from river to sea, the effect of the geochemical barrier is enhanced. The estuary is a place of intensive transformation of sedimentary material in the form of suspended matter, the main source of which is terrigenous runoff. The most of the suspended matter is retained at the stage of mixing river and sea water and enters the sediment. Subsequent transformation of sedimentary material takes place on the river-sea geochemical barrier. Sedimentation substances in open estuaries have different origins. First of all, these are the products of river runoff, abrasions of shores and seabed, the development of bios in the estuaries themselves, as well as substances brought by seawater. The most common type of sediments in the Dnieper-Bug estuary is siltstone silt with a medium degree of sorting, which essentially constitutes the lithological background of bottom sediments. Demolition of this material occurs mainly due to the Dnieper and the Southern Bug [24, 25].

The granulometric composition of the bottom sediments of the Dnieper-Bug estuary is heterogeneous. Samples taken along the Kinburn Peninsula and Kinburn Spit are represented by homogeneous well-sorted quartz sand, which does not contain clay impurities and is 98% composed of psammites. Samples from the section of coast are represented by different particle size classes. So, psammites dominate in the samples taken on the shelf and pelites predominate in the samples taken on the shore. The latter are composed of fine clay particles. This fact is probably the result of constant transgression of the sea. The samples from the profile that crosses the mouth of the Southern Bug are exceptions. In these samples, psammites predominate in the granulometric composition distribution.

The results of determination of radionuclides in the bottom sediments of the Dnieper-Bug estuary are shown in table 4. Distribution of radionuclides in the sediments depending on the particle size was clearly demonstrated in the presented results.

Table 4. Specific radioactivity of the Dnieper-Bug estuary sediments, Bq/kg dry matter.

Nuclide	The researched district	
	Section of the coast	Kinburn Spit and Kinburn Peninsula
	M±m	M±m
^{238}U	69,6±30,5	21,9±7,1
^{226}Ra	22,4±4,2	11,1±2,1
^{234}Th	55,6±10,5	28,2±7,3
^{235}U	1,7±0,5	0,6±0,2
^{214}Pb	18,2±2,8	15,1±3,1
^{214}Bi	17,5±2,0	14,4±1,5
^{228}Ac	28,1±3,1	16,5±1,5
^{212}Pb	27,7±3,0	15,5±1,7
^{212}Bi	32,6±6,7	18,8±6,1
^{208}Tl	11,1±1,5	6,4±0,7
^{40}K	350,0±29,0	214,0±20,5
^{137}Cs	2,0±0,5	0,5±0,2

Thus, the specific activity of ^{238}U from the section of coast samples on an average in three times more than from Kinburn Spit samples. ^{234}Th in the "continental" samples is slightly higher than in the samples from the spit (on an average in two times). In general, the content in the sediments samples of the Dnieper-Bug estuary ^{228}Ac is stable and relatively low. As for ^{235}U and its decay products, it content in the researched samples is quite insignificant, although it varies in a wide range from 0,18 to 2,83 Bq/kg.

Relatively low concentration of ^{137}Cs of Chernobyl origin was determined, in the studied samples of sediments, although the specific activity of this nuclide varies widely – the fluctuations were about 15 times. Due to the predominance of psammitic fraction in bottom sediment samples, this may lead to low concentrations of ^{137}Cs.

Determination of total β-activity showed a range of variations from 16,5 to 96,0 Bq · kg^{-1}c^{-1}. The difference between the samples taken from the water and on the shore is about 2 times.

5 Discussion

The origin of sediments is essential in interpreting the results of γ-spectrometric measurements. The state of equilibrium in the natural decay chains of uranium and thorium depends on how certain deposits were formed – by mechanical precipitation of the suspension or by chemical or biochemical precipitation of the solution. If such an equilibrium exists, the specific activities of all members of the radioactive chain are equal to each other, and vice versa, when deposits are formed by chemical accumulation of aqueous solutions of radionuclides different in chemical properties – age equilibrium cannot exist in principle. Given the significantly different yields of gamma quanta on the decay of a radionuclide, the sensitivity of their determination by the γ-spectrometric method varies in a very wide range. Under the same measurement conditions, the daughter products ^{226}Ra are determined with the highest sensitivity: ^{214}Pb and ^{214}Bi; ^{137}Cs; subsidiaries ^{232}Th: ^{212}Pb, ^{228}Ac, ^{212}Bi and ^{40}K. Much worse conditions for determining the nearest uranium decay products: ^{234}Th and ^{234m}Pa. However, at high concentrations of this element in the studied samples, the use of ^{234m}Pa is quite appropriate and justified, because this nuclide is almost always in equilibrium with the parent ^{238}U.

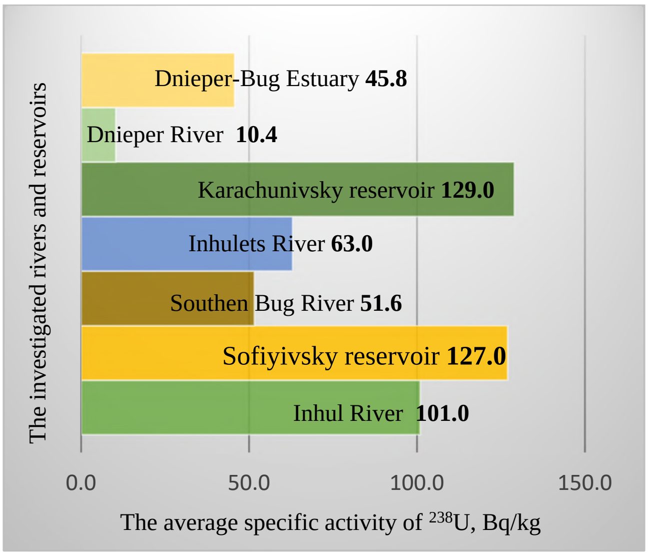

Fig. 6. The averaged values of ^{238}U specific activity in the samples of sediments.

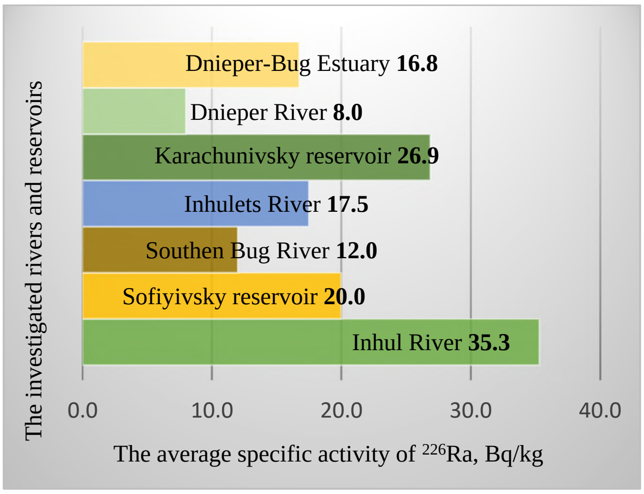

Fig. 7. The averaged values of ^{226}Ra specific activity in the samples of sediments.

The mobility and bioavailability of radionuclides of accidental origin in the terrestrial and aquatic environment are governed by their chemical forms in fallout and site-specific environmental characteristics. The latter determine rates of leaching, fixation-remobilisation, as well as sorption-desorption of the mobile fraction (its solid-liquid distribution). After deposition on the surface of water bodies, radionuclides are subject to physicochemical and biological processes, which leads to changes in their speciation. Dissolved radionuclide is adsorbed on the solid phase by ion exchange. Exchangeable radiocaesium transforms into the fixed form [26].

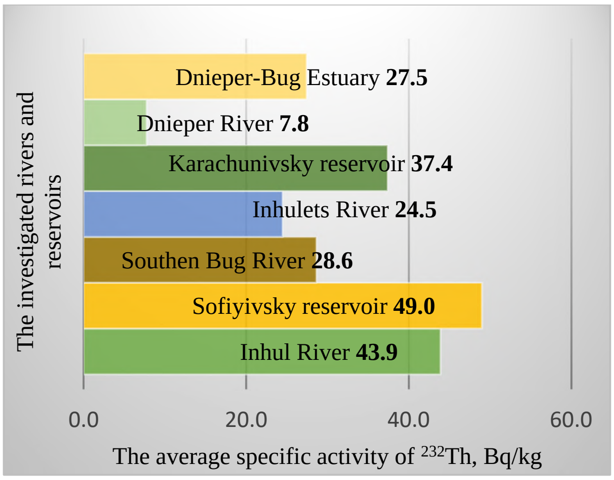

Fig. 8. The averaged values of ^{232} Th specific activity in the samples of sediments.

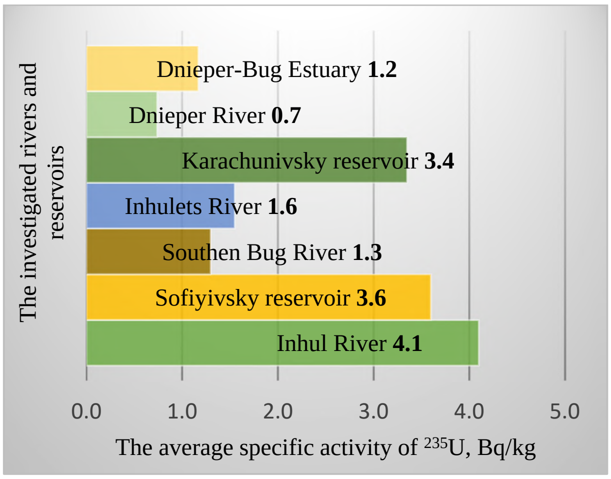

Fig. 9. The averaged values of ^{235}U specific activity in the samples of sediments.

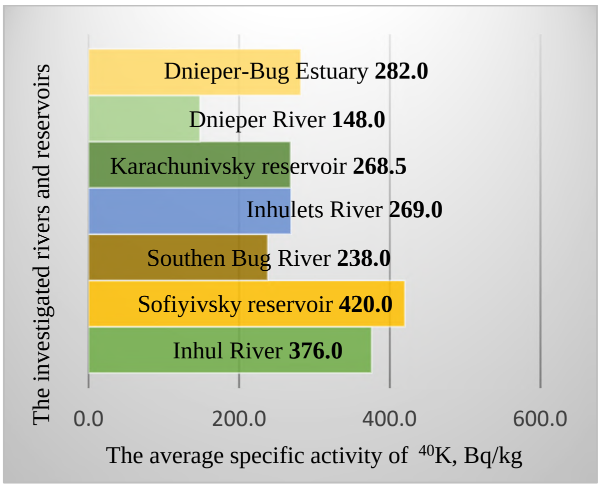

Fig. 10. The averaged values of ^{40}K specific activity in the samples of sediments.

It is now well established that the high retention of radiocaesium in soil and bottom sediments is largely determined by two different processes: fixation and reversible selective sorption. Fixation describes the ‘‘permanent’’ (or at least long-term) replacement of interlattice K- by Cs-ions due to collapse of expanded edges of mineral's crystal lattice interlayers.

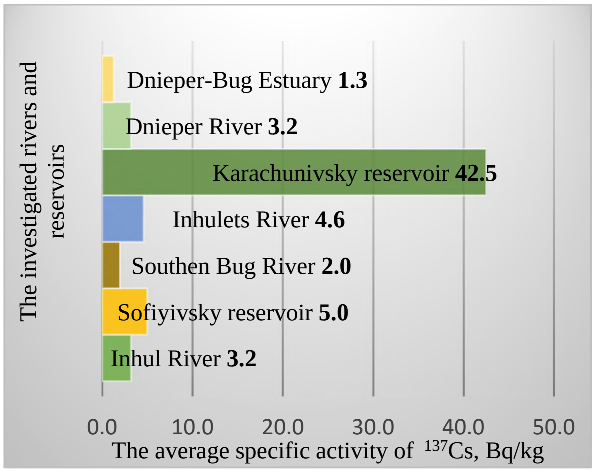

Fig. 11. The averaged values of ^{137}Cs specific activity in the samples of sediments.

The data for long-term transformation of chemical forms of radionuclides in soil and sediment in the long-term after the Chernobyl accident indicate the existence of a remobilization process that is the reverse of fixation [27]. After deposition of radiocesium the fraction of its exchangeable form does not decrease to zero, as should happen during irreversible fixation, in theory. Radiocesium decreases to a certain level, independent of the amount of radionuclide applied, and then does not change significantly because of an equilibrium steady state between fixated and remobilized fractions [28].

6 Conclusions

1. The data obtained in this research can serve as a baseline data in natural radionuclides concentration in sediments rivers flowing into the Dnieper-Bug estuary. The obtained data can also be used for further monitoring of the specific activity of man-made radionuclides, in particular ^{137}Cs.

2. The data shows a significant variation in grain size and at the same time make it possible to identify a tendency to increase pelitic fraction in sediments. According to this indicator can arrange rivers in the following row: Dnieper < Southern Bug < Inhulets < Inhul. However, despite the tendency to silting, in general, natural facial distribution of sediment has preserved, except are areas within a border of large industrial cities (e.g. Inhulets within Kryvyi Rih).

3. The presence of natural radioactive elements in river sediments is due to geological, hydrological and chemical factors. Purposeful sampling into undisturbed sections near the dam of reservoirs makes it possible to reconstruct the history of the formation of radioactive contamination of bottom sediments and, accordingly, catchment areas.

4. In general, data about natural radioactive elements in the sediments rivers flowing Dnieper-Bug estuary

obtained in this research demonstrates moderate specific activity. Which, however, clearly correlates with the granulometric composition of bottom sediments.

5. The radiocaesium of Chernobyl origin determined by us is contained in the sediments of all studied water bodies. The places of its greatest concentration coincide with the stagnant areas of reservoirs, in which the sediment is represented mainly by the pelitic fraction.

6. The section of the E-40 waterway, which plans to construct from the Kiev reservoir to the Black Sea will require regular dredging work. Sediments contaminated by cesium-137 of Chernobyl origin have been slowly covered by less contaminated and clean sediments, offering a natural shield to this man-made pollutant. The International Atomic Energy Agency (IAEA) recommends leaving these sediments in place and avoiding processes that will lead to their resuspension and entrance into water.

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Waste management in Ukraine: organizational aspects

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Abstract. Environmental management emerged as a consequence of an unprecedented strain on the Earth by humans. Each our activity leaves a trail, such as pollutions of air and soil, contamination of water, deforestation, and also tons of wastes. We are confronting environmental problems that are more taxing than ever before. Now we have everyday changes of the climate which is why there is an urgent need to find ways of life that is less damaging to the Earth. Waste management is a particular specialization of the environmental management which studies how to achieve a zero-waste life. The difference between the situation with waste in Ukraine compared to other developed countries is the large volume of waste generation and the lack of infrastructure for waste management. At the same time, the availability of such infrastructure is an essential feature of all economies of developed countries. Also, it is showed to increase of the amount of illegal and uncontrolled landfills and to degrade of the condition of existing dumps. This paper is aimed to explain how the Ukrainian government could educate people about problems of wastes and encourage us to change our habits.

1 Introduction

By adopting the concept of sustainable development, Ukraine has agreed that economic growth and sustainable development require an urgent reduction in environmental impact through changes in the production and consumption of resources and goods [1]. Effective management of natural resources, as well as methods of utilization of waste and pollutants are important tasks to achieve this goal. Furthermore, the modern individual behaviors of the discarding of waste are often deeply rooted in habits of the population [2]. Therefore, encouraging consumers, businesses, industries, countries to reduce waste and their rational utilization should be a priority of every government program. Separate researches propose to modify the current waste management process based as on active participation of citizens and considering the local people and expert's viewpoints [3], as on people who spend time on volunteer activities are also likely to spend time on waste management efforts [4]. An intervention is needed to bring stakeholders together to solve these waste challenges [5].

In this way, following modern studies [6, 7, 8, 9] systematic environmental management including waste management is required. This is especially true given that there are an accumulation of waste in both the industrial and domestic sectors, which has a negative impact on the environment and human health; improper disposal and removal of hazardous waste; disposal of household waste without taking into account possible dangerous consequences; inadequate level of waste use as a secondary raw material due to imperfect organizational and economic principles of their involvement in production; inefficiency of implemented economic instruments in the field of waste management in Ukraine.

Besides awareness of the consequence of waste management practices to the environment is limited as many are not conscious of the connection between waste management and the environment [10].

Researching waste management issues in Ukraine, the situation of closing the Lviv landfill should be considered in detail. Waste from Lviv and some settlements of the region was stored at the Hrybovytsia landfill, which has been operating since 1957, occupies more than 33 $\times 10^4$ m^2, and is the third largest in Europe and one of the largest polluters in the Lviv region.

In 2003, the chief state sanitary doctor of the Lviv region issued a resolution to terminate the operation of the landfill for the city of Lviv. In following years, there were repeated instructions to stop the operation of the landfill, but they were ignored by the city authorities and challenged in courts, as a result of which the landfill continued to accept waste. According to the resolution of decommissioning since 2006 landfill ran illegally.

Despite the landfill ban, in 2006, a few months after being elected mayor, Andriy Sadovyi said the landfill was almost full, but asked the Hrybovychi community to agree

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to continue operating the landfill for next five years, after which he promised to close it. Instead, promises to solve waste recycling problems were not fulfilled for next 10 years, and some work was directly sabotaged or banned by Andriy Sadovyi and his team. Thus, in 2007, the city authorities banned degassing of landfills - primary measures for its reclamation and closure.

In May 2016, after the fire was extinguished, rescuers who were investigating causes of the fire were killed at the landfill due to a landslide with waste. In November 2016, a court ordered the Lviv authorities to close the Hrybovytsia landfill. As of June 2017, monthly volumes of waste have accumulated in some areas of the city. In total in the city - about 9×10^3 tons of waste.

Hence, goal of the research is a development at the government level organizational measures for effective waste management in Ukraine.

2 Presentation of the main materials of the research

The situation with waste management in Ukraine is a rather difficult. Because it is at an initial stage, there are only legislatively approved norms and regulations. Thus, it is proposed to utilize the practice of the European union.

Table 1. Hierarchy of waste management in European union.

Position in the hierarchy	Waste management	
	action	essence
1	Prevention	promote and support sustainable production and consumption models;
		encourage the design, manufacturing and use of products that are resource-efficient, durable, reparable, re-usable and upgradable;
		target products containing critical raw materials to prevent that those materials become waste;
		encourage the re-use of products and the setting up of systems promoting repair and re-use activities;
		encourage the availability of spare parts, instruction manuals, technical information, or other instruments, equipment or software enabling the repair and re-use of products without compromising their quality and safety;
		reduce waste generation in processes related to industrial production, extraction of minerals, manufacturing, construction and demolition, taking into account best available techniques;
		reduce the generation of food waste in primary production, in processing and manufacturing, in retail and other distribution of food, in restaurants and food services as well as in households;
		encourage food donation and other redistribution for human consumption, prioritizing human use over animal feed and the reprocessing into non-food products;
		promote the reduction of the content of hazardous substances in materials and products;
		reduce the generation of waste, in particular waste that is not suitable for preparing for re-use or recycling;
		identify products that are the main sources of littering, notably in natural and marine environments, and take appropriate measures to prevent and reduce litter from such products;
		prevent and significantly reduce marine pollution of all kinds;
		develop and support information campaigns to raise awareness about waste prevention and littering.
2	Preparing for re-use and recycling	promote preparing for re-use activities, notably by encouraging the establishment of and support for preparing for re-use and repair networks, by facilitating, where compatible with proper waste management, their access to waste held by collection schemes or facilities that can be prepared for re-use, and by promoting the use of economic instruments, procurement criteria, quantitative objectives or other measures;
		promote high-quality recycling;
		set up separate collection of waste: for paper, metal, plastic, glass and textiles from households and possibly from other origins;
		promote selective demolition in order to enable removal and safe handling of hazardous substances and facilitate re-use and high-quality recycling by selective removal of materials, and to ensure the establishment of sorting systems for construction and demolition waste for wood, mineral fractions (concrete, bricks, tiles and ceramics, stones), metal, glass, plastic and plaster;
		consider the setting of preparing for re-use and recycling targets for construction and demolition waste and its material-specific fractions, textile waste, commercial waste, non-hazardous industrial waste and other waste streams, as well as preparing for re-use targets for municipal waste and recycling targets for municipal bio-waste.
3	Recovery	ensure that waste undergoes preparing for re-use, recycling or other recovery operations;
		collecting certain types of waste together does not affect their potential to undergo preparing for re-use, recycling or other recovery operations because separate collection does not deliver the best environmental outcome when considering the overall environmental impacts of the management of the relevant waste streams.
4	Disposal	ensure that, where recovery is not undertaken, waste undergoes safe disposal operations;
		regulating disposal operations, including through possible restrictions, and to consider a disposal reduction target, to ensure environmentally sound waste management.

By definition of the European Union in the Directive 2008/98/EC on waste "waste management means the collection, transport, recovery and disposal of waste, including the supervision of such operations and the after-care of disposal sites, and including actions taken as a dealer or broker" [11]. That is, waste management (or waste disposal) include activities and actions required to manage waste from its inception to its final disposal [12].

This Directive proposes the following waste management hierarchy which reflected a priority order in waste prevention and a measure of the safety of waste management's results which are shown in Table 1 [11].

There is the National Strategy of Waste Management in Ukraine until 2030. And all of these actions exist there but just formal. Accordingly, the practice of waste management is needed to improve by the side of the government. Firstly, it will be the organization of waste management, precise in households.

In Ukraine, according to the Ministry of Regional Development, about 10 million tons of waste are dumped annually, of which only 600000 are recycled or burned. The rest is buried in landfills, of which, according to official data, there are more than 6000 in Ukraine. They occupy 9000 $\times 10^4$ m^2; another 1000 $\times 10^4$ m^2 are unauthorized landfills.

In order to assess the state of waste management in Ukraine, we use the following types of information (from official statistic resource of Ukraine):

1. Expenditures on environmental protection by type of economic activity in 2019 (shown in Fig. 1).
2. Waste generation and management from 2010 to 2018 (shown in Fig. 2)
3. Expenditures on environmental protection by types of environmental measures in 2019 (shown in Fig. 3).

Consideration of Ukraine's expenditures on environmental protection by types of economics activity can give us enough answers about how much Ukraine spends on each of them and what type of activity takes the biggest percentage of the expenditures.

It should also be noted that the analysis of expenditures on environmental protection by type of environmental measures shows us which types of measures are the most sponsored. From which we can draw conclusions about the rationality of such expenditures for environmental protection by types of environmental measures.

However, we must remember that expenditures management is an important and one of the most difficult issues in country's waste management activities. The level and dynamics of environmental expenditures depend on country's profits or losses and the level of efficiency of waste management.

The analysis of such information allows us to assess the effectiveness of waste management and expenditures on environmental protection in modern Ukraine. In addition, the analysis of waste generation and management can show us do we rationally manage our waste and how much Ukraine forms, utilizes, burns and deletes to special places or objects all types of waste.

The pie chart shows expenditures on environmental protection by type of economic activity in 2019. In 2019 the number of expenditures on environmental protection was up to 43735862,1$\times 10^3$ hryvnias. The largest percentage was the cost of processing industry, that is 26,701%. Water supply; sewerage, waste management take the second place in the pie chart by percentage of expenditures on environmental protection at the level of 22,173% that is not very higher then percentages of supply of electricity, gas, steam and air conditioning and mining and quarrying which have following percentages.

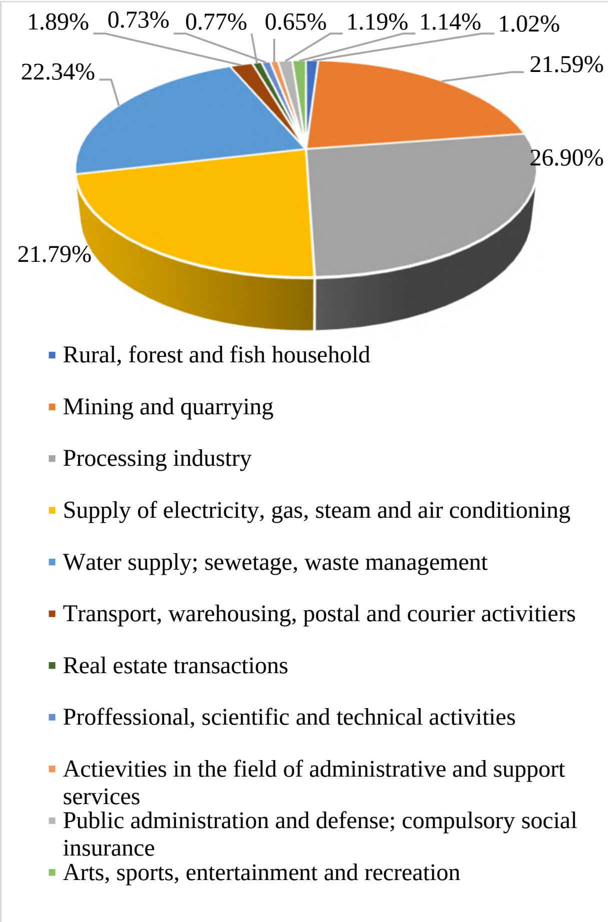

Fig. 1. Expenditures on environmental protection by type of economic activity in Ukraine in 2019.

According to the letter from the Ministry of Ecology and Natural Resources "Regarding specially designated places or objects for waste disposal", we determine that special places or objects - places or objects (waste disposal sites, storage facilities, landfills, complexes, structures, subsoil areas, etc.), for the use of which the permission of specially authorized bodies for waste disposal or other waste operations has been obtained [13].

21,626% and 21,427%. Paying attention to remaining indicators, we can see that ten of them do not gain even 1%, and other do not exceed level of transport, warehousing, postal and courier activities, that is 1,873%.

Analyzing official data of expenditures on environmental protection by type of economic activity, there is not separately waste management. This fact makes it difficult to see the real state of these expenditures.

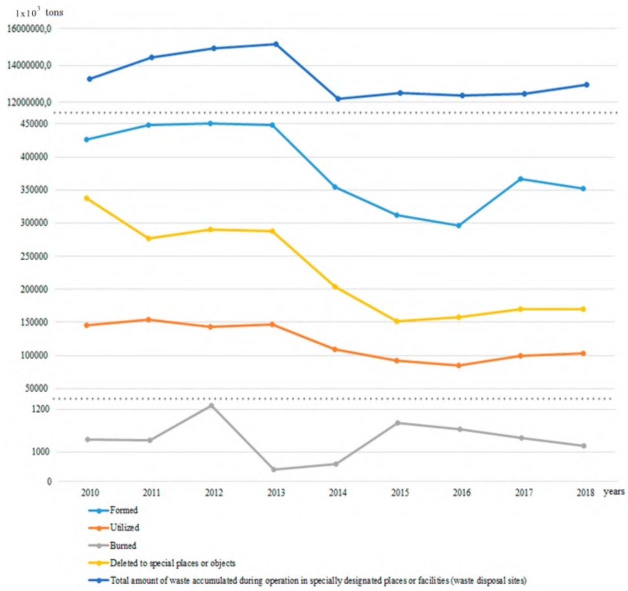

Fig. 2. Waste generation and management in Ukraine in 2010-2018.

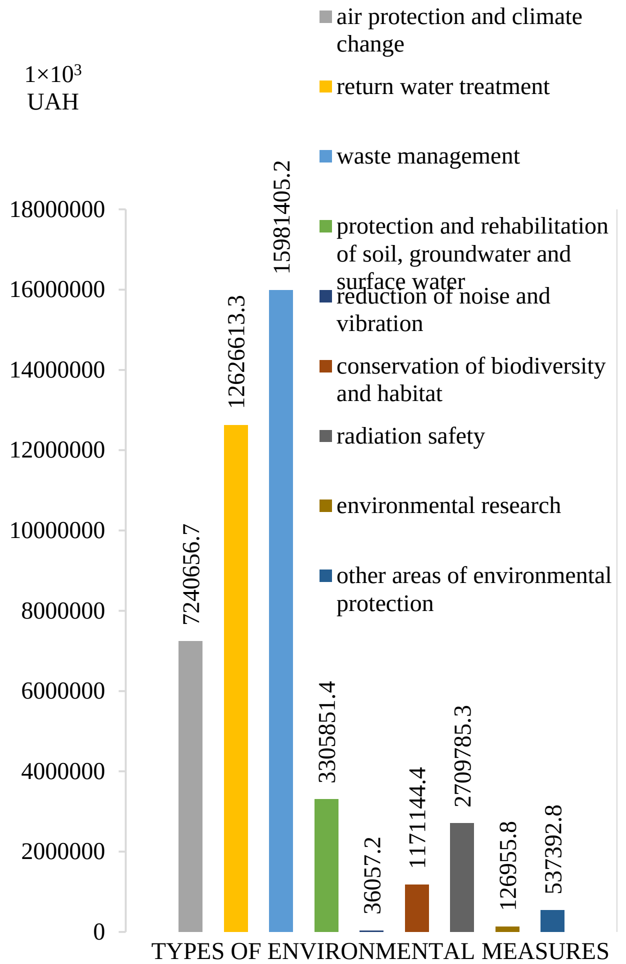

Fig. 3. Expenditures on environmental protection by types of environmental measures in Ukraine in 2019.

The graph shows us waste generation and management in Ukraine by years. We can see that we have extremely high level of total amount of waste accumulated during operation in specially designated places or facilities (waste disposal sites). From 2010 to 2013, the growth trend of this indicator is clearly visible, but in 2014 there was a sharp decline in its level. After which this indicator was stable within limits with the lowest indicator 12205388,8 $\times 10^3$ tons (in 2014) and the highest 12972428,5 $\times 10^3$ tons (in 2018). Also, as in situation with total amount of waste accumulated during operation in specially designated places or facilities (waste disposal sites) we can see that from 2010 to 2013 this indicator had been growing until 2014.

However, in 2014 it had a really sharp decreasing until 2016 after that it had fast growth in 2017 and a little decreasing in 2018. The line of the deleted to special places or objects has decreasing from 2010 to 2011 after that it has enough stable condition until 2013. The amount of deleted waste began gradually decrease until 2015 and then it was stable within limits until 2018. That limits were from maximal 169801,6 $\times 10^3$ tons (in 2017) and minimal 157379,3 $\times 10^3$ tons (in 2016). As we can see data about utilized waste is almost on the same level for each year but also a barely noticeable decrease from 2013 to 2016 in the amount of utilized waste. The maximum value of this indicator is 153687,4 $\times 10^3$ in 2011 and minimal in 2016 is 84630,3 $\times 10^3$ tons.

Summarizing this information, we can tell that the indicator of waste generation is regular higher than the indicator of utilized, deleted and burned wastes.

Thanks to this bar chart, we can consider the amount of expenditures on environmental protection by types of environmental measures in Ukraine in 2019. The total amount of these expenditures is 43735862,1 $\times 10^3$ hryvnias. In general, there are following types of environmental measures: air protection and climate change, air protection and climate change, return water treatment, waste management, protection and rehabilitation of soil, groundwater and surface water, reduction of noise and vibration, conservation of biodiversity and habitat, radiation safety, environmental research and other areas of environmental protection. The largest amount of expenditures compared to others are: waste management, return water treatment, air protection and climate change. Waste management is the biggest and takes the first place in the bar chart with indicator 15981405,2 $\times 10^3$ hryvnias. The second place belongs to return water treatment which is 12626613,3 $\times 10^3$ hryvnias. On the third place are air protection and climate change with indicator on level of 7240656,7 $\times 10^3$ hryvnias. Noise and vibration reduction are the lowest and least influential in the chart and takes only 36057,2 $\times 10^3$ hryvnias. It should also be noted that in comparison with all these indicators environmental research also has a fairly low mark of 126955,8 $\times 10^3$ hryvnias, which is very negative because such researches will help reduce the cost of all other types of environmental measures.

From this bar chart, it is seen that expenditures for waste management is occupied the largest share of total expenditures on environmental measures, and this is a positive trend in waste management at the state level in Ukraine. Worth remembering, new waste management goals require significant changes in the waste management system structure which introduces new problems and one of them is an increase in the costs for the system users (citizens) [14].

The system of general scientific and special, empirical and theoretical research methods is used in the work. In particular, the following methods were used: analysis-synthesis; explanation; formalization; generalization; comparison; deduction, induction; grouping, graphic, systematization etc. In addition, the analogy method was used to consider the existing systems of waste management in the European Union and Ukraine in order to shed light on problematic issues in garbage management in Ukraine.

3 Results

In this paper for increasing the efficiency of waste management, it is offered organizational solutions for household waste management for the Ukrainian government.

When organizing a system of household waste management, we must remember the interconnectedness and responsibility of the government (authorities of different levels of government), business entities and citizens. Only the coordinated interaction and understanding of these subjects of household waste management will allow in the near future to get an effective system that takes into account all the requirements of the present, and sustainable development, and the needs of future generations.

Therefore, we propose to pay special attention to the prevention of household waste management by raising the level of public awareness through such organizational measures that should be implemented at different levels of government in the country and among businesses and citizens (shown in Table 2).

Such measures will help to increase the level of waste management culture among the population. It should be noted that the level of education of the population in matters of household waste management directly depends on the state initiative and active public position of each citizen.

4 Discussion

The problem this article aims to solve in the need to decide the critical situation that has developed with the formation accumulation, storage, processing, utilization and disposal of waste and is characterized by the further development of environmental threats.

Such circumstances lead to a deepening environmental crisis and aggravation of the socio-economic situation in society and necessitates reform and development taking into account domestic and world experience of the entire law and economic system which is regulating the use of natural resources in general and waste management in particular.

The high level of waste generation and low rates of their use as secondary raw materials have led to the fact that in Ukraine every year in industry and utilities accumulate significant amounts of solid waste of which only a small part is used as secondary material resources, the rest end up in landfills.

Table 2. Recommendations about organization of prevention of household waste generation to Ukrainian government.

Sphere	Recommendation
Waste accumulation	every citizen should receive from the waste collection company a memo on the management of household waste with detailed instructions on their sorting and specially equipped places;
	place information on the rules for preparing waste for sorting on each special sorting tank;
	on specially equipped sites for sorting of household waste there should be clear indications about their types;
	carrying out explanatory work to the population directly in places of separate waste collection.
Education	conducting educational events in all schools, universities and crowded places (shopping malls, markets, recreation areas, etc.) about the sorting of household waste and ways to re-use, recycling;
	mandatory introduction of issues related to household waste management in schools and universities.
Production and consumer sphere	create conditions for anti-wastefulness promotions in supermarkets;
	gradually transfer the consumption of food and life by the population on the terms of sustainable nutrition / development, taking into account the regionality and seasonality of products and goods;
	due to the large amount of packaging in household waste to oblige each manufacturer to indicate on the packaging about its danger in case of getting into unsorted waste.
Digitalization	by the concept of "Country in a smartphone" to develop a waste application, aimed at informing the population of the settlement about the place, time and assortment of waste collection; activation of the eco-activity function nearby is possible.

The article provides recommendations on how best to organize the process of preventing the generation of household waste. Further research should be aimed at improving the efficiency of waste management such as: industrial, construction and repair waste, hazardous, agricultural waste, specific types of waste (packaging, waste electrical equipment, batteries and accumulators, medical waste).

5 Conclusions

The proposed organizational mechanism for household waste management should be the first practical step towards the implementation of an effective management system for all types of waste at the government and regional levels. This will create conditions for raising living standards by introducing a systematic approach to waste management, reducing waste generation and increasing its recycling and reuse.

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Zebrafish as a suitable model for studying the mode of action and harmfulness of organophosphate pesticides

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Abstract. The aim of the present work was to investigate the response of zebrafish to the effects of widely-used organophosphates roundup and chlorpyrifos and putative effectiveness of chlorella in terms of decreasing pesticides toxicity. Studied organophosphate pesticide roundup and chlorpyrifos in ecologically relevant concentrations, both individually and in a mixture, evoked the prominent suppression of catalase and total antioxidant capacity in the liver of *Danio rerio* which were consistent with higher levels of lipid peroxidation, protein carbonylation, and DNA strand break. Also, both roundup and chlorpyrifos provoked endocrine disorders registered as induction of vitellogenin and depletion of triiodothyronine as well as neurotoxicity appeared as inhibition of acetylcholinesterase after individual action or activation after combined action. The rate of apoptosis observed by caspase 3 activity was decreased, but in different manner depends on the exposure. The potency of toxicity followed the order: roundup > chlorpyrifos > roundup + chlorpyrifos (due to some kind of antagonistic action between chlorpyrifos and roundup in the binary mixture). Based on the results of CART analysis triiodothyronine, TBARS and caspase 3 were determined as the most significant indices for discrimination of the studied groups. The introduction of *Chlorella vulgaris* in the amount of about 100 thousand cells L^{-1} into the environment did not show a significant bioremediation effect on the harmful effect of studied pesticides for *Danio rerio*, which does not exclude the positive impact of algae on the functioning of the ecosystem as a whole and requires further comprehensive research.

1 Introduction

In case of complex pollution, inherent in natural fresh water reservoirs, the measurement of hydrochemical parameters, as well as the determination of the toxicant concentration in organisms may not be sufficient criteria for hazards assessment [1]. The issue is especially urgent in case of organic pollutants, in particular pesticides, personal care products, etc., which are difficult to detect due to persistent chemical transformations. Also, due to key points of Program on Pesticides and Sustainable Pest Management OECD countries have been working together on methodological approach of the risks of individual pesticides evaluation more quickly and thoroughly (www.oecd.org).

The world population is predicted to rise to 9.7 billion by 2050, which is 30% more than in 2017. Increasing population requires an increase in food resources, 80% of which, according to US Food and Agriculture Organization expectations, will be provided by expansion of agricultural land area, and thus by growing use of chemicals for crops treatment (https://www.who.int/). Pesticides are extremely important in the agrochemical sector and their global production is growing by 11% annually, from 0.2 million tons in 1950 to more than 5 million tons in 2000 (FAO, 2017). As of 2019, Ukraine ranks 6th in the world in terms of pesticide use (https://www.worldometers.info/food-agriculture/pesticides-by-country/). Due to their cumulative properties and long half-live (e.g. 45-60 days for roundup) most pesticides circulate in ecosystems and can be accumulated in non-target organisms and be included in food chains, showing signs of toxicity [2]. Following primary effect, the pesticides' residuals which remain in the environment, are able to exert long-term harmful effects for physiological and biochemical systems of non-target animals. Nevertheless, promotion of green growth strategies and action plan for sustainable use of pesticides that contributes to further risk reduction all over the world, studies conducted by US Environmental Protection Agency showed the presence of micromolar amounts of atrazine and roundup in about 30% of 154 analysed river water samples (https://toxics.usgs.gov/highlights/glyphosate02.html). Moreover, roundup exists in rivers (0.1-0.7 mg/l), sediments (0.0-4.9 mg/kg) and soil (0.5-4.3 mg/kg), sometimes even at concentrations close to toxic [3].

Take into account abovementioned huge amount of pesticides that are using, a promising technology for reducing the risk of chemical pollution of water reservoirs is urgently needed [4]. It is known that microalgae can reduce the level of water and soil pollution by adsorption, accumulation and metabolism of pesticides up to safe levels or their transformation into less harmful or harmless compounds and substances [5]. As an example, unicellular green algae *Chlamydomonas mexicana*,

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Micractinium reisseri, *Scenedesmus obliquus* and *Chlorella vulgaris* managed to decrease in residual concentrations of atrazine in the environment after 14 days of co-treatment [6].

Therefore, the aim of our work was to investigate the response of zebrafish to the effects of widely-used organophosphates roundup and chlorpyrifos and putative effectiveness of chlorella in terms of decreasing pesticides toxicity. We suggest to use the cyprinid fish *Danio rerio*, as a conventional biological model for mechanistic and toxicological studies. Zebrafish demonstrate universal to vertebrates' responses to stress and toxicants, which make these organisms important in extrapolating the results for assessment of the biosafety of human environment. The state of the body was assessed by the indicators of stress and toxicity validated in our previous studies [7-9]. In particular, the oxidative stress block included catalase activity, total antioxidant capacity, lipid and protein peroxidation. The rate of cytotoxicity was determined by DNA strand breaks, acetylcholinesterase (neurotoxicity), vitellogenin-like proteins (endocrine disorders).

2 Materials and methods

2.1 Animal collection and exposures

A toxicity of pesticides was evaluated on the adult zebrafish. Experiments were followed the rules of laboratory animal welfare and were approved by the animal ethics committee of Ternopil V. Hnatiuk National Pedagogical University (No. 2; 11 June 2020). The experiment was conducted according to the National and International animal protection policy. The zebrafish (3.4 ± 0.4 cm and 1.5 ± 0.2 g) used in this study were purchased from the local supplier. Zebrafish were maintained in aquarium tanks with 12 h/12 h light/dark cycle. The fish were fed with commercial food (Aquarius, Kharkiv, Ukraine) daily and water was changed once every three days. The mean values of selected hydrochemical parameters were: temperature 18±0.5ºC, dissolve oxygen around 8.1 $mg \cdot L^{-1}$ (7.9÷8.3 $mg \cdot L^{-1}$), pH 7.6±0.3.

Fish were divided into three experimental groups (30 fish each) and a control group which treated by any of studied pesticides or their combination. Meanwhile, experimental fish were exposed to roundup (R, 15 $\mu g \cdot L^{-1}$), chlorpyrifos (ClP, 0.1 $\mu g \cdot L^{-1}$), and their mixture (R+ClP, 15 $\mu g \cdot L^{-1}$+0.1 $\mu g \cdot L^{-1}$) for 14 days at 20 °C. All exposures were used in the environmentally relevant concentrations. The fish were randomly distributed into 10 L glass aquaria, 15 specimens in aquarium. The trial was duplicated. All studied groups of *Danio rerio* were treated by *Chlorella vulgaris* suspension (100 000 $cells \cdot L^{-1}$) [10]. During the experimental procedure no fish mortality was registered. Also, electrical conductivity, hardness, chloride and oxidizability were analyzed by standard methods and didn't exceed permitted value for fresh- and tap-water.

When the exposure ended, the animals were killed and liver and brain were immediately dissected on ice.

2.2 Oxidative stress assay

Catalase (CAT) activity was determined in the supernatant of liver tissue homogenate (1:10 w:v) by following the decrease in hydrogen peroxide at 240 nm [11]. CAT activity was calculated using the extinction coefficient, $\varepsilon = 40\ M^{-1}\ cm^{-1}$, and referred to the soluble protein. The free radical scavenging capacity of the liver tissue homogenate (1:10 w:v), calculated as percentage inhibition of $ABTS^{+}$, was equated against a Trolox standard curve [12]. Lipid peroxidation was determined in the 10% liver tissue homogenate by the production of TBA-reactive substances (TBARS) as described in [13] at 532 nm. A molar extinction coefficient of $1.56 \cdot 10^{5}\ M^{-1}\ cm^{-1}$ was used. The protein oxidation by the protein carbonyls (PC) was evaluated in the trichloroacetic acid-treated 10% liver homogenate using 2,4-dinitrophenylhydrazine at 370 nm [14]. The protein carbonyls amount was calculated with $\varepsilon_{mM} = 2.2 \cdot 104\ M^{-1}\ cm^{-1}$. Data were expressed as μmol $PC \cdot g^{-1}$ fresh weight (FW).

2.3 Assays of cytotoxicity and apoptotic activities

DNA fragmentation was assessed by the levels of protein-free DNA strand breaks in the (1:10 w:v) liver tissue homogenate in 50 mM Tris-EDTA buffer, pH 8.0 which contains 0.5% sodium dodecyl sulphate (SDS) by the alkaline DNA precipitation assay using Hoescht 33342 dye [15]. Probe fluorescence signal was detected at Ex/Em of 360/450 nm.

For the characteristics of apoptosis, activities of both cytosolic and lysosomal proteases were detected. The activity of an apoptosis executor caspase-3 was assayed at 405 nm ($\varepsilon_{mM} = 10.5\ mM^{-1} \cdot cm^{-1}$) [8, 16].

Acetylcholinesterase (AChE) activity was spectrophotometrically determined in the supernatant of brain tissue homogenate (1:10 w:v) as an increase in optical density of the sample measured at 412 nm [17] with acetylthiocholine applied as a substrate.

Vitellogenin-like proteins were estimated as the alkali-labile phosphate level in blood plasma as described in [18]. The phosphomolybdenum assay was applied to determine the level of free phosphates.

The blood serum triiodothyronine concentration was measured with diagnostic ELISA kit using the 96-well-plate solid phase competitive system (Sigma-Aldrich, USA) according to the manufacturer's instructions. The absorbance was measured at 450 nm in an ELISA reader (Biorad Microplate Reader, USA).

2.4 Statistical analysis

The data are presented as means ± standard error (SE). The normality of data were approved by Kolmogorov-Smirnoff test and, if possible, were normalized the by Box-Cox transforming method. To the data following a non-normal distribution, non-parametric tests was employed. The P-value <0.05 was considered significant.

All statistical operations were performed using Statistica v. 12.0 and Excel 2016.

3 Results and discussion

The antioxidant parameters namely total antioxidant capacity and catalase activity in *Danio rerio* liver were significantly decreased after exposure by organophosphate pesticides when compared with the correspondent control (Fig. 1). Meanwhile, studied chemicals provoked an increase in lipid peroxidation and protein carbonylation level with the most prominent changes found in the R-group. No significant differences were shown in fish responses to individual and combine action of organophosphates.

Roundup and chlorpyrifos caused an increase in DNA fragmentation and caspase 3 activity in hepatocytes and a decrease in AChE activity in fish brain when compared with the control animals (Fig. 2). The cytotoxic signs after combined action of pesticides were differed from individual one. It is highly likely that there was antagonistic relation while combined action. The generally higher level of vitellogenin in male specimen particularly in ClP-group and T3 concentration indicates an endocrine disrupting effect of media.

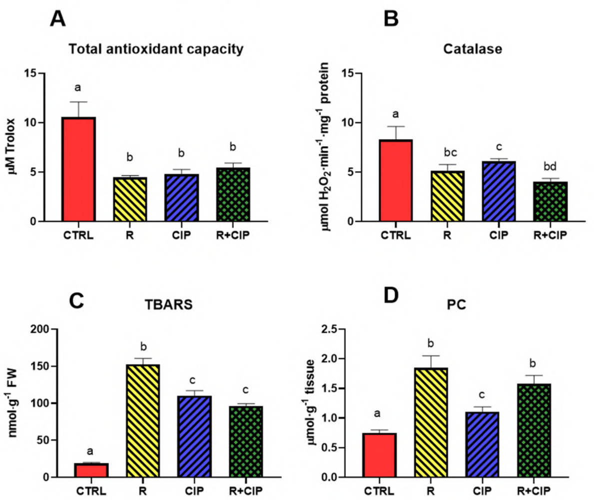

Fig. 1. Oxidative stress parameters in the liver of *Danio rerio* after the effect of roundup (R), chlorpyrifos (ClP) and their combination along with presence of Chlorella vulgaris in the media. Data for A: Total antioxidant capacity, B: Catalase, C: TBARS, D: protein carbonyls, are present as means ± SD (n = 8). The columns that share the same letters indicate the values that are not significantly different (P > 0.05).

Classification tree was built using CART analysis of all studied biological parameters identified 3 splits and 4 terminal nodes (Fig. 3A). Overall, the CART analysis supports an important role of the triiodothyronine in the response and adaptation of animals to deteriorated effects of pesticides even in low environmental realistic concentration. TBARS and caspase 3 activity also pertained to the most important parameters discriminating the experimental groups. No classification mismatch was observed between the experimental groups.

The discriminant analysis helped us to find out the similarity of animals responses to different pesticides ($F_{27,35} = 17.2$, $p < 0{,}0001$). Fish had affected by organophosphorus-containing pesticides reacted similarly. Danio treated by the combination of two pesticides were alike in the response to individual roundup action. The most prominent parameters for discrimination of studied groups were quite close to that selected by CART analysis and included TBARS, T3 and Vtg.

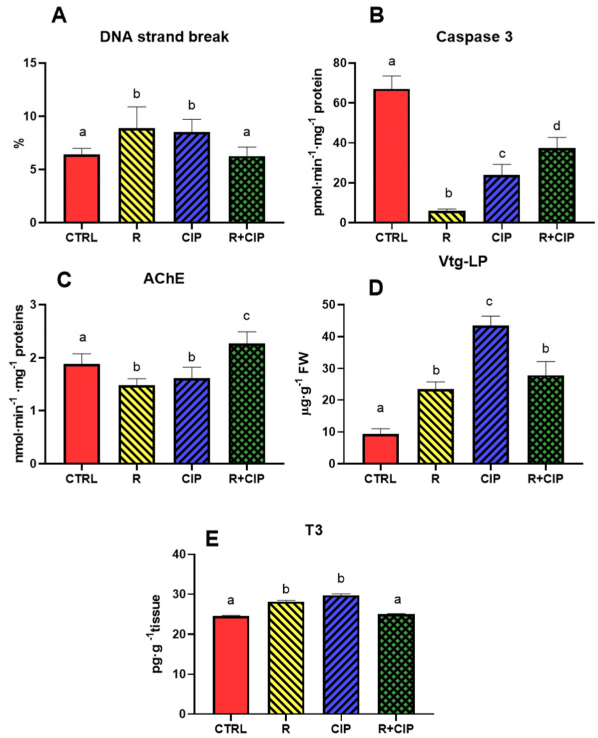

Fig. 2. Biomarkers of cytotoxicity in the liver and brain of *Danio rerio* after the effect of roundup (R), chlorpyrifos (ClP) and their combination along with presence of *Chlorella vulgaris* in the media. Data for A: DNA strand break, B: caspase 3 activity, C: acetyl cholinesterase activity; D: vitellogenin-like proteins; E: triiodothyronine are presented as means ± SD (n = 8).

Organophosphates pertain to the most usage pesticides in the world, particularly glyphosate which takes the first place according to the amount of sale [19]. However, numerous signs of acute toxicity in wide range of non-targets have been reported. When neurotoxicity of organophosphates is well-defined, endocrine disruption is being worth noting. In particular, acute long-term (21 days) exposure of zebrafish at 10 mg·L^{-1} Roundup or glyphosate induced changes in gene expression of *cyp19a1* and *esr1* in the ovary and *hsd3b2*, *cat*, and *sod1* in the testis [20]. Also, 5 mg·L^{-1} glyphosate exposure in Japanese medaka provoked alterations of neuroendocrine-related genes *kiss1* and *kiss2* in female brain in addition to reproductive, developmental, and epigenetic modifications [21]. Compatible effect was also shown for chlorpyrifos after subacute treatment of *Danio* [22]. In present investigations we have proved that both studied organophosphate pesticides namely roundup and chlorpyrifos in very environmentally realistic concentrations interfere with steroid hormones' biosynthetic pathway and have prominent endocrine disruption effect on adult *Danio rerio*. Our conclusion doesn't correspond to EPA statement that chlorpyrifos poses no endocrine disruption risks and is recommended no further testing (https://www.epa.gov/sites/production/files/2015-06/documents/chlorpyrifos-059101_2015-06-29_txr0057162.pdf).

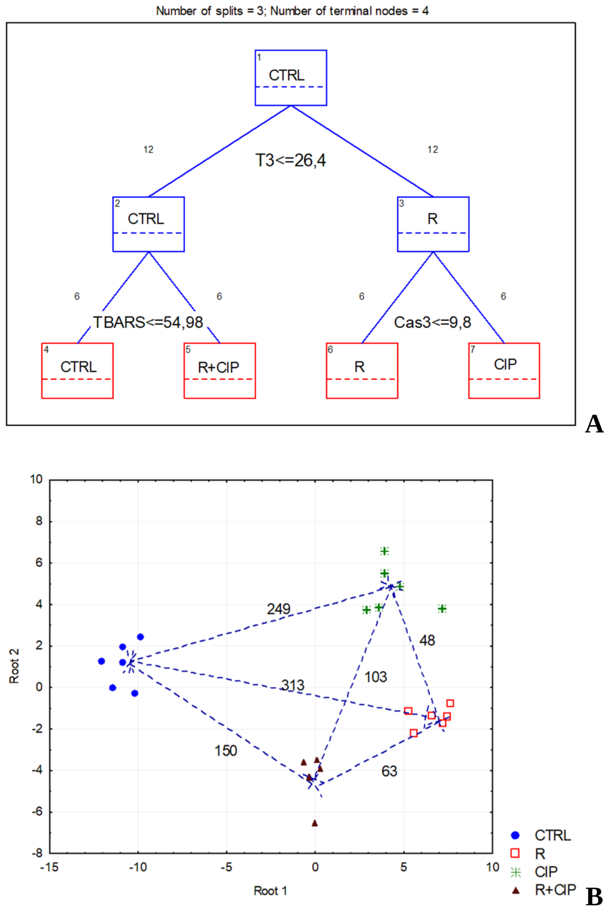

Fig. 3. Classification and regression tree analysis (CART) (A) and discriminant analysis (B) biplots integrating all biological traits of zebrafish *Danio rerio* from different pesticide treated groups.

As we have shown, roundup and chlorpyrifos affect not only steroidal hormones pathways but also hypothalamus-pituitary-thyroid axis. Besides that, triiodothyronine includes into set of most important parameters that distinguish studied groups in CART analysis (Fig. 3A). In fish, thyroid hormones are involved in the regulation of metabolic pathways, somatic growth, skeletal development, reproduction, and behavior [23] and some organophosphates have been reported to alter the thyroid system. As an example, malathion provoked a decrease in thyrotropin synthesis and secretion, reduction of thyroxine and triiodothyronine levels, decline the plasma T_3 levels and T_3/T_4 ratio which caused serious disrupting effects in developmental and growth patterns, behaviors, fitness and survival in catfish and *Senegalese sole* [24, 25]. It might be that organophosphate pesticide not only blocks the T_4 secretion, but also inhibits the thyroidal conversion of T_4 into T_3 [26, 27]. This suggestion is corroborated by some of immunohistochemical studies of thyroid follicles and T_3 and T_4 immunoreactivities in colloid, plasma, and in follicle-surrounding epithelial cells [26].

As was expected AChE activity significantly reduced in fish brain after individual exposure to roundup and chlorpyrifos. Our results keep in line with previous reports devoted to organophosphate pesticide action on fish species including cyprinids. In particular, profenofos exposure (60 μg·L^{-1}) during 60 days caused prominent AChE inhibition in the brain of *Labeo rohita* [28]. A sublethal exposure of *Astyanax aeneus* (Characidae) and stinging catfish *Heteropneustes fossilis* to ethoprophos and Envoy 50 SC correspondingly caused a significant reduction of brain cholinesterase activity [29, 30]. However, in the present study the inhibitory effect of studied organophosphate was appeared in case of chronic exposure rather than acute exposure. Indeed, harmful effects related to the mode of action of the pesticides can be triggered in environmental realistic concentrations that are in times lower than lethal ones.

Despite the inhibitory effect of roundup and chlorpyrifos on AChE activity after their individual action, the combine exposure caused opposite effect, an increase in the enzyme activity. Moreover, this apparent increase in AChE activity was in a good correlation with increasing of caspase 3 activity (r=0.72, p<0.01), key enzyme of apoptosis when compared with individual pesticide action. Some would prove that AChE might be involve in the promotion of various types of apoptosis [31] and very 55 kDa AChE protein induced during apoptosis [32]. Thus, it is plausible that AChE mediates of apoptosis in zebrafish, but further studies are needed to confirm this hypothesis.

A lot of pollutants provoke oxidative stress in animals, including cyprinid fish, which is considered to be one of the main mechanisms of non-specific effects of pollutants [2, 8, 33]. It has been shown that organophosphate pesticides stimulate the generation of ROS and cause lipid peroxidation and/or protein carbonylation. In particular, in neotropical fish *Prochilodus lineatus* after acute exposure (6, 24 and 96 h) to 10 mg·L^{-1} of Roundup [34], in *R. quelen* after 96 h of exposure to 0.2 and 0.4 mg·L^{-1} of Roundup [35], and in *Channa punctatus* [36] after the effects of three sublethal concentrations 3.25 - 6.51 mg·L^{-1} of Roundup the concentration of TBARS in liver and gills tissue was higher than in the correspondent control. Our results support previous findings and reinforce the idea even in low environmental realistic concentration. Moreover, prominent oxidative damage has been in a good agreement with oppression of antioxidant defense estimated by a decrease in activity of catalase and total antioxidant capacity. This phenomenon points out clearly an increased pro-oxidant status in affected fish. These data corroborate evidence that oxidative stress has been arising after glyphosate and chlorpyrifos attenuate detoxification system of animals and potentially follow on neurotoxicity, cardiovascular toxicity, and reproductive toxicity [37].

In general, an increase in TBARS and PC was accompanied by increase of DNA damage in liver of zebrafish, except of R+ClP-group. Thus, it is highly likely that roundup and chlorpyrifos would have caused alterations in DNA integrity of *Danio rerio*. Our data corroborate with previously reported pesticide-mediated DNA damage in different fish species [2, 8]. However, when fish were exposed by mix of organophosphate pesticides unexpected DNA strand break level in line with control was disclosed. Commonly, animals are fitted out with independent cascades of enzymes to alleviate oxidative stress and repair damaged cells produced as a response to exposure to xenobiotics. Meanwhile the combined action of pesticides obviously was powerful enough to trigger apoptosis for eliminating damaged cells.

Discriminant analysis revealed that the response of *Danio* to individual action of chlorpyrifos and roundup was quite similar, because they belong to the same class of pesticides (Fig. 3B). When we compared the effects of organophosphate pesticides in terms of their individual and combined action, no significant signs of additive effect on oxidative stress parameters were disclosed. In the same time, cytotoxic parameters were differed in case of individual and combined pesticide treatment, but no clear dependence was depicted. This however, may be attributed to the antagonistic action of chlorpyrifos and roundup in the mixture. Some would say that the effects of binary mixtures of pesticides are variable and sometimes contradictory [38]. It has been shown the significant antagonistic effects on mortality ratios in *Cnesterodon decemmaculatus* treated by Glifoglex and Glextrin formulations. These authors demonstrated a strong inhibition of Glextrin toxicity, almost completely overridden by Glifoglex formulation. All of these allow us to deduct that it might be some kind of antagonistic action between chlorpyrifos and roundup in the binary mixture, that suppress the predictable effects of the individual compounds.

It has been shown that there is a synergic relation between green algae as a low-cost biosorption and filter material for removal of heavy metals [39]. Meanwhile, information related to organic pollutants including pesticides are controversial. In particular, there was no significant overall reduction of 37 different wild-used pesticides after short-term exposure (1 h). However, long-term exposure to growing cells of *C. vulgaris* significantly reduced the amount of pesticides in water [40]. On the other hand, *C. vulgaris* was exposed to organophosphate pesticides in subacute concentrations, has been reported the most sensitive from different species of diatom, cyanobacteria, and chlorophyta [41]. Obviously, it might have been a reason that in the present study we haven't shown positive bioremediation effect of *Ch. vulgaris* on roundup and chlorpyrifos toxicity to *Danio*. It points to uncertainty of the ratio of commonly used organophosphate pesticides and algae in water media and emphasize the importance of further studies.

4 Conclusion

Thus, the action of ecologically relevant concentrations of roundup and chlorpyrifos, both individually and in a mixture, caused the suppression of antioxidant defense systems in striped zebrafish, consistent with higher levels of lipid peroxidation, protein carbonylation, and DNA damage. Also, exposures provoked endocrine disruptions registered as expression of vitellogenin and depletion of triiodothyronine and neurotoxicity. It might be some kind of antagonistic interaction between chlorpyrifos and roundup when they are in the same media. In general, observed changes in cellular and molecular responses varied in magnitude and frequency, and in some cases suggested causal relationships among studied indices. The introduction of *Chlorella vulgaris* in the amount of about 100 thousand cells $\cdot L^{-1}$ into the environment did not show a significant bioremediation effect on the harmful effect of studied herbicides for *Danio rerio*, which does not exclude the positive impact of algae on the functioning of the ecosystem as a whole and requires further comprehensive research. Thus, runoff from agricultural lands into the surface water that contains even background concentrations of organophosphate herbicides may pose a risk to non-target organisms, and the use of algae in detoxification processes requires more detailed hydrobiological analysis in favor of finding a prospective approach for the removal of pesticides from freshwater bodies as an efficient tool for sustainable development and pollution control [42].

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Trade and economic relations between Georgia and the Czech Republic: challenges in export and import of agri-food products

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Abstract. The article evaluates the importance of trade and economic relations between countries in economic growth. At a time of globalization has been identified the existing problems of the international division of labor for Georgia. Substantiated that the development of trade and economic relations is an important challenge in the condition of a low level of food provision for the population of Georgia. From this perspective, it is relevant to analyse the export-import of agriproducts with those European countries that have similar resource potential, geographic proximity, socio-economic and political characteristics to Georgia, among of which is the Czech Republic. Based on the theories of international trade, in order to assess the trade and economic potential between Georgia and the Czech Republic and to determine trends of development, has been studied main indicators of the above-mentioned countries. Comparative analysis of the data showed that quantitative indexes are similar between these two countries, while the qualitative data in the Czech Republic is higher as compared to Georgia. The paper discusses the agriculture of Georgia as one of the main sources of economic growth, therefore, to increase the resource potential of the sector needs to develop foreign trade and economic relations with the agriproducts. Based on analysis of data on export-import of agriproducts between Georgia and the Czech Republic, has been concluded that the trade balance between the countries is variable and trade and economic relations are at the development stage. The main challenge in agriproduct trade between the countries is a low level of import-export diversification of agriproducts. At the same time, it is substantiated, that the cooperation with the Czech Republic perspective for Georgia not only in trade but also in the sphere of investments and modern technologies. The article argues the need for an optimal ratio of exports and imports in the development of trade and economic relations. Through the empirical studies the current challenges of export and import of agri-food products between Georgia and the Czech Republic have been identified; export-import ratios have been analysed by product type; and the ways to improve trade and economic cooperation between the two countries have been outlined. Promising areas of economic relations and export-import between Georgia and the Czech Republic have been developed.

1 Problem statement

Today, almost every country in the world is involved in the international division of labour; otherwise it would be impossible for a country to provide its own population with agri-food products. An important challenge for any country is the development of trade and economic relations. However, it should be borne in mind that in the context of the international division of labour, a country always needs to import resources, consumer goods and services, and the main source of covering import costs should be export earnings. Export earnings are the main sources for covering import costs in order to maintain the food security [1].

Nowadays, the development of trade and economic relations between the countries is taking place against the background of irreversible globalization processes, which has a certain impact on the modernization of the political and economic environment of Georgia. In view of the above, it is necessary to take into account the experience of economic and political transformation of the leading industrialized countries.

2 Research methods

In the process of research has been used various methods of research, particularly:

- Based on bibliographic and empirical research has been analyzed scientific papers of Georgian and foreign researchers, publications of the National Statistics Office of Georgia, Policy documents of the Parliament of Georgia, analytical reports, etc.;
- Based on comparative method has been determined similarities and differences between Georgia and the Czech Republic in terms of social and economic and other indexes;

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- Analysis, synthesis, induction, and other methods allowed to select and group the data, identify the trends, similarities, and differences;
- Based on statistical methods has been calculated average export and other indexes of agriproducts;
- Based on the grouping method has been determined export material groups by Georgia and the Czech Republic;
- Based on interviews with the experts of the agriproduct sphere has been assessed and refined quantitative and qualitative indexes;
- Based on the household research database has been defined the order between analytical and statistical assessments;
- Based on the household research database, statistical data, materials of the Ministry of Environmental Protection and Agriculture of Georgia, data from ministries of economic profile has been defined the order between analytical and statistical assessments.

3 Background

Production of agro-food products in Georgia is a traditional field; however, a particularly difficult social background among economic problems is related to food security, rising food prices, inflation, negative trade balance between exports and imports of agri-food products [2]. Self-sufficiency in local agri-food products in Georgia is low. According to the data for 2018, the self-sufficiency ratio in wheat is especially low – 15%, corn – 71%, vegetables – 59%, potatoes – 102%, grapes – 152%, meat – 52% (beef – 77%, pork – 45%, poultry – 34%), eggs – 99%, milk and dairy products – 81% [3].

In Georgia, the share of food exports in total exports is low. This figure averaged 9% in 2018. For the first three quarters of 2019, the same indicator is 7.5%, which is lower than the corresponding indicator for the previous year [3].

In Georgia, the share of household spending on food in total consumer spending is high. In 2018, this figure was 42% [3]. Also, a comparative analysis of the recent data revealed that price indexes of food and non-alcoholic beverage are on the upward trend. Prices for most of the food products also went up [3]. As of 2018, the share of household monetary income from the sale of agricultural products was 5.5%, while in 2015 this indicator was 7.1%. Average monthly income also decreased – from GEL 68.5 (2015) to GEL 57.4 (2018) [3]. The poverty rate remains high in the country. The share of the population below the absolute poverty line was 21.9% in 2018 [3].

One of the important factors for improving the economic situation in Georgia and achieving food security is to search for the ways to increase export potential and develop trade and economic relations, especially with European countries. Development of trade and economic relations between Georgia and the leading countries of the world, including ensuring the optimal balance of exports and imports, will have a positive impact on the political and social situation of the countries, especially on the welfare of their population. In this regard, it is promising to share the experience of successful countries and identify opportunities for the development of trade and economic relations between countries. As noted above, it is especially important for Georgia to share European experience and identify current problems of export and import of agri-food products with a country with similar economic and political characteristics, as well as determine the prospects for the export potential of these products. The Czech Republic is included in the list of such countries; therefore the purpose of the study is to identify problems in the export and import of agri-food products between the two countries based on the study of trade and economic relations between Georgia and the Czech Republic and make recommendations on development prospects.

4 Data and empirical analysis

Comparison, analysis, induction and other methods have been used in the research process. The export potential has been estimated using the respective models by commodity groups and by the countries (Georgia and the Czech Republic).

Georgia belongs to a number of small countries. A study by A. Smith [4] identified the importance of the size of a country for its economic development. Countries with large areas, due to the great potential of diverse climatic and natural resources are more capable to secure their own economic self-sufficiency than small ones. According to the same theory, a country should manufacture the goods production of which will cost less compared to other countries, and import the goods production costs of which are higher [4]. D. Ricardo's theory, according to which all countries can benefit from international trade due to differences in production costs, should also be considered. According to David Ricardo, personal interests merge with public interests, and exchange turns all nations / states of the civilized world into one universal society. The arguments put forward are to some extent the basis of the modern theory of trade, and therefore they are so interesting today, even in the conditions of the global economy [5].

The role of trade and economic relations between countries is important to enhance economic efficiency. However, when developing foreign economic relations, it is necessary to take into account not only the costs of export and import, but also the consumer properties of the products purchased. In addition, it is necessary to compare the level of labour costs to the production costs of the exported product with that can be replaced by import.

Export promotion and import substitution [6] are considered as an alternative to the development of international trade and the choice between them depends on the level of development of countries [7], their natural resource potential, the demand and supply situation, the level of development of food markets [8].

The export structure of a country depends largely on the demand in the importing countries. First of all, for the export of products it is necessary to saturate the domestic market, and for the successful sale of the product the structure of demand should be similar to the structure of demand in the exporting country [9]. Modern approaches to international trade theory are based on the "economy of scale". Such conceptual approaches are especially important for Georgia.

Almost every country in the world is engaged in international trade. In line with modern challenges and processes in the international division of labour, countries are in constant need to import resources and consumer products. Georgia, as a participant in the above processes, should look for ways to increase its resource potential, especially in the agri-food sector, where imports are more than three times higher than exports, and the country has many socio-economic and environmental problems [10-13].

As the globalization of the world economy deepens, the effectiveness of international trade is largely determined by the geographical proximity to European countries and the further development of historical and economic cooperation with them [14-15]. Based on theories of international trade, to assess the effectiveness of foreign economic relations between countries and identify current trends in the development of international trade, the current potential and future opportunities of exporting agri-food products between Georgia and the Czech Republic have been analyzed. To identify effective trade and economic potential, the key indicators of the two countries were initially evaluated (Table 1).

Table 1. Key Indicators of Georgia and the Czech Republic (based on [3]).

	Georgia	**The Czech Republic**
Area	69,700 km^2	78,866 km^2
Population	3.7 million people	10.6 million people
Density	58 people/km^2	134 people/km^2
Economic Growth	4.8%	4.3%
GDP Total	$15.086 billion	$215.735 billion
GDP per capita	$4,046.8	$20,368.0
Area of agricultural land in common land fund of the country	49.0%	55.0%
Share of agriculture in GDP	7.7%	2.2%
Share of those employed in agriculture	47.0%	3.0%
Unemployment rate	13.9%	2.5%
Investment in agriculture (of total investment)	0.6%	4.3%
Inflation rate as of 2017	6.0%	2.4%
Added value created in agricultural business	Less than 10.0%	2.2%
Expenditure on education / overall European rate 5-12% /	2.5%	4.0%

Georgia and the Czech Republic are small countries by territory, the area of the Czech Republic is only 1.1 times the size of Georgia, and its population is 2.9 times larger. Both countries are also almost identical in terms of the share of agricultural land in the total land resources: in Georgia this figure is 49%, in the Czech Republic – 55%. The Czech Republic and Georgia show similar economic growth rates: Georgia's growth rate is 4.8%, the Czech Republic's – 4.3%. The opposite situation exists for the key economic indicator – gross domestic product (GDP). GDP of Georgia is 15,086 billion US dollars, of the Czech Republic – 215,735 billion US dollars. GDP per capita are 4 046.8 USD and 20 368 USD, respectively. Thus, the volume of GDP in the Czech Republic is 14 times, and GDP per capita is 5 times higher than in Georgia.

In the Czech Republic, the share of people employed in agriculture is quite small (3%), but the volume of manufactured goods significantly exceeds the respective figure of Georgia. In Georgia, almost half (41.3%) [3] of the population is employed in this sector, accounting for only 7.7% of GDP.

Indicators of investment in agriculture also differ in the two countries. If the volume of investments in agriculture in Georgia is 0.6% of the total investments, then in the Czech Republic it is 4.3%.

Unlike the Czech Republic, Georgia has a high unemployment rate, but it should also be taken into account that the unemployment rate in Georgia is reduced at the expense of the self-employed people. In fact, most of the self-employed people produce the products only to meet their own needs. The latter is partially reflected in the added value created in agricultural business [17-18]. Spending on education in Georgia are also lower (2.5%) than in the Czech Republic (4.0%). In the Czech Republic, this indicator is close to the average European level of spending on education (5-12%).

Thus, the comparative analysis showed that there was a similarity in quantitative indicator between Georgia and the Czech Republic, while the qualitative indicators in the Czech Republic are higher than in Georgia. By developing trade and economic relations with the Czech Republic both countries will be able to enhance e the parameters of production of local agri-food products, increase the welfare of population, and through cooperation develop better access strategies to the European markets, etc.

In Georgia, agriculture is often considered as the main source for growing the country's economy; however, the results claim the opposite [11]. The sector's share in the Georgian economy is declining in dynamics. Moreover, the sector is low-productive, overall output volume is small and growth rates are quite low. In 2004 [12], the agricultural sector of Georgia produced goods worth GEL 1.9 billion, this figure increased to GEL 4.0 billion by 2018 [3], while the average growth rate in the country remaining low. Financing of the sector has increased since 2012, but, on the contrary, both sown area and livestock decreased. In 2017-2018, the annual decline of the sector was about 3% (see Figure 1) [3].

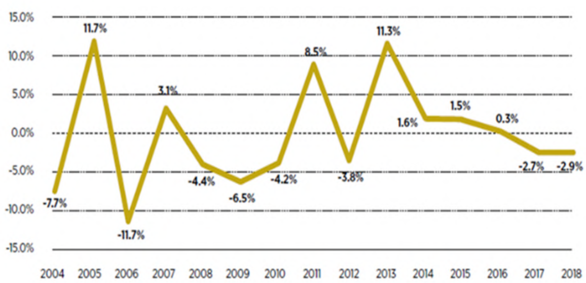

Fig. 1. Annual growth of agriculture in Georgia (%)
Source: National Statics Office of Georgia [3]

Under these conditions, export opportunities for agri-food products are obviously limited. As of 2018, most of the exports (41%) accounted for the CIS countries, with EU countries accounting for 28.3% [3].

The share of agri-food products in the structure of the largest export goods in Georgia is small (see figure 2) [3].

Fig. 2 .Share of agri-food products in exports in 2000-2018 (%). Source: National Statics Office of Georgia [3]

There are only hazelnuts, wines and spirits represented in the top ten export products. Structural changes have recently been made in the export of Georgian agri-food products, in particular, in 2017, hazelnut crop was significantly damaged, and for the first time in many years it fell out of the top five export products of Georgia.

As noted, the import rate of agri-food products is significantly higher than of export and this trend remains unchanged in dynamics (see figure 3) [17].

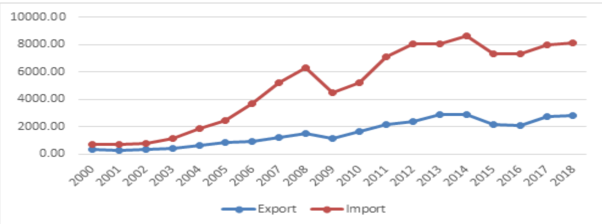

Fig. 3. Dynamics of Export and Import in Georgia in 2000-2018 (million US Dollars). Source: Ministry of Environmental Protection and Agriculture of Georgia

Georgia has a low level of export diversification, which is one of the main constraints in trade and economic relations between the countries. At the same time, the study of the dynamics of diversification of Georgian exports showed that it increased in 2011-2013. However, in recent years there is still a decreasing trend (see figure 4).

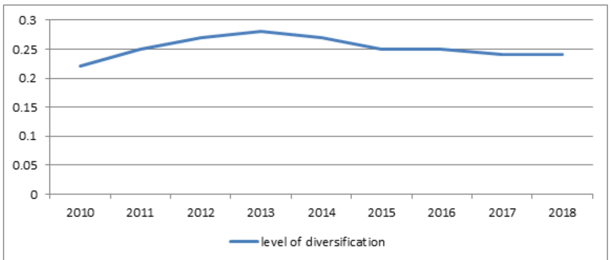

Fig. 4. Dynamics of Export and Import in Georgia in 2000-2018 (million US Dollars). Source: Ministry of Environmental Protection and Agriculture of Georgia [18]

An analysis of trade in agri-food products between Georgia and the Czech Republic showed that the share of agri-food products in the total exports of the Czech Republic in 2018 was 0.6%. According to the data for 2019, agricultural products worth 5.4 million US dollars were exported from Georgia to the Czech Republic. This indicator increased by 55% compared to the previous year, but it is lower than in 2015 and also lower than in 2017 (see figure 5) [25].

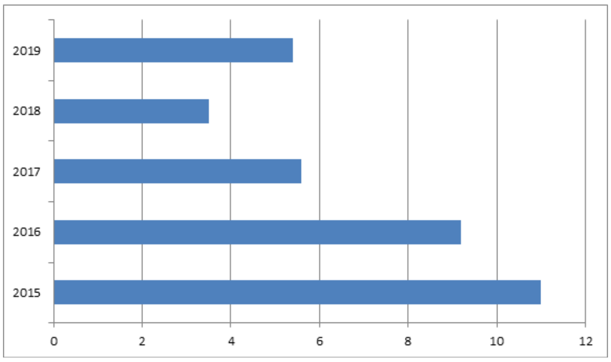

Fig. 5. Dynamics of Export of Georgian Agri-Food Products to the Czech Republic (million US Dollars). Source: Ministry of Environmental Protection and Agriculture of Georgia [18]

89% of exported products from Georgia to the Czech Republic are hazelnuts. In 2019, the export value of this product increased by 53% compared to the previous year. Thus, the main reason for the increase in the export of agri-food products from Georgia to the Czech Republic is the increase in the export of hazelnuts. In previous years, this indicator was characterized by a downward trend. It is also worth noting that in 2019, wine, spirits, fruit jams, dried fruits, soft carbonated drinks, etc. were also exported to the Czech Republic.

In 2019, exports of alcoholic beverages increased almost six fold compared to the previous year. In the export of wine and alcoholic beverages, the trend was slightly downward; in particular, in 2019 this figure was 8% higher than in the previous year. In contrast, in 2018, wine exports to the Czech Republic decreased by 65% compared to 2017, while exports of alcoholic beverages decreased by 62%.

In 2015-2019, import rates for agri-food products from the Czech Republic to Georgia are also of varying tendency (see figure 6).

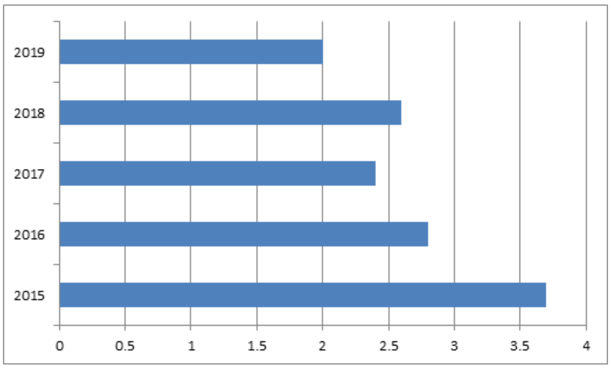

Fig. 6. Import of Czech agri-food products to Georgia [26]. Source: Ministry of Environmental Protection and Agriculture of Georgia

As of 2019, the Czech Republic accounts for 0.2% share in total agri-food imports. This year, agri-food products worth $ 2.0 million have been imported from the

Czech Republic to Georgia, which is $ 0.5 million less than the previous year. In general, in 2015-2019 the import rate is characterized by a decreasing trend.

Thus, trade and economic relations between Georgia and the Czech Republic are in the process of development, and the dynamics of the export-import balance in 2012-2019 fluctuates (see table 2).

Table 2. Georgia's external trade with the Czech Republic in the agri-food sector.

(thousand US Dollars)								
	2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Export	6,804	9,373	9,986	11,037	9,217	5,559	3,483	5,402
Import	1,808	2,366	4,652	3,664	2,799	2,373	2,580	2,048
Balance	**4,996**	**7,007**	**5,335**	**7,373**	**6,418**	**3,186**	**904**	**3,353**

Source: Compiled by the authors on an official data [3]

In 2019, the volume of export of Georgian agricultural and food products to the Czech Republic is higher compared to the previous year, but significantly lags behind the data of 2012-2016, for example, in 2012 the volume of exports amounted to 6.8 million US dollars, in 2013 – 9, 4 million US dollars, in 2014 – 9.98 million US dollars, in 2015 – 11.0 million US dollars, in 2016 – 9.3 million US dollars.

The dynamics of export and import volumes vary according to the types of agri-food products. The change in export volume is shown in figure 7.

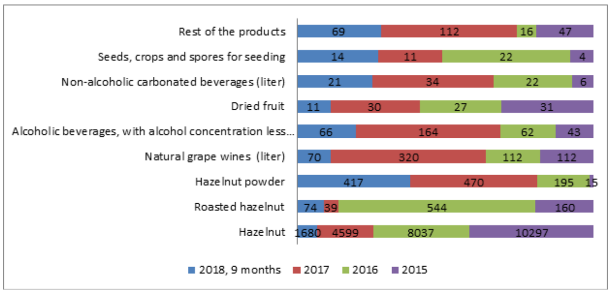

Fig. 7. Export to the Czech Republic by types of agri-food products (thousand US dollars). Source: Ministry of Environmental Protection and Agriculture of Georgia [18]

Hazelnuts predominate in the export of agri-food products (see figure 8).

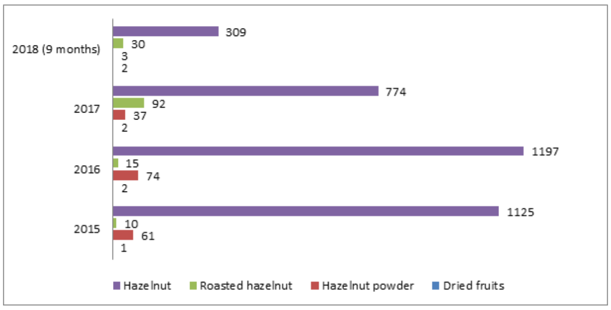

Fig. 8. Hazelnut export to the Czech Republic (tones). Source: Ministry of Environmental Protection and Agriculture of Georgia [18]

The largest share (60%) of top 25 hazelnut export markets of Georgia falls on European countries. The Czech Republic ranks third among the top five countries (Kazakhstan – 1,622 tonnes, Ukraine – 638 tonnes, Czech Republic – 343 tonnes, Slovakia – 274 tonnes, Germany – 256 tonnes) in terms of exports of hazelnut kernels from Georgia.

It should be borne in mind that the European market is characterized by high growth rates. Most of the imported hazelnut kernels in the countries of this region are processed, only a small part is sold in retail networks in the form of packages. Production costs in Europe have been rising lately, making it easier for European companies to purchase finished hazelnut products (e.g. roasted hazelnuts, skinned hazelnuts, diced hazelnuts, raw and roasted hazelnut powder and hazelnut paste) rather than importing hazelnuts directly.

In 2019, the export of hazelnuts to the Czech Republic amounted to 1238.6 tonnes, which is higher than in the previous year (688.9 tonnes in 2015, 794.0 in 2016, 931.9 in 2017, 1082.7 tonnes in 2018).

Various types of agri-food products are imported from the Czech Republic to Georgia: beer, sugar, non-alcoholic beverages, food additives, malt, etc. During the analyzed period, the volume of imports of food additives and beer decreased significantly. The volume of imports of these products to Georgia in 2019 compared to 2018 decreased by 17% and 20%, respectively. In addition, the volume of sugar imports in 2018 amounted to 132 000 US dollars, in 2016 – 1.1 million US dollars, and in 2019 sugar was not imported from the Czech Republic. Such a sharp decline in sugar import is the main reason for the decline in the value of imported agri-food products from the Czech Republic. Over the same period, imports of malt and non-alcoholic carbonated beverages increased, in particular, in 2019, compared to the previous year, the volume of imports of malt increased by 36%, and of non-alcoholic carbonated beverages – 12 times.

As of 2019, agri-food products worth 2.0 million USD are imported from the Czech Republic to Georgia, which is 0.2 million USD higher than in 2012, although lower by 2.6 million USD compared to 2014 (the highest volume of imports was recorded this year – 4.6 million dollars). An analysis of 2013-2016 showed that the volume of imports over this period showed a downward trend.

Different types of agri-food products are imported from the Czech Republic to Georgia (see figure 9, figure 10).

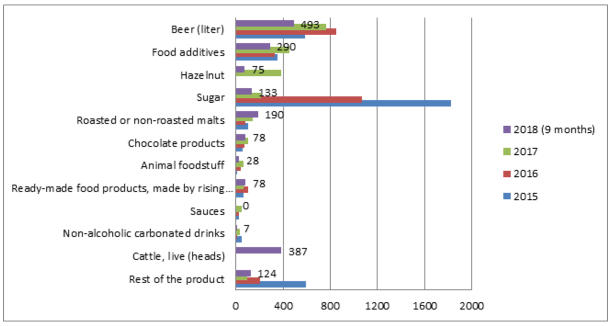

Fig. 9. Import from the Czech Republic by product types (thousand US dollars). Source: Ministry of Environmental Protection and Agriculture of Georgia [18]

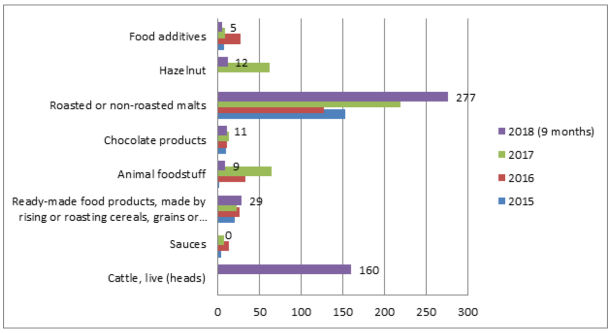

Fig. 10. Import from the Czech Republic by product types (thousand US dollars). Source: Ministry of Environmental Protection and Agriculture of Georgia [18]

5 Conclusion

Thus, the Czech Republic is one of the important partners of Georgia in terms of trade and economic relations. The doubling of relations between Georgia and the Czech Republic is actively discussed at the government level in Georgia. In this regard, Georgia's cooperation with the Czech Republic is promising not only in trade, but also in investment and modern technology. It is also important to diversify the export-import of agri-food products between the Czech Republic and Georgia, on the one hand, and transfer Czech production and modern technology to Georgia.

- Trade and economic relations between Georgia and the Czech Republic are in the process of development. It is expected that the assessments of the development trends of export and import of agri-food products will bring the economic ties between the countries to a qualitatively new level in the future.
- The markets of European countries, including the market of the Czech Republic, have been characterized by high growth rates in recent years. However, these markets are highly sensitive to price and quality. Prices formed on Georgian agri-food products will have a significant impact on export growth. In view of the above, it is necessary to study the factors affecting the value chain of agricultural products, as well as the pricing mechanism.
- The main food products exported from Georgia to the Czech Republic is hazelnut. Given the fact that the confectionery industry began to replace this ingredient with cheaper hazelnuts and raw materials, as well as processed products found in new export markets, it will be necessary to set the direction of formation and improvement of the effective value chain of nuts. However, food safety requirements are high in European countries that exporters of agri-food products, including the hazelnut exporters, must consider [19-22].
- Types of products are limited in the volume of exports and imports of agri-food products between Georgia and the Czech Republic. For the further development of trade and economic relations, diversification of export and import products will be required.
- The characteristics and changes of globalization in trade and economic relations require the development of appropriate government policies. It is extremely important to determine the direction of stimulating economic competitiveness and increasing added value in the country.
- In the future, trade and economic relations between Georgia and the Czech Republic are expected to double. In such circumstances, cooperation with the Czech Republic will be promising for Georgia both in the field of trade, and in the field of investment and the use of modern technologies. In the short term, it will be necessary to diversify the export-import of agri-food products between the Czech Republic and Georgia and begin the process of transferring Czech production and / or modern technologies to Georgia.
- Currently, the data on export statistics of Georgia's foreign trade are incomplete, which creates significant obstacles to the assessment of trade and economic processes between countries and hinders effective cooperation. Adjustment of the database of prices for export-import goods will create a reliable information base for calculating foreign trade indices, facilitate the implementation of foreign trade and bring it into line with international standards.

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Challenges of sustainable and equal development of regions in Georgia

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Abstract. In the present paper is analysed opinions about the tools for sustainable development and the ways to reduce inequality. Has been estimated the importance of regional development programs and strategies as the settlement of the economic and social issues, provided proof of their role in the effective development of regional economic policy. Has been determined the concentration level of economic activity by regions using distribution index to estimate equal development of regions. Has been made the conclusion that none of the regions of Georgia is notably specialized. The concentration level of business sectors in regions is substantiated by the distribution curve. In distribution curve was considered retail and wholesale distribution, as an example of maximally near to ideal distribution. It is proved by the analysis of distribution of curves, that the concentration level of business sectors in Georgian regions is quite unequal and none of them could be highlighted in industry specialization. The paper identifies the problems related to sustainable and equal development of regions, provided conclusions and recommendations to settle the mentioned issue by their estimation. In the process of study has been determined the factors of endogenous development of regions and advisable to improve the quality and efficiency of regional development institutions through the development of trial-programs for regional development.

1 Problem statement

Historically Georgia is a country with a regional system. The regional structures are adapted to the economic, social, cultural, ethnic, and other factors. According to the above-mentioned, there are 12 historical-statistical regions in the country. At the same time, Georgia is distinguished by many difficulties in terms of regional arrangement and a high level of inequality between the regions. Even more, inequality is visible not only between the regions but between municipalities within the regions. The regions differ from each other by areas, population, potential of natural resources, economic development, demographic specifics, social spheres, investment environment, traditions, and other signs.

Sustainable and equal development of regions is a relevant issue for researchers. The unusual difficulties and obstacles are characterized by the developing events in the modern world. At the same time, global economic development, including the economic situation of any country, is assessed based on aggregated data of its constituent and carried out planning of efficient regional policy. The effectiveness of the policy depends on a deep analysis of the object's spatial-territorial characteristics of the policy itself and the usage of sustainable and equitable development mechanisms of regions.

The Association Agreement between Georgia and the European Union obliges Georgia to emphasize and focus on the development of poor regions and territorial cooperation in the field of regional policy [1]. The attempt to develop poor territorial units and achieve equality between the regions may cause a step back from the potential development of economic growth for developing countries. Therefore, the questions to be answered are the following: What factors lead to unequal development of regions? What causes the high and constant level of social inequality between the regions? What mechanisms could be used for equal development of the regions? What factors are the main drivers for the sustainable development of the regions? To answer the questions above, it is needed to provide research.

Recommendations developed based on the research will support in mid-terms the implementation of integrated territorial measures in Georgia, achievement of regional development policy goals, increase competitiveness of the regions, balanced social-economic development and improvement of living conditions in the regions, improvement of infrastructure for support of sustainable development, support particular territories and identify endogenic factors of development, increase the quality and efficiency of regional institutions, development of trial-programs for regional development.

On the assumption of relevance of the issue, we have aimed to identify the challenges of the regions of Georgia in sustain and equal development and elaborate recommendations of its solution.

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2 Research methods

In the process of research has been used methods of analysis, synthesis, and comparison.

The analysis of the documents of the strategy has been made using a comparison model. For achieving the goal and objectives of the study has been conducted desk survey. The existing theoretical and methodological approaches related to issues have been studied through reports, researches, and scientific articles. During the study, statistical calculations were carried out based on official sources (World Bank, Eurostat, Faostat, Geostat, and other); The primary materials necessary for publication were obtained from the National Statistical Office, the Ministry of Economy and Sustainable Development, the Ministry of Environment and Agriculture, the Ministry of Regional Development and Infrastructure of Georgia and various agencies.

For enhanced interviews and focus groups, various guides and questionnaires were developed, depending on the content of each task. The latter relied on information obtained as a result of desk research. The respondents in the research process were: representatives of local and international non-governmental organizations working on regional development issues, professors and researchers from universities and other research institutions; Representatives of the Ministry of Regional Development and Infrastructure and other government agencies; Industry experts, locals, and the representative of the business sector.

To determine the concentration of business activity and level of equal development in the regions has been used different indexes, including distribution and specialization indexes. Also has been used qualitative research tools (semi-structured interviews and meetings with focus groups).

3 Literature review

Finding tools for sustainable development in the regions and ways to reduce inequality is an important area of research in the scientific community nowadays. Sustainable development is in connection with the identification of territorial inequality issues. In this regard, the researchers analysing relevant issues of sustainable development and territorial fairness of the regions [2].

Currently, regions of the world are actively participating in the planning of sustainability with the following three main components: environment, economics, and capital. At the same time, researchers proposed ways to solve the issue related to the inequality development of the regions [3].

In European countries, it is especially important to study sustainable development issues of the regions from the perspective of sustainable resource management and fairness of social security. The researches in this field support and contribute to the formation of an equal society. In this regard, by studying different stages of regional development of Slovenia, researchers identified the connection between sustainable development of the region and health inequality overcoming [4].

Commonly, the concept of sustainable development of the regions is reflected integrated development of society (social, economic, and environmental protective). This type of conception is the basis of sustainable development of the regions in European countries. Scientists have analysed those tools, which are supporting the sustainable development of the regions in economic initiative framework, consequently scientists proposing the ways of sustainable development of the regions [5].

To achieve sustainable regional development and reduce regional inequality, it is important to elaborate on respective programs and strategies. Such programs and strategies are assessed by researchers based on economic and social issues, justified their role in elaboration of effective regional economic policy, identified the differences by location, culture, and other factors [6].

Sometimes, equality between the regions, in developing countries, is achieved through economic development. Frequently issue of disputes becomes on how effective-oriented regional policy supports the distribution of wealth between the regions and vice versa, could it be that equality becomes the main reason for ineffectiveness [7].

Scientists investigate the forms of relationships between the constituent parts of the region for the sustainable development of regions. The movement of a product, labour, or capital within a region may be random and may not indicate a specific direction of flow. [8]. The research literature also provides slightly different views on the definition of a functional region [9].

The main criteria to identify a functional region is the level of its isolation from other regions. The movement of product, labour, or capital not necessary to be explicitly organized within a functional region [10]. Worth mentioning that the regions make a significant contribution to the development of the process of manufacturing diversification in terms of social and cultural heritage, especially in mountainous regions [11].

The scientific papers include discussions on theoretical and empirical issues of economic growth in the regions, researches of the conceptual basics of economic growth, assessments of the paradigms, and trends of the regional development. At the assessing stage of the regional economic policy are discussed issues related to the difference in per capita income, also is sustained the role of areal structure in the formation of the labour market.

Research of equitable development of regions is especially relevant from the density of population and enterprises study prospective. The concentration of population and businesses obviously depends on land price, its characteristics, and constraints. In the case of Georgia, based on these factors, the issue requires deeper research.

However, in the field of spatial economics, should be made the following conclusions: land prices are more expensive the closer the sales market is, costs of housing and relocation increases the bigger the city size is, which reduces the real income of the population. The latter is the main reason why part of the population not willing to live in big cities [12]. We can say that only in a few cities of Georgia are the tendency of cost increase in terms of housing and relocation. Most cities are still less attractive to the citizens and businesses. Consequently, the price of land is relatively low, which allows the creation of centres and achieve high rates of agglomeration.

Nowadays, even more effective planning of regional development policy is a significant challenge for many countries worldwide. The goals of regional "equality" and "efficiency" are the main issues of discussion among the researchers in the field of regional policy. The subject of research and controversy is whether a regional policy guided towards efficiency contributes to an equal distribution of wealth among regions or vice versa, whether an approach guided towards equality can be the cause of inefficiency [13].

The goal of efficiency is to maximize the growth of the national economy and the optimal allocation of resources over time, while the goal of equality focuses on reducing unequal levels of income, wealth, and economic growth between regions. In certain cases, these goals could be compatible, but the significance of unequal development in regions requires the policy providers to focus on one main goal. Therefore, regardless of the choice of policy providers, the necessity to study the factors causing inequality is unavoidable. At the same time, it is necessary to make a benefit and cost analysis that will be obtained as a result of changing the economic growth direction with government intervention.

The effectiveness of regional structures in Georgia in terms of economic development policy objectives has not been studied. Evaluation criteria are accordingly not defined. Research is also complicated by the fact that the regional level of government is not defined by law, but historical districts/regions are subject to policy planning [14].

4 Results of research

The transformation of the economy of Georgia influenced the strategy of regional development, which takes into consideration the solution of their economic, social, and environmental issues. Georgia has certain guidelines for the sustainable development of the regions, for the expansion of regional markets [15]. Strategies and programs for the development of the regions of Georgia were developed. Based on analysis of these documents and the primary data received from the persons who were participated in the elaboration of the aforementioned documents, has been identified that mostly, documents include descriptive data about the regions [16].

However, should be mentioned that Georgia announced its readiness with the other countries of the UN to achieve sustainable development aims and targets by 2030 [17].

Mountainous regions have a key role in the socio-economic development of Georgia. Accordingly, based on an analysis of the socio-economic situation and existing potential, the Strategy for the Development of Mountain Settlements of Georgia presents a strategic vision for the inclusive and sustainable development of regions with an emphasis on the need for equal socio-economic development of the regions [17].

It is very important to determine the levels of governmental bodies for sustainable and equal development of the regions. As of now, Georgia considers four-level government: central, regional, district, and municipal. In terms of institutional and functional aspects, from the named levels, mostly developed the first level.

The second one, the regional level, is determined by historical, cultural, geographical, economic, ethnic, and other signs, and such a division has preserved the centuries. At the same time, it is significant to create steady food manufacturing conditions in the regions. Regional features still firmly bare in minds of the population. The process of regionalization still is irreversible, and it is effective to manage the country and stabilize economic conditions through the regional institutions [18; 19] and optimizing knowledge [26]. However, at the regional level institutional structures, undeveloped infrastructure, cluster relations [20; 21] are weak, there are no conditions for sustainable development, and the difference in wealth fare indexes between the regions is obvious.

By territories largest region is almost 5.6 times bigger than the smallest one. By population of the smallest region as compared to the largest is almost 17 times less [23]. There is a deficiency of urban-type mid-size territories in the country, which causes social-economic inequality between the regions.

By combining assessments of various approaches, theories, and models of sustainable and equitable regional development, we have identified the main characteristics of the regions of Georgia:

- regions are characterized by economic similarity; there are some central places, so-called "Centers of gravity";
- natural resources, ecosystems, or other geographic features within a region are similar;
- the regions are characterized by similar impacts under the influence of various external and internal factors;
- each region includes a small number of high demand settlements and a large number of low demand settlements and it is characterized by manageability.

The grouping of settlements in the regional context showed that the number of different types of settlements is quite asymmetric, moreover the spatial difference in consumer demand between urban settlements, and rural settlements is huge and the regions do not correspond to this index of inequality (see Table 1).

The distribution of GDP across regions is also asymmetric (see Figure 1).

Relatively high GDP is reflected in regions with self-governing cities and industrialized zones. For example, the Autonomous Republic of Adjara, Kvemo Kartli, and Imereti in Georgia. The indicators are especially low in the regions of Guria, Samtskhe-Javakheti, Mtskheta-Mtianeti, Racha-Lechkhumi and Kvemo Svaneti in Georgia.

The growth rate of the GDP of Georgia was 5.1% in 2019 [20]. During the pandemic, there are expectations that this indicator will keep decreasing, according to

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experts, mostly vulnerable and impacted sector will be tourism, which will lead to more inequality between the regions [20].

Table 1. Grouping of settlements by number (pcs.) and average population (people) by regions

Regions	Number of cities	Average population living in 1 city	number of towns	Average population living in 1 town	number of villages	Average population living in 1 village	Spatial difference in consumer demand in urban settlements from rural settlements
Autonomous Republic of Adjara	2	84,693	5	3,078	322	463	189
Guria	2	10,590	5	2,145	186	438	29
Imereti	11	23,168	2	1,834	535	515	49
Kakheti	9	7,947	0	-	333	742	11
Mtskheta-Mtianeti	2	7,054	5	1,430	480	153	56
Racha-Lechkhumi and Kvemo Svaneti	3	2,008	2	474	251	100	25
Samegrelo-Zemo Svaneti	8	15,535	2	2,557	521	387	47
Samtskhe-Javakheti	5	9,107	7	1,304	259	409	25
Kvemo Kartli	7	24,731	5	1,401	351	695	38
Shida Kartli	4	23,589	2	5,428	373	424	68

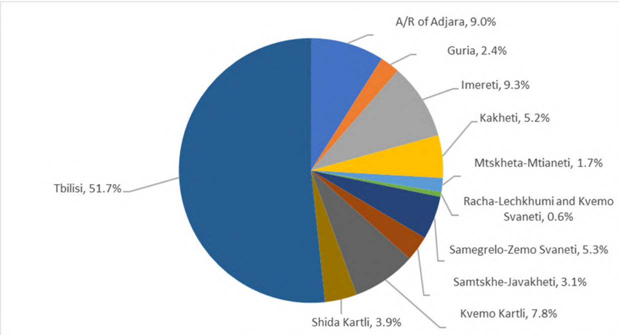

Fig. 1. Regional structure of GDP of Georgia [17; 23]

Significant inequality in GDP for the regions of Georgia was observed even before the pandemic: GDP per capita hovers 2.7 times between the richest and poorest regions. Tbilisi has the largest share in the country's GDP (49%) [20]. In addition, 72% of the total turnover of the business sectors comes from companies operating in Tbilisi. This index is 2.5 times more than other company’s index operating in other regions of Georgia. Georgian economy is quite diversified by its structure, but the economy of Tbilisi is more competitive. 86% of foreign direct investments come to the Tbilisi region of Georgia. Meanwhile, there is a decrease tendency of foreign direct investments in most of the regions of Georgia, such as Guria, Racha-Lechkhumi and Kvemo Svaneti, Shida Kartli, and Mtskheta-Mtianeti [16; 17; 20]. This kind of concentration of the economy is the biggest challenge for Georgia and its regions.

The study of the needs and potential of regional development showed that Georgia, on the one hand, has many challenges for further development, and on the other hand, has significant potential that can be effectively used for deepening of economic development and improvement of the quality of life of its citizens.

To find the ways of equal development of the regions it is vital to know what concentration of economic activity in the regions is.

We have measured the concentration of specific sectors in the regions by using a distribution index, took into consideration regional inequality characterized by the small countries [24]. Analysis of the results showed that none of the regions is notably specialized.

Among the relatively concentrated types of economic activity in the regions, there is only agriculture, forestry, and fish farming, as well as the mining industry, and quarrying. In this regard, the regions of Racha-Lechkhumi, Samegrelo-Zemo Svaneti and Kvemo Kartli stand out. In terms of mining and quarrying, this sector is especially concentrated in the Kvemo Kartli and Imereti regions.

The level of concentration of business sectors in the regions has been precise by distribution curves [20; 25]. In time of making distribution curves has been considered that retail and wholesale is as an example of maximally near to ideal distribution. In this case, involvement in business sectors from the regions is proportionally equal. The deviation from this curve reflects a high concentration in one or more regions (see Figure 2).

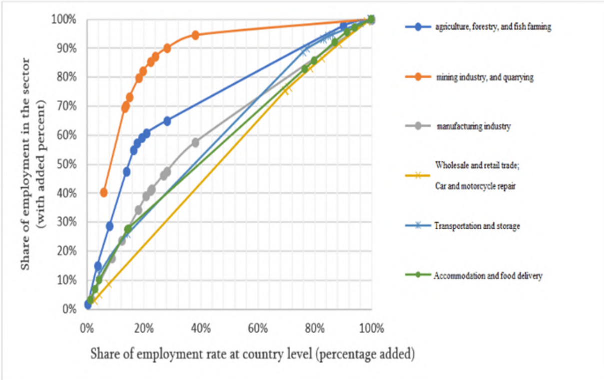

Fig. 2. Distribution curve by regions of Georgia by five sectors [20]

The distribution of the curves also affirmed that the level of concentration of business sectors in the regions of Georgia is rather unequal. This means that none of the regions are distinguished by industry specialization, only a relatively high specialization observed in the Kvemo Kartli region, the merit of which is existing natural resources and "support" on the issuance of permissions for their extraction.

5 Conclusion

Consequently, for the sustainable and equitable development of regions in Georgia, for the effective functioning of the regions is needed strong correlation between the components of the population, the business sector, and the territory. The above mentioned will create and strengthen regional relations, interdependencies, create conditions for sustainable development and a basis for a relatively equal concentration of economic activity.

Based on the results of the study, the following conclusions and recommendations were made:

- indicators of economic activity in the regions of Georgia are very different from each other. These figures are affected by the decision of the population and the business sector about their place of residence, work, and sphere of economic activity. Consequently, the possibilities for sustainable development of regions should be determined not by the principle of territorial similarity, but by the spatial characteristics of territorial units;

- one of the obstacles to the possible benefits of spatial concentration and economic agglomeration is the land price. Most cities in Georgia are less attractive for the population and business, therefore the price of land is relatively low. At this stage of development, low land prices will create an opportunity to create centers and achieve a high speed of the agglomeration process;
- the analysis of distribution indexes by the regions of Georgia showed that the concentration of sectors is not typical for none of the regions, and economic activity between regions is diversified. To increase the concentration and rapid development of the municipality recommended the following: to organize the infrastructure with a focus on the centers of the municipality; Develop and expand ties between municipalities; Create appropriate infrastructure connecting territorial units around municipal centers; facilitate migration to settlements if needed, etc.

In planning regional policy, it is necessary to choose between the goals of "equality" and "efficiency". Should be noted that the EU's “rapprochement” policy is more focused on achieving the goal of “equality”. By the policy of rapprochement with the EU, reducing inequality between regions should be the high priority of Georgia's strategic goals.

Unequal development and weak territorial ties are obvious between the regions of Georgia. It is necessary to establish and develop functional interdependencies between territorial units. Especially, should be improved links between regional centres and the capital city.

The following approaches should be used to identify opportunities for equal development in the regions: a clear focus on efficiency; Concentration of economic activity as a strong side of regional development; Replacing the sectoral approach with a multi-sectoral policy, focused on territorial development; Promotion of specialization, clustering, etc.

The analysis of growth opportunities of the regions of Georgia has proved that the perspective of rapprochement and equal development is more short-term for those regions which have economic centers. In case the regions do not have strong centers, it is recommended that regional policy was initially focused on the creation and development of such centers.

The analysis of the existing four-level government in Georgia (central, regional, district, and municipal) has been proved, that the regionalization process is irreversible nowadays and that is possible to achieve equal and sustainable economic development through regional institutions; lack of mid-sized urban areas aggravates further inequality problem.

Comparison of territorial, demographic, economic, social and other factors of the regions of Georgia showed that there is harsh inequality between social-economic development levels between the regions.

The Study of the needs and potential of regional development showed that Georgia, on the one hand, has many challenges for further sustainable and equal development, and on the other hand, has significant potential to improve economic development and quality of life of its citizens.

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Ecological analysis of the flora of the Kremenets Mountains National Nature Park (on the example of the mountains Divochi Skeli, Strakhova, Masliatyn, Chercha, Zamkova, Bozha)

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Abstract. One of the elements that ensure the sustainability of the environment is the vegetation cover. The vegetation cover contributes to the balanced functioning of ecosystems. It is the national parks rich in phytodiversity that attract the attention of scientists. The article presents an ecological analysis of the flora of the Kremenets Mountains National Park. The research was carried out in the areas of the mountains Divochi Skeli, Strakhova, Masliatyn, Chercha, Zamkova, Bozha. 10 florocoenotypes were identified in the study areas. The most numerous is the nemoral forest coenotype. The flora was analyzed for abiotic factors such as light, temperature, humidity, soil. It is these indicators that have an important impact on the formation of vegetation cover and the life processes of plants. It was found that facultative heliophytes, mesothermal plants, mesophytes, and mesotrophs predominate in the study areas. The vegetation cover has clear forest-steppe features. The classification of life forms of plants is given. Relicts and endemics are confined to steppe and calcepetrophilic areas. Flora synanthropization is observed on the study areas.

1 Problem statement

Vegetation cover as an autotrophic component provides energy through photosynthesis and together with the heterotrophic component is the key to the normal functioning of ecosystems.

In natural ecosystems, the vegetation cover is represented by a wide variety of species and life forms. In all ecosystems, vegetation plays a particularly important environmental and self-organizing role. It determines the spatial, visual boundaries, their structure, internal climate, soil characteristics, the set and distribution of animals and microorganisms, corrects and transforms external interactions, balances and extinguishes them and directs the energy metabolism as a whole. Green vegetation is the only generators of primary organic matter and the main energy storage, on the basis of which chemical reactions, physical and biological processes in ecosystems take place [1].

From an ecological point of view, the study of flora and vegetation cover is important, first of all, in the aspect of that specific, only inherent work, which they perform in the ecosystem as a material component. Of particular importance are the functions of the vegetation cover, such as the absorption of various substances and energy from other components of ecosystems and their synthesis into primary organic substances used for building the bodies of plants and for their internal catabolism; the release of waste products by vegetation, and with them part of the captured energy during their formation; the return to the atmosphere and soil of a part of the accumulated energy and substance during the death of organs or whole plants; transformation by vegetation cover of the properties and states of other components of ecosystems in the process of growth, absorption, accumulation and release of substances and energy [2].

All the parameters of the atmosphere that make up terrestrial ecosystems are under the control of the vegetation cover: air humidity, thermal regime, illumination, gas composition. Moreover, the higher the vegetation, the denser its thickets and the more complex the structure, the more noticeable its role in the transformation of the atmosphere. Plants also affect the thermal regime of soils, moisture, their structure, the nature of organic matter, pH, especially its upper horizons saturated with roots. The performance of the listed functions of phytocenoses is associated with physiological processes: photosynthesis, respiration, transpiration, absorption of water, minerals, and growth. From an ecological point of view, the results of these processes and their impact on the overall ecosystem process are important [3, 4].

It is important the environmental stabilization value of vegetation cover, soil-protecting, water-saving, landscape, aesthetic, scientific and educational. Plants provide protection for rare populations. A rare species can be preserved only within the framework of certain phytocenoses, and hence the need arises for the protection of the phytogenofund and phytocenofond. Many rare and endangered plant species are consortium associated with rare representatives of the animal world. The study of their ecological and biotic properties also contribute to the preservation of populations of endangered species of fauna [5, 6].

Aboriginal species and their populations, which make up the natural flora, are concentrated in groups united by a common growth conditions and ecological-coenotic relationships, forming certain florocoenotypes. Such an analysis makes it possible to understand the features and confinement of certain groups of natural species to certain coenoecological niches, to show the advantage of certain floroceno-ecological complexes, their interpenetration, the genesis of the peculiarities of the formation of a certain flora. An important indicator of the ecological characteristics of phytocenoses is their relation to abiotic factors of the environment (especially light, temperature, humidity and soil), and plant life forms, which are important for plant life, since they affect the course of physiological, biochemical and other processes.

2 Materials and research methods

Stationary research was carried out in the most interesting and typical, in terms of phyto-diversity, mountain areas: Divochi Skeli, Strakhova, Masliatyn, Chercha, Zamkova, Bozha. The main research methods were: morphological-geographical and ecological-phytocenotic description of species and plant communities. The definition of the species composition and the nomenclature of Latin names are filed according to Chronicle of the nature of the Kremenets Mountains National Nature Park [7] and Keys to higher plants of Ukraine [8]. Ecological and cenotic characteristics of flora and vegetation cover according to B. V. Zaverukha [9]. Classification of life forms of plants is filed by Raunkier.

3 Results and discussion

On the territory of the studied mountains, we have identified the following floroceotypes: boreal forest, nemoral forest, meadow, meadow-steppe, steppe, calcepetrophilic, psamophilic, xerophytic-shrub, hygro-hydro swamp, agro-ruderal (Table 1, Fig. 1).

The boreal forest florocoenotype unites 41 species (5%), it is characterized by Holarctic species, which have areas associated with light coniferous and partially mixed coniferous-broad leaved forests: *Pinus silvestris* L., *Juniperus communis* L., *Calluna vulgaris* (L.) Hull., *Rumex acetosella* L., *Pyrola media* Sw., *Orthylia secunda* (L.) House., *P. rotundifolia* L., *Jasione montana* L., etc.

The most numerous nemoral forest coenotype includes 239 (29%) florocenoelements: *Quercus robur* L., *Fagus sylvatica* L., *Betula pendula* Roth., *B. klokovii* Zaverucha, *Carpinus betulus* L., *Corylus avellana* L., *Asarum europaeum* L., *Anthyrium filix-femina* (L.) Roth., *Stellaria holostea* L., *Dryopteris filix-mas* (L.) Schott., *Anemone nemorosa* L., *Hepatica nobilis* Mill., *Clematis recta* L., *Actaea spicata* L., *Rumex sylvestris* (Lam.) Wallr., *Viola reichenbachiana* Jord. ex Boreau, *Dentaria glandulosa* Waldst et Kit., *Lunaria rediviva* L., *Euphorbia amygdaloides* L., *Astragalus glycyphyllos* L., *Astrantia major* L., *Atropa bella-donna* L., *Laserpitium latifolium* L., *Scopolia carniolica* Jacg., *Betonica officinalis* L., *Convallaria majalis* L., *Lilium martagon* L., *Carex pilosa* Scop., *Poa nemoralis* L., etc. This florocoenotype is distinguished by a certain heterogeneity typical for hornbeam-oak, oak and beech forests.

Table 1. Ecological and coenotic characteristics of the flora of the study areas.

No.	Floroceotypes	Number of species
1	Boreal forest	41
2	Nemoral forest	239
3	Meadow	123
4	Meadow-steppe	115
5	Steppe	18
6	Calcepetrophilic	34
7	Psamophilic	19
8	Xerophytic-shrub	18
9	Hygro-hydro swamp	53
10	Agro-ruderal	165
	Total	825

The meadow florocoenotype is represented by 123 (14.9%) florocenoelements. There are almost no relict and endemic species here, but there are many widespread species of the temperate latitude type, mainly of Holarctic and Palaearctic nature: *Equisetum pratense* Ehrh., *Coronaria coriacea (Moench.)* Schischk., *Herniaria glabra* L., *Polygonum bistorta* L., *Lathyrus pratensis* L., *Lysimachia nummularia* L., *Geranium pratense* L., *Centaurea jacea* L., *Hieracium umbellatum* L., *Agrostis stolonifera* L., *Bromus mollis* L., *Phleum pratense* L., *Poa trivialis* L., *P. pratensis* L., *Festuca pratensis* Huds., etc. This florocoenotype is due to the small area of meadows, large areas of the former meadows have been plowed up, some of them have been converted into pastures.

The meadow-steppe florocoenotype includes 115 (13.9%) florocenoelements, there are accumulated species of mainly forest and steppe zonal types: *Ranunculus auricomus* L., *Dianthus andrzejowskianus* Zapal., *Thalictrum flavum* L., *Helianthemum nummularium* (L.) Mill., *Filipendula vulgaris* Moench., *Potentilla patula* Waldst., *P. argentea* L., *Medicago procumbens* Bess., *Polygala comosa* Schkuhr., *Trifolium dubium* Sibth., *Galium verum* L., *Onosma subtinctoria* Klok., *Verbascum thapsus* L., *Salvia dumetorum* Andrz., *Veronica incana* L., *Campanula sibirica* L., *Poa angustifolia* L., etc.

The steppe florocoenotype is small in number 18 (2.2%) species, it consists mainly of Mediterranean and Pontic cenoelements: *Euphorbia seguieriana* Neck., *Polygala podolica* DC., *Asperula cynanchica* L., *Aster amellus* L., *Trinia multicaulis* Schischk., *Helictotrichon desertorum* (Less.) Nevski, *Stipa cappilata* L., *S. pennata* L., etc.

The calcepetrophilic florocoenotype unites 34 (4.1%) species; it is represented by the florocenoelements of chalk, limestone, gypsum deposits and steppe groups:

Asplenium ruta-muraria L., *Minuartia aucta* Klok., *Aurinia saxatilis* (L.) Desv., *Helianthemum canum* (L.) Baumg., *Alysum gmelinii* Jord., *A. calycinum* Stapf., *Sempervivum ruthenicum* Schnittsp. et C.B. Lehm., *Euphorbia volhynica* Bess. ex Szaf., Kulcz.,*Sedum acre* L., *Anthyllis schiwereckii* (DC) Blocki, *Galium exoletum* Klok., *G. besseri* Klok., *Allium strictum* Schrad., *Salvia cremenecensis* Bess., etc.

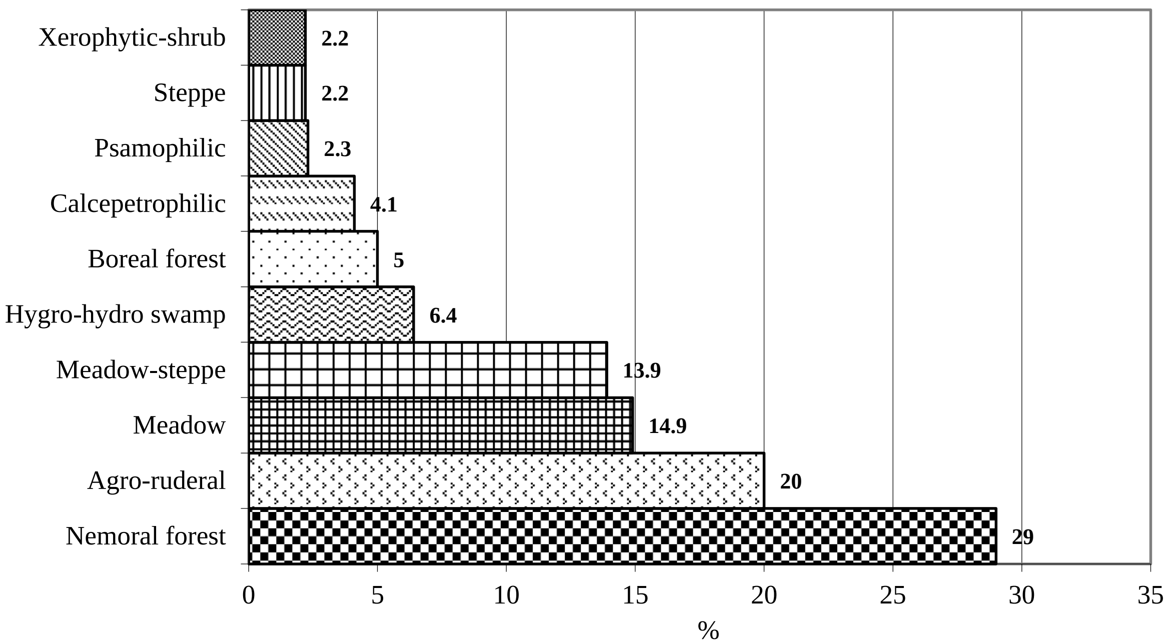

Fig. 1. The ratio of florocoenotypes in the study areas (%).

The psamophilic florocoenotype includes 19 (2.3%) species, these are species of sandy deposits: *Gypsophila paniculata* L., *Cardominopsis arenosa* (L.) Hayek, *Astragalus onobrychis* L., *Potentilla arenaria* Borkh., *Thymus serpyllum* L., *Verbascum densiflorum* Bertol., *Onobrychis arenaria* (Kit.) DC., etc.

The xerophytic-shrub florocoenotype is represented by 18 (2.2%) species: *Spiraea media* Franz. Schmidt, *Crataegus praearmata* Klok., *C. lipskyi* Klok., *Cerasus fruticosa* L., *Rosa livescens* Bess., *R. czackiana* Bess., *R. jundzillii* Bess., *Prunus stepposa* Kotov., *Padellus mahaleb* (L.) Mill., etc.

The hygro-hydro swamp florocoenotype contains 53 (6.4%) florocenoelements: *Ranunculus sceleratus* L., *Caltha palustris* L., *Filipendula denudata* (J. et C. Presl) Fritsch., *Potentilla erecta* (L.) Raeusch., *Lythrum salicaria* L., *L. virgatum* L., *Juncus geniculatus* Schrank., *J. inflexus* L., *Veratrum lobelianum* Bernh., *Molinia careulea* Maench. ex Steud., *Acorus calamus* L., *Phragmites australis* Trin. ex Steud., etc. This florocoenotype includes mainly typical species of sedge and herbaceous-sedge bogs.

The agro-ruderal florocoenotype is formed from segetal and ruderal plants. It contains 165 (20%) florocenoelements: *Fumaria officinalis* L., *F. parviflora* Lam., *Sinapis arvensis* L., *Atriplex prostrata* Boucher., *Thlaspi arvense* L., *Euphorbia helioscopia* L., *Erysimum cheiranthoides* L., *Erodium cicutarium* (L.) Her., *Nonea pulla* (L.) DC., *Strophiostoma sparsiflora* Turez., *Mentha arvensis* L., *Lycopsis arvensis* L., *Carduus crispus* L., *Solanum nigrum* L., *Cirsium oleraceum* (L.) Scop., *Bromus secalinus* L., *Urtica dioica* L., *Setaria pumila* (Poir.) Schult., *S. viridis* (L.) Beauv., etc.

In relation to the light conditions in the study areas, we identified the following ecological groups of plants. The most numerous are facultative heliophytes (shade-tolerant ones - they can tolerate more or less shading, but grow well in the light), these are 538 species (65.2%). These are such species as *Botrychium lunaria* (L.) Sw., *Trollius europaeus* L., *Phyllitis scolopendrium* (L.) Newm., *Anemone nemorosa* L., *A. ranunculoides* L., *Cerastium holosteoides* Fries, *Corylus avellana* L., 8 species of the genus Viola, *Calluna vulgaris* (L.) Hull, *Helianthemum nummularium* (L.) Mill., *Rhodococcum vitis-idaea* (L.) Avror., 5 species of the genus Euphorbia, 5 species of the genus Crataegus, 7 species of the genus Rosa, 4 species of the genus Inula, *Galanthus nivalis* L., *Tragopogon major* Jacq., many species of the Orchidaceae family, *Calamagrostis canescens* (Web.) Roth., etc.

Heliophytes (light-loving - plants of open, well-illuminated areas), their number is 256 species (31%): *Larix decidua* Mill., *Aquilegia vulgaris* L., *Pinus sylvestris* L., *Adonis vernalis* L., *Minuartia aucta* Klok., *Silene vulgaris* (Moench) Garcke, *Gypsophila paniculata* L., *G. fastigiata* L., *види роду Alyssum, Sedum acre* L., *S. ruprechtii* (Jalas) Omelcz., *Hypericum perforatum* L., *H. elegans* Steph. ex Willd., *Fragaria viridis* Duch., *F. vesca* L., *Scabiosa ochroleuca* L., *Potentilla arenaria* Borkh., *Scorzonera purprea* L., *Aster amellus* L., *Stipa capillata* L., *S. pennata* L., etc.

The least numerous group is sciophytes (shade-loving - plants of the lower tiers of shady forests, caves), their number is 31 species (3.8%): *Ophioglossum vulgatum* L., *Cystopteris fragilis* (L.) Bernh., *Athyrium filix-femina* (L.) Roth., *Dryopteris filix-mas* (L.) Schott., *Pteridium aquilinum* (L.) Kuhn., *Asarum europaeum* L., *Asplenium* *ruta-muraria* L., *A. trichomanes* L., *Dentaria glandulosa* Waldst. et Kit., *Hepatica nobilis* Mill., etc. (Fig. 2).

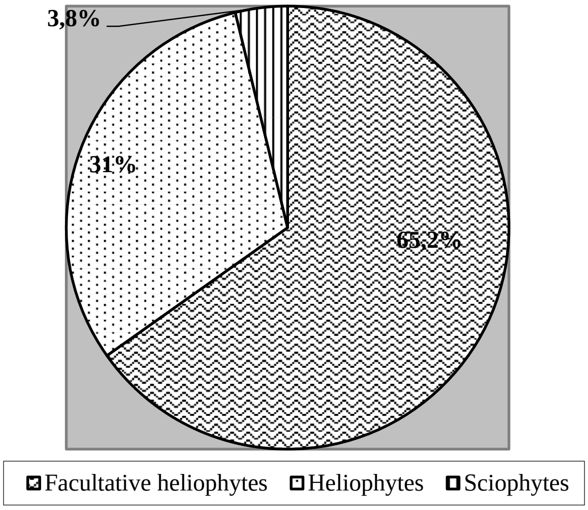

Fig. 2. The ratio of ecological groups of plants in relation to light in the study areas.

In relation to temperature, in the study area, the following groups of plants can be distinguished: mesothermal (the most common), their number is 535 species (64.8%). These are such as *Larix decidua, Actaea spicata* L., *Malva pusilla* Smith., *Daphne mezereum* L., *Polygala podolica* DC., *Staphylea pinnata* L., *Centaurea jacea* L., *Pyrethrum corymbosum* (L.) Scop., *Poa angustifolia* L., etc.

There are 241 species of thermophilic plants (29.2%): *Helianthemum canum* (L.) Baumg., *Sempervivum ruthenicum* Schnittsp. et C. B. Lehm., *Alyssum gmelinii* Jord., *Euphorbia volhynica* Bess. ex Szaf., Kulcz. et Pawł., *Chamaecytisus austriacus* (L.) Link., *Galium exoletum* Klok., *Eryngium planum* L., *Jurinea pachysperma* Klok., *Helichrysum arenarium* (L.) Moench, *Festuca valesiaca* Gaud., etc.

The least numerous group is cryophilic plants, there are 49 species (6%): *Orthilia secunda* (L.) House, *Hedera helix* L., *Pyrola media* Sw., *Lathraea squamaria* L., *Scirpus sylvaticus* L., *Orchis militaris* L., *Arum besseranum* Schott, etc. (Fig. 3).

Depending on the humidity regime in which the plants grow, we identified the following ecological groups in the study areas (Fig. 4). The humid and moderately warm climate of this territory determines the advantage of mesophytes (plants living in conditions of medium humidity), these are 705 species (85.4%). This includes most trees and shrubs, meadow and forest grasses: *Pinus sylvestris*, *P. banskiana* Lamb., *Fagus sylvatica* L., *Quercus robur* L., *Q. petraea* (Mattuschka) Liebl., *Corylus avellana, Dianthus carthusianorum* L. A smaller group is hygrophytes (plants that live in conditions of excessive moisture), this includes 60 species (7.3%): *Caltha palustris* L., *Potentilla erecte* (L.) Rausch., *Coronaria coriacea* (Moench) Schischk. et Gorschk., *Filipendula denudate* (J. et C. Presl) Fritsch, *Myosotis palustris* L., *Valeriana stolonifera* Czern., *Veratrum lobelianum* Bernh., *Pedicularis palustris* L., *Orchis militaris, Molinia careulea* (L.) Moench., etc.

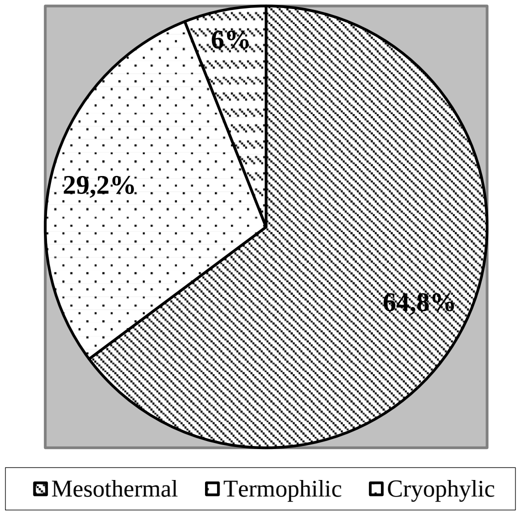

Fig. 3. The ratio of ecological groups of plants in relation to temperature in the study areas.

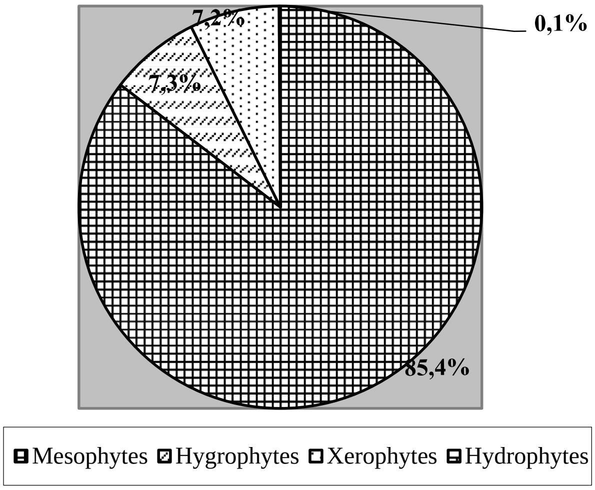

Fig. 4. The ratio of ecological groups of plants in relation to humidity in the study areas.

Xerophytes are plants in arid areas that are able to withstand prolonged atmospheric and soil drought, 59 species (7.2%): *Minuartia aucta* Klok., *Alyssum gmelinii, A. calycinum* L., *Gypsorhila paniculata, G. fastigiata* L., *Sempervivum ruthenicum, Carlina biebersteinii* Bernh. ex Hornem., *C. vulgaris* L., *Sedum ruprechtii, S. acre, Asparagus verticillatus* L., *Stipa capillata, S. pennata* , *Koeleria glauca* (Spreng.) DC., *etc.*

The least numerous group is hydrophytes includes 1 species (0.1%). These are higher aquatic plants attached to the soil and submerged in water only with their lower part: *Phragmites australis* (Cav.) Trin. ex Steud.

Depending on the autoecological characteristics of plants in relation to the gross chemical composition of the soil, the following ecological groups have been identified in the study area (Fig. 5). The most numerous are mesotrophs (plants are moderately demanding of soil nutrients), this includes 368 species (44.6%). These include: *Picea abies* (L.) Karst. *Populus alba* L., *Euonymus verrucosa* Scop., *E. europaea* L., *Chaerophyllum temulum* L., *Tragopogon* major, *Laser trilobum* (L.) Borkh., *Lilium martagon, Ferulago* *sylvatica* (Bess) Reichenb., *Festuca ovina* L., *Bromopsis inermis* (Leyss.) Holub, etc.

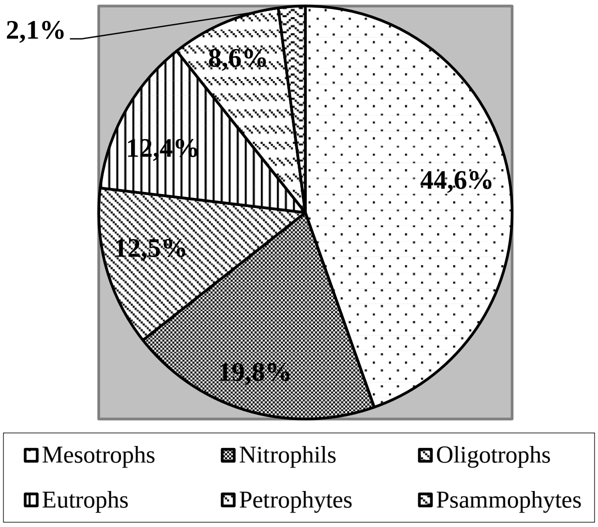

Fig. 5. The ratio of ecological groups of plants in relation to soil in the study areas

Nitrophils (plants are especially demanding for an increased nitrogen content in the soil), this includes 164 species (19.8%), these are mainly weeds, pasture plants, species that settle in forest clearings, garbage places: *Chenopodium album* L., *Ch. bonus henricus* L., *Urtica dioica* L., *Rumex crispus* L., *Chamaerion angustifolium* (L.) Holub., *Atriplex prostrata* Boucher, *Solanum dulcamara* L., *Heracleum sibiricum* L., *Elytrigia intermedia* (Host.) Nevski, etc.

Oligotrophs (plants growing on barren soils), this includes 103 species (12.5%): *Pinus sylvestris, P. bancsiana, Orthylia secunda* (L.) House, *Calluna vulgaris, Pyrola media* Sw., *P. rotundifolia* L., *Ononis arvense* L., *Geum rivale* L., *Gratiola officinalis* L., *Epilobium hirsutum* L., etc.

Eutrophs (plants growing on nutrient-rich substrates), these are 102 species (12.4%): *Fagus sylvatica, Quercus robur, Q. petraea, Q. austriaca* Willd., *Anemone nemorosa, A. sylvestris* L., *Corydalis bulbosa* (L.) DC., *Ficaria verna* Huds., *Stellaria media* (L.) Vill., *Daphne mezereum* L., *Lunaria rediviva* L., *etc.*

A small group of petrophytes or lithophytes (plants that grow on rocks and stony places) are 71 species (8.6%): *Euphorbia volhynica, E. seguieriana* Neck., *Gypsophila paniculata, G. fastigiata, Minuartia aucta, Helianthemum canum, Rosa czackiana* Bess., *R. pimpinellifolia* L., *Cerasus fruticosa* Pall., *Sempervivum ruthenicum, Sedum acre, S. ruprechtii, Salvia cremenecensis* Bess., *Anthyllis schiwereckii, Astrantia major, Dracocephalum austriacum* L., *etc.*

The least numerous group of psammophytes (plants that have a special adaptation to life on the sands) are 17 species (2.1%): *Potentilla arenaria* Borkh., *Cardaminopsis arenosa* (L.) Hayek., *Onobrychis arenaria* (Kit.) DC., *Trifolium arvense* L., *Hieracium pilosella* L., *Linaria genistifolia* (L.) Mill., *Festuca rubra* L., etc.

The flora of the study areas is characterized by a variety of life forms (Fig. 6). Phanerophytes (trees and shrubs) are 74 species (9%). Hamephytes are 25 species (3%): *Helianthemum canum, Calluna vulgaris, Rhodococcum vitis-idaea, Orthilia secunda, Pyrola media, P. rotundifolia, Vinca minor, Thymus serpyllum, Th. pulegioides, Th. Marchallianus*., etc. Hemicryptophytes are 428 species (51.9%): Dracocephalum austriacum, *Astrantia major, Phyllitis scolopendrium*, etc. Therophytes are 228 species (27.6%): *Anagallis arvensis, Xanthium strumarium ,Papaver rhoeas, P. argemone, Bidens tripartita* L., *Herniaria glabra* L. etc. There are 70 species of cryptophytes (8.5%). This includes most types of families Liliaceae, Iridaceae, Alliaceae, Orchidaceae.

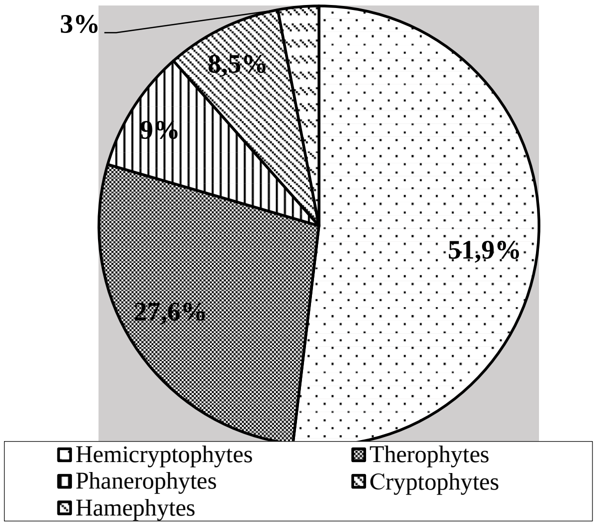

Fig. 6. The ratio of life forms of plants in the study area.

When studying the specificity of the flora of a certain region, the phenomenon of endemism is of great importance. The proportion of endemics in a particular flora characterizes the degree of individuality of a given flora. An indicator of the originality of a particular flora is the presence of a significant number of endemics. The problem of flora endemism is one of the most important indicators in plant geography, both in the scientific and practical sense.

The age of the phytobiota of the Kremenets Mountains National Nature Park can be attributed to the middle Miocene. Already in the lower Tortonian, the ecologically determined development of the flora proceeded in the direction of creo- and xerophytization. In the Upper Miocene and at the beginning of the Pliocene, a dissected landscape with forest-steppe vegetation was formed.

By the middle of the Pliocene, the forest-steppe flora in the region was replaced by the steppe flora, and calceopetrophyton developed. The next mesophytization of the climate, the invasion of the coreal flora forced the plant remains of the favorable period to migrate to the storages - steep, heavily projected slopes with a calcium substrate. The Pliocene was characterized by the development of the calceo-xeromorphic complex with the transformation of the ancient subtropical-forest complex into a modernized xeromesophytic temperate forest complex. During the Pleistocene, the flora underwent several periods of cooling and warming. The results of studying the genesis of the flora indicate that during the Pleistocene, under conditions of a dissected relief, there were constant changes in the ecological conditions of a microrefugium nature, which contributed to the preservation of many ancient species [10].

During the last millennium, two complexes of adventive plants have been formed: archaeo- and neophytes. Endemic species of different ages were formed on the basis of the autochthonous nucleus.

The leading genesis complexes of flora formed at the end of the Pliocene. Then the nemoral, calceopetrophilic, psamophilic, hydrophilic, savanoid- meadow-steppe flora was formed. After xero-cryophytic transformation during the Pleistocene, a steppe complex is formed, a complex of coniferous and birch forests, which acquired a modern composition in the Holocene [10].

In the studied territories, we identified 32 relics (3.9% of the total number of species), of which 7 species are tertiary relics, 25 species are glacial and interglacial, and 60 are endemic (7.2% of the total). The richest in the number of natural endemic species are the families Orchidaceae - 10 species, Rosaceae - 10 species, Poaceae - 9 species, Lamiaceae - 7 species.

Most of the endemic species are coenoelements of calceopetrophyton, calceopetrophilic meadow-steppe areas, steppe and calceopetrophilic shrub groups. The formation of the main autochthonous core of the flora took place in the depths of the old paleocalcepetrophyton, on the basis of which the main primordial complexes arose: savanoid-meadow-steppe, ancient-steppe, and ancient-shrub. The second basis for the formation of one of the main components of the flora was the prsnemoral and prashrub.

The approximate time of the emergence and formation of paleoendems of the flora of the studied territories refers to the period from the Middle to Upper Miocene and the beginning of the Pleistocene, these are such species as *Galium exoletum, Minuartia aucta, Jurinea pachysperma,* etc. In their depths appeared: *Euphorbia volhynica, Galium besseri, Salvia cremenecensis, Betula klokovii*, etc. The group of mesochronoendemics is determined by the period from the beginning of the Pliocene to the middle of the Pleistocene, these include *Salvia dumetorum, Chamaecytisus blockianus.*

In the group of paleoendemics, the oldest, which have ancient subthetic roots, indicate the connection of our flora in the past with the ancient Mediterranean. Some of the endemics are associated with the deciduous forests of Central Europe.

4 Conclusions

The study of the vegetation cover is necessary to maintain the normal functioning and evolution of ecosystems, the stability of biogeochemical processes, the spontaneous development of biota and the preservation of the ecological balance both at the local and global levels.

Both the number and the ratio of florocoenotypes have clear and pronounced forest-steppe features. The meadow-steppe, steppe and calcepetrophilic groupings of the study areas contain a significant number of relict and endemic aboriginal florocenoelements. In the studied territories, there is a significant share of the agro-ruderal florocoenotypes - 20%, which indicates a significant synanthropization of the flora. Now this situation is more and more common in Ukraine.

A general overview of the specificity of the flora of the studied territories indicates its significant heterochronism, heterogeneity, and originality. In the flora of the region, among the prevailing species, neoendemics are manifested, and a number of relics testify to the connection between the modern flora of the ancient flora, the age of which begins from the end of the Tertiary period.

The great natural diversity of ecotopes in the studied territories creates appropriate favorable opportunities for the formation of viable populations of a large number of plant species, very different in their autoecological properties. Such a unique natural ecological situation requires intensifying efforts in the field of protecting the regional environment from ill-conceived anthropogenic interference and creating conditions for the conservation and natural distribution of rare plant species.

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Geography of agricultural exports from Ukraine

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Abstract. Based on the generalization and systematization of scientific and accounting data, the article considers agriculture as one of the leading sectors of the Ukrainian economy, providing 50% of foreign exchange earnings from exports of all goods from the country. The structure and geography of agricultural exports from Ukraine are analyzed. The existing export potential of the studied sector of the national economy and the level of self-sufficiency of Ukraine in agri-food products are revealed. Four specialization types of agricultural exports from Ukrainian regions are established: areas with dominance in export of animal origin products; areas with a dominance in the export of plant products; areas with a predominance in the export of animal or vegetable origin fats and oils; area, with mixed export specialization. Recommendations for the re-profiling of agricultural production in a number of the country's regions in order to increase exports of this product type.

1 Introduction

The agricultural sector is a competitive sector of the economy, able to fill the budget of Ukraine along with such traditional industries as metallurgy, chemical industry, mechanical engineering and others. At present, agriculture is a strategically important part of the country's economy, which forms a significant share of export earnings. By estimation of some world leading economists, Ukraine is able to provide food to more than 150 million people according to its scientific and resource potential [1].

To ensure further growth of agricultural exports and increase of its efficiency, a detailed scientific approach is necessary, taking into account the regional specifics of agricultural development in Ukraine. The issues of commercial and geographical structure of agricultural exports were investigated, the export stream guidelines of agricultural goods were considered in these works. The available export potential of the studied sector of national economy and Ukraine's agri-food products self-sufficiency level were analyzed in them [2, 3, 4, 5, 6, 7].

The research and publications analysis indicates that scientists do not pay attention to the questions concerning the geographical features of agricultural export specialization of Ukrainian regions, the solution of which may contribute to the development of regional export strategy of the country's agro-industrial complex. In general, this provided the timeliness of this work.

The purpose of the study is to highlight the geographical features of agricultural exports from Ukraine.

The information basis of this work was a variety of statistical material collected from various official sources: the State Statistics Service of Ukraine, the State Fiscal Service of Ukraine, the State Customs Service of Ukraine, the Ministry of Agrarian Policy and Food of Ukraine, the UN Food and Agriculture Organization [8, 9, 10, 11, 12,13,14].

The actual material was processed by methods of mathematical statistics [9]. Cartographic material was obtained by using geo-information systems [15].

2 Results and discussion

The potential of Ukraine's agriculture today exceeds coniderbly the needs of the domestic market. As a result, there is a sharp increase in the share of agricultural products in the country's good exports (Fig. 1): less than 15% in 2010 and more than a third of total exports in 2019. Thus, agricultural industry owing to higher yields, the increased agricultural production along with extending demand for it among foreign consumers and opening new markets, has recently become one of the leading sectors of Ukraine's economy. And all this is being observed with an evident decline in other sectors of the economy. According to the State Statistics Service, in January 2020 the share of agricultural products in Ukraine's total exports reached 50% [9].

In monetary terms, foreign exchange earnings from agricultural products in 2010 amounted to $ 4.75 billion, and more than $ 14 billion in 2019.

As for the structure of exports of Ukrainian agricultural products, as presented in Fig. 2, the majority

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are crop products (68%). Fats and oils account for 25% and animal products for only 7%.

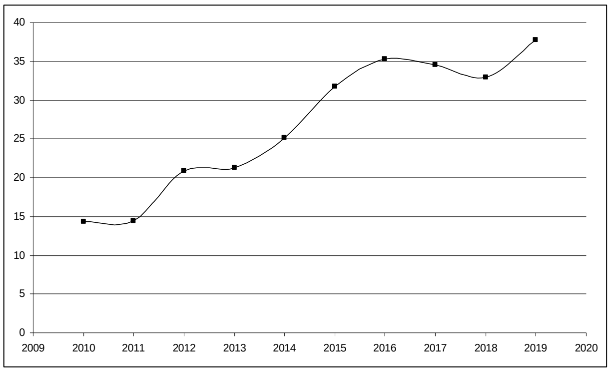

Fig. 1. The share of agricultural products (in%) in exports of goods from Ukraine in the period from 2010 to 2019 (according to the State Statistics Service of Ukraine).

Analyzing the dynamics of agricultural product exports from Ukraine for the period from 2010 to 2019 (Fig. 3) it is obvious that animal products exports remained practically at the same level. There was only a slight decline in the period of 2015-2016. In general, this decline is typical for all agricultural products exports and is associated primarily with hostilities in the Donbass and the loss of the Russian market. Later on, a significant rise of plant origin products, fats and oils export one can observe. This especially relates to crop products. Thus, in 2019, the exports of plant origin agricultural products exceeded in monetary terms almost three times in 2010. For fats and oils - almost twice.

There are several reasons for this. Firstly, new markets are being developed by Ukrainian farmers. Secondly, the cultivation of agricultural products, that are in demand abroad, is significantly increasing. Thirdly, the attitude of state and commercial organizations to agricultural producers as potentially promising players in the foreign exchange market is changing.

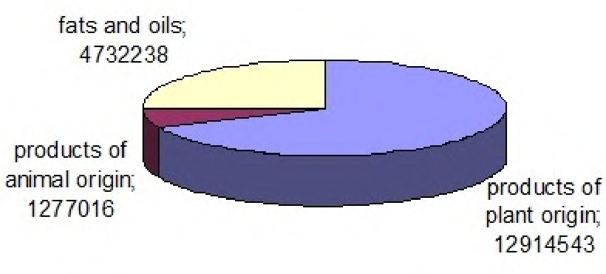

Fig. 2. The structure of Ukrainian agricultural exports in 2019 (in thousands of $, according to the State Statistics Service of Ukraine).

Among products of plant origin, exports are significantly dominated by grain crops - almost 75%. In 2019, they were exported from Ukraine worth $ 9.63 billion.

Every year, Ukraine exports up to 60 million tons of grain crops, being the third largest exporter of grain in the world. Over the past 10 years, Ukraine has increased grain exports by almost 4 times. So in 2019, this figure was 56.7 million tons, and in monetary terms - almost 10 billion dollars. In terms of crops, grain exports in 2019 are represented by wheat, rye, corn, barley and a small amount of legumes.

It is important that according to the State Statistics Service of Ukraine, the sown areas under wheat and corn have remained virtually unchanged over the past five years.The increase in production of these crops is due to the gradual increase in their yield. For example, wheat productivity has increased by almost 20%. In general, the average grain yield in 2019 increased by 2.2 quintals per hectare.

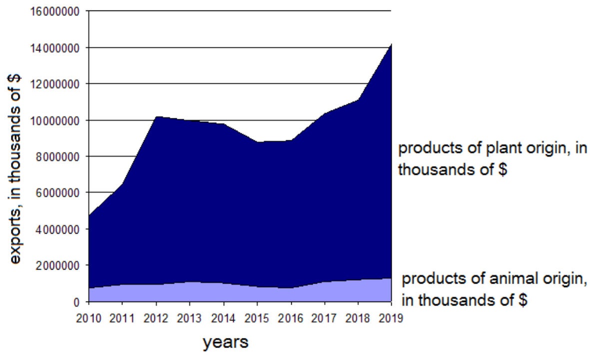

Fig. 3. Dynamics database providing export indicators of agricultural products having animal and vegetable origin from Ukraine in the period from 2010 to 2019 (according to the State Statistics Service of Ukraine).

According to the State Statistics Service of Ukraine, in 2019 the country exported oilseeds worth more than $ 2.5 billion, which is 32% more than in 2018. And the volume of export deliveries increased by more than 40% and amounted to 6.9 million tons. Here, Ukraine confidently holds a leading position in the world food market.

Exports of other plant products (vegetables, live trees and plants, edible fruits and nuts, etc.) from Ukraine are also growing steadily, however, in view of their small volumes, their impact on overall exports is minimal.

Ukraine is a world leader in the supply of sunflower oil to foreign markets. Thus, Ukraine's share in the world exports of sunflower oil amounted to 54.9% in 2019. For comparison, Russia's share in this market at the end of the season was 26.2%, Argentina – 6.2%, the European Union – 5.1%, Turkey – 3.3%. And this occurs despite the fact that the world exports of sunflower oil for the season increased to 11.49 million tons, which is 15% higher than in 2018. Accordingly, Ukraine increased product supplies to foreign markets by 14% up to 6.04 million tons, which in monetary terms amounted to almost $ 4.7 billion. Unfortunately, most of the sunflower oil comes from Ukraine as a raw material, after which it is refined and bottled under local brands. As a result, Ukrainian sunflower oil is sold abroad at a price 3-5 times higher than the purchase price.

The share of animal products in the structure of agricultural exports from Ukraine is extremely small. Despite some growth observed for this group of goods in the period 2017 – 2019, their contribution does not exceed

7%. Such a small share in exports is primarily due to the industry low development level. And if the country's crop products are produced in excess, the domestic demand for livestock products is covered by imports from other countries.

The significant decline in exports of this group, which was observed in the period 2014 – 2016, is primarily due to the closure of the Russian market. For example, if the products of animal origin at worth $ 559.5 million were exported to Russia in 2012, then only at $ 1.7 million in 2016.

The main exports of animal products are meat (55%) and dairy products (36%), including poultry eggs and natural honey (Fig. 4). The share of other products does not exceed 3 – 5%.

Meat in exports is represented mainly by meat and edible poultry offal. In 2019, this is more than 90% of all exported meat. According to the results of 2019, Ukraine has become one of the top three exporters of poultry meat to the European Union countries. 134,262 tons of poultry meat were exported, which is 8.6% more than in 2018. And as the current results of 2020 show that Ukrainian producers continue to increase their sales abroad.

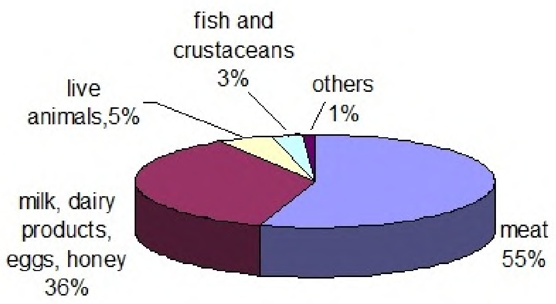

Fig. 4. Structure of livestock exports, 2019 (according to the State Statistics Service of Ukraine).

Next in weight in the structure of exports are a group of goods milk (dairy products), poultry eggs and natural honey. Within this group, about 30% are exports of honey, 23% – exports of chicken eggs and 22% – exports of milk and dairy products.

Ukraine ranks first in Europe and fifth in the world in terms of honey production. Annually, Ukraine produces about 100 thousand tons of honey, which is 6% of the world output. As a result, our country is one of the top exporters of this product.

The geography of agricultural exports from Ukraine has undergone significant changes in recent years. Thus, if until 2014 the CIS countries, including Russia, were one of the main consumers of Ukrainian agricultural products (up to 40%), then as can be seen from the diagram shown in Fig. 5, in 2019 this figure is slightly higher than 7%, as in 2018. This is due to the fact that since 2014, in connection with Russia's aggression, Ukrainian farmers have worked hard to find new markets.

Today, Asian countries are key partners of Ukraine in this area. Purchases of agricultural products by Asian countries in 2019 increased by almost 18% (to $ 9.4 illion) and amounted to 42.6% of total agro-exports of Ukraine.

The volume of agricultural products to African countries increased by 43% and amounted to 14.2% (about $ 3.3 billion) in 2019 [16,17].

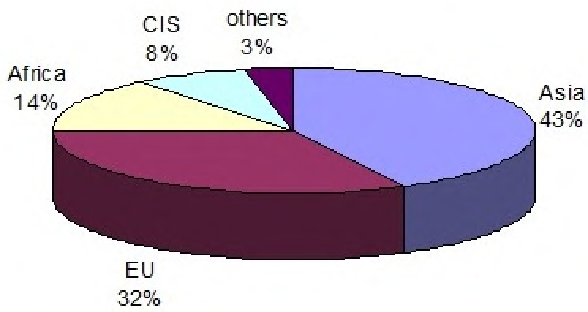

Fig. 5. Geography of agricultural products exports from Ukraine (according to the State Statistics Service of Ukraine).

If analyzed by country, the main consumers of Ukrainian agricultural products are China and Egypt. In 2019, these countries (as well as Turkey) increased the volume of purchasing these products by almost 1.5 times. As a result, they pushed to third place India, which for three years was the leader in this list. In addition to these countries, the main consumers of Ukrainian agricultural products are Turkey, the Netherlands, Spain, Germany, Poland, Italy and Belarus.

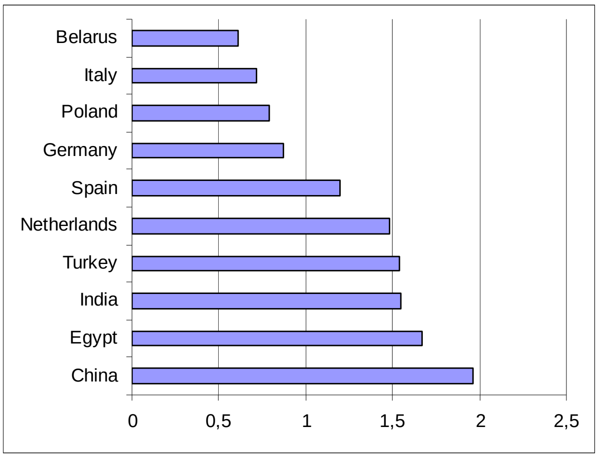

Fig. 6. The main importers of agricultural products from Ukraine in 2019 (in billion dollars, according to the State Statistics Service of Ukraine).

The formation of agricultural production specialization is determined primarily by the natural and climatic features of the region and its resource potential in their interaction with socio-economic factors [3]. The result is the territorial specialization of agricultural production. All this, no doubt, should affect the specialization of the agricultural export potential in the regions of Ukraine. Let's analyze this.

The map analysis of the agricultural export volume by regions of Ukraine (according to 2019) clearly

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demonstrates the spatial differentiation of this indicator (Fig. 7).

Thus, the regions with the highest indicators of agricultural exports geographically form an "axis" stretching from south to north (Odessa, Mykolaiv, Vinnytsia and Kyiv Regions). Further to the east are regions with average exports of agricultural products. Western regions are characterized by low rates. This includes the eastern regions of the country (Donetsk and Luhansk Regions), but this is due primarily to their partial occupation, as well as hostilities.

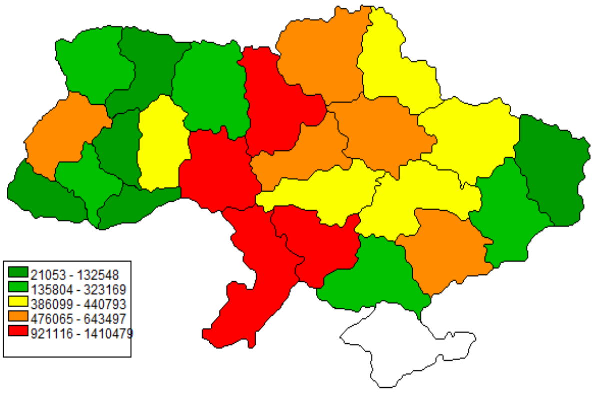

Fig. 7. The size of agricultural exports from the regions of Ukraine in 2019 (in $ thousands, according to the State Statistics Service of Ukraine).

The geography of plant products exports from Ukraine is quite remarkable (Fig. 8). Thus, the regions with the largest exports of these products (Kyiv, Vinnytsia, Odesa and Mykolayiv Regions) form the same conditional vertical "axis", which divides the territory of Ukraine into two symmetrical parts. Around this "axis" are areas with average exports of crop products (Zhytomyr, Chernihiv, Cherkasy, etc.). At a distance from the "axis", in the west and east of the country, are the areas with the lowest exports of plant products (Transcarpathian, Volyn, Donetsk, Luhansk, etc.) The exceptions are Lviv and Zaporizhia Regions.

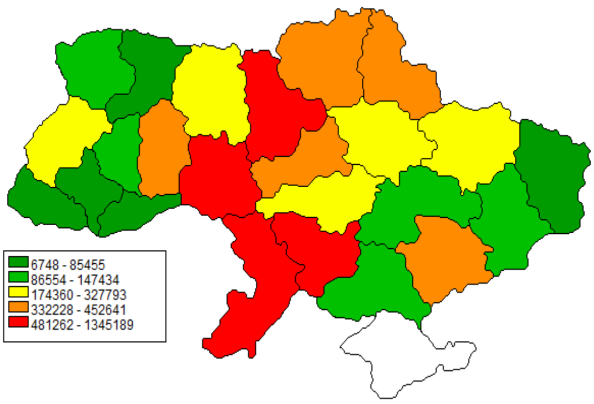

Fig. 8. Exports of plant products from the regions of Ukraine in 2019 (in thousands of $, according to the State Statistics Service of Ukraine)

Such a symmetrical model of spatial differentiation reflects a very ambiguous interaction of natural-climatic and socio-economic factors that determine the specialization of crop production in Ukraine.

Thus, the regions with the same natural and climatic conditions (for example, Vinnytsia and Kirovohrad Regions) differ significantly in export indicators. The main reason for this is economic one. Obviously, the conditions for favorable development of farming are being created in different ways. This means both purely organizational and financial support for this sector of agriculture.

As for livestock products, the picture is much more complicated (Fig. 9). The core of the regions with the largest export indicators (Kyiv, Vinnytsia and Cherkasy Regions) is clearly distinguished in the center of the country. Most poultry farms, which provide the bulk of exports of these products, are concentrated here. Indicators in other regions are distributed very unevenly, without any patterns.

Analyzing the geography of animal or vegetable fats or oils exports by Ukraine's regions (Fig. 10) it is clear that the regions with the highest indicators (Vinnytsia, Kirovohrad, Cherkasy and Dnipropetrovsk Regions) are in the center of the country. The regions with average indicators are located to the south (except for Kherson Region) and to the east (except for Luhansk Region). Western regions have the lowest values of exports of this type (except for Lviv Region).

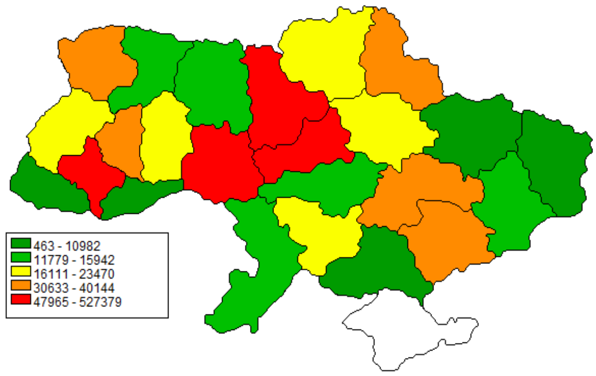

Fig. 9. Exporting products of animal origin from the regions of Ukraine in 2019 (in thousands of $, according to the State Statistics Service of Ukraine)

In general, this zoning corresponds to the natural and climatic characteristics of the regions, which allows to grow oilseeds and, above all, sunflower. High performance in Lviv Region is mainly due to the presence of a large number of commercial entities engaged in the resale these products abroad from the central regions. At the same time, Kherson Region does not use its potential, as well as for the export of other agricultural products.

In order to identify specialization in the exports of agricultural products of the Ukrainian regions, a triangular diagram was made, which shows the ratio of the three main types of products in the exports of Ukrainian regions in 2019 (Fig. 11). The analysis of the diagram allows to establish 4 types of specialization in agricultural exports of Ukrainian regions.

The first type includes the areas with a predominance in the animal origin products. These are: Kyiv, Ivano-Frankivsk, Ternopil, Volyn and Rivne Regions.

The second type is the areas with a predominance in exports of plant products. These include: Chernihiv, Zhytomyr, Zakarpattia, Mykolaiv, Sumy, Kherson and Chernivtsi Regions.

The third type is the areas with a predominance in the export of animal or vegetable origin fats and oils. These include: Dnepropetrovsk, Lugansk, Donetsk and Kirovograd Regions.

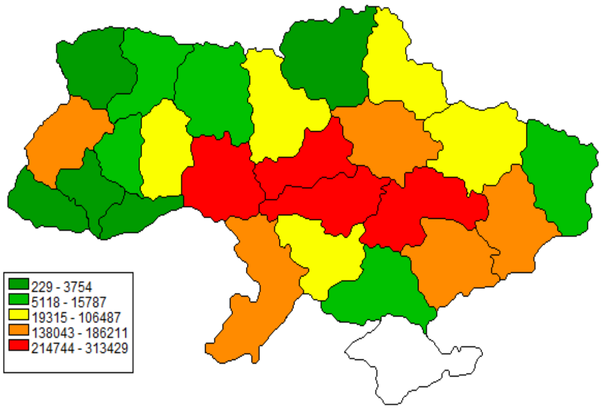

Fig. 10. Exporting fats and oils of plant and animal origin from the regions of Ukraine in 2019 (in $ thousands, according to the State Statistics Service of Ukraine)

The fourth type includes the areas with mixed export specialization, mainly vegetable products, as well as fats and oils. These are: Odessa, Kharkiv, Poltava, Cherkasy, Lviv, Vinnytsia and Zaporizhia Regions.

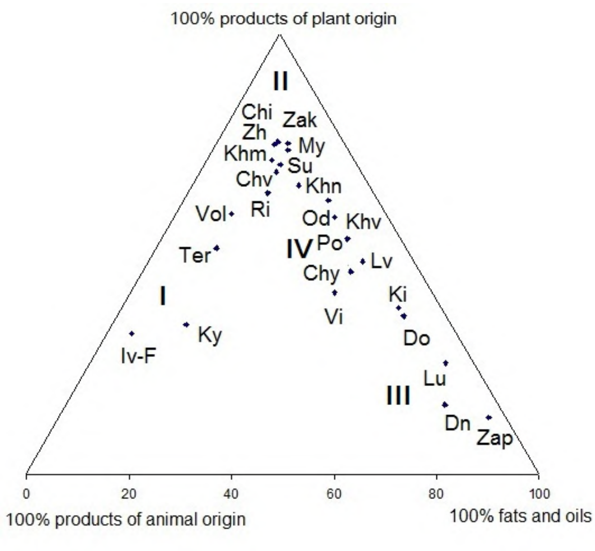

Fig. 11. Specializations in the agricultural export of the Ukrainian regions in 2019 (according to the State Statistics Service of Ukraine)

Spatial localization analysis of each specialization type allows to draw the following conclusions:

1. Products of animal origin dominate the exports of the western Ukrainian regions. The exception is the Kyiv region, in the export of which the products of poultry farms play an important role.

2. Regions whose exports are dominated by fats and oils are localized in the form of a strip stretching from the center of Ukraine to the east.

3. The areas with exports of products mainly of vegetable origin are located in the form of a strip extending from the southwest to the northeast of Ukraine and partly in the southern region of the country.

4. The regions with a combined specialization type of agricultural exports are located in the central and southern parts of Ukraine. The exception is Lviv Region, which specializes in customs transit of products abroad.

Table 1. summarizes data on the value of agricultural export indicators of Ukrainian regions with specialization types. Its analysis allows us to draw the following conclusions:

1. According to the value indicators of agricultural exports, all regions can be divided into three groups:

– the regions with the largest value of agricultural exports over $ 500 million (Kyiv, Mykolaiv, Vinnytsia, Cherkasy, Lviv, Odesa, Zaporizhia);

– the regions with an average export value of agricultural products from $ 150 to $ 500 million (Zhytomyr, Khmelnytsky, Sumy, Chernihiv, Dnipropetrovsk, Donetsk, Kirovohrad, Kharkiv, Poltava);

– the regions with the smallest value of agricultural exports from $ 150 to $ 500 million (Ivano-Frankivsk, Ternopil, Rivne, Volyn, Zakarpattia, Kherson, Chernivtsi, Luhansk).

Table 1. Correlating the values of agricultural export indicators of Ukrainian regions with export specialization.

Agricultural products that dominate exports	Areas with the value of agricultural exports over $ 500 million	Areas with the value of agricultural exports from $ 150 to $ 500 million	Areas with an export value of agricultural products less than $ 150 million
Live animals, products of animal origin	Kyiv Region	–	Ivano-Frankivsk, Ternopil, Rivne, Volyn Regions
Vegetable products origin	Mykolaiv Region	Zhytomyr, Khmelnytsky, Sumy, Chernihiv regions	Transcarpathian, Kherson, Chernivtsi Regions
Fats and oils of animal or vegetable origin	–	Dnipropetrovsk, Donetsk, Kirovograd Regions	Luhansk Region
Combined	Vinnytsia, Cherkasy, Lviv, Odessa, Zaporozhye Regions	Kharkiv, Poltava Regions	–

2. The regions with mixed (fourth) type of specialization have the highest export rates. Exceptions are Kiev (the first type – the dominance of animal products) and Mykolaiv (the second type – the dominance of crop production).

3. The lowest indicators of exports are the regions with a predominance of animal origin products (the first type of specialization) and plant origin (the second type of specialization).

4. Areas of the third specialization type (fats and oil) belong mainly to the regions with average values of agricultural exports.

According to these criteria, the geography map of agricultural exports from Ukraine's regions was built, combining indicators of the total exports value and its specialization (Fig. 12). In fact, it reflects the results of interacting natural and climatic features of the regions and their resource potential with socio-economic factors. It is clear that:

– the central and southern regions of Ukraine have the greatest potential in the development of agricultural exports;

– an exception from this rule is Kherson Region, which is the result of socio-economic factors impact and, above all, insufficient attention from the regional leadership and farms to the development of this extremely important area of the region and the country as a whole;

– to increase the export of agricultural products in these regions it is required to have a balanced combination of crop production (mainly grain) and the cultivation of oilseeds. Thus in the Kirovograd, Dnipropetrovsk and Donetsk areas, for today, it is necessary to make an emphasis first of all, on grain, and in Mykolaiv Region – on oil crops;

– in Zakarpattia and Chernivtsi Regions for increasing agricultural products exports there should be paid more attention to the development of animal husbandry.

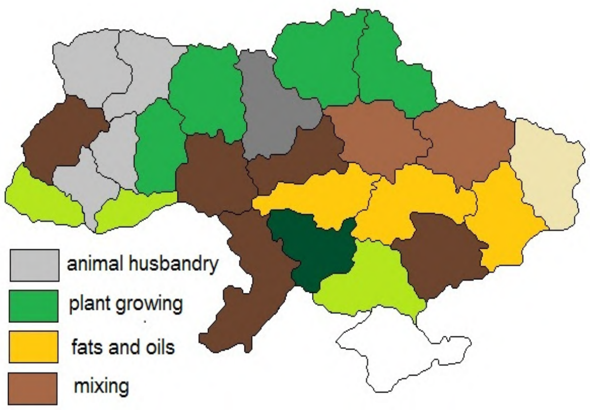

Fig. 12. The geography map of agricultural exports from the Ukrainian regions (according to the State Statistics Service of Ukraine) in 2019. The colors reflect the types of export specialization (4 types), and their intensity – the total value of agricultural exports in the region (3 groups).

3 Conclusions

As a result of the research performed it was established the following:

Agriculture has recently become one ofthe leading sectors of Ukraine's economy, currently providing up to 50% of foreign exchange earnings from exports of all goods from the country.

Given the dynamic characteristics of the agricultural exports growth from Ukraine, we can assume that the country in the coming years may become one of the most important players in the world market of agricultural products.

In the structure of Ukrainian agricultural exports, the majority are crop products (68%), fats and oils (25%), and animal products (only 7%).

Four specialization types of agricultural exports from Ukrainian regions are established: the first type is the areas with dominance in the exports of animal origin products; the second type is the areas with dominance in the exports of plant products; the third type is the area dominated by exports of animal or vegetable origin fats and oils and the fourth type is the area with a mixed specialization of exports, mainly products of vegetable origin, as well as fats and oils.

The geographical analysis of agricultural exports from the Ukrainian regions allowed to develop recommendations for the re-profiling of agricultural production in a number of the country's regions in order to increase exports of this product type.

In this way, by agricultural products geography export expansion Ukraine will be able to create a competitive, export-oriented agricultural industry, and food-processing industry would produce competitive foodstuffs in accordance with the international safety and quality standards. In the result of these transformations, Ukraine will strengthen its positions at the traditional export markets and will trade its new export products with new partnership countries, which will facilitate positive farm products balance of trade. This, in turn, will have a positive impact on the development of our country's economy agrarian sector.

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Use of GIS technology in geographical education

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Abstract. At the present stage, digital information technologies create a new education system focused on the global educational space. In general education schools, in connection with the adoption of the updated program, the section Geoinformatics and cartography provides for the use of developing a map-scheme, modeling and conducting small studies on the topic under study. As a result, digital technology has a place in geographical education. This is due to significant changes in the pedagogical and methodological approach in teaching geography and other disciplines. As a result, the education system has changed, the content of education has been updated, a new approach has appeared, a new attitude to geoinformation technologies in schools. The article discusses the importance of computer technologies in the education system, including the effectiveness and necessity of using geoinformation technologies. The article substantiates the relevance of the use of geoinformation technologies in the teaching of geography.

1 Introduction

It is quite obvious that without modern information technologies it is impossible to achieve competitiveness in the market. The most important of them is the lack of a single or unified market for joint software tools, which would allow partners to use the resources accumulated in different automation systems. Currently, digital technologies are rapidly developing. The number of sites is growing daily. Search engines already refuse to name the exact number of them, citing the impossibility of accounting.

In the modern world, geoinformation technologies are widely used in geography, tourism and many other spheres of human activity. To improve the quality of education in Kazakhstan, the State Program for the Development of Education for 2011-2020 has been developed. The law on the status of a teacher was adopted [1].

In this regard, reforms and policies, changes and innovations in the country's education system can become the basis for every pedagogical community to think, reflect on the past and present. Work with new ideas and face the challenges of an updated program. “Geography” in high school (grades 10-11) - is, creating conditions for students to apply geographical knowledge, skills and abilities aimed at solving geoecological, geo-economic, social, geopolitical and global problems that arise at all levels of geographical space [2].

Technology (from greek. “techno” – art, “logos” – thought, reason, technique, method of production) – a set of methods, processes and materials used in any branch of activity, as well as a scientific description of the methods of technical production [3]. Geographical information – information about objects and phenomena that take place in the surrounding space on the territory of the planet Earth and are accompanied by geographical coordinates (longitude, latitude). The combination of geographic information and computer technology has led to the creation of geographic information technologies or geographic information systems (GIS) [4].

GIS is “... information systems that ensure the collection, storage, processing, display and dissemination of data, as well as obtaining new information and knowledge about spatially coordinated phenomena...”.

Therefore, we offer technologies for using GIS mapping. Here, the main place is occupied by satellite images and remote sensing of the Earth. In our practical work for the last 2-3 years, we have been using this method to develop tourist routes and to draw up map schemes for some sections of geography. When developing routes using remote sensing and GIS technology, we determine the state of the route, the terrain, and dangerous mountain areas for safety purposes. In the research works of graduate students and doctoral students, there is a mandatory requirement to apply remote sensing methods.

Here is a concrete example of how to use remote sensing and GIS technologies in the educational process. From a scientific point of view, this moment has been tested, and is used in the dissertation work of the doctoral student A. Demeuov.

For the first time, the term “geographic information system” appeared in English-language literature and was

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used in two versions, such as geographic information system and geographic information system, very soon it also received the abbreviated name GIS.

2 Initial data and research methods

A breakthrough in the field of creating geographic information systems and the beginning of the development of geoinformatics is the development and creation of the Canada Geographic Information System (Canada GIS). Its history begins in the 60s of the last century and to this day this large-scale geoinformation system is being developed and maintained.

The components of the geographic information system include:

1) data (spatial data);
2) hardware (computers, peripherals, network equipment);
3) software (software);
4) methods;
5) specialists.

There are many examples of using GIS. Currently, almost every Internet user has at least once accessed map resources (such as Google Maps, Bing, OpenStreetMap, Yandex Maps, etc.) that provide information on a free basis. This area is called web mapping.

Along with web mapping, there are network GIS, as well as desktop GIS. Their use in areas of human activity, such as the extraction of natural resources, the study of the environment and climate, as well as education, is growing every day. They are widely distributed all over the world. The Republic of Kazakhstan is also no exception.

For example, in the Russian Federation a closed JSC “Design Bureau Panorama” developed educational-methodical complex “Living Geography”, including a dedicated set of satellite images, guidelines.

The analysis of changes in various spheres of activity over the past decades allows us to speak about the progress that has allowed us to move rapidly in various sectors of the economy. The search for solutions to some problems leads to innovative methods. Innovation impresses with its growth rate and becomes an integral part of our lives.

Online information technology strategies require innovative approaches and organizational restructuring. In order to take advantage of the Internet and counter the risks associated with it, it is necessary to adopt new approaches. Only those who innovatively use traditional advertising strategies or offer fundamentally new concepts can achieve success in the Network. For example, Interactive maps and photos. With the help of several sites, you can get into the universal GlobeXplorer library, which contains satellite aerial photographs of almost the entire surface of the Earth. MapQuest is the first brand to introduce this technology. With the help of GlobeXplorer technology, the consumer sees interactive aerial photos of many cities, rural areas and major tourist attractions. The combination of aerial photography and digital mapping makes it easy for tourists to navigate unfamiliar terrain. For example, AOL (America Online) members and MapQuest users planning a trip can design a travel itinerary, then view the map and see the selected location from a bird's eye view. With the navigation features provided by MapQuest and GlobeXplorer, the tourist can easily navigate the site in all directions and visually find roads, rivers and other landmarks. An attractive and fundamentally new project for promoting the tourist opportunities of our country should be the “Interactive Tourist Map of Kazakhstan”.

The principle of its construction should be that a potential tourist can get comprehensive, interactive information about the country, its tourist opportunities and attractive tourist sites in all regions. An interactive tourist map of Kazakhstan should provide an opportunity for a potential tourist to make a virtual trip along the route chosen and interesting to the client, or excursions, to have a complete idea of the tourist center, this or that attractive tourist object.

Innovation is an implemented innovation that provides a qualitative increase in the efficiency of processes or products that are in demand by the market. It is the end result of a person's intellectual activity, imagination, creative process, discoveries, inventions and rationalization [3]. Since tourism is an important sector of the economy, which is one of the main sources of income in many countries of the world, innovations have also affected its development. Innovation in tourism brings new ideas, services and products to markets.

The main directions of innovative activity in the field of tourism are the release of new types of tourist products, the use of new equipment and technology, marketing, management; identification and use of new markets for products. Tourism is a multi-faceted phenomenon that carries an economic function and the function of satisfying the spiritual needs of a person.

Innovative activities in tourism with the use of high-tech equipment for remote sensing of the Earth (ERS), new materials have influenced the nature and structure of modern tourism. The new era of information technologies has expanded the scope of their application. One of the most striking examples of this is GIS technology.

Geographic information system – a system for collecting, storing, analyzing and graphically visualizing spatial (geographical) data and related information about the necessary objects [4].

At first glance, GIS is a tool for preparing digital maps and printing them on paper or polymer media. However, the real range of GIS applications is much wider, since these technologies are currently used in various fields of activity, including tourism.

To solve the problems of tourism development, interactive maps using GIS technologies are needed. They will mark major resorts, recreation centers, plans of resort areas and adjacent territories, give characteristics of tourist and recreational facilities, information about the quality of service, photos of the room stock, cuisine, beaches, etc. This would provide potential tourists with comprehensive information, since it is believed that GIS is a technology that answers questions instantly. In addition, in some countries GIS tools are used for planning the development of regional tourism [5].

In the opinion of the authors, the work on the creation of tourist GIS can be successful if they focus on the creation of so-called Internet services using GIS technologies.

A big advantage of these services is their popularity among a large mass of Internet users, as well as the availability of detailed maps of major cities. However, according to the authors, the lack of these services for the development of tourism in the Republic of Kazakhstan is the lack of specialized information about tourist and recreational facilities located both within urban areas and outside them and related various attribute information.

In order to solve the problem of increasing income from inbound tourism, there are various strategic programs at the state level in the Republic of Kazakhstan, covering various activities, including the creation of tourist information Internet portals. As an example, you can use the website www.VisitKazakhstan.kz implemented by relevant departments. The site provides a large amount of useful information about tourist and recreational facilities, routes, and so on. However, users often require the presence of interactive tourist maps.

Since, in the current conditions of the world economy, tourism is becoming one of the leading and dynamically developing industries, the relevance of the chosen topic is not in doubt.

According to the UNWTO, tourism ranks fourth in world exports of goods and services (7.4 %). However, in Kazakhstan, unfortunately, tourism is still not perceived as a full-fledged branch of the economy and the subject of scientific analysis. In general, the concept of “tourism” in the republic is more often associated with sports and health promotion, rather than with an economic sector that generates significant revenues, primarily in hard currency. After all, in fact, tourism is a complex multi – faceted manifestation of public life, but first of all, it is a “spatial socio-economic phenomenon”, also in many ways “spatial cognition”, firmly connected with the territory of the country and its individual regions.

3 Results and discussion

In Kazakhstan tourism, it is necessary to pay more attention to poorly developed, but no less interesting tourist products. A striking example is the city of Ridder (Figure 1). It has a unique tourist potential. A strong point in terms of tourism development are: a convenient geographical location (proximity to Russia and China), also this unique mountain area for Kazakhstan is located close to the regional center – Ust-Kamenogorsk, and the presence of a developed transport infrastructure – the city has its own railway station “Leninogorsk” [6].

The environs of Ridder include: Ivanovsky and Stanovoy ridges, the upper reaches of the Black and White Uba rivers. Here is located the West Altai State Nature Reserve, the main object of protection of which are typical for the Western Altai landscapes, in particular-the black taiga. The area of the protected area is 54533 hectares. The region has 8 recreation centers, 2 ski resorts, 4 public organizations of tourist orientation, 4 children's camps.

When visiting Ridder and its surroundings, the priority types of tourism can be distinguished: active (mountain, ski and ski, bicycle and car, sports, equestrian and hiking); ecological and educational (amateur photo safari, spa treatment, fishing and hunting, village, ethnic and ethnographic). The territory of the mountain suburbs of Ridder is suitable for organizing almost all types of geotourism.

Fig. 1. Survey image of the research area (Google Earth).

Free and quick access to the vicinity of Ridder (no special pass to the border zone is needed), allows you to organize tours of short duration up to 2-3 days (“weekend tours”). So, the recreation centers “Belaya Uba”, “Gromotukha” and “Klimovka” serve just such tourists. A wide range of interesting places is covered for making routes of various nature and complexity (mountaineering, mountain tourism, horse tourism, rafting, sport hunting, cycling). In terms of tourism, the Ivanovo and Stanovoy ridges, the upper reaches of the Black and White Uba Rivers are attractive. Here is the largest number of recreation centers, more prepared infrastructure [7].

The most popular places to visit, in the general structure of land use of the city, include water resources – the sources of many Altai rivers: the Gromotukha (spring rafting), Tikhaya, Bystrukha, Zhuravlykha and Filippovka rivers, merging, form the Ulba River (rafting), Lake Kedrovoye (fishing), Malouba Reservoir (trekking, historical tourism, skiing), the Turgusun River (rafting).

The tourist significance of mountain ranges lies in the fact that under the influence of endogenous and exogenous factors, various natural and territorial complexes were formed. Objects of the mountain environment (typical unique mountain complexes, natural monuments) that are of great educational, sports, health, religious and scientific interest. This includes the highest mountain peaks and peaks, passes, bizarre rocks, grottoes, boulders, etc.

One of the most famous tourist places in the vicinity of the city is the “Black Knot” - the junction of the three main ridges of the district (Koksuisky, Ivanovsky and Kholzun). Here is a unique natural monument – the Museum of Giant Stones “Kamennaya Skazka”. At an altitude of 2000 m, stone statues of the most bizarre shapes froze. Here are the “Line Pillars”, “Maryin Utes” and “Stone River”, where the filming of the famous TV series “Eternal Call” took place.

This region is also known for sports tourism. Since 2009, Ridder has hosted auto and motorcycle races 3...4 times a year. They bring together participants and spectators from all over Kazakhstan and some regions of the CIS. Thanks to these events, the city became known as the "Capital of motor racing in East Kazakhstan".

The region is an important destination for skiing and alpine skiing tourism. It is not at all inferior, and perhaps, in terms of technical characteristics, it is somewhere superior to many ski and ski slopes. In the suburbs of Ridder, there are many so-called mountain squirrels, where snow lies almost all year round. For example, the well-known Vyshivanovsky Belok (Voroshilov Peak) (trekking, mountain tourism, summer ski camps, eco-tourism). Ridder is the pearl of East Kazakhstan for skiers.

The first project of a high-mountain base in Kazakhstan-a shelter located far from the benefits of civilization, surrounded by the pristine nature of the Western Altai-is located on the passable protein (1800 m) [6]. In the "Ridderhutte" develops an extensive list of priority areas of tourist activity, which is developed by the sports project of the base, aimed at promoting the development of skiing in Kazakhstan. It allows athletes to train in the summer at home, without going abroad and without incurring huge financial costs.In the vicinity of the 2nd district of Ridder, there is a ski center equipped with an anchor cable lift. Restored ski lift in the Upper Harutoki.

If we consider the development of Ridder as a ski and ski resort, it should be noted that this is a large-scale project, the implementation of which is currently unthinkable without geoinformation support [7]. The relief of the mountainous surroundings of Ridder has a huge tourist potential. For the protection and rational use of this potential, it is necessary to map it at the level of modern science and technology. The objects of research and cartography should be mountain slopes, which will serve as the basis for creating tourist trails in the future.

Ensuring the design, construction, and in the future – the successful operation of many tourist facilities, requires timely and high-quality cartographic support. At the same time, at the stage of development of project materials, it is necessary to solve problems related to the selection of sites of spatial location of various tourist objects and structures. On the one hand, special requirements are imposed on them (for example, for ski routes – slopes for various types of competitions, features of wind characteristics for springboards, etc.), and, on the other hand, transport accessibility must be ensured while minimizing the violation of the unique natural conditions of the region.

The accuracy and other qualities of the compiled map depend on the cartographic source used and the methodology used. Maps should be compiled on the basis of a number of cartographic sources: general geographical, physical, geomorphological maps of the Ridder area of different scales, tourist schemes, extensive use of specialized literature and departmental materials.

Modern GIS technologies allow you to create tourist GIS, i.e. systematized data for the organization of tourist activities [8]. Every tourist visiting Ridder will be able to quickly get any information in the form of maps, digital models, graphs, diagrams and other types of information using GIS materials.

For this purpose, in the preparation of this article was used software QGIS v2.4.0 and data on the topography of the open-source ASTER GDEM v2.0.

So, with the use of tools for morphometric analysis were analyzed the topography of the study area and the resulting maps of the exposure of the slopes (Figure 2), shaded relief, and ruggedness.

Analysis of the exposure of the slopes of the area showed the predominance of south-western and north-eastern orientation, which is clearly demonstrated on the map.

At the heart of the initial stage of the formation of the design of Ridder as a ski resort is the translation of previously obtained by traditional methods of cartographic materials of the city and its mountain surroundings into an electronic cartographic form with their subsequent unification on the basis of a single cartographic basis. In the future, these blocks of the geoinformation system are increased by electronic cartographic data obtained directly in solving the problems of developing a mountain climate resort, including updating data on the results of monitoring (environmental, geological, technological, service, etc.).

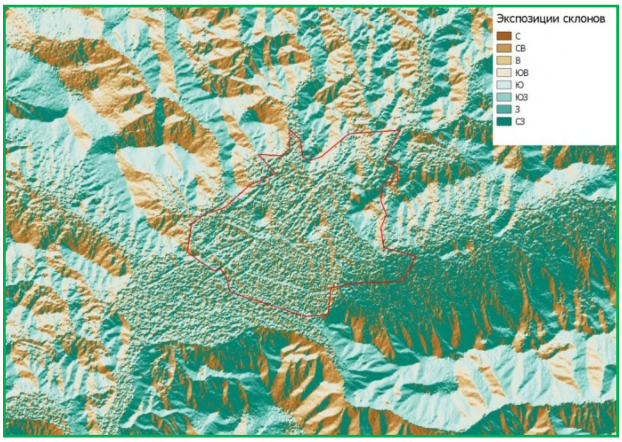

Fig. 2. Slope exposure map.

The second feature of the work on the creation of a block of detailed electronic cartographic materials is the need for 3D data from specialists who perform work on engineering and environmental surveys, design, engineering protection of the territory from dangerous hydrometeorological and geological processes. 3D data has significant advantages in providing information about the nature of the surface and its inhomogeneities. These heterogeneities are caused by the complex geological structure of the region and formed, at present, as a result of the development of geological processes, including requiring consideration in the design of various buildings and structures.

These materials related to 3D data should fully reflect the three-dimensional structure of the mountain area under consideration for ski tourist trails and other auxiliary facilities (Figure 3).

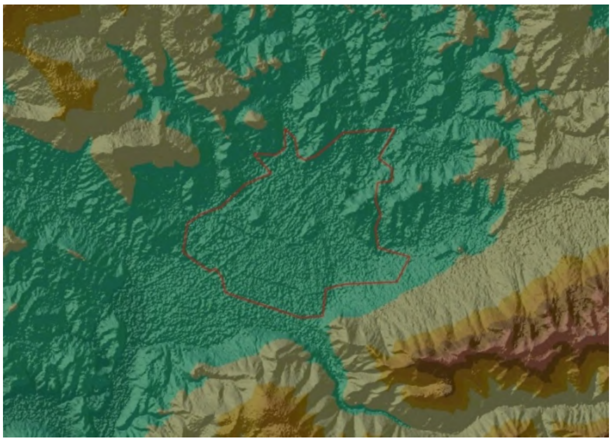

Fig. 3. Washing of the relief of the research area.

For example, economic geography reveals the features of the geographical location of the city – this specific resource, perhaps the most important for development. It obliges to consider the city together with the environment, acting as its partner and at the same time addition, as well as the sponsored territory that it is obliged to serve and take care of. Changes in the city cause a response in the environment. By managing the development of the city, you can also manage the development of adjacent territories. The city, as an object of research, is important for geography, which finds application in it for subsidiary sciences and can realize the potential of an integrator science. Being a set of enterprises and devices that have a strong impact on the environment, the city not only becomes an area with a tense environmental situation, but also a factor that changes the environmental situation within a vast space [8].

The capital of the Republic of Kazakhstan is Nur-Sultan, located in the center of the country in the steppe zone. From the point of view of the relief of the earth's surface, the city is located on the low above-floodplain terraces of the Yesil River, which is the main waterway of the city. The climate is characterized as sharply continental with long cold winters and hot summers.

Nur-Sultan today is an example of sophistication of architectural style, striving to achieve the harmony of an environmentally friendly metropolis. The area of the capital's “green belt” around the city is regularly increasing, it has become a kind of oasis in the center of the steppe. Nur-Sultan is also the political, administrative, business and cultural center of the country, where the central authorities, diplomatic missions, universities, modern medical institutions and cultural centers are located [9].

Currently, the role of the city as a transport, logistics and communication center in the center of Eurasia is increasing. Despite the short period since the beginning of the historical change of the capital, Nur-Sultan became the main city of Kazakhstan during the formation of the young state (Table 1).

In this regard, the role of the city as one of the centers of tourism has increased, as the flow of tourists seeking to visit the capital of our country increases from year to year. According to some foreign tourists, the architectural appearance of Nur-Sultan is at the same time similar to Dubai (UAE) and Tokyo (Japan), and is something in between. The unique architecture of the capital of Kazakhstan embodies the so-called “eclecticism”, i.e. a mixture of different styles. This has been achieved over the past 15 years with the involvement of internationally recognized architects Sir N. Foster and K. Kurokawa, as well as many other architects.

Table 1. Classification of some tourist and recreational facilities in Nur-Sultan.

№	Name	Type of tourism	Subspecies of tourism
1.	Ethno-memorial complex “Atameken”	Historical and cultural	Architectural culture tourism
2.	Palace of Peace and Reconciliation		
3.	Independence Monument		
4.	The Palace Of Independence		
5.	Palace of Creativity “Shabyt”		Tourism of the urban environment and culture
6.	National Museum		Architectural culture tourism
7.	“Astana Opera” Theatre		Tourism of the urban environment and culture
8.	“Khan Shatyr” Shopping Center		Architectural culture tourism
9.	The Monument “Baiterek”		
10.	“Alau” Ice Palace		Tourism of theme parks of culture
11.	“Astana Arena” Stadium		
12.	The Cycle Track “Saryarka”		
13.	Hippodrome “Kazanat”		
14.	Stella “Astana Zhuldyzy” (Stars of Astana)		Architectural culture tourism
15.	Nazarbayev University		Tourism of theme parks of culture
16.	Triumphal Arch (Mangilik El)		Architectural culture tourism

The full list of places offered for visiting is about 70. However, for objective reasons, this article contains only part of the specified list of tourist and recreational facilities.

Currently, the achievements of science and technology offer various tools for human activities to increase efficiency, including for tourism. Such a tool can be called GIS or geographic information systems designed for the collection, storage, analysis and graphical visualization of geographical data. Since there are a lot of materials on this topic in open sources, the authors of the article did not stop at explaining the terminology, but preferred to focus on the results of the work. As mentioned above, geographic information systems have a number of functional properties that allow you to enter, store, process and visualize geographical data. In this regard, the authors of the article used software with an open license Quantum GIS v.2.6.1 [10].

The scheme was based on the list of tourist and recreational facilities compiled earlier. The objects were plotted on space images provided in the public domain through the Google Maps service. Keep in mind that GIS data is stored in layers in vector and raster formats. Thus, in the future, a point layer with the image and names of objects is obtained, as well as a linear layer with the image of the route line. Then the attribute tables of these layers were integrated with the above table of tourist and recreational objects of the research area, the symbols were set, and the layout of the scheme was prepared for printing.

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In the work carried out, the map of the city of Nur-Sultan was used, covering the objects of tourist infrastructure (Figure 4).

Fig. 4. Scheme of a complex tourist route on the territory of Nur-Sultan.

As a result of the work, a map of the tourist route within the city of Nur-Sultan was drawn up, which covers the above types of tourism (Figure 4).

This method of work can be useful both for educational activities in the field of tourism, and for drawing up route diagrams in the development of tourist products using hardware and software tools to obtain high-precision data.

GIS significantly speeds up many stages of mapping. Tourist maps compiled in the GIS environment are characterized by good design, accuracy, attractiveness, speed and production options [11; 12]. In addition, it is possible to analyze any component of the mountain route separately, create a digital terrain model (DEM), organize e-tourism, disseminate information, etc.

4 Conclusions

The use of GIS technology in geographical education is thus acceptable in the development of tourist maps, at school and at university. In practice, we were convinced that high school students in the geography sections together with teachers can use GIS in geography lessons, and we were convinced of the possibility of creating a unified geoinformation system for Ridder and its districts as a mountain climate resort.

The creation of a unified geographic information system of Ridder and its districts as a mountain climate resort should be carried out in several stages, starting with the formation of a block of medium-scale electronic cartographic materials, which is clearly demonstrated in this article. By saturating the unified geographic information system with detailed electronic cartographic materials from various performers, which are received as engineering and environmental surveys are completed at individual sites, it is easy to create a large-scale map of Ridder as a tourist destination in Kazakhstan.

At the moment, we are developing an application for tourist sites in certain regions of Kazakhstan. Internet services using GIS technology were demonstrated in some sectors of the economy during the world exhibition EXPO-2017 in Nur-Sultan.

The use of GIS technologies in educational activities, both in the specialty “Geography” and “Tourism”, and in other specialties, increases the accuracy of data, their reliability, and also clearly demonstrates the current situation and makes it possible to create various models. In turn, the above allows you to improve the quality of higher education.

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Pedagogical possibilities of tourist and local history activities

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Abstract. In the new socio-economic conditions in the education system, forms of organization of tourist and local history activities are developing, which are based on traditions, experience of extracurricular and extracurricular work, taking into account the changes that have occurred in the country. Life requires that the tasks facing educational institutions are resolved quickly and have not just any solution, but one that optimizes the pedagogical process. At the same time, these requirements come into conflict with the state of the education system, the limited ability of most parents to create conditions for the full development of the child. The tasks facing the education system can be implemented in tourism and local history activities. The main task is to create the necessary conditions for the comprehensive development of the child's personality, his social adaptation in the process of participation in various types of tourist and local history activities. However, the school teacher is not ready to organize and conduct tourist and local history activities at school, as he is not professionally prepared for this activity. Questions of the organization, forms and methods of teacher training for the organization of tourist and local history activities are practically not reflected in the educational and methodological literature. There are no scientific studies that would allow us to effectively solve the pedagogical tasks of preparing the organizers of tourist and local history activities in the school.

1 Introduction

Pedagogically correct organized and structured tourist and local history work allows the teacher to implement the local history principle of teaching the subject. Collection and accumulation of local history material for use in the classroom, as a rule, is carried out in hikes and excursions, in the process of search work. Local history is closely related to the development of the basics of science, with the practical application of the basics of geography, biology, mathematics, and other subjects. Contributing to the acquisition of knowledge about the phenomena of the environment and life on the material of the local region. It is the most rational means of learning the general laws of nature by introducing students to the basics of production, makes it possible to link theory with practice, helps to develop practical skills. Local history contributes to the deepening of inter-subject relations in the educational process. For the first time in Kazakhstan, the training of geography teachers and organizers of tourist and local history work has been started since 1987 [1].

The use of local material in the process of perception and comprehension of knowledge helps to resolve the pedagogical tasks of the teacher: its use enriches the content of the teacher's explanation, gives it a specific character, and promotes education in the minds of students the concepts as the answer to new questions for which previous knowledge is not enough; the use of local material depending on lesson plans, changes the relationship between teacher and students.

The involvement of local history material in the process of transferring new knowledge creates a favorable problem situation when students come to a conclusion based on known facts, compare a number of scientific facts and phenomena with the facts of the environment, have the opportunity to critically comprehend and perform independent work.

During the study of local lore, schoolchildren learn the peculiarities of their own character, such important personality traits as mutual assistance, mutual assistance, responsiveness, responsibility, discipline, and tolerance are formed in them. In the course of the implementation of the collective form of activity, students develop a moral consciousness and an idea of the system of norms of moral behavior. So local history activity can act as a means of implementing the tasks of moral education.

In the process of tourist and local history activities, pedagogical directed influence, as a result of systematic and purposeful educational work, positive experience of behavior is accumulated, while favorable conditions are created for the formation of moral qualities of the child's personality. Tourism and local history in their modern understanding are physical development, health improvement and knowledge of the surrounding reality, the formation of valuable spiritual qualities of the individual [2].

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The education of such moral qualities as a sense of duty, responsibility for the assigned task, diligence, commitment, initiative, independence, contributes to the performance of permanent and temporary official duties by young tourists - commander, guide, treasurer, caretaker, kitchen attendant, etc. Mastering these skills also contributes to the formation of a conscious attitude to work, helps in choosing a profession.

Performing local history tasks on the route, constantly being in the natural environment, communicating with the local population, getting acquainted with the monuments of nature, history and culture contribute to the education of spiritual and moral qualities, patriotism. Thus, a system of tourist and local history activities was created.

In this article, we offer only one of the models of the tourist and local history cycle for students "Geography-Tourism", where the whole process is shown in the diagram.

The first course – field practice in topography, geology, botany, meteorology.

The second course year-practical training in zoology, cartography, soil geography, hydrology and geomorphology.

Third year – performing the practice according to the Figure 1.

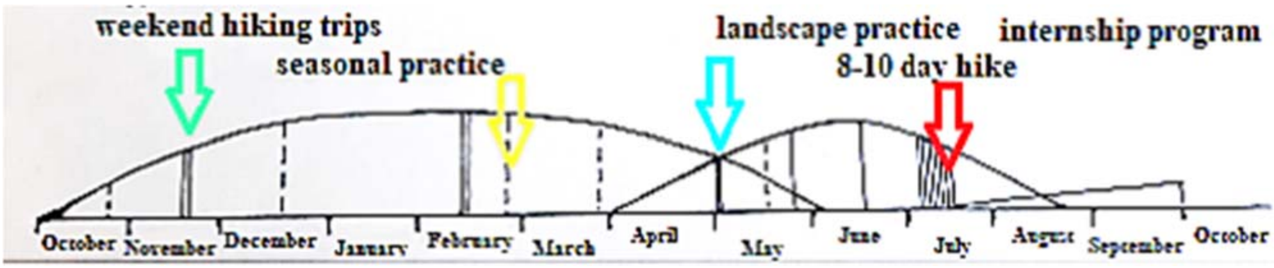

Fig. 1. Tourist and local history cycle for students of the Faculty of Natural Geography.

A. Special training "Big cycle" - instructive and methodical, economic, tourist and local history and physical training.

B. Small cycle. Practical work on the ground, improvement of tourist equipment and tactics. There is a special course on tourist and local history work at the school. Visiting schools and extracurricular institutions.

The fourth year – pedagogical practice at school (tourist and local history work in educational institutions).

Pedagogical universities using this model can prepare future geography teachers for the TLhA.

The novelty of the research is the application of this approach to the educational process at the university.

Using the model of interpretation, we focus on dual education, there is a practice-oriented approach. Students understand, are able and know the importance of tourist and local history work. [1]

Tourism and local history activities (TLhA) are an important means of improving the health and physical development of students. With the current unfavorable ecological state of cities and towns, high noise levels and other traumatic factors, as well as a significant time spent by children in closed rooms, a one-day or two-day hiking trip is an effective means of improving health and preventing diseases. Tourist trips, tourist competitions held in nature, distract them from strenuous educational activities, relieve stress and tension. The days spent in the fresh air give the children a powerful charge of cheerfulness and energy, allow them to work at school with creative enthusiasm and good mood. After a pedagogically well-organized hike, the teenager feels physically well and calm for several days. All this contributes to improving the quality of the educational process [3].

Visiting nature reserves and national parks is particularly popular in Canada, Kenya, the United States and China.

The common distinguishing features of European children's and youth tourism centers are a rich excursion and educational program with a wide range of sports and wellness services. In educational institutions in England, France, Germany, Austria and other countries, when studying individual subjects, teachers use walks and trips to nature in their work with students. Such methods allow students to acquire and maximize the need for knowledge, creativity, and self-determination personally and professionally. Youth tourism has become an integral part of the lifestyle of the younger generation in Germany. A wide network of youth tourist bases within Germany itself (more than 600 youth bases and 400 homes for young nature lovers) is provided for the services of young people, whose stay is very inexpensive for young residents of Germany. In Japan, during the school holidays, students go out to learn various folk crafts. Such excursions, on the one hand, foster respect for work, expand the understanding of the economic potential of the country. On the other hand, such trips can have an important utilitarian purpose - to help with the choice of a future specialty [4].

In Kazakhstan, tourism and local history activities are becoming a mass movement of the younger generation, parents and the pedagogical community in order to learn about the environment and through tourism. The state network of children's institutions of additional education of tourist and local history profile in Kazakhstan began to form in the 60s of the XX century. During the years of independence, the education system of the Republic of Kazakhstan has developed and operates a system of tourist and local history work.

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Over the past decades, there has been a positive trend in the development of tourism and local history (2004-9 stations, 2019-37 stations).

More than 800 thousand children and teenagers participate in the implementation of such programs of the tourist and local history movement of students as “Atameken”, “Bolashak”, “Zhasurpak”, “Shugyla”, “Tugan elge tagzym” and others. Within the framework of the tourist and local history expedition of schoolchildren “Menin Otanym-Kazakhstan”, dozens of hiking, skiing, water, cycling trips, expeditions and excursions are held annually, in which thousands of young tourists and their adult mentors participate. Every year, more than 1,300 specialized yurt and tent camps are organized in the republic, where 140 thousand children have a rest and get tourist skills [5].

In the process of tourist and local history activities, pedagogical directed influence, as a result of systematic and purposeful educational work, positive experience of behavior is accumulated, while favorable conditions are created for the formation of the moral qualities of the child's personality. First of all, these are the qualities that are brought up as part of a tourist group that exists in an autonomous mode-collectivism, responsibility and mutual assistance.

The authors have conducted experimental studies on the possibility of TLhA for 30 years. The result is the training of teachers-organizers on the basis of geographical education in a pedagogical university.

2 Results and discussion

Currently, 37 stations and centers of young tourists-local historians carry out tourist and local history educational activities in the Republic, 23529 schoolchildren are engaged in them. Between the ages of 6 and 18, 651,409 students are engaged in palaces and kindergartens, and 33988 students are engaged in tourist and local clubs and school associations. In general, 57517 children are covered by tourist and local lore directions, which is 1.96% of the total number of schoolchildren in 2018 (Figure 2).

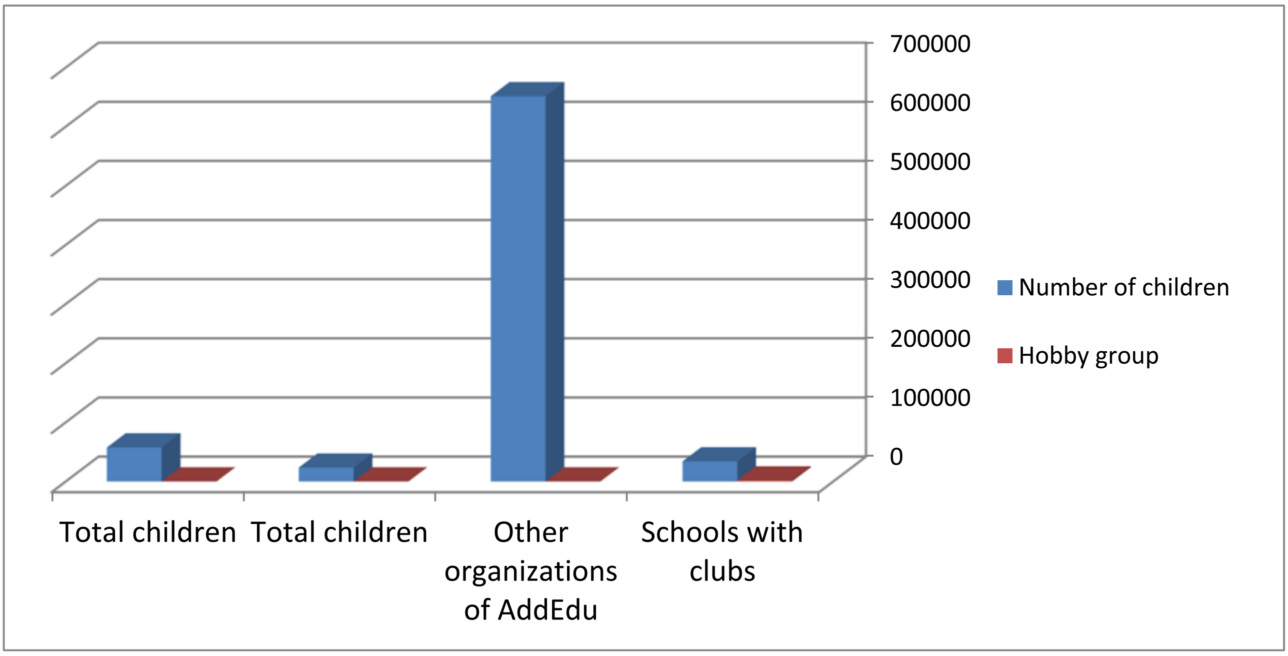

Fig. 2. The number of children employed in tourist and local history circles.

It is well known that with scientific, technical and social progress, the need for a person to assimilate a large amount of diverse information, quickly update knowledge, and improve skills increases. In these conditions, the role of tourist and local history activities, which integrates all the main pedagogical processes, is sharply increasing.

At this time, as a result of the research, the specialty “Geography – Tourism” was opened in the Republic of Kazakhstan, where the methodology of preparing future teachers for the leadership of the TCD of schoolchildren was tested. Similar work is being carried out at the Kryvyi Rih State Pedagogical University, where there is a specialty “Geography. Tourist and local history work”.

The relevance of the development of children's and youth tourism is due to the fact that it allows you to solve many other problems, and one of them is hypodynamia - a sedentary lifestyle, since the current younger generation lives in the era of computerization, modernization of technocracy.

Research scientists confirm the fact that as a result of the achievements of scientific and technical progress, computerization in all spheres of human activity has increased the number of cases of students, the amount of stress and disruptions in learning and behavior as a result of prealablement, insufficient exposure to fresh air, improper organization of leisure and recreation. After all, human health is closely related to the effects of the natural environment on the body and therefore tourism is the best way to solve this problem, which, unlike a variety of sports programs, has all the necessary natural components for health. This is communication with nature, a change of environment, psychological relief, and most importantly physical activity. Tourism is easy to organize, does not need specially equipped halls and platforms. The best sports ground was and still is nature! It is available for people of any age, is a feasible sport, because the load in it is well dosed with rest, and at the heart of ordinary walking. Being one of the most popular sports, it contributes to the education of a healthy and seasoned person, enriches the spiritual life neither in words, but in deeds, cultivates love for the native land. And in order for Kazakhstanis to love their land, it is necessary to instill this love from childhood. Most of all, this is facilitated by hikes, expeditions and trips, in which students have the opportunity to get acquainted with local attractions, with the past and present of their native land, with the traditions and customs of their people, to study the cultural heritage of their ancestors, conducting search activities.

In the educational organizations of the republic there are 7,668 deputy school directors for educational work, 18,402 teachers of additional education, including 851 teachers of tourism and local lore (698 of them with higher pedagogical education; 42 with higher professional education, 84 with secondary special pedagogical education and 27 with secondary special professional education (Figure 3) [6]. Tourist and local history activity is a pedagogical system, in the design of which a model of the system of continuous tourist and local history education was developed.

Engaging in various types of tourism since childhood allows you to cultivate a sense of citizenship, tourist culture and develops the ability to perceive the ideology of hospitality as a national idea, with the implementation of which it is possible to really develop tourism as an effective sector of the economy, ensuring sustainable development of the state with minimal consequences for nature and society [7].

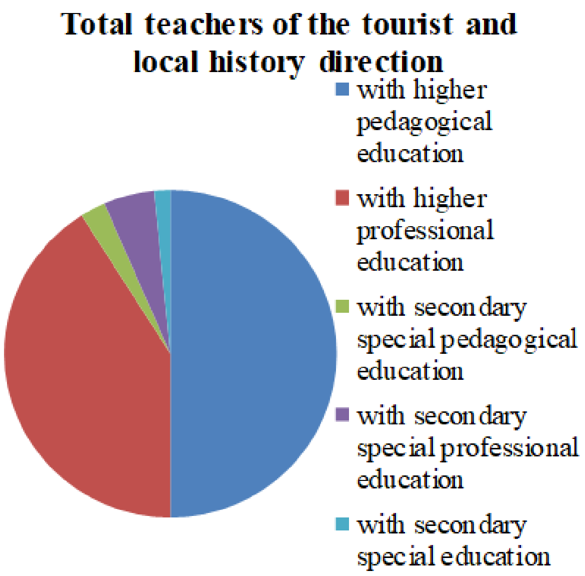

Fig. 3. Number of teachers of tourism and local lore in the Republic of Kazakhstan.

The developed tourist and local history activity is a pedagogical system, in the design of which the model of the system of continuous tourist and local history education is used.

The model of the system of continuous tourism and local history education (SCTLE) is a system of interrelated elements aimed at ensuring the main goal of continuous tourism and local history education-the formation of a harmonious personality and a healthy lifestyle.

SCTLE consists of four main stages of education: kindergarten, school education, additional education, vocational schools and universities. For each stage, goals and objectives are defined according to three parameters: training, education and development.

Kindergarten is the initial stage in the system of continuous tourism and local history education. The main tasks in the field of preschool education are:

- protection and promotion of children's health;
- mental development, physical, moral, aesthetic, environmental, economic, labor education;
- strengthening the role of the family in the upbringing of children.

During this period, children are laid the starting tourist skills, the basics of ecological culture, they receive initial information about their native land, the initial concepts of a healthy lifestyle.

The main tasks of the current stage of development of school education are:

- education for all-orientation of educational programs to high-quality education, upbringing and development of all children;
- the development of creative, spiritual and physical abilities of the individual, the formation of strong foundations of morality and a healthy lifestyle;
- education of a citizen, formation of a system of values and relations corresponding to a multinational society, Kazakhstan's patriotism; formation of a person with a rich spiritual, social and moral potential, capable of perceiving and developing national and world achievements in all spheres of life (fig. 4).

At the school stage of training, children undergo primary and secondary tourist training, learn the culture of behavior in nature, acquire the skills of local lore, research search and scientific design, join a healthy lifestyle, receive comprehensive education, pre-profile and profile training.

An integral part of continuing education and education is additional education, which is implemented on the basis of extracurricular organizations.

The purpose of the modern system of additional education is to create conditions for the formation of a versatile personality, including both modern (initiative, sociability, adequate adaptability, flexibility of behavior, mobility, leadership, organizational qualities, socio-psychological competence) and moral qualities (spirituality, sensitivity, attentiveness, honesty, responsibility, patriotism, tolerance, aesthetics).

The main tasks of additional education are defined:

- involvement of groups of student youth in the process of continuous education, familiarization with the achievements of national culture and sports;

- stimulation of diverse harmonious development, creativity and activity;
- organization of unregulated social communication, rational recreation and entertainment, adaptation to life in society.

Studying in clubs and sections of organizations of additional education, children have the opportunity to study local history, learn the traditions and rituals of their native land, improve and improve tourist skills, learn the basics of ecological culture.

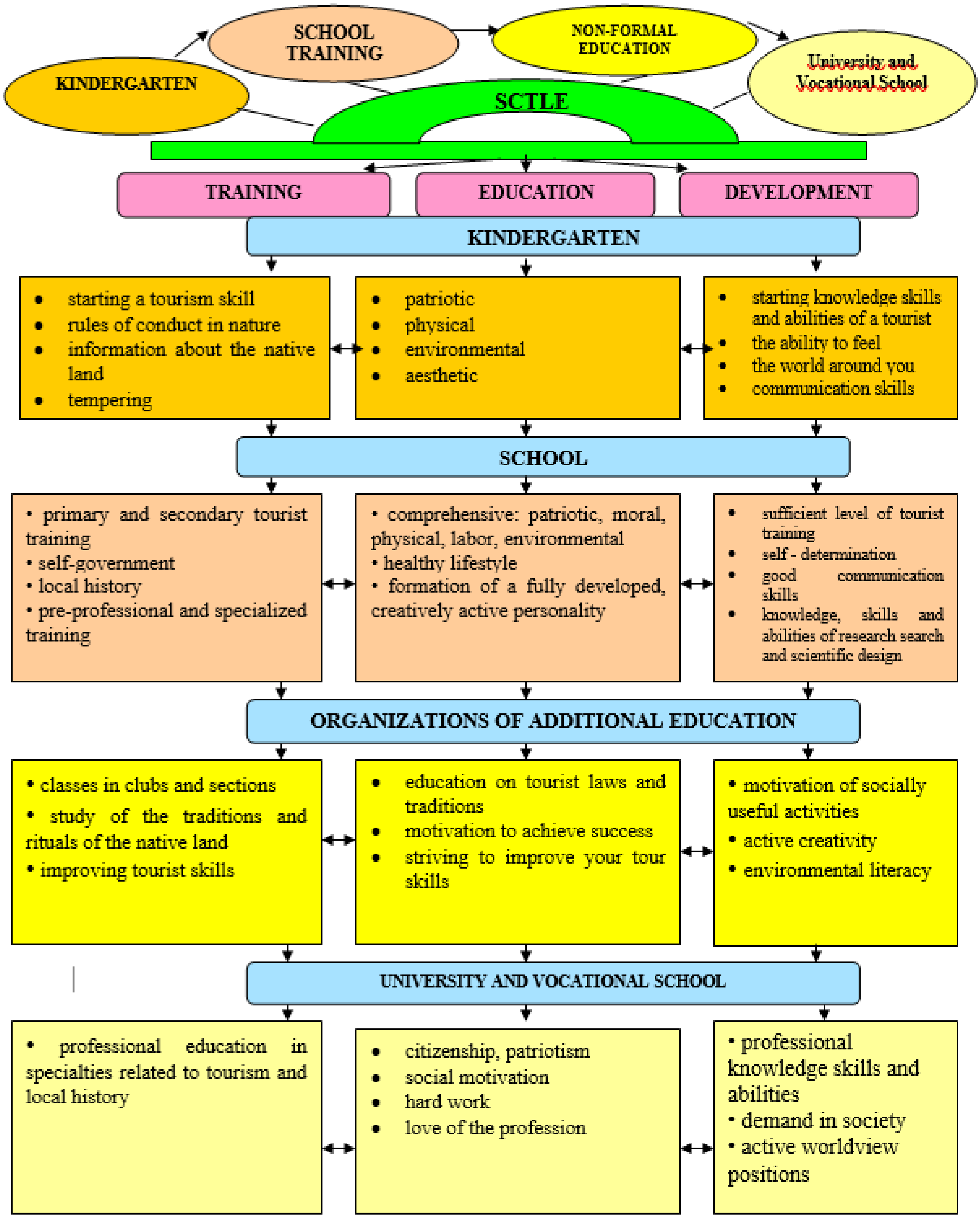

Fig. 4. The system of continuous tourist and local history education (SCTLE) [3].

At the stage of professional education in universities and vocational schools, students receive specialization in professions related to tourism and local history. The purpose of education at this stage is to provide conditions for the development of professional and social adaptation of the future specialist, the formation of a multicultural, humane and moral, physically healthy, highly intelligent, competitive, and therefore creatively developed holistic personality., able to independently formulate problems and practically solve them from high civil positions based on the use of national traditions and the latest achievements of world experience.

An important element of the professional training of a future teacher of geography and organizers of tourism and local history work at school can be the introduction of a special course "Organization of local history work at school" into the training system. The main tasks of this course are students awareness of the importance of tourism and local history work with schoolchildren, students mastery of various methods of studying their native land and readiness for local history and tourism work with students of different age groups. An important component of attracting students to tourism and local history work is their participation in educational excursions and tourist trips.

It is important, at the same time, to attract students to participate in excursions and hikes of various types: object-based (excursions and hikes to certain geographical objects studied in higher education); methodical (excursions and hikes on which students develop the ability to organize and conduct various tourist and local history events at school and out-of-school educational institution) and product (excursions and hikes that a student is able to develop as a finished tourist product that goes beyond the school curriculum, having an age limit) [8].

In the preparation of organizers of tourist and local history work at school, in our opinion, it is necessary to adhere to certain pedagogical conditions identified by O.V. Bondarenko:

- providing the goals of preparation for local history work of personal meaning;
- stimulation of positive motivation of students in mastering generalized local lore knowledge and skills to use them in solving problem situations and cognitive tasks activation of students;
- activity on the basis of personality-oriented and imitation-game approaches;
- a variety of forms and methods of local lore work with the provision of future teachers the freedom to choose ways to solve educational problems and situations of success [9].

Based on a comprehensive approach to modeling continuous tourism and local history education, we can identify the main pedagogical conditions for improving its effectiveness: the implementation of a systematic approach in tourism and local history activities; inclusion of students in various types of TLhA through ensuring the unity of educational and educational work; training of teachers to solve problems and implement TLhA.

In order to identify the effectiveness of the proposed model, the search and selection of indicators of all types of education of the child's personality was carried out. The following indicators of types of education were determined:

- moral-love for the Motherland, respect for state symbols, internationalism, tolerance, respect for the traditions and customs of the people, citizenship;
- physical – starting tourist knowledge, skills and abilities (KSA), strengthening of the musculoskeletal system, lung development, endurance;
- labor – conscientiousness in the execution of labor orders, the manifestation of personal initiative in the performance of duties;
- ecological – love of nature, knowledge of the rules of behavior in nature, understanding of the need for environmental protection;
- aesthetic – the development of aesthetic taste, the ability to observe nature and enjoy the beautiful, the ability to display what you see in creative works.

The indicators of all types of personal education are measured by standard diagnostic tasks developed according to the levels of complexity, taking into account age characteristics, on the basis of which the level of training of pupils (LTP in %) was determined at the stages of ascertaining and forming experiments in the control and experimental groups. High (when reaching 100-81%), medium (80-61%), and low (60-40%) levels were determined to determine LTP.

CG-control group – a part of the group that receives standard tourist and regional knowledge, its participants participate in fragmentary events of the TLhA.

EG-experimental group — part of the group engaged in specialized programs [10].

The competence approach in education originated in the scientific and journalistic literature in the late 1980s. To date, there is a multivariance in the definition of the terms "competence", "competence", which are used with the related concepts of "professionalism", "qualification", "education", etc. Most researchers hold the view that competence is an opportunity not just to have knowledge,but rather to potentially be ready to solve problems with knowledge.

The essential features of competence include the level determined by a combination of the following criteria:

- the level of assimilation of knowledge and skills (quality of knowledge and skills); the range and breadth of knowledge and skills;
- ability to perform special tasks;
- ability to rationally organize and plan your work;
- ability to use knowledge in non-standard situations (functional literacy).

Competence is a parameter of a social role, which in personal terms manifests itself as competence, the person's compliance with the place and time occupied; the ability to carry out activities in accordance with social requirements and expectations.

Tourist and local lore competencies are a parameter of a person's social experience that determines tourist and local lore knowledge, skills and abilities in accordance with the time, place, and surrounding society [11]. The formation of tourist and local history competencies of the younger generation of children provides for the acquisition of behavioral and survival skills in nature, the development of personal qualities (sociability, leadership, strong-willed qualities), motivates self-realization, self-knowledge, cooperation, and a healthy lifestyle.

We consider a comprehensive approach to the education of a well-developed personality in SCTLE at the preschool and school levels along two verticals that reflect all types and forms of TLhA.

During the implementation of the model of the system of continuous tourist and local history education at the stages of preschool and school education, organizational and pedagogical conditions were provided for all types of education: moral, patriotic, physical, labor, environmental, aesthetic.

We consider organizational and pedagogical conditions as a set of elements that contribute to the comprehensive development of the individual.

Organizational conditions are forms of organization and activity of preschoolers and schoolchildren. We refer the content, methods and technologies of the educational process organization to the pedagogical conditions.

We are confident that the measures taken will make it possible to use the entire arsenal of youth and youth tourism to educate the country's comprehensively developed younger generation, form a tourist culture among Kazakhstan's youth and commit to a healthy lifestyle. Tourism and local history have always been a powerful tool in the system of education and upbringing of the younger generation, the formation of a healthy lifestyle, the organization of recreation, leisure and restoration of spiritual and physical strength. After all, Ya. A. Komensky in his writings wrote: “Education is a process of life, not a preparation for the future life» [12].

TLhA in a school develops if it has a tourist organizer from among the teachers. When appointing a school tourism organizer, the school administration should be guided by the candidate's presence of the following important indicators:

- the strength of belief in the great importance of tourism for the school, in the need for it;
- the nature of views on the essence of children's tourism, i.e. the position, the candidate's approach to tourism and local history from the point of view of the tasks of the school, pedagogy;
- the level of tourist qualifications-personal experience of hiking, knowledge of tourism techniques, knowledge of the methods of organizing this work;
- such personal qualities as perseverance, perseverance, but also, at the same time, flexibility, the ability to correctly assess the moment, trend and prospect of the case.

The tourist organizer of the school needs to solve the problem so that, over time, a small but strong tourist asset will form around him from among teachers, parents, students, and production workers. The school needs a group of 3-5 people who are ardent supporters of tourism, who are truly passionate about this form of educational work with children. A school with a developed TLhA system is always distinguished by a large, friendly and strong asset of tourists-schoolchildren, first of all-high school students. As practice shows, in such a school, each class has its own class tour organizer, and the school-wide tourist self-government is implemented through the Headquarters or the Tourism Board.

The role of the student asset, its forms and structure in modern pedagogical science are practically not developed. However, it is possible to distinguish two completely independent factors, two separate, but interrelated goals that are inherent in the existence of a children's tourist asset:

- practical benefits for the organization of tourist and local history work in the school, which gives the labor contribution of the children's assets to the organizational work;
- pedagogical benefits, which gives the work of children in the education of their own social activity.

The activity of the school tourist asset gives a great pedagogical return: the children work for pedagogy and at the same time, working in the field of education, they themselves fall under the influence of the educational process. In this way, through the TLhA, an important task is solved: with the help of the children themselves, to conduct the pedagogical process in cooperation with them, without alienating them from “adult” affairs. Here we have a moment of cooperation in the pedagogy of the teacher with the students, a connection so far in the miniature of the state and public administration of school affairs.

The concept of a tourist asset can be classified according to the following parameters: by the nature of the activity; by the legal type of relations to the activity; by the scale of the activity; by the profile of the activity (specialization); by the level of training; by the duration of the activity. At each stage of the development of the system of tourist and local history work, the school should have its own corresponding structure of the asset and its own content of its work, since the discrepancy between these components of the system creates unnecessary contradictions and leads to failures in the development of the system.

In order to establish a system of tourist and local history work in the school, much is needed, but most importantly-you need a teacher who is ready for a hike, who is able to properly organize and competently conduct a tourist trip with children. In universities, teachers are not trained to conduct tourist work, they are mainly taught the methods of teaching the subject and very little is taught about the necessary practical skills. Therefore, class teachers, in the vast majority, are not ready for a variety of extracurricular educational work with children and do not want to engage in an unfamiliar business, especially in such a peculiar direction as TLhA. It is not enough to teach a teacher only a variety of tourist technologies, it is still necessary to educate him, to instill a taste for tourism pedagogy-the direction of educational work.

In the end, you need to achieve the following three conditions:

- the teacher's awareness of the usefulness of tourism (hiking) for performing their professional tasks;
- the teacher's confidence in their ability to go hiking with children;
- the teacher's sense of comfort in hiking, based on the guaranteed provision of everything necessary for such activities.

When planning work on tourist training, it is necessary: - to study the available personnel, to determine the positions of each employee to be trained, the level of his knowledge, i.e. to assess the degree of readiness of class teachers, teachers, educators to solve the tasks that are set at the first stage of the development of the TLHA system; - to determine the content, training programs, who to teach what, who to convince of what; - to outline specific forms, methods, methods, means of training; - to choose a leader, lecturers, instructors.

It is necessary to approach the tourist training of teachers in a differentiated way: first, to take into account the individual capabilities of each class teacher, and secondly, the needs of the school itself (children) in the development of the TLHA system. When organizing this work, it should be taken into account that school tourism is divided into two independent and interrelated parts - mass and circle tourism. The development of the circle branch of tourism is possible if there is even one well-trained teacher in the school, whose work can be supported by invited part-time circle leaders. It is necessary to attach a young teacher to an experienced teacher-circle leader for individual training and internship, who in a few months will be able to lead the circles in the lower grades. This tandem is also useful because in a large multi-day hike with a group of students, there must be two adults-the head and his deputy. The main concern is the development of the “Mass Tourism” branch, which requires that all class teachers and educators have at least the most minimal training and experience in tourism - personal experience of hiking.

Therefore, the main task is to pass through the tourist training of teachers, without which it is impossible to improve the TLhA system in the school. According to the results of the study, it was found that the weakest link in the training of teachers, as a rule, is the pedagogy of tourism - the teacher's approaches to the content of hikes, goals, and methods.

The educational campaign is held in order to remove the teacher's fear of the campaign, before everything unusual, unusual, which is associated with the campaign and the accompanying pedagogical work. You can only be convinced of the benefits of a hike by participating in it. The hike should be carried out in good weather on a beautiful route, should not be difficult, and in the cognitive aspect very informative. Its program must necessarily include orientation on the terrain using a compass and a map, the most simple (for the first time) obstacles, acquaintance with nature and with a bright excursion object, bivouac breaking (choosing a place, making a fire, cooking, etc.). Important is the preparation of the campaign-the motivation for choosing the route, the distribution of hiking duties, questions of equipment and equipment.

In summing up the results, it is an important stage of the events held. For popularization, the most common and acceptable forms are lectures and seminars. The school should develop its own seminar program based on the existing ones and taking into account individual needs. It is necessary to plan a series of theoretical and practical classes with teachers per year and taking into account the prospects for the growth of tourist qualifications. The seminar on tourist work at school is the simplest option for training teachers, but its fruits are not too weighty, because it mainly takes place in the mode of studying theory. A more effective form of tourist training of teachers is a field seminar, which can be held on the basis of another school, the House of Creativity, the regional Syutur, the local history museum. Significant advantages in the organization of a productive educational process is such a form as a training camp, when participants for a day, for two or even for a longer period break away from the home environment and move to a certain place where they live and study all these days. According to the nature of the organization of the educational process, training camps are divided into a training camp-seminar and a training camp-hike. In the first case, the participants mainly listen to lectures, exchange experiences, and conduct practical exercises on the ground and indoors. In the second case, in addition to the short lecture part of the collection, a full-fledged tourist trip is held for one or two or more days, and at the end - an analysis of the results. A valuable form of systematic consulting assistance to teachers is a tourist corner, equipped in the recreation area of schools or in a special office of the school. The teacher should always have a self-service source of information on tourism and local history at hand. In the tourist corner there should be a map of the district, region, and surrounding areas of the city, a shelf with books and brochures, folders with methodological materials on various topics, forms of documents, tools for copying and working with maps, etc.The most important form of training teachers in tourism is the analysis of the practice of living specific tourist work. And if any of the above forms of training can be applied by choice, then the analysis of practice, the exchange of experience must necessarily be used in addition to all the others. It is necessary to fully draw pedagogical conclusions from the analysis of the work practice: to objectively reveal not only the results, but also the course of the pedagogical process in the campaigns, through the vision of which one can understand both what a friend has achieved and how he achieved it [6].

3 Conclusions

The peculiarity of the organization of training today is the fundamental issue of the organization of the educational process in educational institutions of all levels: from preschool to higher education. This primarily concerns the increase in such forms and methods of teaching that form key competencies, create conditions for development and the ability to make decisions on their own, to learn throughout life. In our opinion, the organization of continuous tourism and local lore education will make it possible to realize these goals. The model created and described in the paper demonstrates the step-by-step nature of educational work. Certain tasks make it possible to choose the most effective forms and methods of work for each level.

The peculiarities of the organization of tourism and local lore work at the stages of preschool, school and additional education should be mass character, the implementation of educational and educational goals, the acquisition of healthy lifestyle skills, the formation of a need for active knowledge of the world around. The organization of such activities should complicate and take into account the age characteristics of children. For example, in kindergarten, from walking to category hikes in high school. The results of tourist trips are used for the local history approach in the subjects of geography, biology, history, literature and a number of other subjects.

In higher educational institutions, the main task is to prepare students for planning and organizing tourism and local history work with children. Therefore, work at universities should be aimed at the formation of subject-specific tourist and local history competence through a specially developed block of academic subjects (methods of organizing tourist and local history work, sports tourism techniques, methods of conducting educational excursions). The second, no less important part should be the acquisition of personal experience in organizing tourist activities. To do this, it is important to organize educational tourist, local history practices, hikes and excursions. Carrying out such work will create a strong motivation for future teachers and a willingness to organize tourist and local history work.

The conducted research confirms that tourist and local history work is a universal means of education and upbringing. And preparation for the management of the implementation of activities is necessary for future subject teachers.

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Methodological approaches to the study of mineral resource potential of regions

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Abstract. The exploration industry of Ukraine is experiencing a protracted crisis. It is confirmed by the curtailment of funding for the development of country mineral resources by 60% last year which causes the closure of exploration companies. The range of problems traditionally solved by the geography of mineral resources is significantly reduced. These reasons encouraged us to consider the main methodological approaches to the study of mineral potential of specific regions. The studied approaches such as natural-geographical, economic-geographical, ecological-geographical, and complex structural-geographical lie in the domain of geographical science. The article emphasizes the urgency to develop structural and geographical course of research, which is based on the studies of mineral resources and the approaches mentioned above including geological one. The structural and geographical course of research is supposed to create real models of mineral resources of the country regions and to suggest specific measures of their structure optimization alongside prospects of their development following modern world tendencies. The research may result in the creation of a long-term concept of balanced development of the mineral complex of the region, the prevision of the use of mineral resources, the justification of resource-saving technologies. A systematic approach to such a concept will ensure the rational use of resources, the formation of new infrastructure, conditions for environmentally safe function of the economy, sustainable and balanced development of the economic complex of the region.

1 Introduction

The geography of mineral resources as a sphere of study does not currently develop in Ukraine. There are almost no publications with the results of natural and geographical studies on the regularities of formation and territorial localization of deposits of different types of minerals, and analysis of their impact on the formation of mining complexes. The problems of effective functioning of regional mineral complexes and optimization of their structure are scientifically neglected. We believe that it is obvious and long overdue the need for a comprehensive (constructive-geographical) approach to the study of mineral resources (MR) of definite regions and the country as a whole. The efficient use of mineral resources based on modern technologies with combination of the economic efficiency of exploration and processing of mineral resources with minimum negative environmental impact can lead to optimal solutions of present complex economic and social problems. In this context the authors suggest a brief overview of methodological approaches to the study of mineral resources and their opinions on the constructive and geographical direction of their study.

To provide a comprehensive systematic approach to constructive-geographical studies of mineral resources of specific regions, it is essential to include the following basic interrelated areas of research: geological-mineralogical, natural-geographical (geo-morphological, paleo-geo-morphological, paleo-geographic, landscape, etc.), economic-geographical and geographical ones.

The geological and mineralogical course of MR research is the most extensive and elaborated approach, and involves a comprehensive study of mineral resources from the material composition study to the development of general concepts of prospecting and exploration of minerals in continental areas, oceans, certain administrative units. The analysis of the development of geological and mineralogical research of the MR universally and in Ukraine is the subject of special consideration which goes beyond the scope of this publication.

The natural and geographical studies made by Ukrainian researchers explore: paleo-geographic and paleo-landscape conditions of mineral formation and forecasts of their deposits by M. Veklych [1, 2].

E. Palienko [4], M. Volkov, V. Palienko, I. Sokolovsky [5], V. Palienko [3] study paleo-geo-morphological, geo-morphological, morpho-structural

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and neo-tectonic criteria for prospecting and exploration of mineral deposits. Landscape-geochemical approaches to the study of mining areas were substantiated by E. Ivanov [7, 8, 18] and others.

The economic and geographical direction of the MR study in Ukraine is represented by the works of I. Gorlenko [10, 11], V. Mishchenko [26], M. Palamarchuk, I. Gorlenko, T. Yasnyuk [12]; M. Palamarchuk, O. Palamarchuk [13]; L. Rudenko, V. Palienko, L. Shevchenko [14, 15, 16] and others.

Ecological and geographical research. We notice that a relatively small number of thorough researches are devoted to the issues of subsoil protection during exploration and mining works. The significant number of publications studies the problems of the negative environmental impact of mining generally or discretely. These are the works of G. Rudko, L. Shkitsa [20], G. Rudko, E. Ivanov, I. Kovalchuk [8] and others. These works consider environmental problems of mining in the context of general environmental issues, propose methodological approaches to their solution, and analyze reasons of ecological crisis situations in certain regions.

The historical course of MR research is represented by works exploring the issues of formation and development of mineral sciences, history of discovery and study of mineral resource potential of definite territories, history of mining in the context of general civilization process, etc. (M. Syvyj [19] and others).

Constructive-geographical approach to the study of mineral resources and related issues are actively promoted in the works of: L. Rudenko, V. Palienko, L. Shevchenko and others[14], L. Rudenko, V. Palienko, V. Baitala and others [15], L. Rudenko, V. Palienko, M. Barshchevsky and others [16], M. Syvyj [17], M. Syvyj, I. Paranko, Ye. Ivanov [18], and others.

Research methods. Research was based on such general principles of cognition as objectivity, causality, universal connection, evolutionary. From the traditional general scientific methods, the following were used: observation (field method), analysis and synthesis, induction and deduction, comparison and analogy, generalization and abstraction, modeling and forecasting.

Within the framework of a constructive-geographical approach to the study of the mineral resource base of the Podillia region, natural-geographical, economic-geographical and ecological-geographical approaches were used, which made it possible to learn the specifics of the mining and industrial nature management of the region and substantiate the principles of its optimization.

The principles of constructive-geographical research of regional environmental management, developed in the works of I. Horlenko [10, 11, 12], I. Kovalchuk [8], V. Paliienko and L. Rudenko [14, 15, 16], H. Rudko [8, 20, 21] and others.

Constructive-geographical analysis, assessment and forecasting of the development of the region's mineral resources complex were carried out on the basis of the proposed algorithmic research schemes. Such schemes made it possible to optimize the research process, to provide a diversified study of mineral resources on the basis of formalization, automation and unification of analytical and synthesizing studies, bringing them to the level of guidance or instruction.

2 Results and discussion

Natural and geographical studies using geological exploration data make it possible to establish and detail the genetic patterns of formation and localization of different types of minerals in the region, predict the location of deposits in new areas and increase reserves within known deposits. They also may determine mining, geological and geo-ecological conditions for future exploitation of deposits, and predict the change in the qualitative characteristics of mineral resources in the area of deposits, etc.

An important form of natural and geographical studies is paleo-geographic reconstructions, which help to reproduce the components of ancient nature of a region: paleo-geology, paleo-relief, paleo-hydrology, paleo-climates, flora and fauna, facile complexes, etc. Paleo-geographic, paleo-landscape and lithological-facile maps based on the results of such reconstructions give an idea of the conditions of mineral accumulation in specific areas and can reliably predict the area of its localization.

M. Veklich [1, 2] carries out paleo-geographic and paleo-geo-morphological studies to predict titanium, zirconium, rare earth deposits within the Ukrainian Shield, as well as studies the conditions of formation of manganese ore deposits in the Nikopol Basin and Cenozoic lignite deposits in Ukraine.

Geo-morphological studies solve a number of important problems while search, exploration and development of mineral deposits. At the stage of geo-morphological search, two types of geo-morphological objects are studied: resource-containing and resource-informative [3, 4]. The former include modern or hidden landforms of various origins, which contain deposits of minerals: placers, building materials, peat, coal, oil, gas, etc.; the latter indicative landforms that allow targeted exploration for minerals. At the stage of field exploration, the assessment of the relief of the location area is prioritized to organize the infrastructure of mining enterprises and to prevent the dangerous geomorphological processes that can reveal in productive and adjacent areas. At the stage of mineral deposit development, the main concern is natural resource rational use, protection and preservation of the natural environment.

Morpho-structural and neo-tectonic studies find particularly successful application in the search for structurally conditioned oil fields in the oil and gas provinces of Ukraine [5, 6]. They are accompanied be the solution of the problems dealing with the determination of optimal structural and geomorphological conditions of hydrocarbon accumulation, neo-tectonic conditions of their migration, etc.

Morpho-structural studies in areas of active tectonic disturbances contribute to the identification of belts and nodes of ore formation of tin, lead, copper, nickel, tungsten, uranium and other ore minerals.

Complex morpho-metric, morpho-dynamic, historical and geomorphological studies are ultimately useful for search and exploration of deposits of diamonds, titanium, zirconium, gold, particularly within the Ukrainian Shield, and in other territories. Historical-genetic, paleo-geo-morphological studies are helpful in searching for brown and hard coal deposits, etc.

Among landscape studies, special attention should be paid to those that involve solving such problems as [7, 8]:

- analysis of the current landscape and geo-chemical condition in the mining regions of Ukraine;
- substantiation of landscape-geo-chemical approaches to the study of mining areas in order to predict the negative impact of extraction and processing of mineral resources on landscape complexes;
- development of recommendations for the preservation and restoration of the diversity of landscape complexes within the areas of extraction and in the territories nearby to the development sites.

Economic and geographical research is the necessary condition for determination of the areas of MR rational use. Such studies establish regional geographical patterns of mineral deposits [9], the degree of their study and degree of development, the structure of industrial relations between mining enterprises, the structure of sectoral and regional consumption of minerals, market conditions, etc. [10, 11, 12, 13]. Economic and geographical studies determine the feasibility and integrated development of mineral deposits, the degree and direction of processing of basic and related minerals, the possibility and effectiveness of mining waste utilization, and so on. They consider possibilities of formation of territorial-production complexes of mineral-raw material direction (as one of the most expedient and progressive forms of rational use of mineral resources) on the basis of separate explored deposits or their territorial groups. L. Rudenko, V. Palienko, L. Shevchenko and others [14] highlight extraordinary importance of formation of territorial-production complexes on the basis of minerals for Ukraine. Their research should be a priority in finding ways to improve resource use.

Generally, economic and geographical studies of MR are conducted in three directions: branch, functional and territorial [10, 11, 13].

Branch direction of the research involves considering the needs of mining industries, their role in structuring industrial complexes. Simultaneously, branch research establishes the level of concentration of certain types of territorial-production complexes, peculiarities of stock placement, mining and hydrogeological conditions, technical and economic indicators of field operation, possibilities and expediency of the complex development, and industrial processing of raw materials.

Branch division aims at the further development of industries based on the development of minerals, establishing their impact on the territorial division of labor and determining the optimal proportions, considering national interests. The results of the study enable to establish the scale of mineral use of a particular region, the potential of expanding and improving the relevant industries within the region.

The functional direction of the study of MR comprises two stages of research [13, 17, 18]. The first stage determines the complex-forming properties of minerals, the developmental prospects of territorial-industrial complexes; and clarifies the nature and degree of the mineral influence on the division of labor in the district.

The second stage of the functional direction of the MR study specificates their role in the functional structure of industry, in the formation of its main links – inter-sector production complexes. At this stage, complexes basing on the use of MR are formed. They are mineral orientated production complexes, such as coal and metallurgy, oil and gas, mining and chemical, etc. The study of mineral orientation systems allows identifying ways of improvement their sector functional structure and territorial organization on the basis of integrated use of minerals, including exploitation and processing of minerals, as well as ways to improve internal and external relations through the use of local resources, reduction of long-distance transportation of raw materials, and transport expanses accordingly.

Territorial direction of MR research involves the study of their impact on the territorial structure of production, especially on the formation of territorial production complexes. To identify the importance of mastering the forms of territorial concentration of mineral deposits in the development of the territorial structure of industry, the researchers distinguish territorial production complexes which are based on mineral resources: centers, nodes, agglomerations, areas of mineral orientation [10, 13, 17, 18]. The composition of minerals determines the production orientation of such complexes.

Peculiarities of deposits (structure, capacity of productive horizons, mineral-petrographic composition of minerals) also affect the role of the corresponding industrial complex in the territorial division of labor. The composition of the MR determines the number of specialization areas of such complexes.

The ultimate goal of the territorial MR study is to develop ways to improve the territorial structure of industry on the basis of rational use of mineral resources, which is necessary to ensure optimal territorial organization of production, the implementation of long-term spatial planning.

The geo-ecological (environmental) direction of the MR research developed predominantly due to the necessity to study the processes accompanying the exploration, extraction and primary processing of minerals [7, 8, 16, 20]. It was caused by the urgent needs of monitoring, analysis, forecasting and minimization of negative impacts of mining and processing industries on the environment. The development of rational schemes of ecologically safe functioning of mineral complexes in the general context of nature optimization added to its importance. Ecological and geographical research is aimed at studying the impact of mineral resource development on the ecological and geographical situation of the regions, substantiation of the principles of ecological policy of these regions to preserve and improve the environment and create favorable living conditions. The influence of mining complexes on all elements of the regions' environment is studied: disturbances and changes in the land fund, air pollution, soil and groundwater, violation of their hydrological regime, etc. The consequence of ecological and geographical studies of the mineral resource base should be the development of a set of measures to improve the quality and preservation of the region natural environment, and the solution of such an urgent environmental problem as justification of reclamation of mining landscapes [15, 16]. Research and publications on MR environmental issues primarily focus on seven issues: protection and rational use of subsoil, surface and groundwater, air, reclamation of lands destroyed by mining, utilization of mining waste, ecological and landscape problems of destroyed areas, resource security and sustainable development issues.

A comprehensive (constructive-geographical) approach to the study of mineral resources lies in the analysis and synthesis of factual data, theoretical and methodological developments of geological, natural, economic, geo-ecological and historical areas of MR study. It aims at solving a number of problems and issues as following: factual assessment of the state of study of the region mineral resource base, assessment of active and stand-by reserves of mineral resources, establishment of patterns of territorial distribution (territorial structure) of the MR, substantiation of opportunities to increase reserves of explored deposits and assessment of promising areas, diversification of the mineral resource of the region, recommendations on the policy of resource conservation and resource substitution in the region, substantiation of the main ways of using the region MR, determination of the place and role of MR in the economic complex of the region, studying the supplies of the region and its administrative units with certain types of mineral resources and recommendations for covering mineral deficit, selection of resource-saving technologies for extraction and processing of raw materials, development and implementation of programs for reclamation of destroyed lands and utilization of mining waste, optimization of environmental situation in the region, etc. [17].

It is obvious and long overdue the need for a comprehensive systematic approach to the study of mineral resources of particular regions, oblasts and districts. The efficient use of mineral resources by means of modern technologies combining the economic efficiency of exploration and processing of mineral resources with minimum environmental negative impact can be one of the ways leading to optimal solutions of present complex economic and social problems. The program of mineral resource base development of Ukraine for the period up to 2030 [24] provides the solutions for urgent problems of the mineral resource complex, the increase of primarily strategic mineral raw materials reserves to ensure stable operation of industrial and agro-industrial complexes in the future. The program suggests comprehensive (geological, engineering-geological, ecological-geological, etc.) study of the territory of Ukraine for the purpose of development of state nature protection policy and counteraction to dangerous natural and technogenic disasters and processes.

The constructive geographical researches with the focus on a comprehensive approach to the analysis of the state and development of mineral potential of the regions can pose an especial value.

Presently we consider very significant from a constructive and geographical point of view the design of the optimal correlation of the rate of development of mining enterprises (industries) and the growth (or creation) appropriate mineral resources. It is urgently required a scientifically grounded comprehensive near-term forecast of the state and regional needs of Ukraine in specific types of mineral resources, based on the actual possibilities of the extraction, the growth of reserves and the geo-ecological situation. The foundation of the economic policy of the state requires the assessment of the mineral potential and the possibilities of its most rational and cost-effective implementation.

On the basis of the above mentioned considerations, Ukraine relevant issues are related to a thorough and comprehensive analysis of mineral resources of some regions and the whole state in order to optimize the functioning of mining and processing industries, creating reliable and effective models of sustainable development, as well as issues of rational use of subsoil resources and solving environmental problems of mining areas.

This is the range of issues that science of *constructive geography* addresses, one of the key tasks of which is the scientific substantiation of rational use of nature in the regions of Ukraine; and the comprehensive study and consideration of zone, provincial and local natural resources and conditions. The area of interest issues of constructive geography relates to the accumulation, analysis and synthesis of all factual data concerning the study, distribution, development and primary processing of mineral resources and the solution of environmental problems provoked by the above processes. These tasks are under consideration of not only constructive geography, but also geology, mineragraphy, geomorphology, paleo-geography, economic geography, economic geology, hydrogeology, geo-ecology, which intermittently causes inconsistency of the proposed solutions.

Therefore, the essence of constructive-geographical research of mineral resources lies in a comprehensive analysis and evaluation of this type of resources being an important component of integrated natural resource potential of the territory. It also suggests the forecast of development trends and ways to optimize the functioning of mineral complexes, assessment the exploration and mining impact on the geo-ecological situation and substantiation of management decisions on the efficient use of mineral resources, utilization of mining waste and minimization of the negative consequences of mining operations in the regions [15, 17, 18].

For the solution of such tasks as constructive-geographical analysis, assessment of MR and the prospect of development of region mineral complexes, a number of algorithmic research schemes were compiled and tested [17]. These schemes enable the optimization of the research process; streamline the study of various aspects of MR with the simultaneous improvement of the result quality. They strive to formalize, automate and unify the analytical and synthesizing procedures of MR region research, changing them guidance or instruction.

Algorithms make it possible to identify the structure, the mechanisms of functioning of mineral complexes, and the trends in their development, to identify the ways of subsoil resources rational use, and to improve the region ecology. They provide for the solution of both theoretical and practical problems, primarily such as methodological justification of strategic directions of complex development, their role in economic complexes of regions, MR integrated use and utilization of mining waste, reduction of environmental tensions, etc.

An important element of the algorithms is the creation of an information database on the current state of the region MR. Scientific analysis and synthesis of information on mineral resources of the territory (region, economic area) requires a huge amount of statistical, cartographic, departmental, and literary data of the quality, quantity and cost parameters of resources. The creation of a data bank comprising information generalization on the territorial categories of three levels: local, oblast and regional ones is ultimately required.

The local level represents information on MR collected within administrative districts (or territorial communities presently). These are general data on individual deposits, ore occurrences, operating and stand-by mining and processing enterprises, as well as preliminary information on qualitative and quantitative parameters of mineral resources of each deposit, their mining-geological and hydro-geological characteristics, volume of production and sales, complexity of use of mineral raw materials, waste and environmental protection measures at each specific mining enterprise. The information allows making substantiated conclusions about the mineral potential of individual administrative districts, determination of the optimal directions of socio-economic development of grassroots territorial units.

The oblast level should provide the collection, accumulation and synthesis of information on MR of separate areas, their potential, ways of optimization use, and considering obtained data substantiates the directions of oblast mineral complexes development in the line with the national concept of mineral base development.

The regional level generalizes the information, combines data on several areas of the region (economic region) and assists the development of mineral resources of large regions of the country, determines the specifics of socio-economic development of large areas.

Thus, the first step in the study of region MR should be made in the creation of a database containing the most diverse and complete information about the object of study. It should be based on a combination of the component and territorial approaches to the formation of a single system of nature management, aimed at solving structural and geographical problems of study, rational use and protection of mineral resources.

Collection of source information in modern conditions is complicated by the fact that statistical authorities receive almost no formalized reports from exploration and mining enterprises and therefore the actual data have to be collected in separate organizations, which to some extent related to the study and exploitation of mineral resources.

The main source of information about mineral resources of Ukraine is the State Research and Production Enterprise State Information Geological Fund of Ukraine "*GEOINFORM UKRAINE*". It is an institution of the Ministry of Ecology and Natural Resources of Ukraine which collects stores and provides information accumulated in the process of geological study and subsoil use. *Geoinform Ukraine* has complete, reliable and objective information on the geological study of the territory of Ukraine, the current state and prospects of development of mineral resources and geological environment, the world situation of mineral resources, and legal aspects of subsoil use.

Regional state departments of ecology and natural resources accumulate information on environment protection measures carried out at mining enterprises (air, water environment, land protection and reclamation works, etc.).

The next stage of constructive-geographical study of region MR involves the analysis of the collected factual material. At this stage, the information is grouped by individual types of raw materials, appropriate cartographic models are built (preferably for each type of raw material), which allow to identify patterns of territorial concentration of deposits and manifestations of minerals within the region. The comparison of the constructed models on different types of mineral raw materials allows to allocate territories (areas, macro bushes and bushes) with the maximum accumulation of raw material resources and, on the contrary, the territories poor in mineral resources. Such models can serve as a reliable basis for optimization of the mining infrastructure of the region, the integration of production based on the rational use of mineral resources, etc. [17, 18].

The study of stratigraphic sections of individual deposits allows establishing their belonging to certain stratigraphic horizons, which helps define the prospects of mineral deposits of certain areas of the region.

Coefficients of industrial exploration of districts are determined: ratio of reserves of industrial categories to total explored reserves of mineral raw materials. The analysis of the development degree of the mineral deposits fund is conducted: assignment of deposits to certain categories (the developed deposits, deposits prepared for operation, reserved ones, deposits eliminated from the balance sheet, deposits aggravated because of certain circumstances: fully explored reserves objects, built-up objects, located on the territory of nature protection objects, etc). The coefficients of development of each mineral are determined (the ratio of reserves of developed deposits to the reserves of all explored deposits). The distribution of existing and reserve deposits within the region is studied, and it is analyzed the current level of extraction of certain types of raw materials at specific mining enterprises, administrative districts and regions. The trends in the extraction of certain types of raw materials are identified. The annual coefficients of provision of mining enterprises with explored reserves are calculated: the ratio of reserves of industrial categories to annual production volumes. It is also established the potential of extraction of definite types of mineral raw materials at the mining enterprises on areas, oblast and province. The ratios between the volumes of raw materials extracted by local enterprises and imported into the region are calculated. An important task of constructive-geographical study is the analysis of the state, region, districts and areas needs of specific types of mineral resources.

The results of analytical research help establish the actual and potential use of MR in the regional and state economy [17, 18] in modern conditions, and consider the ways of effective expanding use of MR.

The next element of constructive-geographical research of MR of regions is their constructive-geographical estimation.

N. Ratner [25] proposes to assess the mineral resource base from two standpoints: industrial and regional. The economic assessment of region MR applies some differences in its approach. If the purpose of the industrial assessment of the MR is to establish the supply of raw materials needed to meet the objectives of the industry, the regional assessment involves the rational use of mineral resources considering ecological balance, determining the role and place of each resource in economic development.

The assessment of mineral resources is based on a rational combination of regional and industrial principles, taking into account economic costs and effects, as well as a set of industrial and regional assessment factors.

Industrial factors (geological, mining, technical and economic) form the socially necessary costs and the estimated price of raw materials. Regional ones (production integration, infrastructure, environmental situation) determine the effect of territorial organization of production and the efficiency of regional use of production resources (labor, material, financial), necessary to achieve this goal [25].

The ideas presented above lie in the basis of consideration of the constructive-geographical assessment of region MR as a consistent solution to the following issues [18]:

- the determination of the industrial value of deposits and manifestations of minerals;
- the assessment of the MR provision of administrative units of regions;
- the assessment of the territorial-production structure of mineral complexes of the regions and the peculiarities of its functioning;
- the assessment of economic and territorial productivity of MR territories;
- the assessment of the rational use of MR;
- the assessment of the environment impact of mining companies in the regions;
- the management decision taking based on constructive and geographical assessments of region MR.

The assessment can be carried out in stages. Firstly, it is assessed the resources of definite industries, secondly, the resources of the region in general.

The ultimate result of such assessment of mineral deposits and their region manifestations is in making decisions on the feasibility of the operation of existing quarries (mining camps, mines), increasing the volume of extraction or conservation on the contrary; determination the prospects and sequence of the operation of the deposits; recommendations for the assessment of promising minerals and additional exploration of deposits with the depleted reserves.

This comprehensive approach to the study of each deposit forms a holistic view of the real value of the deposit regional fund and, accordingly, addresses the feasibility of their operation in modern market conditions or in the future, establishes the futility of individual deposits.

Construction of maps (models) of territorial density and MR security of administrative units of the region helps reliably estimate the saturation density (saturation coefficient - the ratio of the amount of explored industrial reserves to the area of the administrative unit, ton / acre) by individual types of raw materials and districts. The same approach is applied to the assessment of the supply (ton / person) of specific types of mineral resources of administrative units, as well as certain sectors of the economy of the region.

An important task of the research is to assess the needs of regions (at the present stage and in the near future, taking into account market conditions) in the products of local mining complexes; to determine the estimated supply of raw materials from other regions of Ukraine or abroad; to assess critically the existing use of mineral raw materials for various purposes and to justify the proposals on their efficient and rational use.

The further assessment is made on complexity of the mineral resource use of specific deposits and accumulated mining waste in the region. The following aspects should be taken into account: the total use of the main and related components of the deposits, the selective extraction, transportation and separate storage of extracted components, etc. The mining waste pollution maps of the region territory are built and on their basis such wastes are estimated as potential resources of various industries or agriculture. The scales and ways of region utilization of overburden rock, lateral rock and bedrock, enrichment waste and waste of secondary processing of mineral raw materials are also estimated. As a result of the listed evaluation procedures, a generalized prognostic assessment of the use of region mining waste is given both through the construction of recycling enterprises and the reorientation of the existing relationships between enterprises.

The procedure of economic and geographical assessment of region mineral resources mentioned above includes the typology of the latter; assessment of their component by types of raw materials and territorial structure, as well as the separation of territorial or mining production complexes with mineral orientation; assessment of their structure, relationships and features of functioning. As a result of economic and geographical research, it is substantiated the assessment of the production complexation possibilities on the basis of the optimization model of the structure of the mineral complex, rational approaches to the use of MR and mining waste in the region. The final stage of the MR assessment determines general negative environment impacts of mining production and perspective directions of reclamation measures in the region.

The ultimate result of constructive-geographical research should be a long-term concept of development of the region mineral complex, a forecast of the use of mineral resources [26], and the resource-saving technology justification. A systematic approach to the creation of such a concept may ensure the rational use of resources and the design of new infrastructure, maintenance of the conditions for environmentally friendly functioning of the economy, and balanced development of the region economic complex. The development of the concept aimed at forecasting the main events and tendencies in the mineral and raw material complex of the region should undoubtedly be carried out on a large scale, comprehensively, in line with the national decisions.

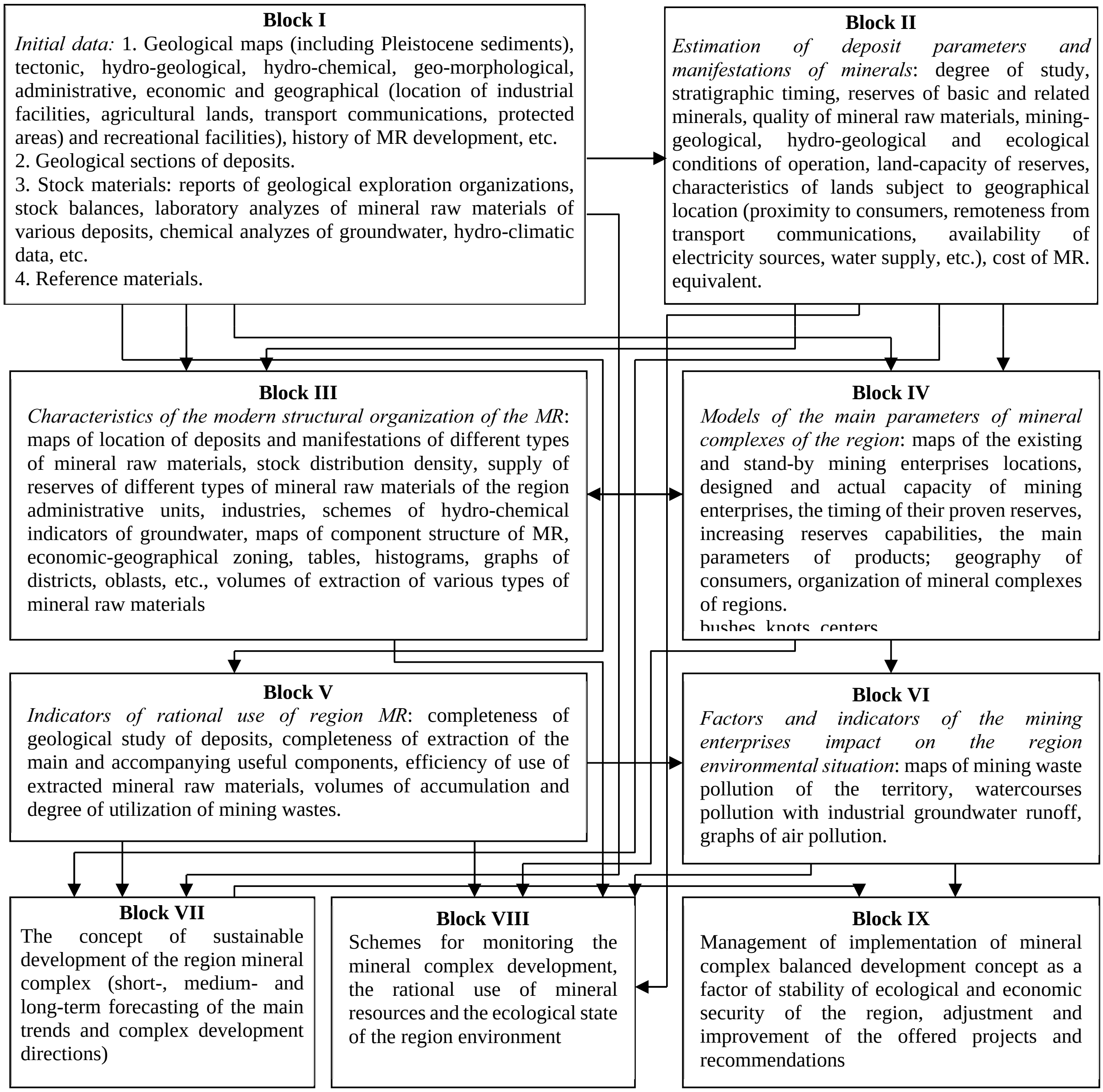

Fig. 1. Block diagram of structural and geographical studies of the regions.

We believe that the concept, concerning national priorities, should take into account the following range of issues:

1. Substantiation of long-term policy of socio-economic development of the region.

2. Proposals for optimal consumption of raw materials by various sectors of the economy, ways of covering the shortage of certain types of raw materials in future.

3. Substantiation of recommendations for the creation of mineral complexes on the basis of new, unusual for Ukraine types of raw materials (eg, saponites, apatites, granular phosphorites, glauconites in Podillya, etc.). The thorough preliminary structural and geographical analysis enables to offer a list of such deposits for investment and priority exploitation.

4. Development of scientifically substantiated forecasts of region needs of specific types of raw materials for the short, medium and long terms. The forecast takes into account the actual volumes of raw material extraction in the region, the possibility of increase or import from

other regions; the expediency of development of the deposits of certain types of raw materials explored in the region, which are currently imported from remote areas.

5. Submission of detailed recommendations on comprehensive, waste-free, rational use of mineral resources of the region.

6. Suggestion of the set of measures aimed at improving the environment in the areas of mining with minimization of its negative impact. Possible changes in the ecological state of the region are forecast considering the increase of production capacity at mining enterprises or the development of new mineral resources for intensively developing industries.

7. Anticipation and implementation of a system of monitoring of environmental protection measures carried out in the region and the consequences of their implementation.

8. Prediction of the socio-economic effect of the mineral resource base expansion, optimization of MR use, improvement of the region ecological condition.

9. Development of recommendations for the optimization of the infrastructure of the region mineral complex.

Generally a block diagram (Fig. 1) demonstrates the sequence and content of constructive-geographical studies of mineral resources of regions.

Constructive-geographical approaches to the study of mineral potential of certain regions of the country are actively introduced into the educational process of a number of higher education institutions of Ukraine (Lviv National University named after I. Franko, Chernivtsi National University named after Yu. Fedkovych, Kryvyi Rih State Pedagogical University, Ternopil National Pedagogical University and V. Hnatyuk). Ternopil National Pedagogical University and V. Hnatyuk delivers in particular a course "Geography of Mineral Resources of Ukraine" for Master degree students, in which methodology structural and geographical research lie in the basis of the presentation of educational materials on the characteristics of the main groups of minerals, the basic laws of their component, functional, territorial structure, their effective use, environmental problems of major mining areas.

3 Conclusions

1. Modern research of mineral resource potential of any territory is based on several basic methodological approaches: geological-mineralogical, natural-geographical, economic-geographical, economic, ecological-geographical, historical and complex constructive-geographical, each of which focuses on separate aspects of studying mineral resources (criteria for prospecting and exploration of minerals, quality composition of raw materials, mining and geological conditions of their extraction, problems of rational efficient use, structure of formed or forecasted economic complexes with clear mineral orientation, subsoil protection, ecological problems of mining areas).

2. We developed the main provisions of the actual constructive-geographical approach to the study of mineral resources of the regions. It consists of the factual data analysis and synthesis, theoretical and methodological findings of the above approaches. The constructive-geographical approach aims to identify spatial (territorial) and temporal-dynamic patterns of mineral resources and their role in the region economic complexes for substantiation of optimization proposals on the structure and efficiency. It also enables the assessment of the environmental stress in the regions caused by mining and processing, search for ways and means to minimize it, general improvement of nature management in the regions.

3. For the solution of the problems of constructive-geographical study of region mineral resource potential, we created and tested a number of algorithmic schemes in the Podolsk region which went through several successive stages. The first stage was devoted to the formation of the database containing various and the most complete information on the object of study at the local, area and regional levels. The database combines component and territorial approaches to the formation of a single system of nature management in the study area. The second stage of constructive-geographical study of region MR provided analysis of the collected factual material which enabled to create cartographic models of territorial concentration of different types of mineral raw materials, and determine the needs of region, oblasts, separate districts (territorial communities) in specific types of mineral raw materials in their economic complexes. The analysis of the collected factual material provided the consideration on the extra ways of efficient resource use. The third stage involved assessing the mineral resource potential of the territory done in stages. Firstly, the assessment of the resources of separate industries, then the general resources of the region was done. Secondly, the assessment of the complexity of mineral resources of specific deposits and accumulated mining waste in the region, then the typification of mineral resources, assessment of their component and territorial structure. Thirdly, the estimation of possibilities of complexing of manufacture on the basis of optimization model of structure of a mineral resource complex was proved. At the last stage a long-term concept of development of the mineral complex of the region was created, the forecast of use of mineral raw materials and substantiation of use of resource-saving technologies were offered. There were considered the possible changes of region ecological condition caused by production capacity increase at mining enterprises or development of new mineral resources.

4. The methodology of constructive-geographical study of mineral resource potential in recent years is actively introduced into the educational process of geographical departments of higher education institutions in Ukraine.

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Geospatial modeling of the infrastructure facility optimal location

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Abstract. The purpose of the research is to reveal current trends in modeling the location of new catering establishments in the study area. The relevance of research in the article is determined by the development of the tourism industry. This applies to catering establishments operating in the lower price category. Such catering establishments include fast food restaurants. The article proposes to use geographic information systems for spatial analysis using software. The researchers used ArcGis software, which allows you to visualize the results of the analysis. Visualization of the results will allow to make the necessary decision on the location of catering establishments. The research was conducted on the example of the Industrialny District of Kharkiv. Analysis of geostatic models can be used to process statistical data in any locality by using a geostatistical method to convert data from a discrete view to a permanent representation. With the help of geostatistics methods, data from a discrete form are transformed into a continuous form. Researchers present mathematical formulas for determining the index of concentration of the actual population in a given area or the projected index. These indicators can be determined on the basis of data obtained during the research. Indicators are presented using elements of the ArcGis software package in discrete form and permanent form. In the research the model of optimization of placement of public catering establishments was developed. It is proposed to place twelve new catering establishments in the studied area of the city with the exact indication of their location. The scientific conclusion of the study will further improve the service to the local population and the promotion of the city of Kharkiv as a object of tourism. The principle of developing a digital map and geodatabase is effective to address issues related to tourism infrastructure, so the developed model can be used in other cities. Further research in this direction may be related to improving geostatistic analysis of data and taking into account more factors..

1 Problem statement

The establishment of market relations in Ukraine, the economic crisis resolution requires restructuring of the national economy, change in the traditional proportions between its branches. Priority development should be given not only to the industries the products of which will satisfy human needs, but also to the non-production sphere. Most developed countries have already gone this way. Thus, over the past 50 years the US economy has undergone dramatic changes, as a result of which the country is mainly focused on the service-producing industries. Today, the service sector provides 70 percent of gross national income and ensures 75 percent of employment, and tourism ranks first in 47 states, depending on its development. It is no coincidence that for the first time in the history of Ukraine, the government has declared tourism one of the priorities of the national economy, as the tourism business is recognized as one of the most fast-payback and highly profitable businesses. The timeliness and expediency of creating a set of measures for the development of this area of activity is based on the adoption of legislation, the main of which are the Law of Ukraine «On Tourism», Resolution of the Cabinet of Ministers of Ukraine «On measures for further development of tourism», the Law of Ukraine on the creation of special economic zones of tourist and recreational type [1]. According to the results of research carried out by the World Tourism Organization, tourism is projected to take the first place among the largest sectors of the economy in terms of revenues. Ukraine, possessing numerous historical and cultural sites, unique recreational resources, will be able to achieve a significant economic effect in the tourism business. While in the developed countries this branch of activity has become a tourism industry, Ukraine is only taking the first steps in this direction. In the world practice, the concept of «tourism industry» includes infrastructure companies engaged in satisfying the needs of tourists, including household services, local industries that produce goods and souvenirs for tourists, goods and equipment for hotels, restaurants, cafes, and also semi-finished food products, etc. A special place in the infrastructure is occupied by hotel and restaurant enterprises because they contribute to meeting such important needs of tourists as accommodation and food.

Developing the tourism industry in Ukraine, trying to enter the international market of tourist services deservingly, it is necessary to reconstruct the existing, build new modern restaurants, able to compete with the

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best restaurants in the world, to gain prestige and popularity.

The solution of this problem is impossible without the development of catering establishments (CE). Unfortunately, there are many problems in this area of the national economy related to the insufficient infrastructure development, inconsistency of quantitative and qualitative characteristics with world requirements and modern needs of not only foreign but also domestic consumers, despite the fact that their percentage of financial turnover in the structure of the tourist product ranges from 20% to 50%.

In addition, CE is an important element of the social sphere, which plays an important role in improving the efficiency of social production and, accordingly, the growth of living standards. They perform very important tasks that are related to health maintenance, leisure of citizens based on the conditions of rational use of time. Moreover, as entrepreneurial entities, they seek to increase productivity and competitiveness. The multifactorial environment of modern catering enterprises forces them to be constantly in search of new opportunities, entries into the market of food services, technology and consumers, an effective management mechanism that is sensitive and able to respond to change and act in conditions of uncertainty. In this regard, entrepreneurs should pay much attention to the organization of the catering establishment, the provision of various types of catering services, so that the establishment meets the requirements of the consumers.

One of the most important success factors, and in some cases even a dominant one, is the correct location of the catering establishment. Correction of a mistake related to a poor choice of location is possible only by re-opening the institution in another location, which entails considerable financial expenses. As a rule, the establishments operating in the lower price category, which primarily include fast food restaurants, depend on the place the most. The main principle of choosing a place for a restaurant, cafe, bar, fast food, etc. is to bring it as close as possible to the consumer. That is, the premises should be located near the places of residence of the potential consumer (near the house, near work, when walking around the city), should be accessible by transport and easy to find. Exceptions may be only super-conceptual establishments, where, according to the authors' suggestion, guests will purposefully gather from all over the city. Thus, the stated above considerations allow us to justify the relevance of finding a solution to the problem of choosing the best location for the catering establishment.

Various aspects of the problem of CE development are reflected in numerous publications of both domestic and foreign researchers. Thus, in [2] the author proposed a systematization of transformational changes of classifications of restaurants by nature of economic activity, types and classes. Also on the basis of comparison of domestic and international classifications the author concludes about the need to expand the classification of restaurants in Ukraine to allow accurate statistical accounting of all existing types of restaurant establishments and to obtain reliable information for the strategic development of the industry and individual restaurant business entities. The publication [3] identifies the directions of development of the main sectors of the restaurant industry. The work [4] is devoted to the problems of restaurant chains, related to the development of competitiveness. The author of the article [5] explores the experience of overcoming the crisis by restaurant enterprises. The article [6] highlights the state of development of the restaurant industry in Ukraine, analyzes the dynamics of changes in sales of products and services, assesses trends in the number of catering establishments of different types and their profitability, identifies features and prospects for restaurant enterprises basing on the analysis. Work [7] highlights the features and impact of the restaurant business on human health, the end results of people's work and the effectiveness of Ukraine's economy.

Quite a large number of publications [8 – 11] highlight the results of research on the development of the catering industry, both in the Ukrainian realities and based on the experience worldwide. The author of works [12, 13] presented the research results on the efficiency of management of restaurant business strategic development, and on their basis the author concludes that possibilities of development and use of potential of restaurant enterprises of Ukraine have considerable prospects, but the current state of economy and management policy of restaurateurs determine slow development of the restaurant industry, creating a large number of obstacles in its path. In the monograph [14] the development of the theory and methodology of the economic mechanism of public catering enterprises functioning formation is investigated, their role in tourism infrastructure is analyzed, theoretical and practical bases of structuring of the tourist branch management system are investigated, suggestions on improvement of a technique which defines volumes of tourist services are given, methodical approaches of a choice of investment policy in branch model efficiency are developed. Additionally, the issues of legal and regulatory support of tourist product market existence are considered and the socio-economic essence of tourism is revealed. However, researchers absolutely do not pay attention to the formation of models of optimal CE placement.

2 Method

Today in Ukraine, in contrast to previous years, the approach to the foundation of public catering establishments is becoming more practical and purposeful. One of the most important steps in decision-making when creating a catering establishment is marketing data and consumer research, i.e. the environment in which the establishment will have to operate. In addition, it is important to find out: location features, characteristics of traffic and pedestrian flows, competitive environment, information on residential, commercial, office infrastructure. Analysis of these data allows us to conclude what type of institution should be arranged in a particular place.

Let us take a look at the general criteria for assessing the area of the city, which is considered as a potential place of CE activity:

Territory: area, shape, compactness.

Type of district: central – business, tourist or leisure area, sleeping, industrial, area on the outskirts of the city or outside the city.

Trends in the development of the district: whether the district is promising, and whether it can attract more wealthy visitors in the future, whether growth and change for the better is expected, or the development of the district is weak.

Characteristics of the population: population, population density, population composition. It is desirable to identify groups of the population by age and type of employment, to determine whether there are trends in the composition of the population, its wealth, the structure of households. This analysis is performed for residential areas. Office areas are studied in a similar way, with such indicators as the differentiation of enterprises by type of activity, the stability of their work, the level of wages in the area. When studying traffic flows in the area it is needed to investigate: the number, intensity, composition of traffic flows, the presence of pendulum traffic, the state of highways, road congestion, the presence of traffic jams. An important component of the analysis of the district territory is the study of pedestrian flows, which are characterized by their type (residents of the district, office workers, visitors, etc.), the intensity of each flow and time. Car and pedestrian flows are plotted on a map for the possibility to determine which of them the planned enterprise can fully use. In addition, information on the movement of public transport in the area is collected: the number of modes of transport, routes, traffic intervals, stops. Availability and level of development of existing CE in the area: services congestion by formats and areas of specialization, uniformity, existing niches. Future competitors are also taken into account: projects that are under construction and development, as well as the availability of vacant plots prospective for the location of catering facilities, opportunities and conditions of delivery of goods in this area, labor resources in the given territory, a situation with attraction of the personnel for the created CE.

Unfortunately, the data that should be used in the study of the district are not always available or is fully reliable in the Ukrainian context. Such data include, for example, the level of income of the population and the volume of sales, which is on average in the CE area. Databases demonstrating the location of CE in the territory have not yet become widespread in Ukraine, but they may become more accessible in the future.

When exploring the area, not only a map is used, but also space and aerial photographs. Photogrammetry methods reveal many things which cannot be assessed with a topographic map, for example, when working with photography it is possible to identify disadvantaged and polluted areas, evening photographs reveal the need for light accents and suggest how pleasant and safe for visitors a visit to CE will be in night time.

That is, decision-making when choosing the location of a CE requires processing large amounts of information and using a set of information technologies designed to model and forecast the spatial development of infrastructure and facilities in the catering industry. Modern means of analysis of territorial location and modeling of spatial development are based on the use of geographic information technologies. Geographic information system (GIS) is an information model of real space according to the established list of features and characteristics, an active and multifunctional database that can be constantly complemented and updated. The main task of GIS is to support management decisions based on spatial analysis, mathematical and cartographic modeling, visualization, forecasting and evaluation. The use of GIS technology allows to create a detailed visualization and conduct a qualitative spatial analysis [15] of the CE placement with reference to the territory. The modeling, the results of which are presented in this paper, was done with the capabilities of the software product from Esri – ArcGIS.

Modern cities, as well as the city of Kharkiv, which was chosen as the object of study, are characterized by high population density, compact housing, the presence of four main areas of distribution: industrial, housing-administrative, utility and recreation areas. These areas involve the presence of different types of CE.

Determination of the peculiarities of the population distribution was carried out on the basis of its density indicators and concentration index. The population concentration index allows to investigate the distribution of the population by administrative units in relation to the general uniformity of its distribution across the territory. This index is calculated as the difference between the shares of the area and the population of the district:

$$IKH = \frac{\sum |P_ч - S_ч|}{2} \tag{1}$$

where IKH stands for population concentration index;

$P_ч$ – the share of the population of the district;

$S_ч$ – share of the district area.

Share of the destricts area:

$$S_ч = \frac{S_{р-н}}{S_{обл}} * 100\% \tag{2}$$

where $S_{р-н}$ – stands for area of the district;

$S_{обл}$ – area of the region.

Share of the population of districts:

$$P_ч = \frac{P_{р-н}}{P_{обл}} * 100\% \tag{3}$$

where $P_{р-н}$– stands for the population of the district;

$P_{обл}$ – the population of the region.

According to the results of calculations, the index of population concentration in Kharkiv region is 63.6%, what indicates the uneven distribution of the population throughout the region, i.e. the population of the region is concentrated mainly in the central part of the region, namely in Kharkiv and suburbs.

In order to assess the sufficiency of CE in Kharkiv city, areas of the city with a high concentration of population and housing density were identified. The diagram (Fig. 1) shows that the lowest population density is in the Kholodnohirsky and Osnovyansky districts of the city, and the highest is in the Moscowsky district.

In addition, the number of catering establishments in the districts of Kharkiv was analyzed. The results of the analysis are shown on the diagram (Fig. 2).

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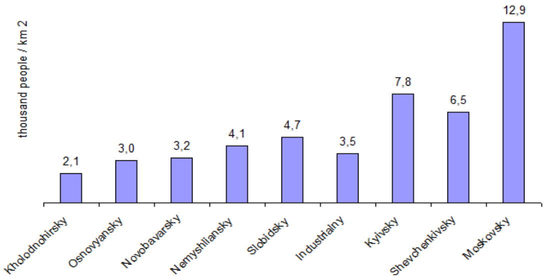

Fig. 1. Diagram of population density distribution by the districts of the city.

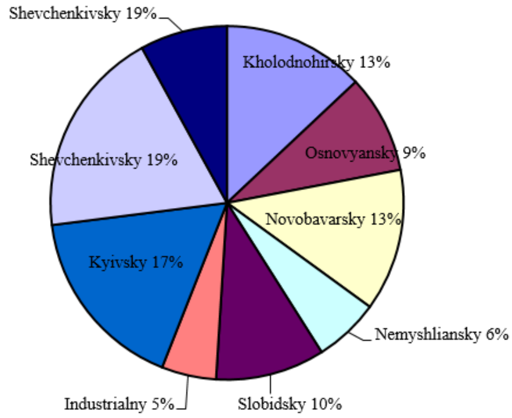

Fig. 2. Distribution of housing and communal services by districts of the city.

This diagram shows that the smallest number of CE is in the Industrialny district of Kharkiv. The obtained data were enough for further spatial analysis. As a result, a cartographic model of the territorial localization of CE was obtained (Fig. 3).

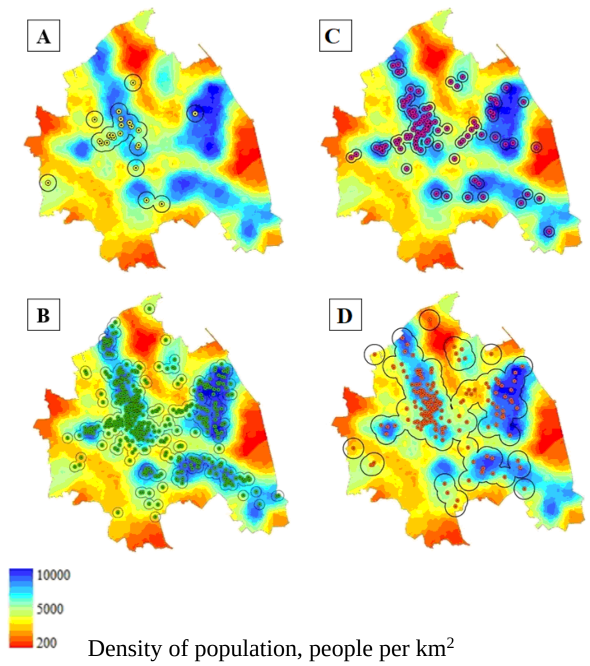

Fig. 3. Visualization of buffer zones for CE of Kharkiv in comparison with the indicator of urban population density. A – public dining rooms; B –cafes; C – fast food establishments; D – restaurants.

Figure 3 shows that most CE tend to densely populated areas, which is a regularity. Our attention was drawn to the Industrialny district of the city, because it has not the smallest number of inhabitants, but the number of CE is much smaller comparing to other districts. While, for example, in the Shevchenkivsky district the number of CE is more than 1 per 1,000 people, in the Industrialny district this ratio is 1 per 3,000 people. It can be concluded that in the Industrialny district of Kharkiv the system of public catering establishments is not properly developed.

Here is a brief historical background about the Industrialny district of Kharkiv. The Industrialny district is a relatively young district of the city. Its foundation dates back to the first five-year plan, when the construction of Kharkiv Tractor Plant was started on the eastern outskirts of Kharkiv. Before its construction, in 1930, there was a railway station «Losieve» with three apartments and a small village Losieve with two dozen yards. Until 1941 the total population of the district was 70 thousand people. In the postwar period, intensive construction of new industrial enterprises and housing estates began. Now the district is the largest industrial district of the city. The territory of the district is 4526,8608 hectares (12% of the territory of Kharkiv). It borders on 2 districts: Nemyshlyansky district in the west; Kharkiv district of the Kharkiv region in the south, north and east. It is one of the greenest areas of the city. The total area of greenery is 980 hectares (including 110,2 hectares of garden squares, parks, sanitary protection zone, etc.), 264 hectares are out of balance. Its population is 153,8 thousand people (10,8% of the population of Kharkiv). The population density amounts 3,397 thousand people per 1 km^2.

Let us consider the transport infrastructure of the area. On the territory of the district there are 150 roads amounting 133 km long, with a total area of 1 million 118 thousand square meters, including of: citywide significance – 203,97 thousand square meters, district importance – 659.76 thousand square meters, local importance – 346,7 thousand square meters. By type of coverage: with asphalt pavement length – 87,02 km, making up an area of 873,06 thousand square meters, with a gravel covering 32,55 km long, with an area of 210 thousand square meters, with a soil surface with length of 14,59 km, an area of 100,3 thousand square meters, with a cement coating length of 4,44 km, an area of 35.97 thousand square meters; railway stations – «Losieve-1», «Losieve-2», «Horyzont»; bus stations – «Zavodska». Characteristics of district roads – roads of citywide significance – 14,97 km, of district significance – 72,25 km, of local significance – 51,38 km.

The branch structure of the district has an industrial and commercial character and is represented by such branches as: food industry (production of soft drinks, milk and dairy products, sausages, collection, purification and distribution of drinking water); mechanical engineering (production of agricultural tracked and wheeled tractors, submersible electric motors and submersible centrifugal pumps, metal-cutting machines, bearings); construction (manufacture of concrete and reinforced concrete structures, special types of cement, expanded clay, gravel, ceramic tiles).

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There are 21 pre-school educational establishments, 19 general educational establishments, two out-of-school educational establishments and one higher educational establishment and a machine-building college in the district.

Objects of trade and consumer services are represented in the district in the amount of: 174 – shops, 246 – retail facilities, 211 – consumer services, 119 – food objects, 5 trading platforms and one market.

The housing stock of the district is 5820 houses, with a total area – 5105.0 thousand m^2. There are 5107 private houses in the district with total area of 640 thousand m^2. There are 711 multi-storey residential buildings with the total area of 3882,7 thousand m^2.

There are 6 squares with a total area of 16,44 hectares on the territory of the district.

For a more detailed analysis of the Industrialny district of Kharkiv on the ratio of population density and location of the transport network and the existing CE, a pedestrian zone with a radius of 400 m for each public transport stop (Fig. 4) was built with the help of GIS.

The constructed model allows to recommend placement of new CE in the Industrialny district of the city of Kharkiv, proceeding from the following factors:

- population density;
- transport interchange (minimization of time spent on visits);
- the presence of existing CE.

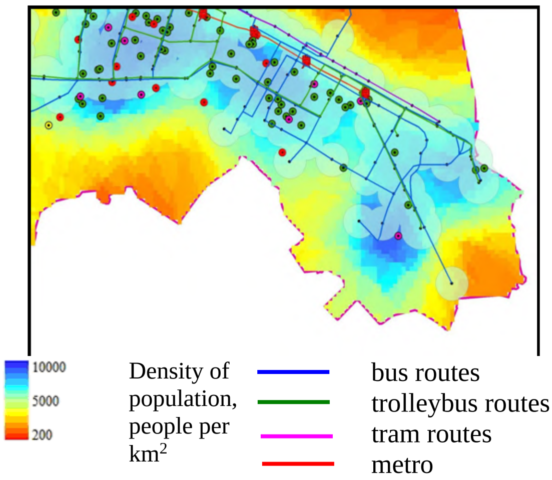

Fig.4. Outlook of buffer zones projected for public transport stops in comparison with CE sufficiency and population density indicators.

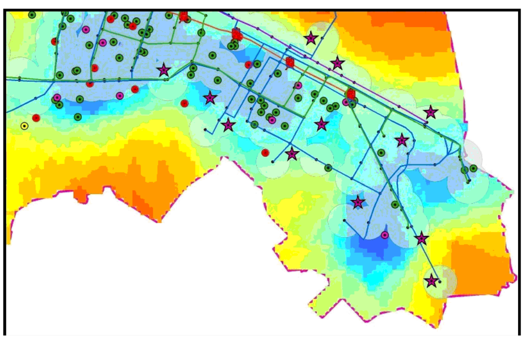

Fig. 5. View of the proposed new HVACs for the Industrialny District.

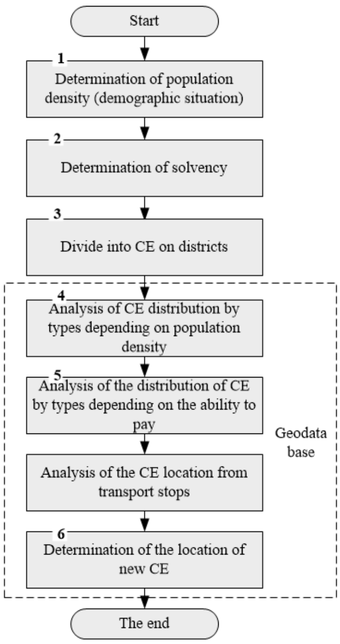

Fig. 6. Algorithm of optimization of CE placement.

As a result of the GIS analysis, 12 new catering establishments were proposed (shown by stars on the map). Particular attention when planning new CE was paid to the transport accessibility – at the intersections of large traffic flows, it was proposed to place larger restaurants, bars, cafes, snack bars and canteens and in larger numbers (Fig. 5).

One of the most important stages in creating an model of optimization (Fig. 6) for the location of CE is the development of a geodatabase, which would include a large number of influencing factors regarding the choice of location of the infrastructure object. The more influencing factors will be taken into account when creating a GIS model, the greater the opportunities will be provided in case of further spatial analysis.

4 Results

1. The digital geoinformation model of the Industrialny district of the Kharkiv city with introduction of a considerable quantity of attributive data is developed.
2. Calculations of the population concentration index in Kharkiv region are performed.
3. The analysis of the territory of a separate city district with the help of geographic information systems on the identification of the optimal number and rational placement of catering facilities is performed.
4. An model of optimization of CE placement based on the results of analysis of a number of factors has been developed.

5 Conclusions

The use of geoinformational technologies to model the location of new CE will allow to take into account many factors, namely, population density, purchasing power, distance from traffic stops, and to solve this problem with minimal time costs and with the least probability of error. It was with the help of spatial analysis performed in the ArcGis geoinformational system that the creation of twelve new catering establishments in the Industrialny district of Kharkiv was proposed, as in the least provided with such establishments district.

In the research, with the help of the ArcGis software package, an optimization model for the location of CE was developed and a map of the existing CE of the Industrialny district of Kharkiv was compiled. This map provided an opportunity to further establish the number and location of new CE. Further it will also allow not only to improve the service to the local population, but will also encourage the promotion of the city as a tourist attraction.

The very principle of building a digital map and database structure will be effective to address any issues related to tourism infrastructure, so the developed models can be distributed among any administrative units. In general, data mining of geostatic models can be used to process statistics in any locality by using a geostatistic method to convert data from discrete to permanent representation. Further research in this direction may be related to improving geostatistic analysis of data and taking into account more factors.

As an example, mathematical formulas were presented to determine the index of concentration of the actual population in a given area or the projected index. These indicators can be determined on the basis of data obtained during the study and presented using elements of the software package ArcGis in discrete and constant forms.

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Bioremediation of toluene by bioaugmentation, biostimulation and natural attenuation

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Abstract. Contamination in subsurface environment is a serious environmental hazard. Main sources of the contamination are petrol, diesel fuel, gasoline at oil refineries, underground storage tanks, transmission pipelines and different industries. Permeable reactive barriers (PRBs), which is a promising technology to remediate groundwater in-situ, are filled with reactive materials for the removal of the contaminants present in groundwater. In this study, groundwater contaminated with toluene is treated in reactor columns by biological processes. This study was conducted to assess the impact of bioaugmentation (BA) and biostimulation (BS) on toluene degradation efficiency. After 44 days of treatment, toluene concentrations were decreased from 5 mg/l to 4.304 mg/l by the natural attenuation treatment (Reactor 2), which represents a 13.9% removal efficiency. Toluene was reduced to 0.0239 mg/l in the biostimulation and bioaugmentation treatment (Reactor 1), which represents a toluene removal efficiency of 99.5%. This study showed that the toluene removal efficiency in the combined BA and BS process was much higher than in natural attenuation (NA) process tested.

1 Introduction

Contamination in subsurface environment has become a serious environmental hazard in recent years. Main sources of the contamination are petrol, diesel fuel, gasoline at oil refineries, underground storage tanks, transmission pipelines and non-petroleum related industries. These hazardous contaminants are in the EPA's (U.S. Environmental Protection Agency) priority pollutant lists. Besides, some of that chemicals in the fossil fuels tend to persist in the environment for a long time. These persistent contaminants have several health risks to humans, animals, and other living organisms. Therefore, this threat needs to be removed carefully from the subsurface environment. Removal of contaminants, especially petroleum hydrocarbons, from soil and groundwater through bioremediation technologies has been commonly practiced by researchers and industry. One of the most common remediation technologies is bioremediation which uses microorganisms to biodegrade hydrocarbon. Bioremediation has been commonly used for cleaning up soil and groundwater contaminated sites and is an environmentally friendly and cost-effective remediation technology.

Total petroleum hydrocarbons consist of three components: aliphatic (or saturated), aromatic, and polar hydrocarbon fractions. Diesel fuels primarily contain a mixture of C10 through C19 hydrocarbons, which include 64% aliphatic hydrocarbons, l-2% olefinic hydrocarbons, and 35% aromatic hydrocarbons. All the above fuel oils contain less than 5% polycyclic aromatic hydrocarbons (PAHs). Biodegradation of petroleum hydrocarbons by microorganisms have been studied by scientists for many years. Microorganisms responsible for degrading crude and refined petroleum products are defined as either eukaryotic or prokaryotic organisms. Some of the species that are effective on biodegradation of petroleum hydrocarbons are *Nocardia, Pseudomonas, Acinetobacter, Flavobacterium, Arthrobacter, Achromobacter, Alcaligenes, Mycobacterium, Bacillus, Aspergillus, Fusarium, Penicillium, and Sporobolomyces.* Bioremediation method can be selected based on the properties of the polluting hydrocarbons and the characteristics of soil and the groundwater where the contaminant is spilled. It is preferred that the hydrocarbons contain carbon chain length of between C10 and C20, because these carbon chains are easier to break. On the other hand, hydrocarbons with C20-C40 carbon chains are hydrophobic, less soluble in water and resistant to biodegradation. Bioremediation is a technology that aims at cleaning a contaminated region by microorganisms and their enzymes. Specific contaminants such as chlorine containing pesticides can be also biodegraded by microorganisms. Microorganisms that degrade these hydrocarbons can be bacteria, protozoa, nematodes, and fungi. Bioremediation of a contaminated site by adding specifically selected microorganisms is called bioaugmentation.

Bioaugmentation technology is used effectively in soils and groundwater where there is not sufficient microbial population available for biodegradation. Bioremediation of a contaminated site by adding nutrients is called biostimulation. Some of the benefits of bioremediation can be summarized as; effective,

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economic, environment friendly, less toxic byproducts, applicable directly on the contaminated area and friendly with the existing flora.

When hydrocarbon-containing contaminants spill on land, degradation by indigenous microorganisms progresses slowly due to low microbial population and activity. Bioremediation is recognized as one of the most cost-effective clean-up methods for the treatment of oil-contaminated soils and groundwater. For instance, bioaugmentation (BA) and biostimulation (BS) are the two main bioremediation technologies commonly used for soil and groundwater clean-up. Bioaugmentation works by introduction of exogenous microorganisms to the contaminated soil or water. Microorganisms may be inoculated with specially cultivated microorganisms with capabilities for degrading a certain contaminant. Biostimulation is used to describe the addition of nutrients, such as nitrogen and phosphorus, to stimulate the existing microorganisms that are capable of degrading contaminants. On the other hand, natural attenuation (NA) processes can include chemical reactions, volatilization, adsorption, and biodegradation.

Bioremediation is the process of using microorganisms to convert organic compounds such as crude oil into non-toxic substances such as CO_2 and H_2O. Any given bacteria can occur naturally and require specialized nutrients. In most cases naturally occurring microorganisms are not in sufficient concentrations to provide complete degradation. Thus, there exists an opportunity to enhance and accelerate the natural degradation by the introduction of additional microorganisms and nutrients. When mixed with water and applied as a slurry to contaminated soil or groundwater, microorganisms break down the molecular structures of the targeted hydrocarbons by utilizing their mass as a source of energy. Because of the high degree of interface between bacteria and the hydrocarbon, the rate of degradation tends to be quite rapid at first, but gradually diminishes as the more biodegradable hydrocarbon is consumed.

One of the most promising technologies for in-situ groundwater treatment is to use Permeable reactive barriers (PRBs). PRBs are filled with reactive materials and they must be permeable than the surrounding aquifer material. When compared to conventional pump and treat systems, PRB method is much cheaper because there is no continuous energy input is needed. The other benefit of PRBs is that replacement of the PRB material is always possible [1]. There are two types of PRBs, continuous PRBs and funnel and gate system PRBs. Continuous PRBs consist of a single reactive zone whereas funnel and gate PRBs consists of permeable gate (reactive zone) placed between two impermeable walls that direct the contaminated plume towards the reactive zone. The mechanisms of interaction in PRBs are degradation, precipitation and sorption. The types of reactive materials used in PRBs are those changing pH or redox potential, causing precipitation, materials with high sorption capacity, and releasing nutrients and oxygen to enhance degradation. Some of the reactive materials used in PRBs are activated carbon (AC), Al, ferric oxide, peat, zeolite, lignite, zero valent metals, fly ash, lime, limestone, sand, and clay.

PRBs consisting of zero valent iron (ZVI) can also be used to treat groundwater contaminated with chlorinated solvents, nitrate, chromium, uranium, and pesticides [2]. In another study, PRB columns filled with olive nut, sand and soil were usefully used to treat wastewater containing nitrate [3]. PAHs were successfully removed from water by using PRB materials of wheat straw and coconut shell [4]. Corn straw, fly ash, Fe-Mn, and zeolite were used as PRB materials to reduce the concentrations of Pb and Cd from groundwater [5]. Steel manufacturing basic oxygen furnace sludge (BOFS) was tested as a PRB material to remove Cr+6 from soil [6]. Two lab scale column studies used ZVI and ZVI + zeolite to treat leachate [7]. In one study, ZVI, zeolite and activated carbon were used as PRBs to treat groundwater contaminated with leachate [8].

Toluene, one of the BTEX (benzene, toluene, ethylbenzene, and xylene) compounds, is a clear, colorless liquid that becomes a vapor when exposed to air at room temperature. Toluene is typically used in a mixture with chemicals such as other solvents and paint pigments. Products that can contain toluene, such as paints, metal cleaners, and adhesives, are used in many industries. Gasoline and other fuels also contain toluene. The specific objective of this study was to investigate the toluene biodegradation efficiency in a freshly contaminated water by combined bioaugmentation and biostimulation processes and by natural attenuation. The term biostimulation is used to describe the addition of essential electron acceptors such as nutrients to enhance the microbial growth [9–11]. The term bioaugmentation is used to describe the addition of essential microorganisms. Several research studies have been conducted on the treatment of hydrocarbons by various microorganisms [12–18].

2 Methodology

2.1 Configuration of PRBs

Two reactors with the dimensions of 0.6 m height and 10 cm diameter are filled with coarse to medium sized sand. Each reactor column will have effluent port for water samples (Figure 1). The column reactors are operated as up flow. Reactor 1 (R-1) is inoculated with specific bacteria and required nutrients (N, P and K) are added. To maintain aerobic conditions, influent tank for reactor 1 is aerated as needed. Reactor 2 (R-2) is used as control and contains only sand and gravel but no bacteria and nutrients. No aeration is performed for reactor 2.

For each reactor, 5 mg/l toluene concentration is prepared as influent sample. All the reactors are fed at an influent flowrate of 1 mL/minute.

2.2 Reactive materials in PRBs

The reactive filler material in the PRBs consists of the following mixed materials (Table 1).

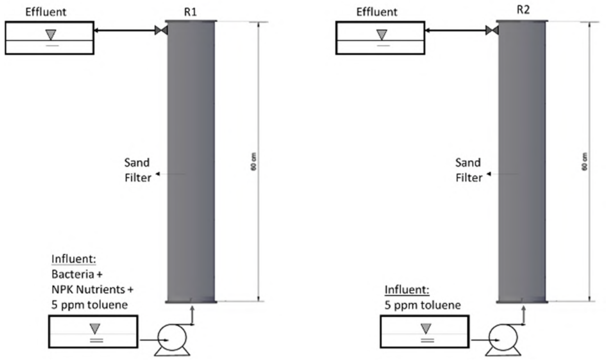

Fig. 1. The schematic of the PRB columns.

Table 1. Properties of filler material in PRBs.

Material	Diameter (mm)	% of SiO_2	% of acid solubility	Bulk density (t/m^3)	Specific gravity
Silica sand	1-2	98±1	1±0.5	1.5-1.70	2.55-2.70
Silica sand	2-3	98±1	1±0.5	1.5-1.70	2.55-2.70
Silica sand	3-6	90±1	10±0.5	1.5-1.70	2.55-2.70
Silica gravel	8-12	90±1	10±0.5	1.5-1.70	2.55-2.70

2.3 Analytical method

An HPLC chromatograph equipped with a UV detector was used for toluene analysis. The UV detector was set to 254 nm. The high-performance liquid chromatography column was a C18 Bond Pack 3 µm (25 cm-4.6 mm) analytical column. Chromatography was isocratic in a mobile phase composed of water-methanol (30-70). The flow rate was set at 1 ml / minute. All chemicals and water used were HPLC grade.

3 Results

3.1 Results of permeability tests

Permeability is the water and air conductivity of the soil or sand. The falling head permeability test is a common laboratory test method used to determine the permeability of fine-grained soils with medium to low permeability such as sand, silt, and clay. Permeability of soils can be performed by using falling head and, constant head methods. In this study, falling head permeability test was performed by using the equation below:

$$K=a.L/A.t.\ln(h_1/h_2) \tag{1}$$

where

K=permeability in cm/sec

a=cross sectional area of the tube used for water elevation change (cm^2)

L=length of the reactor (cm)

A=cross sectional area of the reactor (cm^2)

h_1=distance of the water elevation to the bottom of the reactor before the test (cm)

h_2=distance of the water elevation to the bottom of the reactor after the test (cm)

Reactor-1:

$a=\pi.r^2= \pi.(5)^2=78.5\ cm^2$, $h_1=70$ cm, $h_2=60$ cm, $t_{average}=39.33$ sec, A=78.5 cm^2, L=60 cm

K = 0.779 cm/sec

Reactor-2:

$a=\pi.r^2= \pi.(5)^2=78.5\ cm^2$, $h_1=70$ cm, $h_2=60$ cm, $t_{average}=40$ sec, A=78.5 cm^2, L=60 cm

K = 0.766 cm/sec

3.2 Results of pore volume and porosity tests

Pore volume and porosity tests are used to determine the volume and volume distribution of pores in sand filters on the apparent diameter of the pore inlets. In general, both the size and volume of pores affect the performance of sand filters. Therefore, the pore volume distribution is useful in understanding sand filter performance and determining a material that can be expected to perform in a particular manner.

Pore volume is the volume occupied by water in the reactor. To determine the pore volume, the reactor is filled with water and the amount of water was measured as pore volume.

Reactor 1:

Reactor volume= $\pi.r^2.h=3.14 \times (5)^2 \times 60=4710\ cm^3$

Pore volume=1.06 L=1060 cm^3

Porosity (ε)=1060/4710=0.225

Reactor 2:

Reactor volume= $\pi.r^2.h=3.14 \times (5)^2 \times 60=4710\ cm^3$

Pore volume=1.15 L=1150 cm^3

Porosity (ε)=1150/4710=0.244

3.3 Results of flow rate and hydraulic residence time tests

The hydraulic residence time (HRT) (t) is a measure of the average time a soluble compound remains in a sand filter. In engineering, volumetric flow rate is the volume of fluid passing per unit of time; it is usually represented by the symbol Q.

Hydraulic residence time is the ratio of total water volume pumped to the flowrate as shown below.

Reactor 1:

t=V/Q, where V=1.05 liter=1050 mL, Q=1.2 mL/minute so t=1050/1.2=875 minutes=14.58 hrs.

Reactor 2:

t=V/Q, where V=1.15 liter=1150 mL, Q=1.2 mL/minute so t=1150/1.2=958.33 minutes=15.97 hrs.

3.4 Toluene removal in reactors

Aromatic hydrocarbons such as BTEX compounds and their derivatives are among the most important contaminants of soil and groundwater. BTEX compounds are the most common groundwater pollutants among various petroleum hydrocarbons. BTEX compounds are released into the environment through spilled diesel fuel or gasoline and leaks from underground storage tanks and pipelines during transportation. BTEX compounds are listed as priority pollutants by the US Environmental Protection Agency and are among the top 100 chemicals on the hazardous substances' priority list. Therefore, the development or improvement of existing remediation methods that minimize the environmental damage caused by BTEX compounds has attracted the attention of environmental protection organizations. Biological treatment of contaminated groundwater is a well-established technique and is also known to be cost-effective and environmentally friendly. During the biological degradation process, microorganisms can directly reduce BTEX to less toxic compounds by depleting the carbons present within the structure of BTEX. The performance of the biological treatment method is affected by various environmental factors such as temperature, oxygen, pH and inorganic nutrients. Therefore, these factors must be optimized for the implementation of efficient biological treatment systems. Bioremediation process in the PRBs has two main processes: a) Biostimulation – bioremediation process is enhanced by adding nutrients (NPK) and oxygen. b) bioaugmentation –microorganisms are added.

3.5 Oxygen requirement

For toluene (C_6H_6), the biodegradation reaction will take place as follows:

$$C_7H_8 + 9O_2 \rightarrow 7CO_2 + 4H_2O$$

So, 1 mole of toluene requires 9 moles of oxygen. Since the total concentration of toluene is 5 ppm (5 mg/l), then the amount of oxygen required can be calculated as follows:

Molecular weight of toluene is 92 g. If 92 g of toluene requires 9 x 32 = 288 g oxygen, then 5 mg toluene requires 0.0156 g oxygen. The required oxygen is provided by ambient air through aeration for R-1, but R-2 was not aerated since it is used as control.

3.6 Nutrient requirement

Molecular weight of toluene is 92 g and 1 mole of toluene contains 84 g of carbon (C) per mole of toluene. If 92 g of toluene contains 84 g of C, then 5 mg of toluene contains approximately 0.00456 g of C. As a nutrient, mixture of ammonium chloride (NH_4Cl) and potassium dihydrogen phosphate (KH_2PO_4) as N and P sources, respectively, are used.

Based on the ratio of C:N:P of 100:5:1; if C is 0.00456 g, then N required is 0.000228 g and P required is 0.0000456 g. If 1 mole of NH_4Cl (53 g) contains 23 g of N, then 0.000525 g of NH_4Cl contains 0.000228 g of N, so the amount of NH_4Cl required is 0.000228 g. Similarly, 1 mole of KH_2PO_4 (136 g) contains 39 g of P, then 0.000159 g of KH_2PO_4 contains 0.0000456 g of P, so the amount of KH_2PO_4 required is 0.0000456 g.

In summary, to bioremediate 5 mg/l of toluene in R-1, 0.000525 g of NH_4Cl and 0.000159 g of KH_2PO_4 are required.

3.7 Bacteria requirement

To accelerate the biodegradation process in R-1, one of the commercially available BTEX biodegrading bacteria such as *Alcanivorax sp.* is added to the system as inoculant.

3.8 Toluene removal results

Toluene removal rates for R-1 and R-2 are depicted in Figure 2. Toluene concentration in the influent sample for both reactors were 5 mg/l. After 44 days of treatment, toluene concentrations were decreased from 5 mg/l to 4.304 mg/l by the natural attenuation treatment (R-1), which represents a 13.9% removal efficiency. Toluene was reduced to 0.0239 mg/l in the biostimulation and bioaugmentation treatment (R-1), which represents a toluene removal efficiency of 99.5%. The efficiency of biodegradation was the highest when the BS and BA processes were combined.

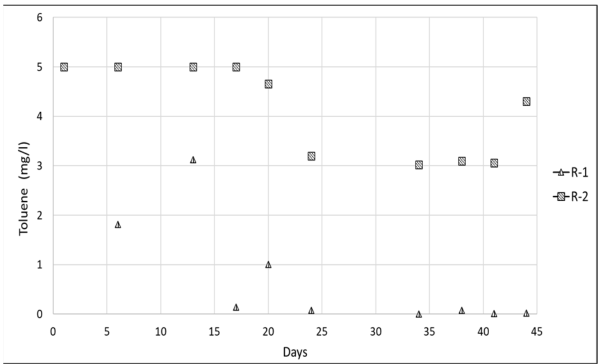

Fig. 2. Toluene removal rates in reactors.

4 Discussion

Bioaugmentation alone may not be effective to improve the remediation of hydrocarbon contaminated soils. Some research studies showed that bioaugmentation improves biodegradation efficiencies temporarily and that biostimulation seems to be a more preferred bioremediation technology to reach sufficient clean-up. Microbial populations are important in the remediation of petroleum hydrocarbon. Molecular methodologies provide help to understand the microbial community structure in remediation systems. Petroleum derived contaminants remaining in soil and groundwater for a long time after contamination along with costly treatment methods have made them one of the most important environmental pollutants. Improvement of hydrocarbon biodegradation is possible by applying different bioremediation technologies such as bioaugmentation and biostimulation alone or in combination. Biostimulation seems to be a more effective remediation methodology for BTEX removal than bioaugmentation alone.

Results of this study showed that combining BS and BA has a higher effect on biodegradation efficiency than NA process. Adding nitrogen and phosphorus, along with microbial inoculation and aeration can create an optimum condition for microorganisms to degrade toluene. This study assessed the effectiveness of bioaugmentation combined with biostimulation process on a freshly toluene-contaminated water. The results of this work justified that the bioaugmentation and biostimulation combined provided the accelerated biodegradation of toluene from the contaminated water through increased microbial biomass. Several different bacterial species would be needed to effectively biodegrade hydrocarbons. Single microbial species do not have the capacity to biodegrade more than two different compounds that are usually present in hydrocarbons. Conventionally, the higher the hydrocarbon degrading microbial population, the more hydrocarbon biodegradation takes place.

5 Conclusions

Petroleum hydrocarbons remaining in water for a long time after contamination along with costly treatment methods have made them one of the most important environmental pollutants. This study confirmed that it is possible to enhance the biodegradation of toluene in water by using different treatment methods such as bioaugmentation and biostimulation in combination. Analysis of toluene indicated that bioremediation of toluene contaminated water is very successful especially when BS and BA treatment are used together. In this study, the toluene degradation in the contaminated water was improved by bioaugmentation with genus Alcanivorax and biostimulation with nitrogen and phosphorus. The study also showed that bioaugmentation and biostimulation resulted in effective toluene removal within 44 days of treatment. The study highlighted the importance of in-situ groundwater treatment combined with bioaugmentation and biostimulation as a suitable strategy.

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Chemistry of medicinal plants as an integral part of ecological education

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Abstract. The degree of variability in the composition of herbal medicines was studied on the example of the preparation of St. John's wort from various Ukrainian producers. The Cu and Zn contents were the most stable compared to other (Fe, Mn, Co, Cr, Ni, Pb, Cd) microelements among plants of different origins. The content of toxic elements (Pb, Cd) did not exceed the established standards. Meanwhile, a 2-3-fold concentration difference was observed for hyperforin, an active pharmaceutical ingredient in St. John's wort. Thus, the existing standards do not ensure the stability of the composition of herbal preparations. As a result, the quality of medicinal drugs can be significantly different. The key reason for the variation in plant composition is environmental influence, including anthropogenic factors. Existing training programs for prospective specialists of the pharmaceutical industry do not pay enough attention to the impact of the environment on the quality of herbal raw materials. Necessary changes to the syllabi of relevant disciplines are formulated to eliminate this shortcoming and ensure sustainable development of raw materials sources for the pharmaceutical industry.

1 Introduction

Medicinal plants have a long millennial history of use. However, even today, they remain an essential part of modern medicine [1]. Many synthesised medicaments were made from plant extracts. By some estimates, about 25% of medications used worldwide are obtained directly from medicinal plants. Besides, they are used by pharmaceutical companies and in food, confectionery, cosmetics, paints, and varnishes.

Most herbal medicines belong to the group of over-the-counter medication and are consumed by patients in self-medication. There is a widespread misconception among consumers that "natural" always indicates "safe", and the consumption of the natural product does not carry a risk [2, 3]. However, some medicinal plants are toxic, primarily due to low quality and non-compliance with standards [4]. Besides, some herbal medicines may have serious side effects or be ineffective [5]. For example, herbal remedies are not usually adequate to treat any acute illness [6].

In many cases, herbal medicines can be used to treat the same diseases as synthetic medicaments. However, a significant difference exists between these two categories of drugs. Synthetic medicaments usually contain one active pharmaceutical ingredient (API). Their characteristics, including chemical and elemental composition, are clearly defined. Clinical trials determine safe consumption doses. The ingress of foreign organic or elemental impurities into the drug is controlled at all pharmaceutical production stages. Unlike synthetic medicaments, each herbal preparation is always a polypharmacy source because it contains a mixture of metals, metalloids and compounds.

Standardisation of plant raw materials and herbal medicines is much more complex and acute than standardisation of synthetic drugs [7, 8]. The complexity is caused by the variability of plant raw materials [9, 10].

The composition and quality of plants simultaneously depend on several botanical, biological, physical and chemical factors [6]. Botanical factors determine colour, odour, taste, some other characteristics [11]. Their knowledge underlies the primary identification of a plant. Physical factors determine moisture, final ash and extractives and characterise the quality of vegetable raw materials [11]. Biological factors determine the level of contamination by microorganisms, such as bacteria and their spores, mould, yeast, viruses, and others [12, 13]. The intensity of microbiological contamination directly affects the quality and safety of medicinal plants. However, the greatest variety of influencing variables falls into chemical factors, affecting API content and inorganic elements in plants [14, 15]. The combined effect of organic and inorganic components determines the therapeutic activity and safety of herbal preparations.

Medicinal plants can contain large and variable amounts of organic compounds. Assessment of the quality of medicinal plants is mainly based on the availability and content of the API. Residues of pesticides, fertilisers and mycotoxins endanger the safety of medicinal plants [16].

Medicinal plants always contain elemental impurities. Chemical elements in plants can be divided into essential elements in biochemical processes and some other elements that do not participate in plant vital functions

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[17]. Essential elements, in turn, are divided into macro- and micronutrients. Macronutrients (N, P, K, Ca, Mg and S) are needed in large quantities for plant growth. Micronutrients are primarily B, Cu, Fe, Cl, Mn, Mo, Zn, and Ni. They are also crucial for plant development but are needed in small quantities. At optimal concentrations, the essential elements are useful while they can become toxic in excess. A plant poorly develops in deficiency of essential elements. In the meanwhile, the content of essential microelements is often not controlled in herbal medicines.

Some other elements (Ba, Be, Sr, Y, V and others) do not contribute to plant development. The role of some elements, e.g. Al and Co, is still being clarified [17]. Non-essential impurities are the product of the interaction of plants with the environment. Both essential and non-essential elements can be toxic to the consumers of herbal medicines. Some non-essential metals (As, Cd, Pb and Hg) are very harmful [18, 19]. Contamination with impurity elements can occur at all stages - from growing and collecting raw materials to herbal medicine production [20]. Monitoring toxic ingredients is vital to prevent the human body poisoning through their consumption of herbal medicines.

The concentration of elemental impurities varies widely depending on various botanical, geological and environmental factors. Plants simultaneously receive chemicals from the environment in several ways [21]. The most natural way is exchanging the plant and surrounding soil and water [17]. However, different plants have different attitudes to the accumulation of other elements; i. e. show different bioaccumulation rates. For example, some plants, known as excluders, maintain metal concentrations at constant and low levels over a wide range of soil composition. Other plants, known as accumulators, show the effect of hyperaccumulation of cadmium or other ions [18, 19]. However, even the high content of toxic elements can sometimes not affect plant appearance [22]. Therefore, contaminated and clean plants can be difficult or impossible to distinguish.

Many works were devoted to the study of plants collected in different geographical locations. Such results allow us to study the cumulative effect of local diversity of plant species within one botanical genus [23, 24] and also the impact on the environment [25, 26]. For example, pollution by heavy metals of small Ukrainian rivers was studied in [27, 28] from the viewpoint of polluted waters influence on the local plant growth.

Pollution of air, soil, and water by human economic activity products has a critical impact on plant development. The effect of agriculture increases the concentration of pesticides and other chemicals [29]. Metallurgy, mining and chemical industries place a heavy burden on the environment. Their activity can lead to emissions of a range of metals, which in turn, enter the plant tissue [30, 31]. Transport, railways and highways with heavy traffic are also essential sources of pollution of soils and waters [32].

Most studies usually indicate elevated concentrations of some elements in plants growing in areas with a high anthropogenic load. Sometimes, the opposite picture is observed when natural factors outweigh human-made factors [33, 34]. In Ukraine, approximately 50% of the bulk medicinal herb feedstock are cultivated under controlled conditions. The rest belong to wild plants [35]. However, cultivated plants are not undoubtedly cleaner than wild plants in impurities [36].

Botanical and geobiological factors can primarily affect API content and, therefore, the quality of herbal medicines. In contrast, environmental factors affect plant quality and the safety of their use due to possible contamination by hazardous substances and microorganisms. Under such conditions, medicinal plant quality cannot be considered separately from the requirements of cultivation and collection of plants, their chemical composition, which differ between producers. However, only limited general information is indicated by producers on the packaging of medicinal herbs. The attention of herbal medicine producers to quality control of plant raw materials is still insufficient. Meanwhile, the quality of plants is primarily ensured by the stability of the chemical and elemental composition.

Thus, the objective situation requires increased attention to the environmental friendliness of plant raw materials. In the long run, this problem can be solved by strengthening the ecological component and forming the necessary competencies in future pharmacists, pharmaceutical industry technologists and ecologists. Such competencies are developed at the theoretical level in learning environmental, analytical and pharmaceutical chemistry [37, 38, 39]. The discipline "pharmaceutical development" contributes to the formulation and study of existing applied problems. The discipline "pharmaceutical quality system" forms an understanding of the need to acquire new knowledge about plant raw materials and use them to improve the production process continuously.

The work aimed to study the variability of the chemical and elemental composition of medicinal plants in the example of St. John's wort. Particular attention is paid to the impact of environmental conditions of Ukraine and the identification of current problems of obtaining high-quality vegetable raw materials. The results allowed the authors to propose the necessary changes to the curricula of a few chemical and technological disciplines in future pharmacists and pharmaceutical technologists' training. The proposed changes aim to strengthen the ecological component of education to ensure the pharmaceutical industry's sustainable development.

2 Experimental

2.1 Sample preparation

The chemical and elemental composition variability was studied using the medicinal plant Hypericum perforatum L., known as St. John's wort (SJW), and purchased in pharmacies in Kyiv. Three well-known Ukrainian companies specialising in the manufacture of herbal medicines have been selected as suppliers. All three companies (hereinafter producers 1-3) harvest hyperici herba in the central, eastern and western parts of the

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country, respectively, located at a distance of 400-500 km from each other.

The elemental composition of similar herbal drugs was studied in [40, 41]. Comparing the results of current and previous works allowed us to assess the stability of the elemental composition of herbal preparations from different regions of the country. Besides the elemental composition, the content of hyperforin, one of the most important biologically active substances in SJW, was determined in the given work.

Before analysis, the herbs were ground in a high-speed rotary mill to obtain homogeneous samples with a grain diameter of ≤1 mm, which were then stored in plastic containers. All chemicals used in sample preparation belonged to the analytical class.

A sample weighing 2 g was placed in a Teflon reaction crucible to analyse the elemental composition. It was treated with 10 ml of a mixture of 30% hydrogen peroxide (H_2O_2) and concentrated 65% HNO_3 (1:4, v / v).

The sample decomposition was performed in a microwave system with a closed vessel by the following three-stage regime: 80% power for 15 min, 100% for 5 min and 80% power for 20 min. After cooling, the transparent solutions were quantitatively transferred to clean volumetric flasks and diluted to 50 ml with twice-distilled water.

Analysis of the hyperforin content was performed by spectrophotometry. Samples for hyperforin analysis (1.0-3.0 g of plant powder) were placed in a flask with a section with a capacity of 250 ml. 100 ml of hexane was added; the flask was connected to the reflux condenser and heated in a water bath at a moderate boil of hexane for 30 min. The flask is then cooled. Its content was filtered through a paper filter into a 100 ml volumetric flask. The volume of the solution brought up to the mark with hexane. Transfer 5 ml of the resulting extract to a 25 ml volumetric flask and dilute to volume with hexane.

2.2 Instrumentation

The elemental composition of plants was studied by flame atomic absorption spectroscopy (FAAS). A two-beam spectrometer Solaar S4 AA (Thermo Electron Co., USA) was used in the experiment. Standard conditions in air/acetylene flame, D_2 correction and external calibration method were applied. Other details of the experiment, including the spectrometer parameters (wavelengths, operating interval, characteristic concentrations, and the width of the slit), were given elsewhere [40].

Identification and quantification of hyperforin were performed by spectrophotometry following the Pharmacopoeia of Ukraine [42]. This technique outperforms others in terms of simplicity, moderate staffing requirements, speed and cost. The spectrophotometric determination used does not separate the content of different derivatives of hyperforin. All compounds, namely hyperforin, adhyperforin and furohyperforin, exhibit absorption maxima at the same wavelength (272 ± 2 nm). For this reason, the total content of all the above compounds was determined and denoted by the term "total hyperforin".

The experiments were performed using a spectrophotometer Optizen POP bio (South Korea). The optical density of the analysed solutions was measured at a wavelength of 272 nm. Quantitative determination was performed using standard solutions. For calculations, the specific absorption of hyperforin was taken to be 8200. SJW extracts were used to prepare standard solutions. California Gold Nutrition EuroHerbs produced extracts. They were certified by Advanced Botanical Consulting & Testing, Inc. (a US FDA Registered, Independent, Third-Party Labs). The concentrations of hyperforin in five reference samples ranged from 0.06 to 0.4 mg/ml.

Three independent samples were examined for each concentration. with different

A calibration graph was plotted to quantify hyperforin in the test samples. Experimental points for optical density in standard samples show high values of the coefficient of determination R^2 ($R^2 > 0.98$) with an approximation linear line. Thus, the selected experimental conditions (primarily the range of solution concentrations) provide linearity. Standard samples can quantify hyperforin.

2.3 Statistical analysis

Measurements of each sample in FAAS and spectrophotometry measurements were repeated at least three times for further averaging. Both own experimental results and the literature data were analysed by statistical methods using IBM SPSS 20. All data were checked for normal distribution using the Kolmogorov-Smirnov test. The results were then expressed either as means for data with a normal distribution or medians for data with asymmetric distributions. The standard deviations of the mean were calculated when necessary.

3 Results

3.1 Medicinal plants and herbal medicines on the officinal market of Ukraine

Medicinal plants and herbal medicines are widely represented in the market of Ukraine. As of November 2020, the State Register of Medicinal Products includes 14714 trade names of medicaments [43]. Of this number, 12561 positions belong to medicines of different pharmacotherapeutic groups. The rest 2153 items are medicinal substances.

Of the total number of registered trade names, 1507 (10.24%) are herbal preparations, comprising 1143 herbal medicines and 364 plant substances. Herbal medicines occupy leading positions among drugs of some therapeutic groups. Figure 1 illustrates the ratio of registered medicines of plant and synthetic origin on the example of five therapeutic groups. According to the international Anatomical Therapeutic Chemical (ATC) classification system, these groups include

1. A03 - means for treating functional gastrointestinal disorders;
2. A05 - means for treating diseases of the liver and biliary tract;

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3. C01A - cardiac glycosides and C01E - other cardiac preparations;
4. G01 - antimicrobial and antiseptic agents used in gynaecology and G02 - other gynaecological agents;
5. R05 - remedies against cough and colds.

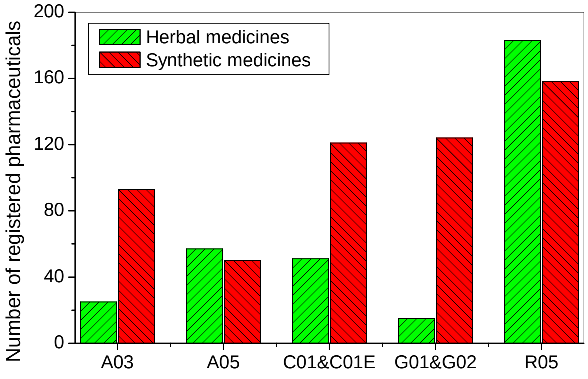

Fig. 1. Number of drugs of plant and synthetic origin for five therapeutic groups registered in Ukraine

The number of herbal medicines in groups R05 and A05 exceeds the number of registered synthetic drugs. Many herbal remedies are used to treat the cardiovascular system's diseases, upper respiratory tract, liver and biliary tract, genitourinary system, etc.

A total of 51 (29.65%) medicinal agents of the 172 registered drugs for the cardiovascular system treatment (groups C01A and C01E) are plant origin drugs. Among the registered drugs of group C01A Cardiac glycosides, all drugs are based on biologically active substances isolated from plant raw materials.

Most herbal medicines are presented on the market in prepared dosage forms - 977 items out of 1143 registered herbal drugs. For example, the range of herbal medicines is dominated by tablets (26% of all herbal medicines), capsules (11%), tinctures (9%), syrups (8%), etc. Of these, 642 positions (65.71%) are occupied by domestic drugs and 335 (29.31%) foreign production.

Only a small part, 166 (14.52%) of the names of finished drugs are presented in the form of officinal preparation (leaves, flowers, grass, fruits, seeds, roots, bark, etc.) of domestic production packaged in packs or packages, of which 32 medicines are teas. The distribution of registered drug substances by dosage forms best illustrates a typical way from herbal raw materials to the pharmaceutical market (Fig. 2).

Most plant raw materials enter the market after significant pre-treatment, including grinding and mixing different parts of the plant (Fig. 2). Then plants turn into powders, extracts, crushed mass, etc. This situation only increases the requirements for the quality of plant raw materials because it is much more difficult to identify plants, assess impurities, etc., at the stage of working with substances.

The analysis shows a rich source of raw materials for the manufacture of medicinal substances in Ukraine. Among 364 substances, 347 (95%) are substances of Ukrainian origin. A relatively high degree of processing of raw materials in the manufacture of a medicinal substance is striking. The primary forms (leaves, fruits, etc.) account for a little over a third of the available positions. The quality of pharmaceuticals depends on the quality of raw materials. In the next sections, such quality indicators as the stability of the elemental composition and organic compounds' content will be studied using some plant examples.

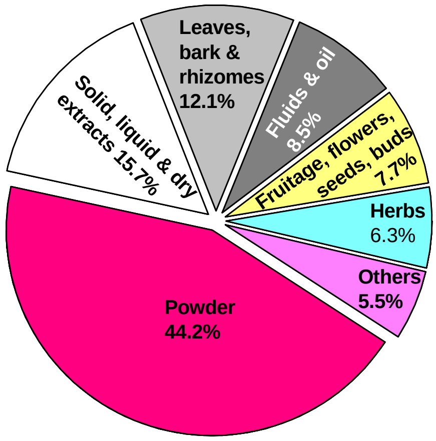

Fig. 2. Structure of registered herbal substances by dosage forms in the market of Ukraine.

3.2 Elemental composition of medicinal plants

Variability of concentration of chemical elements is investigated using the herb St. John's wort. The results of our research for SJW samples of different producers were analysed together with literature data. Among various works, only those were selected, where the authors studied the chemical composition of several (at least three) samples of SJW of different origins. SJW specimens purchased at markets or pharmacies (hereinafter named herbs) and representatives of aerial parts of wild plants collected in different geographical locations (shown as plants) are considered.

Due to natural and anthropogenic variability, the chemical composition of SJW of the same botanical species (Hypericum perforatum) significantly differs from each other, even in one study. Table 1 shows the intervals of the existence of chemical elements in SJW, according to various authors.

The values of R were calculated to quantify the width of concentration ranges for different elements. R is the ratio of maximum-to-minimum concentrations reported in the literature: $R = C_{max}/C_{min}$. The more extensive the concentration range, the greater the value of R.

The R values for Fe, Mn, Cu, Zn, Cd and Pb are illustrated in Fig. 3. The data are presented as histograms N(R), where N – is the number of considered published research. The R values for Cr, Ni and Co are not calculated due to the limited number of non-zero data for these elements.

In the case of copper and zinc, the vast majority of observations demonstrate $R < 5$. The N(R) distribution corresponds to the Gaussian; the average values of R_{av} are 4.41 and 4.15 for copper and zinc, respectively.

For iron and manganese, the picture is a little different. Plants with increased Fe content, when R values vary from 20 to 65, were detected in a significant number of observations. In most of the studied plants, R does not, however, exceed 6. The N(R) for Fe follows Gauss's law, the average value of R_{av} = 13.05. The Mn distribution curve is more extended than for Fe; most R occupies a broad band from 2 to 22. The distribution of N(R) significantly deviates from the normal law. For this reason, typical values of R for Mn are described by a median rather than an average. The median R_{med} = 3.9.

Table 1. The range of concentrations of some essential and toxic trace elements (in µg/g of dry weight) in samples of St. John's wort according to results of various authors.

Country	Sample	No of samples	Fe	Mn	Cu	Zn	Co	Cr	Ni	Cd	Pb	Source
Ukraine	Herbs	3	20,8-60,2	60-145,7	6-12,5	15,4-32,5	0,08-0,35	0,2-0,9	0,8-2,8	0,2-0,9	0,3-0,9	current
Ukraine	Herbs	3	26,7-55,5	56-137,7	5,0-11,9	16,6-31,4	0,08-0,32	0-0,38		0,02-0,89	0,32-0,61	[40]
Ukraine	Herbs	4	10-64,7	55-120,6	7,5-8,4	17,4-19,5	0,1-0,29	0,73-2,0	1,27-2,04	0,23-0,72	0,13-0,73	[41]
Serbia	Herbs	14		25-226	10,0-17	21-56			1,0-8	0,3-3	0,5-3,5	[44]
England	Herbs	22	38-760	59,1-261	4,64-120	23-64		0-1,4	0-5,37	0-1,73		[45]
Bulgaria	Stem	15	25-860	28-109	8,0-25,0						3,0-19,0	[46]
Turkey	Leaves	3	81,7-85,8	29,8-31,9	0,7-0,79	14-14,5		0,024-0,033	0,47-0,57	0,48-0,56	0,23-0,24	[47]
Turkey	Plants	35	54-2990	9,1-197,9	1,8-10,1	13-181,6					12-124,8	[48]
Turkey	Plants	4	159-443	25,4-34,7	12,9-27,4	16,8-44	0,2-0,3	1,3-2,3		0,1-2,8	0,1-1,9	[49]
Slovenia	Plants	8	32,2-115	7,8-75,4	6,3-11,7	27-103,4				0,2-4,2	2,1-25,1	[50]
Estonia	Plants	3		31,8-54,4		29,4-35,5	0,1-0,18	0,12-0,24				[51]
Romania	Plants	14	83-288	31-219		40-96			0,5-4,9	0,1-1,5	<0,1-1,7	[52]
Bulgaria	Plants	8	40-121	12,0-69	5,6-9,1	21,0-47	0,6-1,8	0,9-6,1	0,7-11,7	0,35-0,9	0,7-1,9	[53]

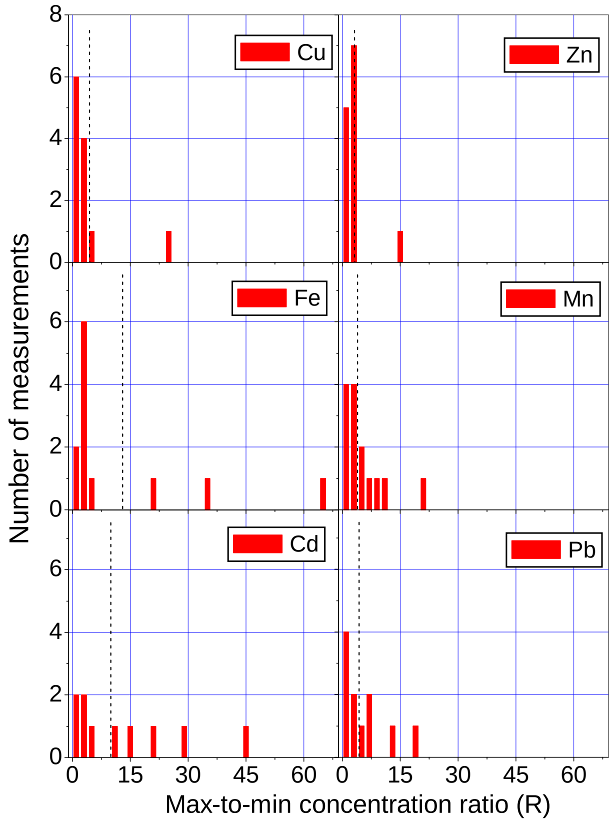

Fig. 3. Histograms illustrate the number of considered research N as a function of R, the ratio of maximum-to-minimum concentrations of elements in plants. Dotted lines show the mean values for components with a normal distribution (Fe, Cu, Zn) and medians for elements with asymmetric distributions (Mn, Cd, Pb)

Histograms for toxic impurities, Cd and Pb, significantly differ from histograms for essential trace elements. Both curves are characterised by an asymmetric, far from a normal distribution. The value of R for cadmium varies in a wide range from 1.2 to 44. It is impossible to determine an average R, which is perceived as the most probable Cd concentration. The median value for cadmium R_{med} = 10. Approximately the same pattern is observed for Pb. However, a significant part of the specimens demonstrates R values in the range from 1 to 7. The median for lead R_{med} = 4.3.

3.3 Hyperforin in Saint John's wort

The average concentrations of hyperforin (Fig. 4a) and some essential elements (Fig. 4b) are shown for herbal samples of different producers.

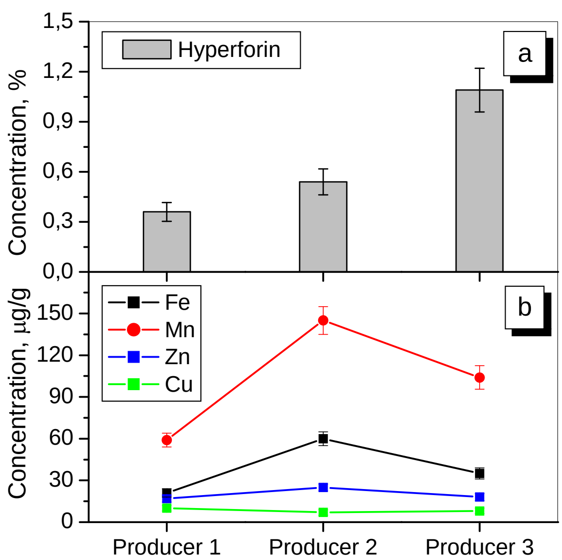

Fig. 4. Measured concentrations of hyperforin (a) and some essential microelements (b) in samples of producers 1-3.

In producer 3, the hyperforin content is almost three times higher than in specimens of producer 1. The indicators of producer 2 occupy an intermediate position, although still slightly closer to producer 1.

Figure 4b illustrates the detected scatter of concentrations of essential micronutrients in samples from different producers. Compared to others, zinc and copper concentrations show the most stable behaviour. In contrast, the concentrations of manganese and iron vary over a fairly wide range. Thus, the highest determined concentration of manganese in samples of producer 2 is actually 2.5 times higher than the lowest concentration of this element in herba of producer 1. A similar situation is observed for iron, where the maximum concentration (producer 2) is almost five times higher than the minimum concentration (producer 1).

The obtained results do not allow the authors to confirm the conclusions made earlier in [40] on the presence of anticorrelation between the concentrations of iron and manganese. However, similar to [40], samples of St. John's wort from producers 2 and 1 again show the highest and lowest concentrations of manganese and iron, respectively. At the same time, the levels of zinc and copper relatively weakly depend on plant origin.

A clear correlation between the concentration of hyperforin and elemental impurities is also not observed. The highest concentration of hyperforin is detected in samples with medium, although relatively high impurity content. Additional research is needed to formulate sound conclusions.

4 Discussion

4.1 Variability of the composition of medicinal plants

The origin of the variability of element concentrations will be considered using histograms shown in Fig. 3. As mentioned earlier, the value of the parameter R for copper mostly varies in a relatively narrow range of 1.1-5.6 and is subject to the normal distribution. It can be assumed that such fluctuations reflect the natural variability of copper concentration.

The effect of natural variability of chemical composition is well known and is inherent in virtually all plants. Native reasons cause it. On the one hand, this phenomenon is due to the biologically determined variability of plants belonging to the same family and genus and different species. On the other hand, the chemical composition variability is determined by the geochemical conditions of their cultivation, such as soil composition, underlying rocks, and natural waters [17]. The study of the causes of variability in plant composition goes far beyond the research topic. It is important to note for our purpose that the chemical composition of medicinal plants can vary widely. Human activity is one of the primary sources of chemical elements, including toxic heavy metals widely used in industrial products and waste, accumulated in plant tissues.

The plant body regulates the required level of copper as an essential trace element. Only one observation [45], covering 22 samples from the studied 136 probes, reports the increase of R to 25.9. The Cu concentration in some of these 22 samples can amount to 120 μg/g amid traditional Cu levels of approximately 5-27 μg/g. Most likely, the influence of anthropogenic environmental factors is observed in such cases.

Very similar behaviour is typical for Zn. In 101 cases among 136 studied samples, the Zn concentration varies in a relatively narrow range of 15-100 μg/g. It corresponds to the R ÷ 1.1-3.8. The increase of R to 14.1 was detected in work [48] only. Such an increase corresponds to the expansion of the concentration range to 12.9-181.6 μg/g. Among 35 samples in [48], the Zn concentration exceeded 100 μg/g in 7 plants only. The increase in Zn concentration above 50-100 μg/g is not typical for most observations. The influence of external environmental pollution may take place in these few samples described in [48].

The shape of histograms in Fig. 3 significantly changes with the transition to the other two essential elements, iron and manganese. For iron, the curve N(R) is still subject to the normal distribution in most samples. The parameter R varies from 1.1 to 5.5, which corresponds to a concentration range of about 20-80 μg/g. Meanwhile, many observations with elevated R are known from the literature [45, 46, 48]. These papers account for 72 samples from the studied 136 probes. More precisely, the iron content exceeded 80 μg/g in 43 plants [46, 48], while the results of individual measurements are not shown in [45]. In all 18 samples reported in [49, 52], the Fe concentration exceeded 80 μg/g despite the moderate value of R. Totally, high iron content was observed in almost half of the studied samples (at least 61 out of 136).

The R values typically vary between 1.1 and 10.2 for Mn, which corresponds to a concentration range of 10-150 μg/g. An expansion of this interval to 21.7 was observed in [48]. An increase of the Mn concentrations to 260 μg/g was observed in some reports [44, 45, 48, 52]. Besides, the distribution N(R) no longer follows the law of normal distribution.

The most likely explanation for the Fe and Mn behaviour seems to be the effect of environmental pollution on the concentrations of these two elements in plant tissues. Iron and manganese are among the most common elements in the earth's crust. Iron is the primary structural material of modern civilisation. The annual steel production is about 1.5 billion tons, tens or hundreds of times higher than the output of any other metals or non-metals. Manganese is widely used in the metallurgy, production of fertilisers, batteries and accumulators. The systematic processing of manganese wastes is established only in ferrous metallurgy. Waste products with Mn in all other applications do not have a well-established systemic utilisation. They mostly remain in the environment. Therefore, it is not surprising that these metals are among the primary contaminants of soil and water in Ukraine [25-28].

Cadmium and lead are not essential elements in plants but are very toxic impurities for the human body. It is impossible to determine the typical or most probable values or ranges of R. The distribution of N(R) is

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asymmetric. The R values non-systematically change in a vast range from 1 to 45 for Cd and vary between 1.1 and 19 for Pb. The R values for Pb are very low in some samples. In such probes, the Pb concentration is a nearby detection limit. The content of Cd and Pb measured in plants does not depend on the plant's needs. In turn, it is determined by the degree of contamination of the plant through contacts with the environment [18, 19, 24].

The hyperforin content was shown to change 2-3 times in samples of different Ukrainian producers (Fig. 4). The quantification of hyperforin is not yet prescribed in Ukraine and EU's Pharmacopoeias but is present in the US Pharmacopoeia. In recent years, it has become increasingly clear that hyperforin is one of the most valuable API of SJW. The detection of hyperforin is also essential for plant identification because it can be considered a promising SJW marker.

The results obtained for hyperforin were compared with the published literature data. The hyperforin concentrations in SJW samples of six Russian producers demonstrated a 2-3-fold variation [54]. The concentration range varied between 0.36% and 1.16%, which agrees well with the results obtained in this study.

Table 2 also compares the average levels of hyperforin in herbal remedies (SJW extracts) available on the German pharmaceutical market. These results were obtained by recalculating and averaging the primary data from [55]. The direct comparison of the current results with [55] is difficult because herbal samples and extracts were studied in these works, respectively. However, the concentration coefficients stated in [55] allowed us to estimate the range of hyperforin concentrations in the used plant raw materials (Table 2).

Table 2. The average content of hyperforin in medicines of the herb St. John's wort from European producers according to [55] and the estimated range of hyperforin in plant raw materials.

Trade name (producer)	Dosage form	Average hyperforin in herbal drugs, %	Concentration factor *	Estimated range of hyperforin in medicinal plants, %
Jarsin 300 (Lichtwer Pharma)	Sugar-coated tablet	2,49	4-7:1	0,36-0,62
Neuroplant 300 (Dr Willmar)	Film-coated tablet	4,14	2.5-5:1	0,83-1,66
Texx 300 (Krewel-Meuselbach)	Film-coated tablet	2,5	4-7:1	0,42-0,71
Felis 425 (Biocur)	Capsule	2,75	3.5-6:1	0,42-0,71
Futuran (Madaus)	Capsule	1,54	3.5-6:1	0,22-0,44
Helarium 425 (Bionorica)	Capsule	2,14	3.5-6:1	0,36-0,61
Laif 600 (Steigerwald)	Film-coated tablet	1,86	5-8:1	0,23-0,37

* concentration factor is the ratio of the mass of raw materials (St. John's wort) to the mass of the extract obtained from it

In most cases, this interval coincides with the results of the current work. Also, the results of [55] very well illustrate the high degree of variability in the content of hyperforin. For St. John's wort extract, the hyperforin content should be at least 3% [56]. Only the preparation Neuroplant 300 met this criterion among all products studied in [55].

4.2 Approaches to the safe use of herbal medicines

The obtained results and literature data give a clear idea of a sizeable difference in chemical and elemental composition between plants grown in different conditions. For example, the content of hyperforin in SJW, one of the most significant APIs, varied almost threefold in drugs from different producers. It gives reason to believe that the effectiveness of such medicines will also be different.

The findings of SJW studies mainly apply to other herbal medicines. However, a buyer of such drugs will not receive any information about API's content. The same problem applies to the variability of the elemental composition.

The outer packaging available to the consumer shows only plant name, producer name and address, keeping time, method of application, including features of use and dosage, contraindications, adverse drug reactions, and warnings.

More information can be found in the instructions for medical use of the drug, approved by the Ministry of Health of Ukraine. The main sections of the instruction (for example, the herb SJW) are as follows.

The composition of the drug: the active substance is herba hiperici. The manufacturer is specified. The dosage form is grass. Pieces of leaves, stems, flowers of various shapes and unripe fruits, greenish-yellow, greyish-green, green, dark green, bright yellow or yellow with black dots, greenish-brown, sometimes pink-purple.

The indicated pharmacotherapeutic group and code ATX A01AD11.

St. John's wort contains many compounds: tannins, flavonoids (hyperoside, rutin, quercetin, myricetin, leucoanthocyanidins), saponins, dyes (hypericin, pseudohypericin), essential oil, resinous substances, carotene, and ascorbic acid. This complex of APIs has astringent, anti-inflammatory and some antimicrobial action. It promotes tissue regeneration, has a moderate effect on bile secretion, stimulates gastric secretion and more.

Indications for use and contraindications, appropriate safety measures are also described. As mentioned above, there are no reservations about the variability of chemical and elemental composition.

The studied concentrations do not exceed the permissible limits in the studied Ukrainian samples. However, some literature data indicate the presence of severe contamination of SJW with toxic metals. For example, poisonous cadmium has been determined in commercially available medicinal plants or plants in food supplements. Concentrations up to 3 and 1.73 μg/g were found in some SJW samples in [44, 45], respectively. An even higher cadmium level, with 4.2 μg/g, was found in wild plants [50]. According to EU guides or US Department of Agriculture standards in medicinal plants and food additives, the maximum permissible concentration of Cd should not exceed 1 μg/g. WHO established even stricter standards for herbal medicines - no more than 0.3 μg/g [57].

A similar situation is observed for Pb. Instead of the allowable 2-5 μg/g in plant raw materials, 17 μg/g was observed in SJW stems [46]; 25 μg/g [50] and even 124 μg/g [48] in wild plants.

Exceeding certain limits applies not only to highly toxic impurities but also to some essential trace elements. Unlike the most poisonous metals (Pb, As, Hg and Cd), the toxicity of essential trace elements is much lower. Their permissible doses are not usually regulated in medicinal plants. However, many norms standardise optimal or safe consumption of these metals in functional and supplementary foods, spices, herbal supplements, etc. For example, adequate intake of Mn is recommended at 1.8-2.3 mg [57]. The minimum risk level or tolerable daily intake is 2-5 mg and 5 mg, respectively. Thus, the safe daily consumption of the most Mn-contaminated medicinal plants [44, 45] should not exceed 10 g of herba per day. Allowed consumption with minimal risk is approximately 20 g. Norms for iron are slightly milder than for manganese, but iron content is much higher in some plants. Therefore, according to the standards, the tolerable daily intake of some of the most Fe-contaminated plants [48] will be limited to only 5 g per day.

Among the essential trace elements, chromium is the most toxic. According to the Ministry of Health of Canada, this element is already standardised together with the most toxic metals. The consumption of wild SJW with a Cr content of 6.1 μg/g, studied in [53], maybe only about 5 g. The reason is the limitation of adequate intake at 25-35 μg [57].

In Ukraine, wild plants account for about 50% of plant raw material. The reason for collecting wild plants is primarily economic. The current situation will not change quickly, although the general direction of development is to increase the share of cultivated plants in the raw material.

Increased impurities in wild plants are usually associated with human economic activity. Excessive accumulation of toxic contaminants in plants does not always affect their appearance [22]. It creates an additional danger of consuming contaminated plants, which cannot be foreseen only by external inspection.

In addition to the direct effect of accumulated toxic impurities, the mutual influence of elemental composition on API content and vice versa was evidenced [58, 59]. The most straightforward mechanism that explains this effect is the formation of organometallic compounds, which reduce biologically active substances' concentrations.

The problems with unfavourable plant chemistry are part of a broader problem of damaging the ecology of regions. Solving the problem of plant quality cannot be resolved without solving environmental issues. Ecology's impact on the quality of plant raw materials is inherent in Ukraine and other countries. The presence of plant products from different countries on the Ukrainian market only exacerbates this problem. Thus, to ensure the sustainable development of a raw material base of the pharmaceutical industry, the formation of appropriate environmental competencies should be guaranteed in training future specialists in the field.

Standardisation could remove many questions about the stable quality of herbal medicines. However, different countries have different safety standards, and the medicinal plants are qualified according to various algorithms. In a sense, the lack of a single generally accepted method of standardising medicinal plants reflects the problem's complexity. Plants can be considered as "living factories" that produce a variety of chemicals. They include primary metabolites, i.e. those that are important for the growth of the plants themselves (proteins, amino acids, carbohydrates) and secondary metabolites (flavonoids, terpenoids, alkaloids, etc.). All these components work together, providing a synergistic effect in the finished herbal medicine.

All drugs are chemicals, whether they are synthesised in chemical laboratories or plants. Therefore, irrespective of their source, all medicinal chemicals must meet similar quality standards (identity, purity and stability) and ensure clinical efficacy and safety. Reliable and consistent quality is the basis of the efficiency and safety of herbal medicaments.

Due to the complexity and variability of plant products' components, it is not easy to establish a quality control parameter and maintain consistent quality from batch to batch. The variability of the properties of medicinal plants and herbal medicines in the absence of reference standards begins with collecting raw materials. It only increases during the storage and further processing of plant products. Evidence of both benefits and risks is specific to the product tested. It cannot always be extrapolated to other products, as is always the case for synthetic preparations.

The question of the quality of herbal medicines has two sides - external and internal [7]. The first external issue concerns possible contamination (toxic metals, microbes, pesticides, etc.), adulteration and misidentification.

The internal factor is related to the complexity and potential variability of the components of herbs. Implementation and compliance with Good Agricultural and Collection Practice (GACP) and Good Manufacturing Practice (GMP) reduce the risk of external factors adversely affecting herbal medicines. Ideally, standardisation procedures should cover the entire industry, from medicinal plant cultivation to their clinical application. However, there are currently no generally accepted approaches to creating a comprehensive quality assurance system [60]. Producers of herbal remedies apply their own experience and methods to quality assurance.

The influence of internal factors must be regulated through the use of modern analytical and pharmaceutical methods. Intensive use of modern instrumental analysis can significantly increase knowledge about the composition of plant raw materials. However, the availability and low price of herbal medicines are some of their main advantages. High cost due to the use of complicated and expensive analytical methods regularly offsets this advantage. The most promising way to improve standardisation procedures is the optimal ratio of technological operations' simplicity and dosed application of modern analytical techniques.

Controlled and stable API content, the absence of contaminants are the main factors that shape herbal medicines' quality. On the one hand, virtually all stages of obtaining raw materials and further processing are regulated in Ukraine by relevant guidelines. On the other hand, API content was shown to vary in the products of different producers. Thus, the existing requirements for medicinal plants do not fully meet modern needs, which are becoming more. The unpredictable variability of the composition combined with the lack of pharmacological and clinical data for most herbal medicines is the main obstacle to the broader use of natural products in medical practice.

4.3 Environmentally-affected chemistry of medicinal plants in the context of ecological education

Medicinal plants of Ukraine include about 2215 species, of which 233 (10.5%) are cultivated and introduced species; the rest are wild [61]. A significant amount of medicinal plants is grown in specialised and homestead farms. Among the total number of wild plants (about 1975 species), only 482 species have resource value, forming resource-significant massifs on large areas (> 1 ha) or have significant distribution. The studied above SJW has a significant distribution and large reserves within Ukraine.

The official medicine of Ukraine uses about 200 types of medicinal plants. The State Pharmacopoeia of Ukraine [62] includes 198 monographs on plant raw materials and 88 monographs on herbal medicines (extracts, tinctures, etc.).

Among medicinal plants, there are 44 wild species, 32 wild and cultivated species introduced into the culture due to limited reserves of raw materials, 33 cultivated sorts, and 89 imported plants. Increasing demand for herbal medicines necessitates the expansion of production, improved technology, expanded the collection of plant raw materials, and increased its quality requirements.

However, the number of certain types of medicinal plants is decreasing, and the natural reserves of some wild species are entirely or partially depleted. About 200 species are listed in the Red Book of Ukraine, and more than 70 are regionally rare [61]. Many wild medicinal plants have limited resources. More than 50% of them are significantly distributed but grow scattered or sporadically. Harvesting of such plants in natural places of growth is unprofitable.

The shortage of plant raw materials is due to the ecological load, changing climatic conditions, and anthropogenic factors. In addition to reducing plants' natural habitat, damaged ecology also deteriorates their quality due to contamination with various pollutants. The expansion of the base of raw materials is possible by their introduction into the culture. Therefore, the cultivation of plants essential for the pharmaceutical industry will enhance in the future.

The formation of professional knowledge, skills, and abilities related to medicinal plants is an essential component of training specialists for the pharmaceutical industry. They include understanding the chemical composition of plants, biosynthesis and accumulation of biologically active substances during plant ontogenesis, and quality control methods of plant raw materials.

The formation of the ability to anticipate changes that occur with raw materials under environmental factors is among the essential requirements. These skills are necessary to choose the optimal conditions for cultivation, harvesting, drying and storage, standardisation and quality control methods of plant raw materials and herbal medicines following the requirements of pharmacopoeias and national standards.

The competence that needs to be formed can be called the ecological thinking of a future specialist. It includes the desire to preserve the environment, the ability to act socially responsible and socially conscious, and the ability to assess and ensure the quality of professional work performed.

At present, the existing curricula of some related disciplines are not perfect. The introduction of particular environmentally-oriented educational elements in the programs of disciplines will contribute to the formation of the ability to operate in conditions of use of raw materials, the quality of which depends on the environment.

We propose to do this consistently, starting with the study of analytical chemistry at the bachelor's level and ending with developing particular components for the discipline of "pharmaceutical quality system" within a master's programme (Table 3).

Introducing the necessary topics into syllabi and the definition of expected knowledge and learning outcomes will ensure continuity and consistency in industry specialists' training.

The proposed approach allows the graduation of specialists who will meet the requirements for sustainable development of Ukraine in the coming decades. They will be able to predict changes in plant raw materials under the influence of environmental and climatic conditions, respond promptly, and take measures to prevent deterioration in pharmaceutical products' quality. They will also be able to move to models of balanced consumption and production of medicines based on medicinal plant raw materials.

Conclusions

1. The stability of elemental and chemical compositions of herbal medicines was studied using samples of herba St. John's wort of different origin. Own experiments were conducted using samples of three different Ukrainian producers purchased in pharmacies.

The measured chemical and elemental compositions of herbs were compared with the literature on SJW herbal preparations and wild plants.

2. Among the trace elements, the concentrations of copper and zinc in plants show the best stability, usually ranging from 10 to 100 μg/g. The normal distribution of the sample number vs Cu and Zn concentrations and relative stability of the composition suggests that the environmental influence on these elements' content is minimal compared to other elements.

3. In contrast, the concentrations of manganese and iron in St. John's wort vary over a broader range. Many plants demonstrated traditional concentrations range from 10-20 to 100-150 μg/g. In some studies, the content of Fe and Mn has increased tens or even hundreds of times. Both Fe and Mn are essential elements necessary for plant life. However, they are also among the most common metals used in modern civilisation. Therefore, the anthropogenic load on plants seems to be much higher concerning Mn and Fe compared to other elements. The state of the environment causes significantly higher iron and manganese content in some plants.

4. Usually, the concentrations of other studied essential trace elements, Ni, Co, Cr, do not exceed 1-1.5 μg/g. Concentrations above 2 μg/g were not found in the studied samples and are also abnormally rare in the literature. The slightest variation in the content of these elements in the soil or water tangibly affects their concentration in plants. This fact complicates understanding the causes of these elements' variability in plant tissues. The detected concentrations of these elements in plants do not exceed the existing norms concerning their content in dietary supplements or herbal preparations.

5. Toxic cadmium and lead are not vital elements in plants. Therefore, their content depends entirely on the environment of plant growth. The large concentration interval observed in various works reflects the environmental influence on the content of hazardous impurities. Among the herbal drugs, the Pb and Cd content met the existing standards in all studied cases. Some samples collected in the wild exhibited dangerously high levels of these elements.

Table 3. Proposed changes in the content of educational components for the formation of environmental thinking of bachelor and master students of pharmacy.

<table>
<tr><th>Name the topics</th><th>Expected knowledge</th><th>Learning outcomes</th></tr>
<tr><td colspan="2">Bachelor's degree; Educational component: analytical chemistry</td><td></td></tr>
<tr><td>Sampling and sample preparation.
Classical and instrumental analysis.
Processing of experimental data.</td><td>Methods of sampling and sample preparation of vegetable raw materials.
Physicochemical methods of analysis.
Quantitative characteristics of the quality of vegetable raw materials.
Statistical methods of data analysis.</td><td>Ability to:
• choose the methods of analysis and sample preparation adequate to the practical tasks of determining the content of elements in medicinal raw materials;
• critically evaluate and analyse the results.</td></tr>
<tr><td colspan="2">Bachelor's degree; Educational component: pharmaceutical chemistry</td><td></td></tr>
<tr><td>Pharmacopoeial methods for the quantitative determination of toxic and heavy metals in plant raw materials.</td><td>Requirements for the quality of medicinal plant raw materials.
Pharmacopoeial methods of quantitative determination.
Actual intervals of the content of essential elements and impurities in comparison with their admissible concentrations.</td><td rowspan="3">Skills to:
• use methods of State Pharmacopoeia of Ukraine to analyse the quality of raw materials;
• anticipate possible complications in developing herbal remedies;
• apply modern instrumental methods to determine the characteristics of plant raw materials.</td></tr>
<tr><td colspan="2">Master's degree; Educational component: pharmaceutical development</td></tr>
<tr><td>System for monitoring the technological process and product quality.
Pharmaceutical development of technological process and strategy of drug control.</td><td>Components and content of the stages of taking medicinal plant raw materials.
Methods of quality control of medicinal plant raw materials, intermediate products and finished herbal medicines.</td></tr>
<tr><td colspan="2">Master's degree; Educational component: pharmaceutical quality system</td><td></td></tr>
<tr><td>Application of the pharmaceutical quality system during the life cycle of the drug.
Risk management for quality.</td><td>The system of organisation of quality control of technological process and products.
Variable composition of medicinal plant raw materials as a risk factor in the production of herbal medicines.</td><td>Ability to:
• develop a quality system for a pharmaceutical company that produces herbal medicines;
• manage the risks that may arise due to environmental impact on raw materials' quality;
• gain new knowledge to improve herbal medicine production continuously.</td></tr>
</table>

6. The content of hyperforin varies between 0.35 and 1.15%. The measured API concentration is almost three times higher in the samples of producer 3 compared to producer 1. There was found no clear correlation between the elemental composition and API content.

7. The existing standards governing collecting and processing herbal raw materials and manufacturing herbal medicines do not fully ensure the composition's stability and, therefore, herbal medicines' effectiveness. Accordingly, the environmental impact on the quality of plant raw materials needs increased attention in a narrow sense. In a broad sense, improving environmental knowledge is necessary among specialists involved in herbal medicines and other herbal preparations.

8. The problem can be solved by forming the required competencies in the training of prospective pharmacists and technologists of industrial pharmacy. Necessary changes to the syllabi of some fundamental (analytical and pharmaceutical chemistry) and technological (pharmaceutical development and pharmaceutical quality system) disciplines are proposed to ensure the pharmaceutical industry's sustainable development.

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