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- ## Description

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Short Biosketch

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Chapters

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- **Valeriy Antonik , Yevgeniy Babets , Irina Antonik and Irina Melnikova**

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Abstract

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Technical solutions to the problem of the negative effects of underground mines and open pits on the ecosystem and landscape of the territory prioritize intensification of iron ore raw material processing, including wider introduction of technologies for reprocessing off-grade ores, tailings retreatment, wider use of waste rocks (quartz) in construction, introduction of internal overburden stockpiling technologies. Promising biological reclamation technologies include stimulation of natural overgrowth processes on the surface of dumps and tailings facilities by remote hydro-application of a fertile substrate mixed with mineral fertilizers and seeds of perennial grasses, shrubs and arboreous plants to the surface of technogenic objects.
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Optimization of Landscape Disturbances in the Territory during Mining

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ABSTRACT

Mining causes significant disturbances of the landscape due to both construction and operation of open pits and underground mines and disposal of ore mining and concentration wastes on the earth's surface.
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Keywords: Iron ore mining; disturbance; landscape; reclamation; territory; technical; biological methods.

1. INTRODUCTION

Iron is the fourth most abundant element and accounts for about 5% of the earth's crust. Commonly found in the form of iron ore, iron has been used for over four thousand years in the making of weapons and tools [1,2]. On a very limited area of 43.1 thousand hectares, the Kryvyi Rih iron ore basin contains 15 iron ore deposits. The mining techniques utilized here include both open pit and

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underground. As of 2023, there are 8 iron ore underground mines that specialize in rich iron ore mining (47–67% Fe) and 5 mining and beneficiation plants (GZKs) that mine weak iron ores (under 46% Fe) that need to be concentrated. Most iron ore mines are located within the city of Kryvyi Rih, while GZKs surround the city in a semicircle, their names corresponding to their location – the Northern GZK, the Central (western) GZK, the Southern GZK, the GZK of the Mining Department of "ArcelorMittal Kryvyi Rih" and the Inhulets GZK located in the southern part of the city. Iron ore extraction is almost exclusively performed on surface mines through open pit mining operations, which is characterized by high productivity and low security risks compared to underground mining systems [1,2].

The most destructive action on the region's landscape is produced by GZKs' facilities, i.e. huge open pits (nine of which make up over 6 thousand hectares), beneficiation complexes and gigantic waste accumulation areas (overburden and oxidized ore dumps). There are also 8 tailing ponds for iron ore concentration wastes. These are vast hydro-engineering structures in the form of reservoirs enclosed between slime and overburden dumps and filled with slurry (a mixture of fine iron ore wastes and water). The total area of each of the current tailing ponds can reach 700-800 hectares and, being a multilevel structure, they can rise above the surface by 150-180m (e.g. the "Obiednane", Karta I of the Southern GZK and Karta IV of the GZK of the Mining Department of "ArcelorMittal Krivyi Rih" [3].

Reduction of negative consequences of long-term mining operations that result in disturbed urban and farming lands, ruined natural landscapes and hydrogeological conditions of the environment is one of the essential tasks of environmental protection and stabilization in Kryvyi Rih iron ore basin. According to the data provided by the Institute "Hipromashzbahachennia", a thousand tonnes of the rock mass mined produces about 200t of marketable iron ore products (a fifth), while about 2.5t of fine-dispersed dust and 1.8t of poisoning gases are discharged into the air, 40m^2 of lands is allotted, 50 m^2 is flooded and 110m^3 of highly mineralized water is created [4].

At present, external overburden dumps and tailing ponds of five Kryvyi Rih GZKs contain over 4 billion m^3 of iron ore mining and concentration wastes; their total area exceeds 12 thousand hectares (ha): dumps – 5 thousand ha, tailing ponds – over 7 thousand ha. Shear and caving (crater formation) zones caused by underground mining make over 5 thousand ha of urban lands. In general, over 34 thousand ha of urban and suburban lands is technogenically disturbed and needs restoration. The total area of Kryvyi Rih makes 43.1 thousand ha and its mining and industrial landscapes comprise about 48.8% of this area, this value tends to increase. About 20 thousand ha should be added to this as these mostly arable lands are adjacent to the GZKs and become degraded under the action of dust and highly mineralized water filtrates from tailing ponds and waste dumps. Soils within a 15-20 km radius of Kryvyi Rih industrial enterprises are contaminated with heavy metals and often salinized and swamped as well [3]. Only in the central part of the city today there are more than 600 hectares of land requiring reclamation. Yet, in spite of considerable legal requirements and increased publicity, owners of Kryvyi Rih enterprises are very reluctant to finance environmental steps and restoration rates remain extremely low – up to 1,.5% of the areas annually, greatly lagging behind mining rates with a yearly 2.1% increment [4].

In the city with 600 thousand residents, the above examples indicate a rather critical environmental situation that requires application of an integrated approach. Restoration and reclamation of disturbed lands are the most vital steps of improving people's life quality and reducing the technogenic influence of mining on the local environment and, which is even more vital, reducing rates of involving new areas subject to further extensive use of mineral raw materials.

Similar problems of landscape ecology are typical not only for Kryvyi Rih, but also for other regions where metal ores, coal, and many types of non-metallic materials are mined [5,6], which determines the relevance and practical importance of the issues considered in this section.

The scientific work aims to generalize national and foreign experience in optimizing landscape disturbances caused by activities of mining enterprises and develop individual organizational issues and technology of restoring disturbed lithosphere areas in Kryvyi Rih iron ore basin.

Restoration and reclamation of technogenically disturbed lands usually involve two stages – mining-engineering (preparatory) and biological. At Kryvyi Rih iron ore basin, choice of mining-engineering operations depends on the type and degree of landscape disturbance, which in their turn are associated with technologies of previous operations conducted. Within land allotment boundaries at iron ore underground mines, there are caving zones, craters, sinkholes of overburden and off-grade ore materials resulted from underground mining. Open pit mining operations result in mined-out open pits, waste dumps, tailing ponds and settling ponds. In most cases, operations of the mining-engineering stage in caving, crater and mined zones imply only backfilling of voids with rocks followed up by planning horizontal sites.

In Kryvyi Rih, surface technogenic structures in the form of dumps and multilevel tailing ponds are rarely used for backfilling voids and usually remain artificial landscape formations in the form of huge hills (dams and waste banks). Small-scale single-level dumps can reach 15-40m, while large ones – up to 180m and more. The areas occupied by dumps can vary from 1-2ha to 800ha and more. Mining and engineering works of dump reclamation involve dismantling temporary structures (railway lines for dumpcars, power lines, substations, etc.). After that, bulldozer planning of horizontal and slightly inclined upper sites and other accessible layers is undertaken followed by earthing.

More complicated procedures of the mining-engineering stage occur in case of reclaiming tailing ponds when issues of surface cleaning and planning are to be solved as well as eliminating some hydrological problems.

At the final stage of disturbed land restoration at Kryvyi Rih iron ore basin, biological reclamation of sanitary-hygiene character aims at consolidating the upper dusting layer of the ground through either planting vegetation or applying special long-term binding substances.

There are suggested engineering solutions to reduce the impact of anthropogenic disturbances on the ecosystem of Kryvyi Rih iron ore basin, the technology for processing off-grade ores at underground mines and open pits, methods of concentration tailings re-treatment, use of waste rocks in construction, transition to the technology of internal (in-pit) dumping. Promising technologies of improving processes of biological reclamation include stimulation of vegetation and technogenic biocenoses through remote application of the fertile substrate mixed with mineral fertilizers and seeds of grass ameliorants, shrubs and arboreous plants to the surface of disturbed lands.

The largest areas of ore mining enterprises' disturbed lands are overburden and off-grade ore dumps, dams and tailing ponds. Physical and chemical properties of rocks composing the mentioned technogenic objects determine the degree of agrochemical suitability of substrates for planting vegetation. Observations over natural overgrowing of these technogenic objects allow distinguishing three groups of suitability of rocks: suitable (fertile and conditionally fertile), hardly suitable and unsuitable. The first group of rocks is most often used for reclamation to create the upper fertile layer (chernozem, loam, loess). The second group of rocks is the major part of the weathered rocks at dumps and it contains few nutrients for plants because of its poor mechanical composition, yet it is conditionally suitable for planting. The third group includes hard rocks unsuitable for planting without creating local areas of restorative substrate. According to physical properties, absolutely unsuitable soils are large hard rocks (under 3% of fine fraction), while as to their chemical properties they are strongly acidic, strongly alkaline or salinized [7-9].

Waste dumps of underground mines commonly have the following mineralogical composition: granites (2%), martite jaspilite (21%), hematite-martite hornstone (42%), quartz-sericite-chlorite schists, hematite talcose schists (33.5%) and loam (up to 1.5%). As for the granulometric composition, fractions of large lumps, gravel and detritus (21- 30%) prevail, while sand and dust make 12% and 8% accordingly. Mine dumps of off-grade ores have a similar mineralogical composition, but unlike waste rocks, they contain up to 40-46% of poor ores (martite-silicate quartzite, martite jaspilite, disperse-hematite or martite quartzite). As to their chemical composition, waste rocks have plenty of silica, soluble iron and metal oxides. These elements are mostly deprived of phyto-toxic properties and are sources of microelements necessary for plants (silicon, aluminum, calcium, magnesium, iron, etc.). The reaction of the aqueous extract is close to neutral. Rocks have a medium and high water absorption rate. The given data indicate the fact that the rocks at mine dumps are either conditionally or hardly suitable for biological reclamation, yet, in general, they are quite suitable for grass, arboreous plants and shrubs [9].

The rocks of open pit overburden at dumps are usually lumps of 10-150mm with prevailing fractions of 20-70mm and a small quantity (up to 7%) of the 10mm fraction as well as the 151mm fraction (15%). The mineralogical composition of open pit overburden is noted for a mixture of loam, limestone and sand (2-3%), amphibolite (10%), quartz-chlorite, quartz-biotite and quartz-amphibole-chlorite schists (54%), low metallic (Fe< 10%) quartzite (31%), oxidized ores and brown ironstone (2-3%). According to their agrochemical composition, hard rocks of overburden as well as waste rocks of underground mines are conditionally suitable for vegetation as they have optimal soil pH (4.5- 7.5), though they contain very little if any organic substances [7,9].

Concentration wastes stored at tailing ponds are crushed or ground ore materials produced after extracting ore components. The mineral composition of tailings is characterized by availability of chlorite, biotite, feldspar, calcite, magnetite and clay minerals. Oxides of silicon (62%), iron (up to 24.6%), magnesium, calcium and aluminum prevail among chemical elements. Admixtures of various elements including those of heavy metals make 8-9%. Stockpiling of tailings at tailing ponds is accompanied by gravitational differentiation of ground materials. So, the mineral and chemical composition of mature tailings can vary much in certain places [10-13]. When dehydrated, fine fraction tailings can be subjected to weathering, which results in dusting. Thus, wastes should be either kept wet constantly or consolidated on the surface. Vegetation growing at tailing ponds without considerable earthing is complicated because of high salinization of substrate and strong consolidation (cementation) of the surface after drying.

Connection of soil and plants is essential for successful biological reclamation. In mining, displacement of geological strata occurs when in-depth rocks, which differ in their granulometric and chemical composition from zone surface soils, outcrop. Thus, plants growing on these rocks find themselves in changed edaphic conditions. Efficiency of artificial vegetation in biological reclamation depends on the choice of plants capable of surviving in particular specific conditions. For this reason, it is recommended:

- to prefer plants that grow naturally in the biotopes in close proximity to the reclamation zone;
- to use the plants which are highly adaptable to poor soils where they grow and bear fruit intensively;
- the plants selected should be oligonitrophilic and drought-resistant.

When selecting plants, one should consider biochemical and species compatibility of arboreous plants and shrubs to be planted in the same area.

Practice indicates that at reclaimed sites with 0.3m fertile soil layers (loam, loam and quartzite) such species of trees and shrubs can be planted as the pinnately branched elm (Ulmus pinato-ramosa Dieck), the black locust (*Robinia pseudoacacia* L.), the sharp-leaved maple (*Acer platanoides* L.), the Asian sumach (*Ailanthu saltissima*), the Chinese elm or the English elm (Ulmus parvifolia), the false indigo (*Amorpha fruticosa*), the Tartarian honeysuckle

(*Lonicera tatarica*), the golden current (Ribes aureum), the common smoke tree (*Cotinus coggýgria*), the viburnifolious spirea (*Physocarpus opulifolius*), the sloe (*Prunus spinosa*), the blueash (*Syrínga vulgáris*). The vegetation technology in these conditions should envisage adding minimum 2-3kg of organic substrate (e.g. reclaimed sediments of sewage facilities or peat) and no less than 20-30g of mixed nitric-phosphoric-potassium nonorganic fertilizers to every planting pit. Watering plants is essential during their planting as well as minimum 3-4-times watering in dry summer seasons in the first year after planting [14].

Besides the above mentioned and successfully tested plant species, some authors recommend to plant the following trees and shrubs at hard-rock dumps of Kryvyi Rih region: the Tartarian maple (*Acer tataricum* L.), the Lombardy poplar or the pyramidal poplar (*Populus nigra* pyramidális), the rattlertree (*Pópulus Salicaceae*), the Scots pine (*Pínus sylvéstris*), the Crimean pine (*Pinus nigra* subsp. pallasiana), the European ash (*Fraxinus excelsior*), the narrow-leaved olive (*Elaeagnus angustifolia*), the cherry plum (alycha) (Prunus divaricata), the apple tree (*Malus domestica*), the Circassian walnut (*Juglans regia*), the green ash (*Fraxinus lanceolata*), the black mulberry or the mulberry (*Morus Moraceae*), the narrow-leaved oleaster (*Elaeágnus angustifólia*), the common privet (*Ligustrum vulgare*), common sea buckthorn (*Hippophaë rhamnoidesa*), the cinnamon rose (*Rōsa majalis*), the tetrastemonous tamarix heath (*Tamarix tetranda*), the loose tamarix (*Tamarix laxa*), the false hawthorn (*Crataegus fallacina*), the red dogwood or the bloodtwig dogwood (*Cornus sanquinea* L.), the nutwood (*Corylus avellana*)), the black elderberry (*Sambucus nigra*), the bird cherry shrubs (Padellus magaleb) [15-18].

Biological reclamation of highly steep slopes of waste dumps and multilevel tailing ponds of the GZKs is one of the urgent problems at Kryvyi Rih iron ore basin. Vast areas of stripped slopes of these structures are powerful sources of dusting due to weathering which leads to intensive air and soil contamination. This problem is especially evident at southern dumps and tailing ponds of Kryvyi Rih GZKs where there are three waste dumps and three multilevel tailing ponds concentrated on a rather small territory. They not only occupy large areas of hundreds of hectares, but also are 150- 180m high. The dust formed at slopes of these structures spreads for 7-8km along wind plumes covering residential areas and farming lands. The dust from waste dumps and tailing ponds is known to contain not only quartz compounds, but also toxic substances including those from the first and the second hazard groups (compounds of lead, zinc, cadmium, manganese, iron, etc.) [3]. Thus, solution of the problem of dusting reduction at slopes of technogenic objects of the GZKs is one of the most important aims of making open pit mining more environmentally friendly.

It is known that with the lapse of time, piled rocks of dumps reclaimed in their finite contours may become overgrown with vegetation thanks to the seeds brought by the wind, birds and animals, and this confirms suitability of dump rocks for vegetation. Qualitative composition and density of formed green massifs primarily depends of the dump's age, the degree of weathering in the upper rock layer and the quantity of fine fraction particles as well as the mineralogical composition of piled rocks. Thickness of the newly formed conditionally fertile layer also depends on the slope angle: the greater the angle is, the greater probability is of the upper fertile layer being washed off and the fewer plants remain on the slope surface. Poor vegetation is observed at 5-6-year-old dumps and in large-fraction zones. Indirectly, the seeding rate depends on the wind rose, precipitation, temperatures and even slope orientation (at eastern, western and southern slopes, vegetation rates are 1.8-2.3 times greater than those at northern slopes). It is considered that biological reclamation will reach its final stage if vegetation density at the slope makes minimum 65% of the surface, though this process may continue [19].

Observations conducted reveal that vegetation of technogenic areas with minimum 3-6% of fine fraction (> 2 мм) starts 2-3 years after their formation. First, some humble vegetation types appear – the bladder campion, the fireweed, and the longleaf. With poor competitiveness, these plants quickly occupy the area and prevail in the vegetation cover, thus exhausting the soil. Appearance of other ceonomorphes (the bluegrass, the axseed) indicates the beginning of the next stage of demutation, i.e. appearance of long-rooted plants that causes increased grass variety and improved soil-protective properties of vegetation. At Kryvyi Rih iron ore basin, early seeding involves up to 35 plant species, 54% of which belong to weedy coenomorphes, 12% - steppe weedy plants. The surface of waste rocks backfilled 15 years ago and earlier can be intensively overgrown with vegetation in spite of the absence of reclamation and its surface remains uneven, hilly with 0.5-1.5m height differences [9,19].

The inventory of the species composition of self-sown plants on the surface of one of the typical Kryvyi Rih waste dumps (waste dump No.9 of the “Pokrovska”) mine) formed in 2000-2012 shows that the degree of its self-overgrowth as of 2020 made from 55% (on the slopes) to 95% (on the upper platform). The slopes of this dump are mostly filled with medium sized lumps of rock (5 to 20cm in diameter). At the moment of the survey the rocks were sufficiently weathered, fine fraction made 20 - 30 %, a humus layer was formed on 40 - 70 % of the area. The degree of the surface overgrowth on the eastern slope made up to 85%, on the southern slope - up to 95%, on the western slope - up to 85-90% and on the northern slope - up to 45-50%. The plant species included grasses such as the longleaf, the tumbleweed, the blueweed, the roundleaf henbane, the curled thistle, etc. There were also shrubs: the brier, the hawthorn, the fustic, the red dogwood, and trees: the robinia, the black poplar, the Lombardy poplar, the maple, the Chinese elm, partly the field maple, the apricot.

The most intensive vegetation was noticed at the foot of the slope, the middle and lower levels of the slopes (up to 10-15m in height) were populated with young shrub growth of plants, apparently resulted from mature tree seeds sowing or expansion of neighboring trees by root shoots. As the height of the slopes increased, the density of plants decreased and at the height of 20-30m the vegetation was about 2 times less than below. The plateau surface of the dump under survey consisted mainly of the well-weathered fine (0.5 - 3mm) substrate, although there occurred medium (5 to 20cm in diameter) and even large (over

40cm) size fractions. The humus layer of 0.5 - 1.5cm had been formed almost on 80% of the area. As a result, 95% of the entire upper surface of the dump was densely covered with vegetation, except for a small number of separate areas of up to 5m in diameter in places with large lumps of rock. The grass layer was of the same species composition as on the eastern and southern slopes, but there had appeared areas of succulents. The variety of shrubs was complemented with the dogwood, the high cranberry and the mealy tree. The condition of mature trees (the robinia, the field maple, the ash-leaved maple, the European ash, the Chinese elm, the black and the grey poplars, and the apricot) was quite satisfactory despite the summer survey period (August) and absence of precipitation for the last 2 months.

The height of 8-10 year old trees was 5 to 9m, crowns looked normally formed; there were observed intensive young root shoots of maples, European ash and acacia trees. The results of the survey enable the conclusion that within 10-15 years stable biocoenosis was formed on the surface of the dump under study. The identified plant species spontaneously settled and successfully vegetating on the slopes and the top area of the dump can be recommended as of high priority when implementing projects of biological reclamation of waste rock dumps. When choosing methods and technology for landscaping steep slopes, it is advisable not to perform expensive mining operations such as terracing with excavators or earthing the surface, but to focus on finding technologies to stimulate natural overgrowth processes on slopes, providing primarily artificial plant seeding. These results completely correspond with the opinion of experts of Kryvyi Rih Botanical Garden of the National Academy of Sciences of Ukraine who believe that natural plant expansion is the most effective from both the biological and economic point of view among five known scientific methods of landscaping mining dumps and wastes of coal mines [8,15].

One of the practices of biological reclamation of waste dump slopes consists in applying a layer of up to 40-50cm of potentially fertile substrates (poor chernozem, loams or their mixture) to cover the slopes of waste dumps or crater-formation zones and subsequent planting [8,18,19], however, this method is very time consuming and expensive.

There is a method offering a hydraulic fill of seeds together with the soil substrate mixture onto the slopes of 35-40°. In 1989, the employees of the Research Ore Mining Institute (NDGRI) tested the technology of slope reclamation by means of an updated hydromonitor at InGZK dumps. Yet, this method cannot be widely applied because of absence of required standard equipment proposed by its authors [20,21].

At present, the market of special-purpose equipment for remote landscaping of hard-to-reach areas (including dump slopes) offers powerful hydroseeders (e.g. hydroseeders by Turbo Turf, AGROTEC, Bowie Victor (USA), etc.) which allow sowing plant seeds within the 30-60m distance from the equipment location. For application on slopes of waste rock dumps, Kryvyi Rih Research Ore Mining Institute (NDGRI) has successfully tested and proposed for implementation mixtures consisting of a nutrient substrate, combined fertilizers, a mixture of seeds legume grasses, trees and shrubs adapted to biotopes of dumps. Once applied to bare rock, the mixture accumulates in gaps between rocks and creates "spots" for seeds germination, primarily that of grasses and over time - tree crops. Seed germination and subsequent plant establishment are significantly larger after repeated one- or twofold application of the pulp with the nutrient substrate, as well as after watering plantations in summer evenings in hot dry weather. Modern equipment makes it possible to perform hydroseeding on slopes at relatively low material and financial costs. For example, the HM-750 - HARV Turbo Turf with the capacity of 2,800 liters allows sowing or watering 3,300m^2 of slopes irrespective of their dip in only 17 minutes.

Considering the time necessary to fill the hydroseeder tank and its redeployment, a team of 3 persons can perform 3-4 work cycles and cultivate over 1ha of land during a shift. The technological schemes developed by the authors allow the successful use of the hydroseeder both for seeding from the bottom along the slope and from the top downwards. The working radius can vary from 30m (using a stationary hydrothrower) to 60m (using a pressure hose and a manual hydrothrower) [22].

In recent years, dumps of oxidized ores storage in open pits and off-grade ores in mines have become a significant source of dust formation. Their designed height is not provided with measures to reduce dust formation. For instance, in the vicinity of the residential area of Inhulets and Central City districts of Kryvyi Rih, at the GZK of the Mining Department of the PJSC “ArcelorMittal Kryvyi Rih”, an oxidized ore dump with a design elevation of +180m is now being formed. In total, over 210 M t of oxidized quartzite was stockpiled at the company as of 2020, and the annual rate was about 3 M t [23]. Since oxidized ore dumps are actually stockpiles of raw materials, which does not allow using traditional methods of reclamation, it is necessary to develop special methods of fixing slopes of such dumps to prevent dust formation, e.g. by applying special long-term binders such as latex, bitumen wastes and the like. However, in this case preservation of surface rock stockpiles will do little to optimize the landscape structure of the region, so a more radical way is certainly the requirement to stockpile oxidized ores into internal waste dumps of post- mining areas of open pits. The second way to solve the problem of oxidized ore dumps is prohibition on mining such ores (and even more so on their stockpiling) without their use for concentration. In this regard, it is necessary to develop appropriate legislative regulations obliging owners of mining enterprises to invest in implementation of techniques and technologies of oxidized ores concentration that have been known since the 1990s.

One of the promising methods of concentrating low-grade oxidized ores stockpiled in dumps of underground mines is the technology tested at a number of Kryvyi Rih enterprises. The technology was developed and tested by scientists of the Department of Geology and Applied Mineralogy of Kryvyi Rih National University together with specialists of the Research Ore Mining Institute (NDGRI) [24]. On the basis of investigations of the mineralogical composition of iron ore raw material wastes in the dumps of iron ore underground mines of Kryvyi Rih iron ore basin, the optimum methods of their concentration were substantiated, the technology and the design were developed of the plant for production of iron ore concentrate with 65-67% iron content from rejects of the Grinding-Sorting Plant (GSP) after their regrinding to the particle size of less than 0.1mm. The main objectives of ore preparation were to achieve the maximum possible release of ore and rock particles in ground products and, at the same time, to avoid overgrinding (sludging) of ore minerals. "Wet" gravity concentration of the ground material using concentration tables, cone and screw separators was proposed as the main concentration operation. Gravity, magnetic and flotation methods were used to recover ore minerals from wastes of the main concentration operation (rejects of GSPs of all underground mines of Kryvyi Rih iron ore basin) and low-grade (total iron content 46-52 wt.%) rich hematite ores of open pits "Northern" (Mine management of the Mining Department of PJSC "ArcelorMittal Kryvyi Rih") and "Southern" (Ilyich Iron and Steel Works of Mariupol). The ordinary hematite quartzites with the average iron content of about 37 wt. % of Kryvyi Rih iron ore deposits were also tested. Based on the results of experiments with all types of raw materials, iron ore concentrate with the total iron content not lower than 65 wt% was obtained. Pilot tests confirmed the laboratory data. In accordance with the proposed technology, three commercial concentration plants for processing substandard ores and GSP wastes have been built and are successfully operating.

Based on the results of the NDGRI research [24], the technological scheme to concentrate oversize products of the GSP of Frunze underground mine with the grain size 40-0mm was developed with the expected parameters of separation of GSP waste fractions (off-grade ore). The schematic diagram of the proposed technology is shown in the figure.

According to this scheme, it is expected to obtain sintering ore with the Fe_{tot} content of 56.1% at the yield of 37.1% from the initial material with the Fe_{tot} content of 42.0%.

The modelled tests [23] of crushing the oversize product of the DSF at Frunze underground mine on the laboratory model of the centrifugal crusher of the NPO "Tsentr" with a change in linear velocity of the rotor from 9 to 16.26m/s showed the selectivity of destructing rich ore minerals and poor quartzite. The value of destruction of poor quartzite proved to be twice less than that of rich minerals. It was found that after preliminary concentration of the initial product by means of selective grinding in the centrifugal crusher, the material in the 1-0mm size class was the final product in terms of quality characteristics, while the material in the 10+1mm size class had to undergo further concentration. Investigations of concentrating narrow classes of sizes of ore ground in the centrifugal crusher and subjected to dry magnetic separation enabled obtaining magnetic products with the Fe_{tot} content of 54.6-60.2%, at the yield from the operation of 22.1-45.0%.

Implementation of the described technological solutions can reduce the amount of wastes in dumps, involve already formed dumps and stores of hematite off-grade ore into retreatment and, consequently, enhance economic performance of Kryvyi Rih iron ore basin enterprises, intensify the use of raw ore, reduce rates of pits and dumps area spreading (thus reducing erosion of landscapes) and simultaneously reduce the impact on the environment of residential areas. However, this technology has not yet become widespread due to mining enterprises owners' reluctance to invest in new developments, and therefore new off-grade ore dumps continue to be formed.

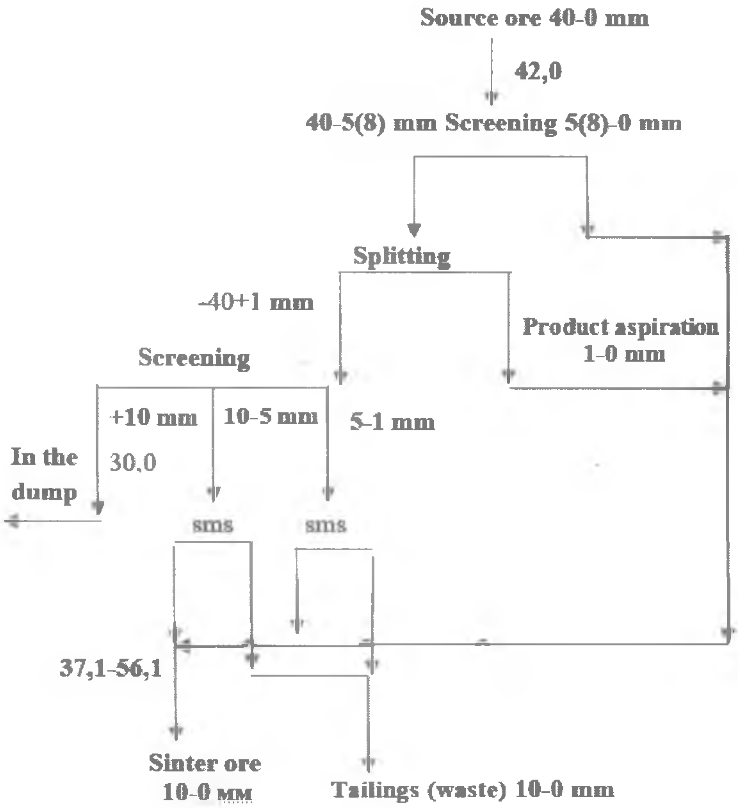

Fig. 1. Technological scheme of "dry" magnetic separation of hematite ore with the expected separation rate (with a fraction yield of +10 mm - 30%)

Reclamation of tailing ponds is another big problem for Kryvyi Rih region today. For instance, Kryvyi Rih Botanical Garden has presented its developments on biological reclamation of the tailing pond surface by planting reeds. However, due to its labor-intensity (only manual planting of seedlings) and necessity to constantly maintain a certain level of substrate moisture in the planting areas; this method has little potential for widespread implementation. In addition, this method does not solve the problem of reclamation of multilevel tailing pond slopes.

In a certain way, the problem of tailings can be solved by reducing the volume of their formation through retreatment and more complete extraction of iron, up to 20-24% of which currently remains in wastes. For instance, since the start of its operation, the GZK of the Mining Department of the PJSC "ArcelorMittal Kryvyi Rih" has accumulated over 310 M m^3 of concentration tailings in its ponds and over 6 M m^3 are being added annually [10]. Implementing the technology of sludge retreatment, the company could produce at least one fifth of its annual sinter volume from processing tailings, which would correspondingly reduce raw ore production by approximately 8-10 M m^3 a year.

Currently, there is developed a method of obtaining iron-containing concentrate and fluxed crushed stone directly from tailings without storing them in tailing ponds. According to this technology, output sludge is fed to 1mm class screens where coarse particles of natural and industrial origin are separated and then transported to a special storage area for dewatering (drying) and subsequent use as breakstone (Fe ≤ 2.0%) for construction operations. The sieved material with fractions ≤ 1mm is transported as the iron-containing raw material to the sinter plant to form charge. One plant of the kind can process up to 2.6 M m^3 of sludge, producing up to 45,000t of iron ore concentrate and up to 9,000t of breakstone. Simultaneously, reduction of the final quantity of concentration wastes enables excluding up to 20ha from use per year [25]. Despite the obvious effectiveness of the described technology of reducing the volume of concentration wastes, owners of mining enterprises, unfortunately, do not implement it on a large scale.

Transition of pits to the technology of internal dumping both within operating and dead open pits can be a significant reserve for reducing the current rate of sludge-dumping facilities growth at mining and beneficiation plants. The most acute problem now is the backfilling of the almost worked-out open pit "Northern" which has several owners, including the PJSC "ArcelorMittal Kryvyi Rih" and creates a lot of inconveniences and hazards to residents of the Central City district of the city. One of the problems with its backfilling is lack of a technically and economically acceptable option for owners to deliver waste rock to the reclamation area.

The situation with Open Pit No.1 (the GZK of the Mining Department of the PJSC "ArcelorMittal Kryvyi Rih") which started operating in 1959 is characteristic of Kryvyi Rih ore basin. The first shell of the pit was worked out in 1976 and during 1979 - 1985 its cavity of 20 M m^3 was backfilled with overburden rocks by internal dumping. After that, the resulted surface was reclaimed with soft rocks, including a layer of fertile soil. Subsequently, this area of about 8ha was transferred to a cottage cooperative, which is a rare example of complete restoration of disturbed lands [26].

The second shell of the open pit was worked out in 1987 at the depth of - 300m. After stopping all operations, the cavity of the pit was filled with water to the level of -200m. Since 1995, water flooded Pit No.1 dent has been used for stockpiling (up to 60%, 8-10 M m^3 annually) overburden of Pit No.2-bis applying the technology of internal dumping by backfilling from the outer walls with bulldozers and a walking excavator. Lack of national and foreign experience in backfilling deep pits waterlogged for over 1/3 of the wall height has caused the problem of instability of walls of the internal dump, thus complicating movement of mining equipment on the work front to the pit centre and considerably reducing safety of operations. As of 2020, dumping was only performed in places with the highest wall stability using the excavator with a 100m boom ESHa -11/100. However, this will also not solve the problem of complete backfilling of the mentioned pit - the diameter of the unfilled part exceeds 800m, and the remaining cavity capacity is up to 75 M m^3.

Scientists of the NDGRI have conducted research to determine the geophysical state of the rock massif and engineering calculations of stability of the walls of flooded Pit No.1 on its entire perimeter, developed regulations and safety data sheets of bulldozer - excavator equipment when continuing internal dumping for the final mining-engineering reclamation of the pit. Considering the high degree of danger of technological equipment operation on piled walls, a number of options have been suggested for further backfilling of the flooded open pit, including: use of stackers with the cantilever length of up to 190 m, building of a continuous aerial ropeway with car discharge in the center of the pit, use of self-propelled vibratory stackers and even use of the remote-controlled Cat bulldozer with the integrated MineStar control panel [26]. Thus, formation of an internal dump in the flooded Pit No.1 of the PJSC "ArcelorMittal Kryvyi Rih" is an example of an original, innovative and, to a certain extent, experimental work on reclamation of pits with complex hydrogeological parameters.

Thus, the long-term activities of mining enterprises in Kryvyi Rih iron ore basin have negatively impacted the landscape structure of the region. In order to change the situation for the better, joint efforts of the state and city authorities, scientists and the public are required to solve the following tasks:

1. At the state and legislative level:

- a significant increase of material responsibility of economic entities for violation of the Ukrainian environmental legislation and recommendations of international environmental programs is required;
- it is necessary to introduce a requirement to the National Building Code (NBC) of Ukraine on mandatory development of the landscape planning section in all projects on construction and reconstruction of mining enterprises;
- it is necessary to place all developers of projects for mining enterprises under obligation to include not less than 10% of the annual income from the forecast production for works on reclamation and optimization of disturbed landscapes in the estimate;
- in the Tax Code of Ukraine, the preferential tax on the disposal of every tonne of mining wastes should be abolished and the tax rate should be raised to the objective level of hazard class 3, which is due to the content of highly toxic heavy metals in the composition of these wastes.

2. At the local government level:

- an inventory of the city territory should be conducted to identify all places of technogenically disturbed lands and ugly landscape formations;
- a strategic action plan to optimize the landscape structure of the city in cooperation with design and engineering organizations and enterprises of the city should be developed;
- it is necessary to include in Comprehensive environmental programs of the region and the city specific works on the gradual implementation of the strategic plan to enhance the landscape structure of the city with the annual allocation of not less than 15% of the city's environmental fund and funds of enterprises for these purposes;

3. At the level of mining enterprises, primarily mining and beneficiation plants:

- under the pressure of high tax rates for increase of volumes of accumulated wastes and the threat of significant fines for mismanagement of leased land plots, it is necessary to significantly increase investment in development of measures to intensify iron-ore concentrate production, namely in the technologies of: concentration tailings retreatment, oxidized ore processing, internal dumping in the worked-out areas of open pits;
- funding for reclamation of disturbed lands should be significantly increased.

2. CONCLUSION

Reducing the scale of technogenic disturbances of the earth's surface in the areas of mineral deposit development, including in Kryvyi Rih iron ore basin, is possible through a comprehensive solution to the problem in two directions. The first is significant reduction of the rate of new destructive impacts on the environment by transiting from extensive mining methods to comprehensive production intensification that enables the decreased amount of waste accumulation on the surface, and the second is optimization of the already formed landscape disturbances by technical and biological methods of restorative reclamation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Number of Published papers: He is the author of more than 220 scientific articles, 5 manuals, 22 guidelines and 4 inventions (patents).

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Research Area: He is an expert in the field of monitoring and management of processes and objects of open pit mining, enrichment, iron ore products pricing for export purposes. He has been engaged in research for mining and enrichment enterprises of Ukraine, Armenia and Russia for over 40 years. Under his leadership, there have been developed methods, techniques, control systems and algorithms for complex technical systems in mining production, a methodology of control, diagnostics, identification and adaptive management of non-stationary objects of the enrichment technology, new designs of elements of AG mills implemented at enrichment plants of Ukraine and Russia, which enhanced their performance. While working at the NIGRI, he has participated in and headed investigations of economic and geological assessment of mining reserves, reclamation of disturbed lands, enhancement of processes of ore extraction and ensuring technical safety of mining production, development and implementation of regional systems for geomechanical monitoring of the rock massif state in areas affected by voids, development of an optimal pricing system for iron ore products when organizing exchange trading in the modern market conditions, etc.

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