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To cite this article: V Antonik *et al* 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **1049** 012002

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# Ways to reduce technogenic landscape disturbances in mining production

V Antonik<sup>1</sup>, E Babets<sup>1,3</sup>, I Antonik<sup>2</sup> and I Melnikova<sup>3</sup>

<sup>1</sup> Scientific Research Ore-Mining Institute of Kryvyi Rih National University, Gagarin ave, 57, Kryvyi Rih, 50086, Ukraine.

<sup>2</sup> Kryvyi Rih State Pedagogical University, Gagarin Ave., 54, Kryvyi Rih, 50086, Ukraine.

<sup>3</sup> Kryvyi Rih National University, V. Matusevych Str.11, Kryvyi Rih, 50027, Ukraine.

E-mail: viantonik096@gmail.com, ebabets@gmail.com, ira07108kr@gmail.com, i-melnikova@ukr.net

**Abstract.** Iron ore mining is followed by significant disturbances of the earth's surface caused by both iron ore mining facilities (underground mines and open pits) and disposal of mining and concentration wastes on the surface (waste and substandard ore dumps at underground mines, overburden and oxidized rock dumps at open pits, tailings storage facilities at mining and beneficiation plants). In addition, operation of mining enterprises leads to creating hundreds of kilometers of above-ground pipelines, technological roads and railroads; drilling and blasting operations at underground mines and open pits lead to seismic phenomena and geotectonic disturbances of the surface in the form of sinkholes and craters in places of underground workings. The presented scientific work aims to generalize the practice of measures to optimize landscape disturbances caused by mining and develop individual issues of arrangement and technology of reclamation of disturbed surface areas in conditions of Kryvyi Rih iron ore basin. Technogenic surface disturbances accumulated during the period of economic exploitation of the region require a comprehensive solution in two directions. The first one consists in reducing the rate of new destructive impacts on the state of the relief by switching from extensive methods of deposit exploitation to all-round intensification of production (introduction of low-waste technologies, concentration waste re-treatment, oxidized ores processing, transition to technologies of internal dumping). The second one involves optimization of already formed landscape disturbances through reclamation. It is recommended to implement a number of methods of improving individual technogenic landscape formations by engineering and biological methods.

## 1. Introduction

Kryvyi Rih iron ore basin includes 15 iron ore deposits located on a relatively small area of 43.1 thousand ha. Both underground and open pit mining methods are used here. As of 2022, there are 8 iron ore underground mines specializing in rich iron ore mining (47-67% Fe content) and 5 mining and beneficiation plants (GZKs) engaged in open pit mining of lean (under 46% Fe content) iron ores which are to be concentrated. Most iron ore underground mines are located within the city of Kryvyi Rih, while GZKs surround the city in a semicircle, their names corresponding to their location – the Pivnichnyi GZK, the Tsentralnyi (western) GZK, the Pivdennyi GZK, the Novokryvorizkyi GZK of the PJSC “ArcelorMittal Kryvyi Rih” and the Inhulets GZK (located in the southern part of the city).



The most destructive action on the region's landscape is produced by GZKs' facilities, i.e. open pits (the area of nine main open pits makes up over 6 thousand ha), beneficiation complexes and gigantic waste accumulation areas (overburden and substandard oxidized ore dumps, tailings storage facilities (TSFs)). There are eight TSFs that are complex hydro-engineering structures in the form of reservoirs created by dams of dried tailings and overburden and filled with pulp (a mixture of ground iron ore raw material wastes and water). The total area of a modern tailings storage facility can reach 700-800 ha, and being a multilevel structure it can rise 150-180 m above the surface (e.g. "Obiednane" that includes Karta I and Karta IV of the Pivdennyi and the Novokryvorizkyi GZKs respectively) [1].

Reduction of adverse effects of long-term mining operations (disturbed urban and farming lands, ruined natural landscapes and deteriorated hydrogeological conditions) 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", one thousand tonnes of the rock mass mined accounts for only about 200 t of marketable iron ore products, the remaining 800 t consists of mining and concentration wastes. At that, about 2.5 t of fine-dispersed dust and 1.8 t of poisoning gases are emitted into the air, 40 m<sup>3</sup> of land is allotted, 50 m<sup>3</sup> is flooded and 110 m<sup>3</sup> of highly mineralized water is made [2].

At present, in Kryvyi Rih, waste dumps and TSFs contain over 4 bn m<sup>3</sup> of iron ore mining and concentration wastes; their total area exceeds 12 thousand ha (dumps – up to 5 thousand ha, TSFs – over 7 thousand ha). Displacement and caving (crater formation) zones caused by underground mining occupy over 5 thousand ha of urban lands. In general, there is over 34 thousand ha of urban and suburban areas, which are technogenically disturbed and need restoration. The total area of Kryvyi Rih makes 431 km<sup>2</sup>, its mining and industrial landscapes comprise about 48.8% of this area, and they tend to increase. To this, 20 thousand ha should be added as these mostly farming lands are adjacent to the GZKs and are being degraded under the action of dust and highly mineralized water filtrates from TSFs and waste dumps. Soils within a 15-20 km circle from Kryvyi Rih industrial objects are contaminated with heavy metals and often salinized or swamped [1]. In the city's central part alone, there is over 600 ha requiring immediate reclamation. Yet, in spite of the current legal requirements and the increased level of public involvement, Kryvyi Rih enterprises' owners are very reluctant to finance environmental measures and rates of disturbed land restoration remain extremely low – up to 1.5% of the areas annually - and they greatly lag behind mining rates with a yearly 2.1% increment [2].

Under current conditions, tens of thousands of residents of areas with open pits and underground mines as well as dwellers of villages located close to the city have to live in close proximity to technogenic structures. Sanitary protection zones make just several hundreds of meters (1000 m for open pits, 150 – 500 m for dumps and TSFs). At that, some residential areas are practically surrounded by mining landscapes and not only contact with the disturbed landforms but also are exposed to their harmful emissions, primarily dust. Parts of residential areas of the Pivnichnyi GZK, settlements of Verabove, Rakhmanivka, Stepove, Myroliubivka, villages of Novolativka rural territorial community and others are examples of such territories. The mentioned facts indicate that the current environmental situation in the city of Kryvyi Rih with over 600 thousand residents is critical and requires a comprehensive approach to its solution.

There are many works aimed at intensifying mining production and preventing or reducing significantly the rate of new mining landscape formation. Since the 1980-s, the issues of disposing overburden from open pits in internal dumps have been actively discussed in Kryvbas [3–5]. Yet, the developed technologies are hardly implemented practically and all pits of Kryvyi Rih GZKs continue the long-standing practice of land consuming external dumping.

Over the recent years, significant landscape disturbances have been caused by oxidized ore dumps of the Southern group of mining and beneficiation plants. For example, at the

Novokryvorizskiy GZK, the Mining Department of the PJSC “ArcelorMittal Kryvyi Rih” is now creating a dump of oxidized ores on the eastern wall of open pit No. 3 with a design elevation +180 m and oxidized ore disposal areas at dumps No. 2-3 and “Stepovyi-2”. As of 2020, the enterprise disposed over 200 Mt of oxidized quartzites (about 3 Mt annually) [6]. To concentrate weak-magnetic oxidized ores, in the 1980s, a mining and beneficiation plant of oxidized ores (KGZKOR) was being built with the participation of Ukraine, Bulgaria, East Germany, Romania and Czechoslovakia in Dolynska, Kirovohrad region. The design capacity of the plant was 26.4 Mt of ore annually. Despite over 1.7 bn USD invested in the construction, due to self-liquidation of the CMEA and subsequent prolonged stagnation of the Ukrainian economy, the project is not yet completed. The owners of the current mining and beneficiation plants of Kryvyi Rih are still reluctant to implement technologies for concentrating oxidized ores [7] and this potentially useful resource is intensively being stored in dumps.

Another equal problem consists in availability of substandard ore mass fractions (SOMFs) of underground mines that contain less than 46% of iron and are disposed in temporary dumps. Since SOMFs are a useful resource to be further concentrated, such dumps with millions of tonnes of the rock mass are not reclaimed in a traditional way and remain intensive sources of dusting near residential areas. There exist many methods of concentrating lean ores [6–9], but in fact, SOMF dumps have been raising around Kryvyi Rih underground mines for years.

TSFs of GZKs are another factor of significant environmental and landscape problems for Kryvyi Rih. The amount of tailings can be reduced by decreasing volumes of their production through their re-treatment and more complete recovery of iron, up to 20–24% of which currently remains in wastes. For example, since the beginning of operation of the Novokryvorizskiy GZK (the PJSC “ArcelorMittal Kryvyi Rih”), its TSFs have accumulated over 310 Mm<sup>3</sup> of tailings and over 6 Mm<sup>3</sup> of new tailings are added every year. Implementation of the technology for this resource re-treatment could enable production of a fifth of annual volumes of agglomerate from re-treating the tailings and accordingly reduce production of raw ore by nearly 8–10 Mm<sup>3</sup>/year [6, 7, 10, 11]. The proposal to dewater tailings and use them for backfilling mine workings and worked-out open pits is also of interest [12].

At present, there exists a method of obtaining iron-containing concentrate and fluxed broken stone directly from tailings without disposing them in TSFs. One installation of this kind can process up to 2.6 Mm<sup>3</sup> of slime annually, produce up to 45 kt of iron ore concentrate and up to 9 kt of broken stone. At the same time, the calculated reduced final amount of concentration waste makes it possible to eliminate up to 20 ha of land from use annually. Unfortunately, despite obvious effectiveness of the described technology, the owners of the mining enterprises do not implement it widely.

Issues of optimization and reclamation of surfaces of worked-out and finally formed mining landscapes are treated in a large number of works by national and foreign authors. Great experience in designing and conducting reclamation works in the coal, ore mining and construction industries is accumulated in Russia [13, 14]. In Ukraine, problems of restoration of disturbed lands in mining production are covered by scientists of Dnipro State University [15], Dnieper Institute for Nature Management Problems and Ecology of National Academy of Sciences of Ukraine [16, 17], Donetsk and Kryvyi Rih Botanical Garden [18, 19], as well as Kryvyi Rih Research Iron Ore Mining Institute [20].

A new trend in solving problems of optimizing technogenic landscapes is implementation of eco-oriented technologies aimed at activating the biosphere revitalization potential. Deposition of production wastes containing organic matter on the surface of disturbed lands is one of them. It helps both reduce dusting and accelerate formation of a fertile layer favorable for plant settlement [17].

The presented 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.

## 2. Methods

The conducted brief analysis of known developments on the problem of optimizing mining landscapes enables stating that nowadays there is no single universally recognized approach to solving this problem. At the same time, there is a clear tendency to search for solutions in two directions: by engineering and biological methods.

Engineering-technological methods of optimizing landscape disturbances in ore mining are designed to help reduce the rate of technogenic development of new territories by limiting underground mine and open pit facilities and allocation of new areas for disposal of ore mining and concentration wastes.

To reduce the volume of substandard ore mass fractions (SOMFs) of Kryvbas underground mines, the method of processing the oversize products of crushing and sorting plants (CSPs) with an average iron content of about 37 wt.%. Laboratory tests on crushing oversize products of CSPs show that the degree of crushing of poor quartzites is two times lower than that of rich minerals. After preconcentration of the initial product by selective crushing in a centrifugal crusher, the material in the 1-0 mm grain size class is the final product by its qualitative characteristics, and the material in the 10+1 mm grain size class should be subjected to further concentration. It is substantiated that for a more complete processing of the underground mine ore, screened out materials of DSF should be subjected to regrinding to a grain size of less than 1 mm. In this case, maximum release of ore non-metallic particles is achieved in ground products. Wet gravity concentration of ground raw materials using wet tables, cone and screw separators is used for final recovery of ore components. Application of the proposed method to concentrating samples of the screened out materials of all Kryvbas underground mines' CSPs and low-grade (iron content 46-52 wt.%) rich hematite ores of open pits "Pivnichnyi" and "Pivdennyi" (Ilyich Iron and Steel Works of Mariupol) and run-of-mine hematite quartzites (iron content about 37 wt.%) from Kryvbas deposits enables obtaining marketable iron ore concentrate with iron content of minimum 65 wt.%.

To reduce the level of landscape disturbances, various methods of optimizing the technogenic relief are applied. According to the established practice, restoration of technogenically disturbed lands usually includes two reclamation stages: mining-engineering (preparatory) and biological.

Mining-engineering reclamation works depend primarily on the type and degree of a landscape disturbance. In Kryvbas, there are two types of such disturbances: the first one includes consequences of deepening below the daylight surface; the second one is associated with works that lead to piling up rock masses on the surface. As for the degree of surface disturbances, they can be significant or relatively small. Pits, caving zones, sinkholes and cracks within the land allotments of underground mines are examples of significant disturbances of the first type. The second type of landscape disturbance is associated with creation of dumps for underground mines' waste rocks and substandard ore materials, and multilevel overburden and substandard ore dumps and TSFs on the surface of open pit mining areas.

In most cases, operations of the mining-engineering stage in zones of caving, sinkholes and worked-out small pits are reduced to backfilling voids with rocks, followed by leveling horizontal areas and covering them with a layer of fertile or conditionally fertile soil.

In open-pit mining areas, besides worked-out open pits, reclamation is required for waste dumps, TSFs, and settling ponds. In Kryvyi Rih basin, dumps are very rarely used to backfill mined out areas of open pits and usually remain man-made landscape formations in the form of huge hills, mounds and slagheaps. Small single-level dumps can reach 15-40 m, while large multilevel ones - up to 180 m or over. Areas occupied by dumps can also vary widely: from 2-5 ha to 800 ha or over. Operations of the mining-engineering stage of dump reclamation

are reduced to dismantling temporary facilities (railway tracks for dumpcars, power lines, substations, technological roads, etc.), followed by bulldozer leveling of horizontal and slightly inclined (up to  $18^\circ$ ) areas of upper sites and all accessible berms and finally total earthing of the rock surface with a soil layer of 0.2-0.5 m to 1.0 m and over (depending on the type of subsequent biological reclamation). For 5 - and more year-old dumps, the surface layer of which contains over 7% of fine fractions (particle diameter  $\leq 1$  mm) local earthing can be conducted if there is lack of soft rocks.

Application of the fertile substrate to  $35-40^\circ$  slopes is one of complicated problems of engineering preparation of waste dumps and multilevel TSFs for subsequent reclamation. Attempts to earth their surface with soil from the upper berms prove ineffective, as soft rocks are easily washed away by precipitation.

Operations of the mining-engineering stage of reclamation at TSF are complicated by the fact that in the course of their implementation, it is necessary to not only solve problems of leveling and earthing the surface, but also eliminate hydrological problems, dismantle pulp lines, decant towers and pumping stations.

During the final stage of reclamation of waste dumps, TSFs and other areas of disturbed lands of open pits and underground mines, biological reclamation of the sanitary-hygienic character is usually conducted to consolidate the surface dusting layer of the soil by planting vegetation. Directions and methods of biological reclamation should primarily be selected on the basis of agrochemical suitability of the substrate for planting vegetation. Observations over natural overgrowing of technogenic objects' surfaces allow distinguishing three groups of suitability of rocks: suitable (fertile and conditionally fertile), marginally suitable and unsuitable. The first group (chernozem, loam, loess) is usually used for earthing to create the upper fertile layer. The second group is the major part of the weathered rock mass of 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 the nutrient substrate. Absolutely unsuitable soils include coarse hard rocks (under 3% of fine fraction), as to their chemical properties – they are strongly acidic, strongly alkaline or salinized.

Waste dumps of underground mines commonly have the following mineralogical composition: granites (2%), martite jaspilites (21%), hematite-martite hornstones (42%), quartz-sericite-chlorite schists, hematite talcose schists (33.5%) and loam (up to 1.5%). As for the granulometric composition, fractions of coarse lumps, gravel and broken stone (21-30%) prevail, while sand and dust make 12% and 8% respectively. Mine dumps of substandard ores have a similar mineralogical composition, but unlike waste rocks, they contain up to 40-46% of lean ores (martite-silicate quartzites, martite jaspilites, disperse-hematite or martite quartzites). As for their chemical composition, waste rocks comprise considerable amounts of silica, soluble iron and metal oxides. These elements are mostly deprived of phyto-toxic properties and are even sources of microelements necessary for plants. The degree of water absorption is medium and high, pH is close to neutral. Thus, waste rocks from underground mine dumps are potentially an acceptable substrate for herbaceous plants, tree crops and shrubs.

The open pit overburden at dumps is usually represented by lumps of 10-150 mm with prevailing fractions of 20-70 mm and a small quantity (up to 7%) of up to 10 mm fraction as well as the 151 mm fraction (up to 15%). The mineralogical composition of open pit overburden is noted for a mixture of loam, limestone and sand (2-3%), amphibolites (10%), quartz-chlorite, quartz-biotite and quartz-amphibole-chlorite schists (54%), low metallic (Fe) quartzites (31%), oxidized ores and brown ironstones (2-3%). According to their agrochemical composition, hard overburden rocks as well as waste rocks of underground mines are conditionally suitable for vegetation as they have optimal soil pH (4.5-7.5); they contain very little if any organic substances, though [3, 5].

Wastes of concentrating plants stored at TSFs are crushed or ground ore materials produced after extracting the major part of iron ore. The mineral composition of tailings is characterized by availability of chlorides, biotites, feldspars, calcites, magnetites and clay minerals. Oxides of silicon (62%), iron (up to 24.6%), magnesium, calcium and aluminium (4-5%) prevail among chemical elements. Admixtures of various elements including those of heavy metals make the remaining 8-9%. Tailings storage is accompanied by gravitative differentiation of ground materials due to which the mineral and chemical composition of mature tailings can vary considerably in certain places. Vegetation growing on the TSF surface without earthing is complicated because of high salinization and strong consolidation of the surface after drying.

Selection of plants is one of the key issues of successful biological reclamation. In useful mineral mining, there occurs displacement of geological strata, and thus the plants settled on these rocks face changed edaphic conditions. Successful artificial planting during biological reclamation requires selection of plants that are most able to survive in specific conditions, i.e. which naturally settle and grow in natural biotopes adjacent to the reclamation zone, as well as use of plants able to adapt to poor soils. Plants should be oligonitrophilic and drought-resistant.

Biological reclamation of highly steep slopes of waste dumps and multilevel tailings facilities of GZKs is of great significance for Kryvyi Rih iron ore basin. Vast areas of bare slopes of these structures are powerful sources of wind-caused dusting.

This problem is especially evident at dumps and TSFs of the southern GZKs where there are three waste dumps and three multilevel TSFs on a rather small area. They not only occupy large areas of hundreds of hectares, but also are 150-180 m high. The dust formed at the slopes of these structures spreads for 7-8 km along wind plumes covering residential areas and farming lands.

The qualitative composition and density of the resulting green massifs primarily depend on the age of the dump, the degree of weathering of the upper rock layer, the proportion of fine fraction particles and the mineralogical composition of piled rocks. Thickness of the newly formed conditionally fertile layer also depends on the slope angle: the larger the angle is, the more likely the fertile layer will be washed away by water flows and the less vegetation covers the slopes. Poor vegetation is observed at 5-6-year-old dumps and in large-fraction zones. Indirectly, self-seeding depends on the wind rose, precipitation quantity and quality, temperatures and even slope orientation (at the eastern, western and southern slopes, vegetation rates are 1.8-2.3 times greater than those at the northern slopes). Biological reclamation is considered to reach its final stage if vegetation density at the slope makes minimum 65% of the surface. It should be noted that self-seeded plants on slopes are the most resistant to complicated agrochemical conditions and do not require additional care.

Based on scientifically and practically proven suitability of wastes of iron ore underground mines and overburden of open pits to function as a substrate for vegetation, it is expedient to stimulate natural planting of steep slopes of waste dumps by artificial application of seeds of plants capable of self-overgrowing to these slopes starting with ruderal vegetation (for newly built dumps) and ending with tree and shrub crops. Seeds of plant species should be selected for each dump individually considering data on its age, the degree of surface rock weathering (% of fine fraction) and agrochemical parameters of the rock environment.

To implement the idea of stimulating natural overgrowth of slopes of waste dumps, the method of hydroseeding is proposed. Hydroseeders are currently available on the market in a wide range and they allow creating a hydraulic mixture jet up to 30 m. For application to waste dump slopes, we have successfully tested and proposed for implementation hydro-mixtures consisting of a nutrient substrate, fertilizers, a mixture of seeds of legume grasses, trees and shrubs adapted to biotopes of dumps. Once applied to bare rocks, the mixture accumulates in gaps between rocks and creates spots for germination of seeds, primarily those of herbaceous plants and over time - tree crops as well. The degree of seed germination and subsequent plant establishment

is significantly larger after repeated one- or twofold application of the pulp with the nutrient substrate, as well as after watering plantations in hot dry weather. The process flows developed by us make it possible to perform hydroseeding in both bottom-up and top-down directions.

Methods of applying a mixture of fertile substrates and binders (e.g. latex brands SKP-65PG, SKS-60PG, SPK-40PP, etc.) with added seeds of herbaceous plants should also be used to temporarily fix and plant the surface with vegetation, especially that of slopes of dumps of substandard ores (underground mines) and oxidized ores (open pits).

Application of hydroseeders and hydroseeding technology for biological reclamation of the surface of TSFs which is practically unsuitable for plants is also promising. To do this, it is first recommended to make multiple (up to 5-7 layers) hydro-applications of the initial fertile substrate (e.g. organic-mineral material composed of the city sewage system sludge and nitrogen-phosphorus-potassium fertilizers). After that, 1-2 layers of hydro-mixture of the fertile substrate, mineral fertilizers, binders and seeds of herbaceous plants - saltworts and steppe grasses are applied. After 2-3 years of this kind of reclamation, a nutrient mixture with seeds of steppe perennial leguminous-grass plants and seeds of drought-resistant shrubs can be applied to the surface of TSFs. Sprouts should be watered during dry and hot summer months, especially in the first year of vegetation, (1-2 times a month) at the rate of 2-3 liters of water per 1 m<sup>2</sup> by hydroseeders.

In Kryvyi Rih, there are disturbed landscape areas with complicated hydrogeological conditions. Restoration of such areas requires unconventional technological solutions and methods of reclamation. Worked-out open pit No. 1 of the Novokryvorizkyi GZK (the PJSC “ArcelorMittal Kryvyi Rih”) is an example of such areas. The first shell of the open pit was worked out in 1976 and during 1979 - 1985 its cavity of 20 Mm<sup>3</sup> 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 8 ha was transferred to a dacha cooperative, which is a rare example of complete restoration of disturbed lands.

The second shell of the open pit of over 49 ha was worked out in 1987 at the depth of -300 m. After stopping all operations, the cavity of the pit was filled with water to the level of -200 m. Since 1995, water-flooded pit No.1 dent has been used for storing (up to 60%, 8-10 Mm<sup>3</sup> annually) overburden of pit No.2-bis applying the technology of internal dumping by backfilling from the outer walls with bulldozers and excavators. Lack of national and foreign experience in backfilling deep pits water-flooded to over 1/3 of the wall height has caused the problem of instability of slopes 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 is only performed in places with the highest wall stability using the excavator with a 100 m boom EK -11/100. However, this cannot solve the problem of complete backfilling of the mentioned pit - the diameter of the unfilled part exceeds 800 m, and the remaining cavity volume makes up to 75 Mm<sup>3</sup>. Various methods to continue operations are proposed, including use of stackers with a cantilever arm of up to 190 m; construction of a circular ropeway with car unloading in the center of the pit; use of self-propelled vibratory stackers and remotely controlled equipment (for example, a Cat bulldozer with an integrated MineStar control system). Thus, formation of an internal dump in high-flooded pit No. 1 (the PJSC “ArcelorMittal Kryvyi Rih”) can be considered an original, innovative and, to a certain extent, experimental work in the field of pit reclamation.

### 3. Results and discussion

Implementation of the above engineering and biological methods to solve the problem of optimizing mining landscapes of Kryvbas (provided sufficient funding and activities of the owners of the mining enterprises) can yield positive results.

Thus, production tests of methods for additional recovery of iron from CSP screened out



materials confirm the above laboratory data. In compliance with the proposed technology, three experimental concentrating plants were built and have been successfully operating for several years. Large-scale implementation of the proposed technological solutions will reduce the amount of wastes in dumps, enable re-treatment of substandard hematite ores in current dumps and storage areas and, consequently, enhance economic performance of iron ore enterprises, intensify use of ore materials, decrease dump area growth rates, reduce landscape erosion and ease the burden on the environment of residential areas. Industrial implementation of the proposed methods of concentrating substandard ores of CSP wastes will allow underground mines not to create SOMF storage areas and, thus make it possible to save dozens of hectares of urban lands.

An uncontrolled increase of oxidized ore dumps that are actually storage areas for raw materials for subsequent re-treatment is a significant problem for Kryvyi Rih environment and landscape. Due to this, application of traditional methods of earthing and planting to these objects is not expedient. It is more feasible and economically sound to use special methods of fixing the surface to prevent dusting by applying special long-term binders such as latex or bitumen wastes. The second way proposed by us consists in planting vegetation (perennial herbaceous plants) by applying a hydro-mixture of the nutrient substrate, mineral fertilizers and seeds of appropriate grasses to their surface using modern hydroseeders.

However, in any case, conservation of surface rock storage areas contributes little to optimization of the landscape structure of the region. Thus, a more radical way is to demand that oxidized ores should be stored in internal dumps of mined areas of pits or, in general, prohibit mining such ores without their further concentration. In this connection, it is necessary to develop appropriate legislative norms obliging the owners of mining enterprises to invest in implementation of oxidized ore concentrating machinery and technologies known since the 90s of the last century.

As mentioned above, storage of overburden in the mined out area of open pits remains an actual and practically unsolved problem for Kryvyi Rih GZKs. For example, in the center of the city there are two almost worked-out open pits "Pivnichnyi" and "Pivdennyi" which are shared by several owners. The company "Rudomain" is currently cleaning up iron ore deposits in the "Pivdennyi" open pit, and disposing overburden in the external dump. At that, a responsible approach implies internal dumping for which there are a sufficient number of mined out areas in the pit. A similar situation takes place in the pits of the Mining Department of the PJSC "ArcelorMittal Kryvyi Rih", where, for example, up to 60% of the overburden of pit No.2-bis is used to backfill the worked-out pit No.1, and the remainder (up to 1 Mm<sup>3</sup> annually) is transported to external dumps No.2-3. External overburden dumps are intensively formed at the other mining and beneficiation plants of Kryvyi Rih without any search for alternative ways to solve this problem. These facts indicate that without strict legislation, the economic entities of Kryvyi Rih mining enterprises prefer obsolete land-intensive technologies of disposing mining wastes in external dumps.

A similar situation occurs with respect to TSFs. The well-known positive experience of Metinvest mining and smelting company in re-treating tailings of the Pivnichnyi GZK is still the only example of implementing innovative technologies in Kryvbas. At the other GZKs, lack of large-scale implementation of technologies for re-treating tailings leads to a progressive increase in areas of their storage. A recent example of this is the increase of the area of the TSF "Obiednane. IV Karta" (the PJSC "ArcelorMittal Kryvyi Rih") by 400 hectares at the expense of farming lands of Novolativka rural territorial community of Shyrokye district.

In addition to re-treatment of concentration tailings, transition of GZKs to backfilling worked-out areas of open pits with tailings is a significant reserve for reducing the current rate of their area increase.

Among other ways, previously created TSFs, especially multilevel ones, should be optimized by engineering and biological reclamation to plant the surface with vegetation by the above-

described hydraulic method.

Long-term (over 140 years) exploitation of Kryvyi Rih ore deposits has resulted in landscape disturbances that cannot be removed but they should be transformed into plant biogeocenoses. This activity should involve engineering and biological methods with final planting of trees and shrubs, stimulation of self-restoration of vegetation in hard-to-reach areas of technogenic landscape formations.

Biological reclamation of areas disturbed by mining operations is prevalently of a sanitary-hygienic character with the main task of planting vegetation on a technogenic object in the shortest time possible in order to reduce the negative impact of dusting on the environment or increase the aesthetic level of the landscape. Our practice indicates that in the climatic conditions of Kryvbas at areas of biological reclamation with not thinner than 0.3 m potentially fertile soil layers (loam, loam and quartzite), the following species can be most successfully planted: 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*), Lombardy poplar (*Populus nigra pyramidális*) and the black poplar (*Populus nigra*) take root less successfully. Among shrubs, the false indigo (*Amorpha fruticosa*), the common smoke tree (*Cotinus coggygria*), the viburnifolious spirea (*Physocarpus opulifolius*) and the blueash (*Syrínga vulgáris*) show best establishment and growth. In these conditions, the vegetation technology should envisage adding minimum 5-6 kg of a nutrient substrate (e.g. chernozem with organic-mineral materials of the city sewage system sludge or peat) and 30-40 g of mixed nitric-phosphoric-potassium nonorganic fertilizers. Watering plants during their planting as well as minimum 3-4-times watering - in the dry summer season in the first year after planting is essential.

The similar technology of planting seedlings can be recommended for biological reclamation of old waste dumps without earthing but containing over 7% of the fraction diameter  $\leq 1$  mm. In this case, planting holes for seedlings can be made directly in the rocks, but they should be filled with minimum 8 kg of the nutrient substrate with of 50 - 60 g of mineral nitrogen - phosphorous - potassium fertilizers.

The most reliable and least expensive way of solving the issues of technogenic landscape reclamation is to stimulate processes of self-overgrowth. Observations show that plants grown from seeds even in complicated agrochemical conditions are highly viable and hardy, and most importantly – they reliably vegetate without additional care. One of the ways to stimulate self-overgrowing is targeted dispersal of plant seeds over the surface of the object under reclamation. The best way to solve this problem is hydroseeding applying typical hydroseeders that allow using complex hydro-mixtures, including nutrient substrates, mineral fertilizers and plant seeds. Technical characteristics of modern hydroseeders allow remote application of seeding mixtures to the most hard-to-reach areas of reclamation, including steep slopes of waste dumps. An important advantage of this method is that there is no need for any costly and dangerous mining-engineering operations on preliminary preparation of slopes of dumps and other complex landscape formations for reclamation. The same hydraulic method can be used to remotely conduct initial reclamation works by repeated application of the nutrient (fertile) substrate to the most unsuitable for plant growth surfaces, e.g. TSF slopes or stone surfaces, etc.

Selection of the seed composition is the key to hydroseeding. Based on our experience, mixtures should be composed of mainly three groups of plants (herbaceous, shrubs and deciduous plants) for vegetation to cover all possible levels. In some cases, when temporary planting is required (e.g. on substandard ore storage areas), seeds of perennial herbaceous plants suffice. The species composition of plants in each case is selected depending on the age of the dump or other landscape formations, the agrochemical state and the fractional composition of rocks of the surface. The best way to consider these three factors is to study in advance the species composition of plants that have already settled on the object or on neighbouring areas with

similar conditions by the time of the planned reclamation. For example, in 2020 we developed a project for reclamation of a waste dump (operated in 2012-15) of one of the underground mines in the center of Kryvyi Rih. The total area of the dump was 8.8 ha, of which the area of bare slopes with a slope angle of 35 - 40° was 3.9 ha. The technology was chosen to stimulate natural planting of steep slopes by hydroseeding grass, shrub and tree seeds. To justify the species composition of the seeds for hydroseeding, there was made inventory of the species composition of plants self-established during 2000-2012 on the surface of the adjacent dump of the same mine. The studies showed that the degree of self-growth as of 2020 averaged 65% (on the slopes) to 95% (on the upper platform). The slopes of the dump mostly consisted of medium-sized rock lumps (5 to 20 cm in diameter). At the time of the study, the rocks were sufficiently weathered, the fine fraction made 20 - 30%, the humus layer of 0.7-2.1 cm was formed on 40 - 70% of the area. The plants of the formed layer included grasses (the longleaf, the tumbleweed, the Swiss ryegrass, the knotgrass, etc.), shrubs (the wild rose, the fustic, the red dogwood, the false indigo,) and trees (the robinia, the black poplar, the Chinese elm, the ash-leaved maple, etc.). At the time of the survey, the condition of mature trees was satisfactory, crowns looked normally formed, there was intensive young root-shoot of maples, ash-trees and acacia trees. Thus, the identified plant species made up the main list of seed species for hydroseeding slopes of the waste dump to be reclaimed.

#### 4. Conclusions

The long-term activities of mining enterprises in Kryvyi Rih iron ore basin have adversely impacted the landscape structure of the region. Optimization of technogenic surface disturbances accumulated during the period of economic exploitation of the region requires a comprehensive solution in two directions. The first one consists in reducing the rate of new destructive impacts on the state of the relief by switching from extensive methods of deposit mining to intensification of production. The second one involves restoration of the landscape through reducing technogenic relief disturbances by engineering and biological methods. To do this, it is necessary to:

- increase financial responsibility of economic entities for violation of the Ukrainian environmental legislation and recommendations of international environmental programs concerning the rational use of minerals and land resources, disposal and recycling of industrial wastes;;
- introduce a requirement in the National Building Code of Ukraine on mandatory development of the landscape planning section in all projects on construction and reconstruction of mining enterprises;;
- oblige all developers of projects for mining enterprises to include allocations for reclamation and optimization of disturbed landscapes in the estimate;
- include in Comprehensive environmental programs of the region and the city specific works on gradual elimination of previously accumulated landscape disturbances (currently under abeyance) with annual allocation of minimum 15% of the city's environmental fund and funds of enterprises for these purposes;
- raise tax rates for increased volumes of accumulated wastes and introduce environmental fines for mismanagement of leased land plots;
- significantly increase enterprises' investment in development of measures to intensify iron ore production, namely in technologies of tailings re-treatment, oxidized and substandard ore processing, reduction of external dump areas through tax benefits and subsidies from the state, regional and city environmental budgets;
- introduce innovative technologies for restoration of natural ecosystems on mining landscape areas by stimulating the process of disturbed lands self-overgrowth using the hydromethod

of remote application of nutrient substrates and seeds of herbaceous plants, trees and shrubs to the surface of complex landscape formations.

### ORCID iDs

V Antonik <https://orcid.org/0000-0003-0761-0920>

Y Babets <https://orcid.org/0000-0002-5613-9779>

I Antonik <https://orcid.org/0000-0003-4445-6934>

I Melnikova <https://orcid.org/0000-0002-6934-3269>

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