TOPICAL PROBLEMS OF RECLAMATION OF TECHNOGENICALLY DISTURBED LANDS OF KRYVBAS

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Abstract. Restoration of the landscape and land resources disturbed by mineral mining of is one of the major tasks of environmental protection in Kryvyi Rih iron ore basin. The article deals with the topical problem of reclamation arrangement and technology on disturbed areas. Ukraine's legislative provisions adapted to the European and world standards make the methodological background to the work which is aimed at considering the most efficient methods of reclamation of individual technogenic landscape formations. It is determined that restoration types, trends and methods should be chosen considering the technical state and length of functioning of a technogenic object, composition of rocks and the shape of the surface under reclamation.

Introduction.

Long-term activities of Kryvyi Rih ore mining enterprises, especially open pits of ore mining and concentrating combines (GOKs) have resulted in disturbance of large areas of urban and agricultural lands, landscape and hydrogeological conditions of the environment. At present, external waste dumps and tailing ponds of five Kryvyi Rih GOKs contain over 4 B m^3 of iron ore mining and concentration wastes; their total area exceeds 12 thousand ha (dumps - 5 thousand ha, tailing ponds - over 7 thousand ha). Within Kryvyi Rih iron ore basin, there are over 34 thousand ha of urban and suburban lands are technogenically disturbed and require reclamation, their restoration rates remain very low - 0.2-1,7% of the areas annually. Displacement and caving (crater formation) zones caused by underground mining make over 5 thousand ha of urban lands and require reclamation as well. Now, in the city's central part alone there are more than 600 ha of mined lands requiring immediate reclamation.

It is common practice in Ukraine that enterprises mine minerals under the authority of special licenses granting the right to temporary long-term (20-50 years) use of a subsurface site limited by a corresponding *mining lease*. Typically, under the authority of the obtained special permit for mining an economic entity leases land from local communities (*land allotment*) and develop a land management plan in which the layout of all facilities for economic activities on the allotted site is substantiated. Under Paragraph 4, Article 66 of the current Land Code of Ukraine, restoration (reclamation) of the disturbed land is obligatory on all post mining areas [1]. Under Paragraph 1a), Article 96 and the addendum to the Land Code provided for by the Law of Ukraine No. 1708-VI of November 5, 2009, a tenant is to "provide use of land according to the designated purpose and *bring it to the previous condition at their own expense* in case of illegal change of its relief…" (hereinafter the translation is ours). Paragraph 2, Article 166 of the Land Code states that "lands that have undergone changes in the structure of their relief, ecological state of soils and country rocks are subject to reclamation".

In view of the above, the problem of restoration of lands disturbed by mining is topical and indispensable for every mining enterprise of the city. As reclamation is an expensive process, the enterprises tend to apply the most rational and cheap technologies. The present article considers the most efficient methods of reclamation of individual technogenic landscape formations.

The current state of reclamation issues. Typically, reclamation of technogenically disturbed lands comprises two stages: mine-engineering and biological.

The main purpose of the mine-engineering (preparatory) reclamation (MER) stage is fulfilment of works on relief optimization and creation of surface areas suitable in their form for further economic use.

The character, volume and content of operations on the MER stage may vary greatly for each particular site of the area under reclamation due to the kind and degree of technogenic disturbances of the land surface. Within land allotment boundaries at iron ore underground mines, appearance of displacement zones and sinkholes (craters) at places of voids resulted from underground mining is the most common change of the landscape. In some cases, waste rocks are stockpiled on the surface forming heights – dumps. After geological processes of the surface caving stabilize, MER on the territory of underground mines' allotments provides for, first of all, filling of created sinkholes with waste rocks.

Surface mining operations result in creating open pits and external dumps of waste overburden or off-grade ores (in Kryvbas they are mostly dumps-stockpiles of so called oxidized ores). Besides, if surface operations are applied to mining lean ores with iron content of 17 to 45 %, they require concentration to reach marketable standards (60% and more) at specialized concentrating complexes which results in not only iron ore concentrate but also relatively barren concentration tailings. These wastes are typically placed on the surface as individual technogenic facilities – tailing ponds of an areal or a multilevel type. Areal tailing ponds are created in locations with large natural ravines or gullies and are relatively low hydraulic structures (under current concentration technologies tailings are transported and stockpiled in the pond in the form of slurry). Multilevel tailing ponds are high hydraulic structures resembling dumps. The above mentioned technogenic facilities (open pits and places of mining and concentration wastes accumulation) create huge areas of disturbed lands of hundreds of hectares. The existing open pits may reach the depth of 500 m and more, dumps and multilevel tailing ponds may rise 150-500 m above the surface. It should be noted that return of the GOKs' post-mining areas into the previous state is practically unachievable. That is why, reclamation of the mentioned territories can just be cosmetic and aimed at solving sanitary and hygienic tasks on reduction of contaminating impacts of the disturbed areas and technogenic facilities on the environment. At that, vertical walls of the open pits and steep slopes (over 18°) of "young" dumps and tailing ponds are practically inaccessible for any reclamation operations. Mine-engineering and followed-up biological reclamation can only be implemented on horizontal and slightly inclined areas.

Analysis of the available data shows that rocks of dumps, tailing ponds and backfill areas of displacement zones are conditionally suitable for biological reclamation and on the whole have a favorable influence on growth of trees and shrubs [6;7;8].

With the lapse of time, piled rocks of dumps and tailing ponds may become overgrown with vegetation. As in terms of latitudinal-zonal position, the area of Kryvyi Rih iron ore deposits is located in the south steppe (fescue-feather grass) sub-zone of the steppe zone, and in terms of geobotanical subdivision it belongs to Cis-Azov-Black Sea sub-province of the Euro-Asian steppe region, spontaneous formation processes possess traits of this sub-province.

The floristic investigation of slopes of open pits *Yuzhnyi* of the underground mine administration of the PJSC "ArcelorMittal Krivyi Rih" (PJSC AMKR) and *Severnyi* of GOK "Ukrmekhanobr" enable stating that ruderal vegetation (*mock cypress, bladder campion, horseweed*) is first to appear. With the lapse of time, the species composition gradually expands. Re-establishment of vegetational cover on the areas undergoes its first stage (weeds invasion) during the first two years.

Appearance of plants of other coenomorphs (e.g. *narrow-leaved bluegrass, coronilla*) is the first indication of the second stage of re-establishment - invasion of long-rooted plants. This stage results in not only increased phytodiversity but also enhanced soil-protective properties of vegetation. Totally, there are 33 overgrowing species of which 54% belongs to weed coenomorphs, 12% - to steppe weeds and 12% - to meadow weeds [9].

Observations show that areas filled with waste rocks 15 and more years ago are now intensively overgrowing. On this surface a multiple-aged uneven stand of trees has emerged. In some places the stand has closed with vegetation planted during previous steps of greening post mining areas.

Field inspections of iron ore dumps of Kryvbas show that the dumps without intentional planting are overgrown with such arboreal species as the apricot tree, the European white birch, the thorn, the Nanking cherry, the sour cherry, the Siberian elm, the oleaster pear, the common pear, the English oak, the Norway maple, the ash-leaved maple, the large-leaved lime, the black locust, the alycha, the Crimean pine, the Scotch pine, the white poplar, the Canadian poplar, the Lombardy poplar, the domesticated apple, the wild apple, the Fraxinus excelsior. Also there can be found bushes and lianas – the creeper, the Russian olive, the red raspberry, the common sea buckthorn, the dogberry, the black cherry, the bird cherry shrubs [10;11]. Seeds of these species have been brought to the dumps either by wind (anemochorously) or by animals (zoochorously).

The represented data demonstrate that the problem of reclamation of disturbed lands at Kryvyi Rih iron ore deposit can and should be solved through both intentional reclamation works and facilitation (stimulation) of self-revegetation processes in hard-to-reach areas of technogenic landscape formations.

One of the main conditions of successful reclamation of disturbed lands is sufficient financing as well as determining legal and economic issues of arranging and regulating reclamation works considering interests of the state and local authorities, a subsurface resources user and the population of the territories nearby developed deposits.

For Kryvyi Rih with its 8 of 11 Ukraine’s largest iron ore mining and processing enterprises the problem of reclamation is one of the priorities in terms of environmental activities. The regional Program on solving Kryvbas environmental problems for 2011-2022 provides allocation of 24,9 bn UAH, including 3,96 bn UAH - for rational use of lands and reclamation of disturbed lands. At that, 324 mln UAH are only allocated direct for restoration of 116 ha of disturbed lands [12]. At the same time, roughly calculated area of lands disturbed by all mining enterprises of the city made 7301 ha (as of 2017). Expenses on reclamation of territories of these economic entities total 52,5 bn UAH for complete restoration of the topsoil (at 2018 values) [13]. It is quite obvious that centralized financing from the environment fund is not sufficient. According to the current legislation, reclamation of lands after mining is duty of the subsurface resources user [14]. But it is at this stage of the exploitation of the deposit that the problem of financing reclamation works appears as completion of mining and sales of products do not allow mining enterprises to use current cash flows. Due to this, to compensate for reclamation of disturbed lands, a subsurface resources user should have a special reserve fund. However, practically no user has a fund for this purpose at present. Nor are there completely developed and institutionalized norms of economic assessment of disturbed lands, normative and methodological framework for creating liquidation funds to finance reclamation [13].

Implementation of mine-engineering reclamation of disturbed lands of Kryvyi Rih region

The scope of these works depends on the actual character and the disturbance rate determined, in turn, by the technology previously applied. As mentioned above, disturbed lands within underground mines' allotments can include caved areas, craters, cave-ins, waste dumps of sinking operations, etc. Surface mining areas subject to reclamation include dead open pits, waste dumps, tailing ponds, settling ponds, etc.

Cavities of open pits and voids of the land surface caused by mine workings are the most difficult to reclaim. The amount and rates of mine-engineering reclamation of the mentioned areas are limited and will mostly depend on available land resources applicable to backfilling.

Waste materials resulted from sinking are predominantly used to backfill craters and voids. As volumes of cavities of these formations do not exceed 1-1.5 mln m^3, their backfilling is quite applicable. Yet, reclamation periods of these areas are limited by yearly output of waste materials produced, averaging 20-30 thousand m^3/year, and in case of considerable voids (of hundreds of thousands m^3), their reclamation may take decades. This process can be accelerated at the expense of auxiliary resources like overburden, yet it requires extra unproductive expenditures.

Reclamation of dead open pits is even more complicated. After de-activation of these open pits, no operations are undertaken including those of water pumping resulting in their gradual inundation and turning into water reservoirs - lagoons with granite banks. In Kryvyi Rih, there are some former granite open pits of this type on the territory of Zarechnyi micro-region (*Oktyabrskyi* open pit) and Karachuny (*KDZ* open pit). Open pit № 1 of Novokryvorizskyi GOK (up to 200 mln m3) is half filled with water and located within the PJSC AMKR allotment.

At present, this open pit is backfilled with waste materials from adjacent open pits № 2-bis and № 3 of the mentioned enterprise. The area is reclaimed by applying internal dumping using dump trucks and extraction-and-loading excavators of a dragline type (ЭШ-6/45) with a flexible bucket hanger. In Kryvyi Rih iron ore basin, stockpiling of waste rocks into dead open pits for their backfilling should be considered *one of the best* dumping methods requiring no extra areas for mining waste disposal.

The same reclamation technology is applied to a 3,89 ha site of the dead open pit of the mine named after Valyavko-Severnaya at the PJSC AMKR. This dead open pit of 2,4 mln m^3 was backfilled with overburden in 2016-2017. Hard rocks of the backfill were covered with a 1,5-2 m layer of conditionally fertile soil (loam). Currently, here biological reclamation (planting of trees and shrubs) is undertaken to create a green area of general use. The mentioned reclamation targets exclusion of the reclaimed area from the GOK's allotment list and its transition to the city land fund.

Open pits of the existing Kryvyi Rih GOKs have excavations ranging from 300 mln m^3 (Petrovo open pit of CGOK) to 4,2 bln m^3 (InGOK open pit) that cover the surface area from 270 to 650 ha. Backfilling of such huge open pits is possible only at the expense of overburden or off-grade ores from external waste dumps. However, the return of millions of cubic meters of rocks requires almost the same expenditures as their removal from the open pit, i.e. billions of hryvnas. For this reason, only *a special fund* can become the source of reclamation expenses for this type of operations at open pits. The fund should be financed by means of depreciation payments during the whole operational cycle of an open pit, these payments being included into the cost of end products.

The mentioned approach can be implemented for newly created open pits of the same economic entity as existing Kryvyi Rih open pits created in the 1950s-1960s and privatized by current owners have no reclamation funds at all. For this reason, there is no possibility of backfilling currently mined open pits of the region because of considerable expected costs of such operations which are unproductive. Most likely, huge craters from dead open pits of Kryvyi Rih GOKs will turn into silent ugly reminders of the frontal economy.

Preliminary calculations indicate efficiency of mine-engineering reclamation of dead open pits by backfilling in case of their relative low volume of up to 25-30 mln m^3 and availability of corresponding amounts of waste rocks. For larger open pits, it would be more efficient to form initial *internal waste dumps* not only for overburden, but for off-grade (oxidized) rocks as well. This very approach will provide an opportunity to save hundreds of hectares from mining waste disposal (waste dumps) and reduce expenditure for reclamation of dead open pits. It would be quite expedient *to enact into law and order* all "old" and operating Kryvyi Rih GOKs to start developing relevant technologies and designs of stockpiling re-processed waste rocks and oxidized ores in particular into internal waste dumps only, while further development of external waste dumps both in height and width should be banned. Development of technologies of stockpiling ore concentration tailings inside the mined-out part of open pits is also quite promising.

The technology of internal dumping should predominantly depend on the technology and advance of open pit mining operations. Advancing - longitudinal mining creates the most favorable conditions for internal dumping as there is a mined-out space that can be reclaimed (backfilled) next to the pit walls in the opposite to mining direction. At deeper open pits, there can be circular haul roads along the perimeter of an open pit. That is why, backfilling should be started below the lowest road (usually by the overpass method), backfilled sites being used for constructing new roads.

For mining deep open pits, internal dumping parameters are specified by individual mining designs and should envisage step-by-step backfilling of mined-out benches. If waste materials of ore mining include not only overburden rocks, but also off-grade ores (for example, oxidized ores which are potential iron ore materials), an internal dump should be formed by differentiating a "cultural" zone (a storage for potential raw materials to be re-processed) and a waste disposal zone.

In mine-engineering reclamation of the open pits backfilled to the height of their final contours and multilevel tailing ponds that are not going to be used as raw material sources for backfilling and are suspended as artificial hills and mountains, a technogenic relief as close to the natural one as possible is formed, it being safe and suitable as to its geometrical parameters and shape quality for people and animals. This stage should include the following operations: sanitation of disturbed lands to remove industrial waste, temporary facilities and rubbish; development of the vertical and finishing land leveling of the disturbed surface to meet safety standards for environmental objects and protect them from linear and plane weathering; fixation of unstable surfaces of weatherable techno genic formations by engineering and chemical means.

Vertical land leveling should be applied to dump slopes of overburden rocks (flattened to meet angles of natural slopes of 30-37°) and excavation terraces at open pits. Berms of overburden dumps are to be subject to fragmental cleaning and caving; slope edges are to be subject to wall control followed by downward caving along safety banks; horizontal parts of the berms are to be subject tofinishing land leveling.

After leveling the areas to be reclaimed, there are conducted final operations of mine-engineering reclamation, namely, earthing of all horizontal and slightly inclined (up to 18°) sites with 1.5-2 m layers of conditionally fertile soils (loams) and 0.3 m layers of fertile soils (chernozem). It should be noted that the fertile layer should be applied to the leveled surface after its natural shrinkage only under the action of precipitations (in 1-2 years at the earliest). The material for earthing is stockpiled (according to the standards of GOST 17.5.3.06.85) soft overburden rocks.

In engineering reclamation of the 'beach' surface of tailing ponds containing fine fraction slurry, no earthing is envisaged as only banks are cut and leveled because the surface itself is potentially suitable for biological reclamation.

Implementation of biological reclamation of Kryvyi Rih disturbed lands

According to 17.5.3.04-835302-85 GOST (with N1 changed and approved in September, 1986 (ИУС 11-86)) "Nature protection. Lands. General requirements to land reclamation", technogenically disturbed lands should be predominantly turned into arable fields and other farm lands. Yet, reclamation of lands disturbed by the activity of underground mines and concentrating plants of Kryvyi Rih iron ore basin located mostly within the city area is not reasonable from the agricultural point of view and does not comply with the General development plan of the city. For this reason, the sanitary-hygienic trend of biological reclamation is implemented which envisages fixing surface (dusting) layers of soil by planting trees, shrubs and perennial herbs.

Interconnection of soil and plants is one of the key problems to be solved by biological reclamation. Mineral mining involves displacement of geological strata when underlying rocks different in their granulometric and chemical composition from zone surface soils come up to the surface.

Investigations indicate that *waste rocks* resulted from sinking operations and *stripping rocks* of open pit mining are noted for almost the same characteristics. As for its mineralogy, this substrate is presented by granite (up to 2%), jaspilite martite (up to 21%), hematite-martite hornstone (up to 42%), quarts-sericite-chlorite shales, hematite talcose shale (up to 33,5%) and loams (up to 1,5%). In granulometric composition, coarse fractions of lumps, gravel and crushed rocks (21-30%) prevail, while sand and dust make 12% and 8% respectively.

As for their chemical composition, rocks are characterized by a great amount of silica, soluble iron and metal oxides. Concentration of ions of heavy and toxic metals and parameters of their natural radioactivity indicate low toxicity of single samples of these rocks related to the fourth class of hazard and toxicity. In the present form, the given elements cannot be absorbed by plants and have phytotoxic properties. Moreover, silicon, aluminium, calcium, magnesium, iron and other elements are microelements that are vital for plants. Reaction of the aqueous extract of rocks is close to neutral. The rocks are of medium and high absorption rate.

It is worth noting that at dumps and multilevel tailing ponds subject to biological reclamation and surrounding landscape formations above the daylight surface, an artificial hydrological mode characterized by absence of underground aquifers is formed. Water content of the surface layer is supplied only by precipitations and intensity of their evaporation. Considering Kryvyi Rih region's climate with its scarce rains and high air temperature in summertime, it can be stated that there are created quite dry weather conditions for plants, this fact being taken account of while choosing plant species.

Thus, plants occurring on dump rocks find themselves in changed edaphic conditions relative to the earth's surface ones. That is why, successful artificial planting for biological reclamation requires choice of species capable of surviving under certain specific conditions. To achieve this, the following steps are recommended:

- privileging the plant species naturally growing in natural biotopes adjacent to reclamation zones;
- using plants with evident adaptive properties in "poor" soils, i.e. those growing and fruiting intensively;
- using oligonitrophilic and drought-resistant plants.

While choosing plant species, it is necessary to consider biochemical and specific compatibility of arboreal and dumetosous species suitable for planting in the same area.

The following trees are recommended to plant in hard rocks: the Norway marple (*Acer platanoides*), the apricot tree (*Prúnus armeniáca*), the Tatarian maple (*Acer_tataricum L.*), the Chinese elm or an English elm (*Ulmus parvifolia*), the Lombardy poplar (*Populus nigra pyramidális*), the Scotch pine (*Pínus sylvéstris*), the Crimean pine (*Pinus nigra subsp. pallasiana*), the Fraxinus excelsior (*Fraxinus excelsior*), the angustifoliate olive (*Elaeagnus angustifolia*), the alycha (*Prunus divaricata)*. The following species of bushes are recommended for these conditions: the Russian olive **(***Elaeágnus angustifólia*)*,* the common privet (*Ligustrum vulgare*)*,* the common sea buckhorn (*Hippophaë rhamnoidesa*)*,* the tamarix (*Tamarix tetranda*), the cinnamon rose (*Rōsa majalis*)*,* the hawthorn deceptive (*Crataegus fallacina*), the dogberry or the bloodtwig dogwood (*Cornus sanquinea L.*), bird cherry shrubs or the Mahaleb cherry (*Padellus magaleb*), the indigo bush (*Amorpha fruticosa*).

Biological reclamation of extremely steep slopes at dumps and multilevel tailing ponds of mining and concentrating combines is one of urgent problems of the landscape environment of Kryvyi Rih region. Vast areas of bare slopes of these formations are powerful dusting sources under the action of wind that causes intensive pollution of the atmospheric air in surrounding areas. This issue is especially evident at dumps and tailing ponds of the southern group of mining and concentrating combines (GOKs) of Kryvyi Rih where these technogenic formations take hundreds of hectors and are up to 150-200 m high.

The resulted blowing erosion dust from wind plumes at dump slopes spread over 7-8 km covering dwellings and agricultural lands with a dust mantle. The dust from dumps and tailing ponds in its chemical and mineralogical composition is known to contains not only quarts-containing compounds, but also elements of toxic substances of the 1st and 2nd hazard classes (compounds of lead, zinc, cadmium, manganese, iron, etc.). There are evident hazards for people's health and the whole environment resulted from dust of the mentioned composition in the surface zone. Thus, solution of the problem of reducing dust content on the slopes of technogenic objects of Kryvyi Rih GOKs is essential for ore mining greening.

Biological reclamation operations conducted by iron ore mining enterprises involve application of fertile substrates (poor chernozem, loams and their mixtures) of 40-50 cm thick to cover dump slopes and crater-formation zones followed by planting. This method should consider slope angles. If they exceed 18^o, chernozem or loam earthing becomes inefficient as potentially fertile substrates are unable to be fixed on these slopes and are washed off with precipitations.

Considering the fact that all slopes of operating GOKs' dumps have natural dumping angles (35^0 and over), application of this greening method is almost impossible. The method is also cost-ineffective - 1 ha of the slope surface of 0.4 m thick requires 4-4.5 thousand m^3 of soil to be delivered and bulldozed. Uniform soil covering of slopes can be reached only with the slope height of under 20-25 m. Earthing of slopes also requires dozens of hundreds of tons of scarce conditionally fertile soils.

Application of manual hole digging technologies to planting the slopes of fine fraction using ropes is also of little efficiency and expensive for 20-35° slopes. Subsequent planting and watering becomes very complicated and sometimes even unfeasible. The mentioned operations at coarse-grained hard rocks conducted at "young" slopes (of 20-25 years old) of operating GOKs and underground mines are not permissible as it becomes hazardous for employees' health with safety standards violated.

There is a patent offering a hydraulic fill of seeds together with the soil substrate mixture onto the slopes of 35-40°. Yet, this method cannot be widely applied because of absence of required standard equipment suggested by its authors.

In 1989, the employees of our Institute tested the technology of slope reclamation by means of an updated hydromonitor at InGOK dumps [16]. Herb seeds were put into the water container of the hydromonitor and applied onto slopes with a hydro-jet. However, the method did not gain broader acceptance because of absence of the required equipment, the limited range of action of the hydromonitor (up to 20 m) and very low establishment of plant seeds at rocky slopes (5-7%) as well as massive mortality of vegetative plants without watering during the first year.

To increase plant establishment, there were made efforts to encapsulate seeds with life-giving substrate before their applying onto dump slopes by the hydro-method. Yet, this method failed to be developed because there is no standard equipment to perform such operations which are also not cost-effective.

In compliance with the above-mentioned, we consider that natural plant expansion to remain the most effective method of dump greening. Many researchers including those of Kryvyi Rih Botany Garden of the Ukraine's National Academy of Sciences confirm the advantage of this approach to dump reclamation at ore mining enterprises [8]. Researches indicate that dumps are capable of being overgrown with trees, shrubs and herbs within 10-15 years. There are 32 species of self-planted trees and shrubs at Kryvyi Rih open pit dumps reclaimed intentionally, *the Lombardy poplar, the white poplar* and *the European white birch* being the most widely spread species.

Thus, natural plant expansion is the most efficient method among five known greening methods for GOK dumps and coal mine wastes from both biological and economic points of view. Some methods of encouraging and accelerating plant expansion can be considered useful and recommended like planting 2-3 rows of high-yielding trees or shrubs at the distance of up to 1-1.5 m from the upper edge of the slope.

After coming into fruiting, plants start active colonization of dump slopes under the action of wind, precipitations and birds. Plant expansion can be enhanced by manual dissemination of seeds from slope edges (1kg of seeds consumed per 10 lin.m of a site). Yet, this method is hazardous when employees come too close to the slope edge (up to 1 m), so the dissemination zone usually makes a few meters from the upper part of the earthfill. Application of flying apparatuses (for example, drones) can make seed dissemination along dump slopes entirely safe. The flight courses of drones along objects and dissemination intensity can be easily programmed.

The biological stage of reclamation of plant expansion sites can be considered finished when vegetation density at slopes makes not less than 65% of the surface and this process can be continued.

Horizontal sites of dumps, filled open pits and tailing ponds at the city outskirts can also be subject to forestry-engineering and agricultural reclamation.

In forestry-engineering reclamation of dumped hard rocks, it is important to create a potentially fertile soil layer which is sufficient for developing a tree root system. Ideally, this layer comprises two components - the continuous covering layer of quaternary loams or loess soils of 1-1.5 m thick and a 0.2-0.4 m covering layer of humus-containing substrate (chernozem) in the amount of up to 3000 m^3 per 1 ha. If chernozem is not available, *a local hole-digging method* of planting can be applied which enables saving both fertile substrates and costs required for reclamation.

In this case, a hole of up to 0.3×0.3×0.35 m is dug directly in the available substrate including weathered hard rocks of the dump, while the fertile soil (chernozem) of 10-15 dm^3 together with a combined nitrogen-phosphoric fertilizer (up to 100 g per root) is put directly into the hole while planting. The plants are watered (10-15 l). The rest of the hole is filled with fine fractions (up to 3 cm in diameter) of rocks or loam.

Agricultural reclamation envisages turning disturbed lands into farm fields, so the brought surface fertile layer of soil should be not less than 0.5 m thick. Initial agrochemical conditions of the layer are essential including the content of humus, nitrogen-phosphor-potassium compound and microelements. If the soil is lean, some *land improvement* steps are taken including improvement of the lean soil structure by its mechanical cultivation, improvement of chemical conditions to make them suitable for plants by using fertilizers and chemical ameliorators and biological activation by introducing humus and soil bacteria, mulching by organic and non-organic materials.

Conclusions

The presented material enables the following conclusions:

1. The regional degradation of lithosphere during the 140-year

operation of Kryvyi Rih iron ore basin resulted from application of frontal economy principles has long reached **the point of no return**, this process being escalated.

2. Restoration of disturbed lands and landscape structures of Kryvyi Rih region is one of the most urgent problems of creating a healthier environment.

3. Neglected issues of reclamation of technogenic disturbed lands of dead and operating iron ore mines and objects of mining and concentrating combines require huge investments which are not currently available.

4. Urgent implementation of Regulations on obligatory accumulation of special funds (payments included into mineral mining costs) intended for reclamation of disturbed lands and landscape structures by all mining enterprises exploiting mineral deposits is required.

5. Costs necessary to form a reclamation fund should be determined as obligatory for all mining designs, this being reflected in regulatory design documents (DBN A.2.2-3:2014) and controlled by examining design plans and specifications.

6. Open pits, dumps and tailing ponds of mining and concentrating combines are the most urgent problem within the structure of technogenic disturbed lands and landscapes. Application of internal dumping can be considered as a promising method of reducing negative effects of mining on the earth's surface. The local hole-digging and advanced methods of activated plant expansion at dump slopes are the most cost-effective for greening external dumps and multi-level tailing ponds.

References

1. Zemelnyi kodeks Ukrainy [Land code of Ukraine]. (2001). As of October 25, 2001, N 2768-III (changed and supplemented in 2002-2018). Kyiv [in Ukrainian].

2. **Antonik, V.I., Petrukhin A.V., Antonik, I.P.** (2017). Vplyv vidvaliv ta khvostoshovyshch zbagachuvalnikh kombinativ Kryvorizhzhia na stan ekologii prylehlykh terytorii [Influence of dumps and tailing ponds of concentration plants of Kryvyi Rih region on the environment of adjacent areas]. Visnyk Kryvorizkoho natsionalnoho universytetu - Journal of Kryvyi Rih National University, 44, (pp. 161-166). Kryvyi Rih: Mineral [in Ukrainian].

3. **Masiuk, N.T.** (1974). Osobennosti formirovaniya estestvennyih i kulturnyih fitotsenozov na vskryishnyih gornyih porodah i mestah proizvodstvennoy dobyichi poleznyih iskopaemyih [Peculiarities of forming natural and cultural phytocenoses on stripping rocks and mining sites]. Rekultivatsiya zemel. Trudyi Dnepropetrovskogo DSHI. - Reclamation. Works of Dnipropetrovsk DSKhI, 21, (pp. 63-85) [in Russian].

4. **Zabaluyev, V.A.** (2010). Formirovanie agroekosistem rekultivirovannyih zemel v stepiUkrainyi: edaficheskoe obosnovanie [Formation of agricultural ecosystems of reclaimed lands in Ukrainian steppes: edaphic substantiation]. Kyiv [in Russian].

5. **Chibrik, T.S.** (2002). Osnovyi biologicheskoy rekultivatsii: Ucheb. posobie [Foundations of biological reclamation: Teaching guide]. Yekaterinburg: Ural [in Russian].

6. **Vremennyie rekomendatsii** po ozeleneniyu gornorudnyih otvalov Krivbassa (1977). [Temporary recommendations on greening ore mining dumps of Kryvyi Rih iron ore region]. Kryvyi Rih: B.i. [in Russian].

7. **Mazur, A.Yu., Smetana, N.G.** (1996). Struktura i rekultivatsiya landshaftov Krivorozhya [Structure and reclamation of landscapes of Kryvyi Rih region]. Biologicheskaya rekultivatsiya narushennyih zemel - Biological reclamation of disturbed lands. (pp. 91-92). Yekaterinburg [in Russian].

8. **Mazur, A.Yu.** (1997). Rost i razvitiye sosny kryimskoy i robinii lzheakatsii na zhelezorudnyih otvalah Krivorozhya [Growth and development of the Crimean pine and the locast at iron ore mining dumps of Kryvyi Rih region]. Biologicheskaya rekultivatsiya narushennyih zemel - Biological reclamation of disturbed lands. (pp. 159-169).Yekaterinburg [in Russian].

9. **Antonik V.I., Grishko V.N**. (2017). Proyekt rekultivatsii narushennyih zemel Shahtoupravleniya po podzemnoy dobyiche rudyi (na pravah Shakht) PAO AMKR, oboznachenie 2396 RPPZ. Razrabotan Krivorozhskim nauchno –issledovatelskim gornorudnyim institutom Krivorozhskogo natsionalnogo universiteta. Babets E.K. i dr. [Design of reclamation of disturbed lands of underground mining Administration of the PJSC AMKR, 2396 RPPZ. Developed by Kryvyi Rih Research Ore Mining Institute of Kryvyi Rih National University. Babets, Ye.K, et al]. Kryvyi Rih [in Russian].

10. **Antonik V.I., Antonik I.P., Grishko V.N**. (2018). Faktory, opredelyayuschie vybor vidov rasteniy dlya biologicheskoy rekultivatsii tehogenno – narushennyih zemel Krivbassa [Factors to determine plant species for biological reclamation of technogenic disturbed lands of Kryvyi Rih iron ore region]. Suchasni tehnolohii rozrobky rudnykh rodovyshch. Ekoloho-ekonomichni naslidky diialnosti pidpryiemstv GMK. Do 85-richchia zasnuvannia NDGRI: Zbirnik naukovikh prats za rezultatamy roboty V Mizhnarodnoi naukovo-praktichnoi konferentsii - Modern

mining technologies. Environmental and economic consequences of mining and concentration plants activity. 85-year anniversary of NDGRI: collection of research works within the fifth international scientific and practical conference. (pp. 152-155), Kryvyi Rih [in Russian].

11. **Korshikov, I.I, Krasnoshtan, O.V**. (2012). Zhiznesposobnost drevesnyih rasteniy na zhelezorudnyih otvalah Krivorozhya [Viability of trees at iron ore dumps of Kryvyi Rih iron ore basin]. Donetsk: B.i. [in Russian].

12. **Reshenie Dnepropetrovskoy oblastnoy rady** ot 21.04.2011 # 110-6/VI «Pro dolgosrochnuyu programmu po resheniyu ekologicheskih problem Krivbassa i uluchsheniyu sostoyaniya okruzhayuschey prirodnoy sredyi na 2011-2022" [Resolution of Dnipropetrovsk region council of 21.04.2011 # 110-6/VI "On the long-term programme of solving environmental problems of Kryvyi Rih iron ore basin and improving the environment for 2011-2022"]. Dnipro [in Russian].

13. **Peregudov, V.V., Gamalinskiy, I.A., Guk An.Yu., Guk Al.Yu.** (2017). Ekonomicheskie aspektyi rekultivatsii narushennyih zemel [Economic aspects of reclamation of disturbed lands]. Kryvyi Rih: GP GPI «Krivbassproekt» [in Russian].

14. **Kodeks Ukrainy «O nedrakh»** ot 27.07.1994 #132/94-VR [Code of Ukraine "On natural resources" of July 27, 1994 # 132/94-VR]. [in Russian].

15**. Sposib rekultivatsii vidvaliv skelnykh porid ta pristriy dlia yoho zdiisnennia** (Pat. 85669. Ukraina. MPK A01V79/00) [Method of reclamation of hard rock dumps and a device for its implementation (Patent 85669. Ukraine. MPK A01V79/00) [in Ukrainian].

16. **Hilchenko, N.V., Belik, A.I.** (1989). Otchet po NIR NDGRI «Issledovat i razrabotat effektivnuyu tehnologiyu rekultivatsii otkosov otvalov INGOKa» 2.1-8-0-7-68-R. Kn.1. (# gos. Registratsii 01880083802) [Report on researches of Kryvyi Rih Research Ore Mining Institute "Investigation and development of the efficient reclamation technology for InGOk dump slopes" 2.1-8-0-7-68-R. Kn.1. (# 01880083802)] Kryvyi Rih: NIGRI [in Russian].