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# New technology of reclamation of slopes of waste and excavated rocks of mines and quarries

V Antonik<sup>1</sup>, L Shtanko<sup>1</sup>, I Antonik<sup>2</sup> and V Ivachenko<sup>1</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, 54 Gagarin Ave., Kryvyi Rih, 50086, Ukraine

E-mail: [viantonik096@gmail.com](mailto:viantonik096@gmail.com), [shtanko.ludmila20@gmail.com](mailto:shtanko.ludmila20@gmail.com), [ira07108kr@gmail.com](mailto:ira07108kr@gmail.com), [ivash135@gmail.com](mailto:ivash135@gmail.com)

**Abstract.** The urgent environmental problem of industrial Kryvbas is the reduction of dust formation from wind erosion of bare surfaces, especially slopes, dumps of iron ore mines and quarries. The best way to reduce the dusting of dumps is to afforest their surface with trees and bushes, but naturally this process can take up to 15-20 years, and the well-known scientific developments to solve this problem are ineffective or too time-consuming. The objective of our work is to create the innovative technology for active stimulation of self-organized vegetation of hard-to-reach steep slopes of dumps. To implement the idea, it is proposed to use standard hydroseeders for a new purpose, in particular, HM-0-HARV Turbo Turf hydroseeder, which is able to create hydroflow at a distance of 30-50 m. The article describes in detail the essence of the developed technology, method of organizing and conducting hydraulic sowing from both the lower and upper edge of the dumps. It is recommended to include seeds of herbaceous grass and legumes, deciduous trees and shrubs, mineral fertilizers and nutrient substrate (sewage sludge) in the seeding hydraulic mixture. The proportion of seeds of various plant species, fertilizers and nutrient substrate in the hydraulic mixture for sowing on the slopes of Kryvyi Rih dumps, which have a neutral soil acidity and contain at least 3% of the fine fraction of rocks in the surface structure, is substantiated. According to the results of testing the proposed technology, it is concluded that applying a mixture of seeds of herbaceous plants, trees and shrubs in combination with mineral fertilizers and nutrient substrate to the surface of dump slopes by hydroflow accelerates their self-organized vegetation by about 3-4 times. It is shown that crop care measures in the first year of plant vegetation (periodic watering and, if necessary, fertilizing using hydroseeder) can save up to 60-75% of seedlings and help stabilize newly created biogeocenosis in subsequent years.

## 1. Introduction

The most difficult issue in the reclamation of mineral composition of iron gangue and overburden dumps of open pits of mining and processing plants (GOK) is to carry out biological reclamation of hard-to-reach slopes, which usually have a natural angle of slope of free-deposited loose rocks (30° or more). The surface of the slopes of newly formed dumps (up to 3-5 years old) is mostly covered with large pieces of rock, contains almost no humic substances, therefore both agrochemical and mechanical properties are not suitable as a substrate for plant habitat. Over the years, lump fractions of shale rocks of the surface layer of dumps gradually evaporate and as a result of oxidation and precipitation water action are crushed, crumble and then the slopes become more suitable for plant habitation, including spontaneous overgrowth from seeds of



shrubs, trees and herbaceous plants that accidentally brought by wind, birds or animals. It is known that self-overgrowth of technogenic-disturbed areas begins in the second or third year after the cessation of their formation in areas containing more than 3-6% of the fine fraction. At first, representatives of ruderal vegetation appear, and later the species composition gradually increases. Observations show that up to 35 plant species take part in early self-overgrowing processes on Kryvbas dumps, of which coenomorphs include 54%, steppe weed species to 12%, and meadow weeds up to 16% [1]. Subsequent stages of demutation gradually lead to the emergence of long-rhizome plants, including trees and shrubs. Under favorable conditions, the vegetation can cover up to 60 - 70% of the surface of waste dumps in 15-20 years by self-overgrowing, which some authors consider one of the cheapest and most reliable methods of biological reclamation of man-made landscape formations [2].

Since self-overgrowing in general is, a natural, and haphazard process, the quality of the natural landscaping of the surfaces of the dumps looks quite diverse and, especially on the slopes, often there are significant bare areas that become sources of air pollution and require mandatory measures for dust suppression, including through artificial planting.

In the practice of purposeful work on biological reclamation of slight ( angle up to  $18^\circ$  ) slopes of man-made objects of mining enterprises, there is a positive experience of applying conditionally fertile soils (low-fertile chernozem, loam) layer of 40-50 cm followed by planting trees and shrubs. But if the angle of the slopes exceeds  $18^\circ$ , then grounding the surface of the slopes with soft rocks becomes ineffective. This is because the fertile substrate is almost not kept on steep slopes, subsequently subject to significant water erosion during precipitation and slides down. Attempts to preliminarily prepare the slopes for the application of a layer of soft soil by cutting the cross terraces with an excavator - dragline every 10 – 11 m of the slope height, also failed in practice due to significant technical complexity and cost of implementation. The same disadvantage has a patented method of forming waste heaps with slopes up to  $30^\circ$ , followed by biological reclamation, in which waste masses are placed in the heap by layer-by-layer dumping with simultaneous compaction and earthing of the surface and creating a vegetative cover. At the same time, horizontal enclosed terraces are formed in the slopes with a 30 m interval [3].

Various methods of direct planting on the slopes of a heap by making holes 10-20 cm deep for planting directly in rocky soil, followed by the introduction of a nutrient substrate, fertilizers, and water into such holes were also studied. It is proposed to protect such pits from backfilling and erosion from the side of the slope with special racks [4]. However, the process of creating holes in the rock substrate on the slopes by humans is a dangerous and time-consuming process that requires work using special protective cables, which is extremely unprofitable and unreasonably expensive.

Noteworthy is the method of hydro washing of plant seeds with a soil mixture on the slopes of dumps with an angle of  $35-40^\circ$ . However, this method has not been implemented in the absence of the equipment proposed by the authors for the implementation of such a hydro washing system [5].

At present, the technology of hydroseeding of perennial herbaceous plants is widely used in international practice in the reclamation of disturbed lands, including backfilled slopes. Unlike conventional sowing, hydroseeding is carried out by a water flow, to which, together with grass seeds, a nutritious substrate (mulch) and various fixing emulsions can be added [6]. Straw, hay, chopped tree leaves, pine needles, soybean stalks, etc. can be used as mulch. Fertilizers and bacterial preparations that promote the accumulation of organic matter can also be added to the composition of the hydro mixture. In world practice, for example, the drug Biobert, developed in France based on peat and Agrobiol, developed in Germany and widely used in Austria and Spain [7].

The use of reclamation technologies with the application of various ameliorants, which promote the accelerated formation of a nutrient substrate, in particular on the surface of rocks,

is promising. In Poland, for example, in the reclamation of man-made disturbed lands of mines, components of sewage sludge are successfully used as ameliorants [8].

Thus, despite the availability of some scientific and practical experience in the biological reclamation of mining wastes and enrichment of iron ore, the search for modern technologies for landscaping hard-to-reach slopes of gangue and overburden rocks of mines and quarries remains an urgent issue of landscape ecology in regions with the developed mining industry.

The work aims to develop and test the method and technology of active stimulation of self-organized vegetation of hard-to-reach slopes of dumps of gangue and overburdened rocks of iron ore mines and quarries.

## 2. Methods

The developed technology is proposed for use in solving problems of biological reclamation (landscaping) of hard-to-reach slopes of gangue of iron ore mines and overburden of quarries of mining and processing plants, regardless of the age of dumps, degree of stability of incline layer, and mineralogical and fractional composition of the surface layer. The task is accomplished by seeding the slopes of the heaps by watering a mixture of seeds of perennial grasses, trees, and shrubs using a typical hydroseeder.

In the developed technology of hydroseeding, it is offered to use the HM-0-HARV Turbo Turf hydroseeder as the most productive and acceptable for simultaneous drawing on a surface of slopes which do not have vegetative soil, not only seeds of plants but also water mix of nutrients that will promote initial enrichment of the substrate in the locations of plant seeds. The HM-0-HARV Turbo Turf hydroseeder is freely available on the market of the corresponding goods and, according to the instruction, is characterized by the following main technical parameters: l / minute, the range of spraying the hydraulic mixture using a stationary ejector up to 35 m, and using a nipper hose - up to 60 m. In practice, any other similar water seeding technique can be used.

The main stage of work on biological reclamation of slopes of heaps by hydroseeding is the preparation of the mixture. According to the developed technology, the mixture includes water, seeds of perennial grasses, trees and shrubs, and mineral fertilizers. As mulch and primary nutrient substrate, it is recommended to add sewage sludge to the mixture, which is an organo-mineral mixture produced from municipal sewage and its agrochemical parameters meet the requirements of the state standard of Ukraine [9]. According to the Ministry of Agrarian Policy and Food of Ukraine, the sludge is a high-quality concentrate of humic substances with elements of antioxidant plant protection system (tripeptides), has sorption properties, and contains several microorganisms capable of decomposing soil toxins. The use of the mixture optimizes the structural condition of soils, increases the content of available plant nutrients. The sludge contains significant concentrations of phosphorus, nitrogen, and potassium, that's why this mixture can act as a mineral fertilizer, the estimated application rate of which is 20 - 35 t/ha, depending on the derived state of agrochemical parameters of specific soils. At present, the sludge of treatment plants has passed a toxicological, radiological, and microbiological examination and received a positive assessment for all parameters [9].

The process of hydroseeding consists in the fact that the mixture with all additives hydroflow, created by the equipment of the seed drill, is applied in a certain layer on the slopes of the dumps within a radius of 30-50 m from the location of the seed drill. After applying the mixture on the slope surface, the sludge solution of sewage treatment plants and mineral fertilizers create a favorable temperature and temperature regime for germination and plant development in the places of the runoff between lumps of rocks.

The composition of the mixture is recommended to include seeds of perennial cereals - legumes, which should be sown in spring and early summer. The addition of tree and shrub seeds into the mixture creates a real probability that under the cover of grassy vegetation these

seeds will eventually germinate and give a stable growth that will not require additional care.

It is known that the waste rock dumps are chemically characterized by the presence of a significant amount of silica, soluble iron, metal oxides, and low sodium content. The reaction of aqueous extraction of waste rocks and quarry rocks is close to neutral. Rocks have medium and high absorption capacity, contain potassium and phosphorus therefore these rocks are considered potentially favorable places for plant growth. In order to ensure the highest probability of formation of a stable biocenosis, it is recommended to use plant seeds of three biological groups on the slopes of mining dumps:

- cereal with a loose bush and rhizome cereals, which quickly create a good turf and give it greater tensile strength in the horizontal direction (for example, red fire, annual ryegrass, stokolos, etc.;
- legumes (taproot), which form long roots, securely fasten turf with the soil of the slope, and subsequently contribute to the enrichment of the substrate with nitrogen (eg, sainfoin, clover, alfalfa, and other species);
- seeds of deciduous trees and shrubs (it is recommended, first of all, to use certified seeds of white acacia, elm, and amorphous shrubs).

In addition to seeds, mineral fertilizers and sewage sludge should be added to the mixture for hydroseeding, the amount of which is determined by table 1:

**Table 1.** The recommended proportion of fertilizers and sewage sludge per 1000 liters of water.

Nº	Name of components	Unit	Quantity per 1000 liters of water
1	Nitroammophos (nitrogen-phosphorus )	kg	90
2	Potassium (potassium salts)	kg	15
3	Treatment plant sludge	kg	250

As part of the mixture, sludge from sewage treatment plants is used as a starting soil, enriched with the necessary minerals, which also serves as mulch. The recommended proportion of sewage sludge to water is 250 kg/1000 l.

The proposed HM-0-HARV Turbo Turf hydroseeder has a 2.8 m<sup>3</sup> tank, is equipped with an independent 27 hp petrol engine, a hydraulic pump, and a mechanical (paddle) hydro mixture mixer.

It is recommended to move the hydroseeder to the reclamation area with the help of a tanker trailer device, which will also provide a water supply for the preparation of the mixture. After delivery of the hydroseeder to the site, the tank capacity is loaded with water to a volume of approximately 1 m<sup>3</sup> (1000 l), then the sludge of treatment plants, fertilizers, and seeds are loaded, and, finally, the tank is filled with water to full capacity. After tightly closing the hatch of the tank, turn on the engine to thoroughly mix the loaded mixture for 10 - 15 minutes. The approximate composition of the seeding mixture for one filling of the tank of hydroseeder is given in table 2. According to the results of testing, such composition of the hydraulic mixture is recommended for landscaping the dump slopes, which have near-neutral pH of rocks and contain at least 3% of the fine fraction ( $\leq 1$  mm) in the structure of slope surface.

During the operation of the hydroseeder, the hydraulic mixture is constantly maintained in the state of suspension by constant mechanical stirring by the blade mechanism of the tank. The resulting mixture is pumped under pressure into the spray and then sent by the operator to the treated area.

**Table 2.** Composition of components for preparation of disposable mixture.

Name of components	Unit	The required quantity of components
Water	L	up to 2090
Sewage sludge (DSTU 7369: 2013 [9])	kg	500
Mineral fertilizers including:	kg	210
nitroamophos	kg	180
potassium	kg	30
Seeds of grasses, trees and shrubs including	kg	39
-meadow fescue ( <i>Lolium pratense</i> )	kg	4
-Italian ryegrass ( <i>Lolium multiflorum</i> )	kg	3
-leyss ( <i>Bromus arvensis</i> L.)	kg	4
-yellow melilot ( <i>Melilotus officinalis</i> )	kg	15
-sainfoins ( <i>Onobrichis sativa</i> lam)	kg	3
-alfalfa ( <i>Medicágo satíva</i> )	kg	3
-black locust ( <i>Robínia pseudoacácia</i> )	kg	3
-lacebark elm ( <i>Úlmus Ulmaceae</i> )	kg	2
-bastard indigobush ( <i>Amorpha fruticosa</i> )	kg	2

The HM-0-HARV Turbo Turf hydroseeder according to the technical possibilities allows to carry out seeding in two ways:

- directly from the work site above the tank of the hydroseeder using a special stationary ejector, attached to the body of the hydroseeder and connected to the pressure pump by a short hose. This option is convenient and safe for the operator, but can be used only in conditions of close access to the sowing area, for example, to the bottom edge of the slope, and allows to sow from one point only a sector with a radius of 30 m;
- sowing with the use of a pressure hose up to 30 m long with a manual ejector. This method allows the operator to move more freely within the operating point and get as close as possible to the sowing area, even in the presence of certain landscape obstacles.

The working point for placing the hydroseeder can be both at the bottom of the slope (hydroseeding is carried out along the slope from bottom to top, by direct flow) and at the level of the upper edge of the slope (hydroseeding is carried out from top to bottom, by spraying).

When carrying out hydroseeding from the lower point of the slope, the operator, standing on the upper working platform of the hydroseeder, can rotate the stationary ejector in the horizontal plane by 80 - 100°, and in the vertical plane - can tilt it up or down within 40° from the horizontal, providing thus the output of hydroflow and hydroseeding direct current over the entire plane of the slope in a radius of 30-35m. The task of the operator is not only to move the ejector nozzle but also to control the jet velocity by adjusting the revs of the pump, the need for which arises, for example, when changing the distance from the hydroseeder to the seed surface. It is important to constantly ensure the formation of a hydroflow of such intensity that the mixture is evenly laid on the surface, there are no unsown gaps, and that the mixture does not flow in significant flows from the slope. The approximate rate of consumption of the hydro mixture is 1-0.9 l/m<sup>2</sup>. For visual determination of the treated area by the operator, a dye (green, blue, etc.) can be added to the mixture.

When carrying out top-down water seeding works, the hydroseeder should be installed as close as possible to the border of the upper slope edge or the inner edge of the embankment

slope, and hydroseeding should be carried out not by direct flow, but by mounted spraying with the ejector position from horizontal to the lowest possible position. The distance of the sowing zone and the uniformity of hydroseeding in this case is regulated by the current force of the hydro mixture.

In areas where there are complications with hydroseeding with a stationary ejector (for example, due to the impossibility of installing a hydroseeder at the required point, with an insufficient range of the seeding mixture flow, and so on, it is necessary to use a pressure hose up to 30 m with a manual ejector. In this case, an operator, holding an ejector sprayer, can sow along the entire length of the slope to a width of 50-60 m. It is important to note that sowing with a hose requires at least two workers: the first one (the operator) controls the ejector and directly conducts hydroseeding and the second worker supports the hose at a distance of 4-5 m from the operator and helps to carry the hose when the operator moves along the slope.

To reduce the risk of runoff of the seeding hydro mixture on the sloping surface in both types of its application, it is recommended to sow in two phases. During the first phase, approximately half of the planned volume of the mixture is distributed over the sowing area, and the rest is distributed during the second phase. At the same time, cover the missed places with a mix and achieve a more uniform distribution of the mixture over the entire sowing area.

Care of hydroseeding should consist of the following:

- in case of prolonged dry weather during June-September in the first year after hydroseeding it is recommended to carry out watering of plantings (not less than 1-2 times a month, up to 4-6 times a season, including using a hydroseeder). The best time for watering is in the evening, after 7 pm;
- if there are signs of deviations in the development of grass cover (plants during the growing season become pale green or yellow), then it is recommended to use a hydroseeder to fertilize plants (up to 50% of the area) in June - July with a solution of mineral fertilizers water. The recommended working mix should include (per filling hydroseeder): nitro amorphous (nitrogen-phosphorus) fertilizers - 110-120 kg, potassium fertilizers - 30 kg, water - 2500 l;
- under the optimal conditions, the plants after germination should be evenly distributed on the sloping surface, without gaps and clusters at the bottom. If these conditions are not met or mechanical damage (erosion) of slopes has occurred, it is recommended to reseed poorly landscaped areas (up to 30% of the area) in autumn or spring of the next year.

### 3. Results and discussion

It is known that the level of the air pollution with dust in Kryvyi Rih is at least 2 times higher than sanitary standards. Dozens of bare dumps of mines and quarries located within the city play a significant role in creating this environmental problem. Therefore, the innovative technology of biological reclamation of the dumps of mines and quarries developed and described above is extremely important and relevant for industrial Kryvbas. The article proposes an innovative way to stimulate and accelerate 3-4 times the self-organized vegetation of the most complex parts of dumps – their steep slopes – by hydroseeding with a mixture of grass seeds, trees and shrubs in combination with mineral fertilizers and nutrient substrate. The tests have shown that the proposed hydroseeding technology can also be successfully used for rapid (in 3-5 years) landscaping the landforms of any man-made nature, including horizontal sections, slopes of multi-layer tailings dumps, slopes of craters in places of geotectonic shift and pits in areas of completed underground works, etc.

The advantage of the proposed technology is that, unlike traditional methods of landscaping the man-made areas, the use of hydroseeding technology completely eliminates the need for expensive and dangerous work on preliminary technical preparation of surfaces, including the slopes of dumps of any steepness and age, before conducting biological reclamation.

The recommendations described in the article regarding the composition of the seeding hydraulic mixture (see Table 2) are adapted for use in landscaping the slopes of gangue dumps of mines, which have near-neutral pH of soil and contain at least 3-5% of the fine fraction with a diameter not exceeding 1 mm in the rocks of slope surface. At the same time, the simple technology of preparing a mixture from various components using modern hydroseeders, in particular HM-0-HARV Turbo Turf hydroseeder, allows easy combining various types of seeds of herbaceous and woody plants and related components in the hydraulic mixture depending on the agrotechnical condition or hydraulic regime of the territory or on the agrochemical composition of the derived substrate of the surface of reclamation objects.

Special attention should be paid to the possibility of using the developed method of hydroseeding for temporary landscaping and removing the dust from the surface of warehouses of substandard fractions of ore materials in iron ore mines and dumps of oxidized ores in quarries. Since these man-made objects are actually warehouses of potentially useful iron ore raw materials that can gradually be selected for further concentration, the biological reclamation of their surface by afforestation becomes impractical, but landscaping by hydroseeding their surface with a layer of herbaceous plants is an extremely rational measure from ecological and economic point of view.

The death of plants due to drought is always the main cause of failures while attempting to biologically reclaim the slopes of dumps in many known ways. The experience shows that the developed technology of using hydroseeder allows caring for plantings and crops on steep slopes and in other difficult landscape conditions, for example, watering and fertilizing plants in the hot summer months, especially in the first years of vegetation. This significantly increases the efficiency of work on landscaping the slopes and with correct application of the crop care regime recommended in the article, it is possible to maintain up to 60-75% of seedlings in the most critical first year of vegetation. In the next 2-3 years, as usual, the mechanism of self-renewal of perennials with gradual stabilization of the newly created biogeocenosis is launched, and then the need for care disappears.

#### 4. Conclusions

Based on the materials of the article, the following conclusions can be made:

- (i) Control of dust formation from wind erosion of bare surfaces of gangue dumps and substandard ores in mines and quarries of mining enterprises is an important and urgent environmental task of industrial Kryvbas.
- (ii) The greatest difficulty in reducing the dusting of dumps is their slopes with an angle of inclination of 30 degrees or more, and the most reliable solution to this problem is self-organized vegetation of their surface by trees and shrubs, which can naturally take 15-20 years or more.
- (iii) The latest technology of stimulating and accelerating the self-organized vegetation of dump slopes by 3-4 times by applying a mixture of seeds of herbaceous plants, trees and shrubs in combination with mineral fertilizers and nutrient substrate to their surface by hydroflow has been developed and tested.
- (iv) As equipment for remote sowing of dump slopes, it is recommended to use standard hydroseeders for a new purpose, in particular, HM-0-HARV Turbo Turf hydroseeder, which is able to create hydroflow at a distance of 30-50 m.
- (v) It is recommended to include seeds of four groups of plants in the composition of the hydraulic mixture for landscaping the slopes of dumps: herbaceous grasses, herbaceous legumes, deciduous trees and shrubs, which will quickly create a green "cover" of grass and humus, and in 2-3 years ensures the development of three layers of landscaping.



- (vi) Inclusion of a reasonable amount of components of mineral fertilizers and sewage sludge to the composition of the hydraulic mixture is intended to create a primary nutrient substrate for germination of seeds applied to the slope surface.
- (vii) The mixture and proportion of seeds together with other components, which are substantiated in the article, are recommended for sowing on the slopes of most gangue dumps of mines and quarries in Kryvyi Rih, which have near-neutral pH of soil and contain at least 3% of the fine fraction ( $\leq 1$  mm) of rocks in the surface structure. Under other agrotechnical conditions, the composition of the hydraulic mixture can change arbitrarily.
- (viii) In the hot months (June-September) of the first year after sowing the slopes, it is recommended to water them, and, if necessary, nourish the soil with solution of mineral fertilizers or sewage sludge using hydroseeder. Care measures allow saving up to 60-75% of seedlings in the most critical first year of vegetation.

### ORCID iDs

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

L A Shtanko <https://orcid.org/0000-0002-3818-6424>

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

V A Ivachenko <https://orcid.org/0000-000287769968>

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