JUSTIFICATION OF PHYTOREMEDIATION TECHNOLOGY OF DEGRADED LANDSCAPES ON THE BASIS OF ECOSYSTEM APPROACH

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1. Introduction

The final stage of the development of minerals in the mining regions is the initial stage of the process of mining and restoration of disturbed lands, in particular waste dumps. Usually, external overburden dumps are subject to phytoremediation with full restoration to the state of the primary ecosystem. Forestry reclamation in mountainous regions includes a set of agrotechnical and phytomeliorative measures aimed at creating sustainable vegetation cover on the surface of technogenic rock masses.

World experience in the field of phytoremediation of industrial lands shows that there are problems associated with the creation of sustainable plant communities. As well as the selection of the assortment of woody and shrubby vegetation, the availability of elements of the mineral nutrition of plants and the long-term exposure of the toxic substances of the massifs to the flora and fauna. Therefore, identifying priority environmental factors for the restoration of disturbed mining landscapes and determining effective measures for directed phytoremediation is an urgent problem.

2. The object of research and its technological audit

The object of research is the development of natural and survival of artificial plant communities on the surface of the waste dump of the liquidated «Selydivska» coal mine of the State Enterprise «Selydivvugillya» (SE «Selydivvugillya», Selydove, Ukraine).

The «Selydivska» coal mine of the «Selydivvugillya» State Enterprise has been in operation since 1963 and was liquidated in 1996. On the territory of the mine there is a waste dump of 18 hectares. The volume of stockpiled rocks is 5.4 million m³. The rock heap is flat, without chopped terraces. A road is laid from the mine’s industrial site for transporting rock mass. Two sites for storage and rock planning is preserved on the dump.

For the study of plant diversity, sections of the dump, differing in the exposure of the slope and the vertical arrangement, are selected:
- foot of the dumps (including drainage ditches around the perimeter of the lower dumps base);
practice of general restoration of degraded landscapes [1].

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...are an effective tool to reduce the content of Zn, Cd, Mn, Pb and Cu metals on mining lands in the UK. It is found that fourteen years after the first tree planting, the metal concentration in the soils decreased: Cd – by 52 %, Cu – by 48 %, Zn – by 47 %, Pb – by 44 %, Mn – by 35 %. Nevertheless, it is unclear which particular tree species have hyperaccumulative properties that produce the greatest increase in biomass.

One of the promising areas is the cultivation of energy crops, in particular, the species Miscanthus, Ricinus, Jat- ropha, Populus [3]. But despite the informativeness and comprehensiveness of the presented concept of phytoremediation, the effectiveness of the predicted results is called into question.

At the Gumuskoi silver mining plants in Turkey [4], the effects of the accumulation of As, Ag, and Pb from the soil by tree-shrub plants were studied, which makes it possible to use them as bioaccumulators and phytoremediation. But the given concentrations of heavy metals in the roots and leaves of plants do not allow to say with certainty about the effectiveness of the bio-mowing process in time.

The technical and biological reclamation of degraded lands in the coal region of Ostrava-Karvina in the Czech Republic, where approximately 281 landfills and waste dumps are located, can be quite large-scale [5]. However, the options and the most appropriate land restoration tech-

3. The aim and objectives of research

The aim of research is determination of the dominant types of vegetation on the surface of the rock dump of a coal mine to justify the target phytoremediation of mining territories. To achieve the aim, the following scientific ob-

1. To investigate the plant diversity of the rock dumps and identify the dominant species for potential phytoremediation of mining landscapes.

2. To justify the appropriateness of applying the phytoremediation methodology of technogenic slopes of waste dumps with sod mats.

4. Research of existing solutions of the problem

Integrated technical and biological reclamation is the main area of optimization of mining territories. The land restoration technologies existing today do not sufficiently take into account the environmental component in the practice of general restoration of degraded landscapes [1].

So, in [2] it is shown that forestry phytoremediation can be an effective tool to reduce the content of Zn, Cd,
In this context, a set of measures for phytoremediation and phytomelioration of degraded lands is crucial for the sustainable functioning of the landscape and restoration of biodiversity [11].

5. Methods of research

The following methods are used to complete the research objectives:

1. The method of full-scale study of the plant variety of the waste dump to identify dominant species and their use in the phytoremediation technology of degraded mining landscapes.

2. Methods of phytoremediation and stabilization of technogenic slopes of waste dumps with sod mats. The method consists in applying plant communities selected from a ravine-girder network of the selected area, with a sod of 40×10 cm in size to the surface areas of the dump with different exposures.

6. Research results

6.1. Research of plant diversity of the waste dump. Stable zonal vegetation is formed on the dump, especially at the top of the dump, characteristic of the steppe zone (Fig 1).

The development of such a biogeocenosis is associated with the activity of the wind. The dump is located on a plain and surrounded by farmland. The average wind speed is 3–6 m/s. East winds prevail. Wind erosion is a determining factor in the application of black soil particles to the surface of the dump from adjacent farmland. The accumulation of chernozem is also promoted by primary vegetation, with the help of which particles of fertile soil are retained.

The natural vegetation cover of this steppe zone is formed mainly by perennial grasses well adapted to a dry climate. The phytocenosis of the waste dump is heterogeneous both in appearance and in the composition of plants. The basis of the vegetation cover is made up of representatives of the family Cereals, Legumes, Compositae, and Cruciferous (Table 1).

At the foot of the dump there is a rather high indicator of species saturation (the number of plant species per unit area), 5...11 species per 1 m². The dominant species is perennial grasses of the family of Cereals and Legumes (creeping wheatgrass, shoreweed saline, ordinary reed, sickle alfalfa, mouse nut, white acacia). Rhizome wild cereals are unpretentious plants, have a powerful root system and are able to grow rapidly in all directions, capturing new territory. An important role is also played by sodgrains, which form dense sods that contain dead remains of old stems and tend to vigorously absorb atmospheric moisture and hold it for a long time. Soddy cereals are able to keep the rock mass on the slopes of the dump, strengthening them and thereby prevent the slope from slipping, erosion processes, and also contributes to the rooting of tree-shrub species. Around the perimeter of the lower base of the dump, especially along the drainage ditches, there are a large number of species from the family Asteraceae. Many of them are medicinal plants (common wormwood, common chicory, common yarrow, common dandelion, curly thistle, prickly thistle, common tansy).

Along the technological road to the dump, there are mainly garbage plant species (ragweed, creeping wheatgrass, white gauze, field sow thistle, bitter wormwood, common wormwood, herbal wormwood, medicinal dandelion, bird highlander, field sow thistle, common colza, etc.). The species saturation here is 1–5 species per 1 m².

The slopes of the dump, having a slope of 40–60°, are weakly sod. The richest diversity of vegetation is observed on lower, more humid slopes, where the floristic composition is similar to that at the foot of the dump. In addition to cereals and weeds, such herb species are often found, such as common tar, Descurainia Sophia, field bindweed, Tatar lettuce, odorless chamomile, Field yarut, ordinary colza, etc. On the upper slopes of the dump, growth conditions are more complicated due to a decrease in the amount of moisture and wind activity. If on the lower slopes the species richness reaches 9 species per 1 m², then on the upper slopes

| Family                  | Plant species                                                                 |
|-------------------------|-------------------------------------------------------------------------------|
| Asteraceae (Compositae) | Ambrosia artemisiifolia, Cirsium arvense, Tragopogon dubius, Lactuca tatarica, Taraxacum officinale, Sonchus arvensis, Tanacetum vulgare, Artemisia absinthium, Artemisia vulgaris, Matricaria inodora, Crepis paludosa, Onopordum acanthium, Achilles millefolium, Cichorium intybus, Carduus crispus |
| Poaceae (Gramineae)     | Calamagrostis epigeios, Calamagrostis arundinacea, Bromus inermis, Poa pratensis, Avena fatua, Festuca vulgata, Festuca pratensis, Asperuloites litoralis, Agropyron repens, Phragmites communis |
| Fabaceae (Leguminosae)  | Robinia pseudoacacia, Vicia crassa, Melilotus officinalis, Medicago falcata, Lotus corniculatus, Ornithopus perpusillus, Lathyrus pratensis |
| Brassicaceae ( Cruciferae) | Descurainia sophia, Erysimum cheiranthoides, Capsella bursa-pastoris, Thlaspi arvense |

Table 1

Species vegetation diversity in the waste dump of the liquidated «Selydivska» coal mine

Fig. 1. Plant groups on the surface of the waste dump: a – foot of the dump, b – the second tier of the dump, c – the top of the dump
This indicator is 0–3 species per 1 m². The most adapted and very unpretentious species settled here, for example, common bruise, bird highlander, medicinal sweet clover, yellow reseda, field bindweed.

On the dump there are 2 sites for storing the rock with absolute elevations of +28 m (lower platform) and 40 m (top of the dump). On the lower site after the liquidation of the mine, unplanned rock heaps remained, as well as piles of construction waste, and caused the development of specific vegetation. The dominant species on unplanned rock piles is empty oats (wild oats), which grows in symbiosis with flax moss. In the lowlands and ravines between the hills of the rock, the same plants are found on the lower platform as on the lower slopes of the dump. Species saturation in the unplanned hills reaches 0–4 species per 1 m², in lowlands and depressions – 2–6 species per 1 m².

During the study period, a thick grass cover was formed on the top of the dump for the vegetation typical of floodplain meadows, which in itself is an interesting fact, considering that the dump height is 40 m. The main species are dominant: common chicory, cypress spurge, common sap, creeping wheatgrass, yellowness left-handed, small serebella, common tansy, wormwood, common wormwood, medicinal dandelion, yarrow, shepherd’s bag, odorless chamomile, horse sorrel. It should be noted that meadow vegetation has certain requirements for soil moisture. These plants are mainly mesophytes, that is, they do not tolerate both strong drying of the soil and prolonged waterlogging. They are also very demanding on soil nutrition and usually prefer soil rich in nutrients. At this facility, a large amount of nutrients is provided by the accumulation on the surface of particles of fertile soil from adjacent farmland as a result of aeolian activity.

Along with steppe grasses on the upper plateau there are many common meadow grasses characteristic of the forest-steppe zone, meadow steppes subzone. Here a type of vegetation is formed, characteristic of flood meadows with moderately moist fertile soils. One of the dominant species is common reed, which forms dense thickets.

The study of the previous stage shows that the development of sustainable phytocenosis on the surface of waste dumps is a long-term process. Even at the stages of their operation, pioneer plant species are formed on their surface, the role of which is the primary accumulation of organic matter and the creation of prerequisites for the development of phytocenosis [13]. Therefore, the use of plant species typical of the territory of mining landscapes and resistant to pollution is a promising area of phytoremediation.

On the slopes of the waste dump of the liquidated «Selydivska» coal mine of the Selydiv coal state enterprise, the technique of phytoremediation of the slopes of sod mats with vegetation typical of the area is applied.

The objective of the research is assessing the survival rate of plant communities in the form of sod mats on the surface of the slopes of waste dumps and the feasibility of using this method as a phytoremediation measure. Covering disturbed areas with a layer of sod plants, represented mainly by wild cereals with powerful root systems, allows the development of artificial phytocenosis in areas lacking vegetation. Sod cover promotes loosening of soil and drainage, it is important to eliminate sloping water erosion.

The methodology for the introduction of sod mats consists in applying rectangular pieces of sod with natural vegetation selected on a ravine-girdler network 40×40×10 cm in size to the slopes of the waste dump. Sod planting on a selected site of the slope surface is performed with excavation of the rock under the size of the sod mat to the depth of immersion about 10–12 cm to prevent unwanted slipping of samples on the slope surface. After placing specimens with herbaceous vegetation, they are irrigated with water to increase contact with the rock substrate.

The slope surface of the dump is conventionally divided into 8 sections in accordance with the sides of the horizon (Fig. 2). In each of the sections along the slope, 3 points are selected located at the level of the upper and lower bases, and the midline of the dump. Thus, on 24 selected sites, sod deposits with grassy vegetation are applied, which are selected from the slopes of nearby ravines and arroyos. 4 samples of sod mats are applied to each plot.

6.2. Substantiation of the phytoremediation technique for technogenic slopes of waste dumps with sod mats.

One of the most difficult tasks of phytoremediation of waste dumps is the greening of their surface. The greatest problem is represented by slopes, on the surface of which processes of surface erosion, filtering of combustion products or leaching of heavy metals from the rock and the like.

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leaching of acid and salt components present in the rock is intensively taking place. The presence of these chemical components is the main limiting factor limiting the survival and growth of plants. Subsequently, the concentration of aggressive substances decreases as a result of leaching and water erosion, and the rock mass becomes a potentially suitable medium for vegetation. Surviving plants need to be subject to water erosion, and the rock mass becomes a potentially suitable medium for settlement and the growth of various forms of vegetation. 5 years have passed since the end of the dumping of the rock mass and a significant part of the toxic salts was washed out of the surface layer of the rock on the dump slopes. The average pH of the extract of the rock substrate at various points of the dump varies in the range of 5.0–6.2, which generally corresponds to the acidity level of potentially fertile soils.

As a result of a survey of the dump slopes, it turned out that on the upper and lower tiers the vegetation growth conditions are most favorable, as evidenced by survival at 53 % and 34 %, respectively (Table 3). On the middle tiers, the plants take root weakly. For the southern slopes, the most satisfactory values of survival, the plants take root weakly. For the southern slopes, the most satisfactory values of survival of plant communities are noted.

### Table 3

| Slope exposure | Number of sod mats, units |
|---------------|--------------------------|
|               | Low tier | Middle tier | Upper tier |
| N             | 4*/1**   | 4/0        | 4/0        |
| NE            | 4/0      | 4/0        | 4/1        |
| E             | 4/0      | 4/0        | 4/0        |
| SE            | 4/1      | 4/1        | 4/2        |
| S             | 4/4      | 4/2        | 4/3        |
| SW            | 4/4      | 4/1        | 4/2        |
| W             | 4/4      | 4/1        | 4/2        |
| SW            | 4/5      | 4/0        | 4/1        |
| Total         | 32/17    | 32/5       | 32/11      |

Note: */** — the number of planted/grafted samples; N — north; NE — northeast; E — east; SE — southeast; S — south; SW — southwest; W — west; NW — northwest

The upper tier of vegetation runs along the contour of the upper base of the dump, at the top of which a phytocenosis has formed that is characteristic of bog and meadow ecosystems. The thickness of the fertile layer at the apex varies between 8–12 cm. The survival rate of vegetation in the upper tier is lower than in the lower tier due to the insufficient moisture content in the rock substrate, but significantly higher than in the middle tier. This is due to the presence of a self-regulating, stable functioning ecosystem with a high species richness of flora and fauna at the top of the dump; it has a positive effect on the good survival rate of plant communities.

### 7. SWOT analysis of research results

**Strengths.** The method described above and tested in practice for phytoremediation of slopes of waste dumps with sod mats with vegetation typical of the selected area...
is a promising area for phytoremediation of mining lands. The application of this technique will accelerate the process of natural restoration of the natural and technogenic landscape and minimize the emission of dust particles from the surface of waste dumps.

Weaknesses. The disadvantage of using the method of introducing sod mats is that when applied to the substrate, the sod ones are first insufficiently closely connected with the lower rocky substrate, which can lead to their slipping from the slopes of the dump and rupture. Another disadvantage is the need to apply a significant amount of sod coating to the surface of the dumps, which creates an additional problem in the search and removal of plant materials from natural phytoceneses.

Opportunities. Covering the damaged areas with a layer of sod plants, represented mainly by wild cereals with powerful root systems, allows to quickly establish an artificial phytocenosis in areas lacking vegetation.

Threats. The method may be generally unsuitable for use in conditions of excessive content of toxic compounds or heavy metals in the rock mass, extreme pH values (5.5 ≤ pH ≥ 8.5), insufficient or excessive wetting of the rock substrate, and the like.

8. Conclusions

1. The plant diversity of the waste dump of the liquidated «Selydivska» coal mine of the state enterprise «Selydivugillya» is investigated and dominant species are identified to justify the target phytoremediation of mining territories. It is established that due to wind erosion, chernozem fractions are applied to the surface of the dump from adjacent farmland, which contributed to the development of primary vegetation. The species diversity of the vegetation is made up of the species of the family Cereals, Legumes, Asteraceae, and Cruciferous. Plant diversity varies from 0–3 species per 1 m² (slopes) to 7–12 species per 1 m² (top of the dump).

2. The feasibility of applying the method of phytoremediation of technogenic slopes of waste dumps with sod mats as an alternative environmental technology to restore the mining landscape to its natural state is substantiated. It is found that on the upper and lower tiers of the dump surface, the survival rate of sod samples is 53 % and 34 %, respectively.

Acknowledgement

The authors express gratitude to DAAD (Deutscher Akademischer Austauschdienst, German Academic Exchange Service) for opportunity to carry out presented above research in the framework of joint educational project «EcoMining: Development of Integrated PhD Program for Sustainable Mining & Environmental Activities» between Technical University «Bergakademie Freiberg» (Germany) and Dnipro University of Technology (Ukraine).

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