Methods to improve the waste rock dumping efficiency and reclamation under the north condition

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Abstract.
The mining industry adversely affects the environment. The ecosystems of the northern regions, where due to harsh climatic conditions, are particularly sensitive to this negative impact and have a low ability of local natural complexes to overgrowth. However, the current reality is that the principles of environmental protection are sacrificed to the stable economic development of the region. In such circumstances, the social responsibility of business and the promotion of rational subsoil use methods become a thing of great importance. In accordance with the Russian Federation legislation in the field of mineral resources use, the subsoil user undertakes, adjusted by the project of the mineral deposit development, to carry out the reclamation not only of the open pit itself, but also all other territories, disrupted as a result of the company's business. Open pit mining, in the main, is associated with the need to store a large volume of waste rocks in dumps. In modern open pits, more than a third of a land allotment is occupied by waste dumps, and the cost of their reclamation has a dominant influence on the budget of restoration work in general. This study is devoted to the peculiarities of waste dumps reclamation in the North, methods of its efficiency increasing and ways of rational dumps formation, taking into account the requirements of subsequent reclamation.

1. Introduction: regulatory and legislative framework for reclamation in Russia and social responsibility of business

Most of the legal instruments governing the reclamation requirements for land disturbed by open pit mining, in particular the waste rock dumps, were developed and adopted between the 1980s and 1990s. Consequently, these regulatory requirements have petered out and are no longer relevant. The design of open pits, waste dumps, stockpiles of pre-production mined ores and off-balance ores needs different strategies to be held, to harmonize mining methods with the legislation norms. One of the mining first necessities to be carried out is scientifically based reclamation standards for the territories of the North and the Arctic due to allocation of great number of mineral deposits on these territories and specific nature sensitivity for technogenic burden.

By Russian state standard (GOST) 17.5.1.01-83 "Nature Conservation. Land reclamation. Terms and definitions" [1], land reclamation is a set of works aimed at restoring the productivity and economic value of the disturbed land, as well as improving the environment in accordance with the interests of society. This definition focuses on restoring land productivity and in the interests of human society, but not in the interests of nature as a whole. By the ecological dictionary [2], reclamation is an artificial restoration of soil and vegetation fertility after a technogenic disturbance of nature. The economic cause of recovery is on the first place here as well. These definitions do not force for reclamation in cases
where there is no economic need to restore land, that is, when the cost of reclamation will not pay off by increasing the fertility of the soil.

Society as a whole, aware of the harmful effects of pollution and soil disturbance, has not yet mastered the technologies paid for by these criteria to compensate for the caused harm and restore nature. Therefore, the society forces mining companies to implement environmental measures of various kinds of payments, taxes, fines, which significantly increases a mining projects appreciation.

Reclamation of disturbed lands at open pit mines is still not accepted to be a basic technological process, despite the fact that each project of mineral recourses deposit development necessarily includes the relevant volume. It regulates the amount of productive horizon soils and potentially-fertile layers removal, location and parameters of its stockpiles, performance and quantity of technological equipment engaged in set of restoration works, volumes of flattening and planning of anthropogenic relief, volumes of application of soil and vegetative material, reclamation measures and measures for landscaping of the restored area, calendar plan for reclamation works.

Deposits development projects undergo an environmental expertise. State environmental authorities are monitoring the implementation of the reclamation requirements.

Formation of multi-tiered waste dumps (see Figure 1) with a tier height up to 30 m and consecutive level-by-level filling allows reducing the energy consumption costs for the transportation of rock mass one and a half or even two times [3]. At the same time, fuel consumption for vehicles, car fleet, labor, air pollution of the atmosphere with exhaust gases and dust are significantly reduced.

![Figure 1. Multi-tiered waste dump at Kovdor open pit](image)

It is effective to place waste dumps along the perimeter of the open pit at a close distance [4]. In Figure 2 a mining plan is shown, in which waste dumps occupy two thirds of the mining allotment area, and are evenly spaced along the contour of the open pit mine.
Figure 2. Mining plan with uniform spacing of waste dumps

It is effective to place waste dumps along the perimeter of the open pit at a close distance [4], what allows to begin the reclamation work at an earlier time period. The use of multi-tier dumps with small tires height increases on 5-9% the waste dump squire compared to the variant of single-tier dumps [3].

In accordance with the Russian state standards (GOSTs) [1, 5], the disturbed lands of all categories are subjects to be reclaimed, taking into account high range of specific factors such as: the natural conditions of the area, the geographical arrangement of the disturbed site, area development management, the disturbed land real situation, the degree of self-restoration ability, the plans for post-mining use of the disturbed lands, sizing, textural and chemical composition of rock waste, their agrophysical properties. Asset 1.6 [5] prescribes that the dump height is defined on a case-by-case basis, but at the same time the GOST limits the height of the reclaimed external dumps to 50-100 m. It turns out that dumps above 100 m are not required to be reclaimed. Asset 1.9 [1] obliges to decrease angle or tier slope, to release the reclaimed surface from large fragments of rocks (dimensions are not specified), to cover the surface with soil layer (potentially fertile). Nevertheless nothing is recommended for the situation, when nature vegetation ability is so poor that nothing but mosses and lichens can grow.

Based on a detailed analysis of the legal regulations on the restoration of disturbed lands by surface mining, authors consider it appropriate to revise some assets in accordance with modern approaches, technical and regional features of the dumping and placement of rock dumps. In this regard, the project documentation for the mineral deposits development, along with paragraphs about nature protection, should necessarily include principled design decisions on the reclamation of disturbed areas, but with the obligatory consideration of regional features and directions of use of newly formed anthropogenic objects (quarries, excavations, embankments, waste dumps, etc.).

2. Methods to improve the waste rock dumping efficiency and reclamation under the North condition

The reclamation as general for the subsoil user is mostly unprofitable but necessary expenditure item included in the overall estimate of the mining enterprise construction during the project development phase. The process is complicated by the fact that it is hardly possible to start the mining-technical phase of reclamation earlier than the basic processes at the mine would be completed. In most cases, this is the period of completion of the ore production, when the operations no longer gives sufficient inflow of
money. Therefore, funds for the reclamation should be found in advance and fixed in the company's accounts, taking into account the possibility of their value changing over time.

It should be noted that the reclamation worthiness and the success of the fertility restoration of the disturbed lands depends not so much on the strictness of the supervisory agencies, but on the care of the subsoil user about his image of the socially responsible Entrepreneur. The level of social responsibility for the mining business is higher; the greater impact the society can have on the structure and scope of its development in a particular region.

Our European colleagues have accumulated a wealth of experience in the social sphere-to-business interaction. One of the authors of this article had the opportunity to be on probation at the Tagbau 21 highland open pit close to Saalfelden (Austria) in order to learn more about the experience of reclamation. Striking for the Russian specialist seemed the situation in which the company developing the deposit had to make concessions to public opinion and satisfy the claims of environmentalists, who found in the swamp to be drained during the mining and capital works, a rare species of amphibian. The water pond was created on the opposite slope of the mountain, where the disturbance of the natural landscape was not planned. The entire population of amphibians and their habitat neighbors was carefully resettled prior to the mining start, and throughout the life of the open pit mine was supposed to carefully monitor the level of water pollution and trends in changes in rare subspecies population.

Such cases of responsible and careful attitude, of course, are inherent in the domestic mining practice. The land status in terms of the possibility of their occupation is clearly defined by subsoil use legislative instruments: it is assumed that in specially protected natural areas there are no disturbing natural landscape and increasing over the background level pollution of the atmosphere, hydrosphere and biosphere works are not carried out. In practice, however, it can be seen how quickly, if necessary, land status can change from "untouchables" to conventional farmland or forestry, similar to the recent events that have often occur at the federal roads construction. After the closing of mining enterprise, such areas are sufficiently reclaimed in a direction to the original target of land using.

At present, Russia is strategically developing the Arctic regions [6]. The development of the mining complex plays a significant role in the implementation of this direction of public policy [7, 8]. The open pit mining of solid mineral deposits, which dominates the structure of the complex, has its own peculiarities of development under the Arctic conditions.

In the regions of the North and the Arctic it should be taken into account that the natural zone of vegetation distribution depends not only on the geographical location of deposits, but also on the absolute altitude of terrain. In the highland tundra zones biological reclamation of disturbed by mining and waste dumping operations lands is almost impractical, due to the hard climatic conditions where nothing but mosses, can grow. For example reclamation of such areas for the purposes of trees grow is not advisable to provide for the cultivation as business wood place. Ripening of trees to the commercial conditions under the North condition takes more than hundred years. That’s why it is economically unfounded to make attempts of wood harvesting caring out at such disturbed areas, and despite the existing legislation the reclamation budget should be invested in forest nursery in more favorable areas, while the reclamation of waste dumps should be taken under the at lower requirements, just to prevent nearby territories erosions.

In general practice of open pit mining and designing of its reconstruction projects, waste dumps reclamation initiates after the final boundaries have been reached, and this process could be postponed for decades in case of dealing with high multi-tiered dumps, with a tier height of 80 meters or more. Taking into account, that producing of mine product at that period is already finished the financing of these works should be determined. In that case technology of dumping not higher than 30 m tiers with a consistent tier filling and a consistent gradual “tier by tier” reclamation of the dump can help to manage the reclamation task efficiently.

Climatic conditions in the areas of the Russian Arctic do not allow expecting an early self-recovery of the areas disrupted by mining: a short growing season is unfavorable for rapid soil re-tracking, but lack of heat, plant life is partially offset by an abundance of light over a long polar day [9].
Timely and well-organized reclamation plays an important role in the restoration of land in such a situation. First, it is the organization of removal and storage of the productive horizon’s soils covering the territory of the mining claim, in case if it is physically and technologically possible, that is, there is enough space for the work of technological equipment and the thickness of the soil layer to be removed exceeds 10 cm. The layer of impoverished hillside tundra soils in the Murmansk region rarely reaches 10 centimeters, further in depth most often potentially fertile soils – podzols layer can be found, in which the pedogenenic process has not yet managed to penetrate to a greater depth. Its thickness does not exceed 15 centimeters. In order to avoid acidification of the removed soils, storage yards are formed, which height should be limited up to 5 meters.

After the completion of mining operations, the relief formation suitable for the root habitat soil layer evolution should be immediately initiated. Deep borrow excavations most commonly are stopped to be drained and left for self-flooding, supported by flattening the slopes of the upper benches, forming a beach zone attached to the prognosticated level of saturation plane. The slopes of the waste dumps tiers are also flattened in accordance with the chosen reclamation purpose.

The pre-removed and stored soils are applied to the formed surfaces using technological equipment. Phytomeliorative measures and planting of seedlings are carried out. However, proper allowance must be made for the fact of the northern regions deficiency of the fertile soils. Its purchasing increases the cost of reclamation works, which provokes the need for new methods of soils neogenesis using the potentially fertile layer resources.

To increase the efficiency of roadside sandpits reclamation in the permafrost zone region of northern Yamal, a technology is applied that involves using of bentonite-gummat solutions to spread on flattened surfaces. Bentonite is a natural non-toxic clay material that swells on wetting, turning into a gel mass that well binds loose soils. Thus, a peculiar soil matrix is created. The formulation of the applied solution, along with phyto fertilizers and humus, includes seeds of perennial grasses, which are highly survivable, manage slopes to be sodded in a short growing season and create a root layer. This method of increasing the effectiveness of reclamation is recommended for use in all territories of the northern and Arctic regions.

The reclamation efficiency in mining enterprises is affected discernibly by the formation of external dumps during the mine operation, taking into account parameters of their subsequent reclamation, while one of the main methods to increase the efficiency of dumping is considered its maximum possible filling from the geotechnical and technological points of view.

The capacity of the dumps is influenced by such determining parameters as the angle of repose of the waste dump slope (\(\beta\), degrees), the height of the tiers (\(H\), m) and the width of the inter-tier terrace (\(W\), m). The closer the general slope angle of the dump to its stability maximum, the higher the tiers of the dump and the smaller the width of the inter-tier terrace are, the larger is the amount of overburden placed in the slope part of the dump (\(V_2\), m\(^3\)). The scheme of the slope part of the external waste dump with its elements is shown in Figure 3.
This issue was studied in detail in the monograph of prof. I.I. Russkiy "Technology of waste dumping and reclamation in quarries" [10]. In the paragraph devoted to the main parameters of dumps determining, taking into account subsequent reclamation, it is noted that with an increasing volume of dumped material, the area occupied by slope parts also increases and makes up about 30% of the total waste dumps area, therefore, the volumes of overburden placed in the slope parts of the dump must be taken into account in evaluation of the waste dump design capacity. Nevertheless, prof. I.I. Russkiy mentions that when the slope gradient is unfoundedly lower than the angle of the stable standing of the dumped rock type, the capacity of the slope parts decreases. However, the work does not mention the role of the width of the inter-tier terraces in determining the capacity of the slope parts, which should be considered more detailed.

The angle of the waste dump stable standing differs according to the geotechnical characteristics of the dumped rock types, as well as the height of tiers. As for the width of the inter-tier terraces, it must first of all corresponds to the safety of dumping operations in accordance to the technological equipment involved in the complex of dumping and reclamation works parameters. All while, during the waste dump design period, the further parameters of its subsequent reclamation has a necessity to be taken into account, i.e., the width of the inter-tier terraces during the first-time formation should ensure that it will permit reduction to the minimum safe size for machines and mechanisms work after the mining technical stage of reclamation, a significant part of which is the flattening of the slopes of the dump tiers, aiming bringing them into compliance with the chosen reclamation assigning slope angles. Nevertheless, the currently existing standards for the technological design of mining enterprises do not adequately regulate the width of the dump inter-tier terraces and the procedure for its determining [11, 12]. Design centers determine this parameter based on existing corporative regulations, which, however, is fraught with exceeding rational values, leading to an unreasonable decrease in the capacity of the slope parts of the dump, or, otherwise, to critical reducing the terrace width, leading to a unsafe decrease in the waste dump stability.

A methodology of the waste dump’s inter-tier terrace’s rational width calculating (W_t, m), based on the principle of geotechnical stability and keeping its required minimum (X, m) after the flattening of the dump tiers slopes during the reclamation works is submitted in the presented research. A scheme for the calculating of the rational width of the inter-tier terrace is illustrated bellow (figure 4).

![Figure 4. The rational width of the inter-tier terrace calculating scheme](image)

The target parameter is presented as the sum of the minimum for machines and mechanisms safe operation terrace width after the completion of the mining technical reclamation stage (central part, X, m) and two edge sections (a, m) that are subjects to backfilling or pushing downhill during the slopes flattening:

\[
W_t = X + 2a, \text{ m.}
\]
The letters α and β denote, respectively, the angle of the tier slope during the waste dump formation and the angle of the slope flattening in accordance with the chosen purpose of reclamation. The tier slope horizontal projection — “b” is a leg of a right triangle (ABC) adjacent to the angle α, the height of the dumping tier in this case plays the role of the opposite leg, therefore, using these parameters, we can express parameter b as:

$$b = H \times \cotg \alpha, \text{ m.}$$

(2)

The letter “a” indicates the width of the edge parts. The dimensions of the edge parts are also components of the “tier after its flattening” slope triangle (DEF) leg adjacent to the flattening angle β or angle of repose:

$$b + 2a = H \times \cotg \beta, \text{ m;}$$

$$a = \frac{H \times \cotg \beta - b}{2} = \frac{H}{2} (\cotg \beta - \cotg \alpha), \text{ m.}$$

(3)

(4)

Transform equation (1) and obtain a formula for calculating the rational width of the inter-tier terrace:

$$W_t = X + 2a = X + 2 \times \frac{H}{2} (\cotg \beta - \cotg \alpha) = X + H (\cotg \beta - \cotg \alpha), \text{ m.}$$

This calculation method has been tested for the iron ore open pits of the Kola Peninsula representative conditions. According to the design standards of this complex of deposits, generalized by the type and geotechnical properties of both mineral recourses and overburden, mainly rock type, the heights of dump tiers are assumed to be 30 m. The slope angle of the tier is 38°, the width of the inter-tier terrace is 62.5 m, after flattening slopes to an angle corresponding to the chosen purpose of reclamation — 18°, reduced to 10 m:

$$W_t = X + H (\cotg \beta - \cotg \alpha) = 10 + 30 (\cotg 18° - \cotg 38°) = 64.0, \text{ m.}$$

In this particular case, a deficiency of the inter-tier terrace width of 1.5 m was found. After the flattening of the dump slopes, a decrease in their stability is predicted over time, which may entail their deformation, creep, as a result, occupying a larger area than is suggested by the reclamation project, and lead to emergency situations during the mechanisms work on the flattened terraces.

3. Conclusion
This paper discusses the environmental, social, technical and economic prerequisites for the efficiently reclamation of such technogenic formations as waste dumps. The main purpose was to formulate recommendations to reduce the negative consequences exerted by industrial enterprises on the ecology of the region by increasing the efficiency of dumping and reclamation works in the quarries of the Arctic and the Far North.

The waste dumps reclamation issue in cases when dumped rock type can be used as potential technogenic raw materials and dump itself as a technogenic deposit requires theoretical, normative, and practical study. Biological reclamation of such waste dumps during future flotation processing will significantly impair the extraction of the useful component, while the removal of the sodded layer from the dump will lead to additional losses of potentially useful materials.

An analysis of the features of reclamation in severe climatic conditions was carried out and methods for increasing the efficiency of its implementation were proposed.

Methodology for the waste dump inter-tier terrace width calculating taking into account the parameters of a relief that is safe and stable for subsequent reclamation works:

$$W_t = X + H (\cotg \beta - \cotg \alpha), \text{ m.}$$

Using this methodology, for the rational inter-tier terrace width for iron ore quarries of the Kola Peninsula waste dumps determination, it was assessed, that its minimum width should be at least 64 m for a dump tier of 30 m high and a slope angle of 38°.

To increase the root layer formation rate on reclaimed surfaces, it is proposed to use bentonite-gummat solutions, which, due to the binder components, create a soil matrix of potentially fertile rocks under conditions of scarcity of soil-plant layer, saturating them with components useful in plant growth in combination with seeds of perennial grasses.
Regulatory documentation on the formation and subsequent reclamation of technogenic relief (waste dumps and mineral resource stockpiles), especially for the climate conditions of the North and Arctic regions, requires a mandatory revision.

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