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Substantiation of the intensified dump reclamation in the process of field development

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Abstract

Purpose is to substantiate intensification of dozer dump reclamation in the process of open pit-mining.

Methods. Analysis of methods intended to intensify reclamation activities in the context of open-pit mineral extraction under different mining and geological conditions has been applied. Innovative operation schedule of dump reclamation has been developed on the basis of critical analysis and proper analytical research.

Findings. Operation schedule to form a dozer dump has been substantiated taking into consideration rock suitability for reclamation making it possible to mitigate impact of mining on the environment. Algorithm to calculate dozer dump parameters has been developed as well as a digital topographic model of selective dump formation.

Originality. The developed operation schedule for selective formation of the external dump differs from the available one in the simultaneous layer dumping to intensify surface of its dumped share in the process of open-pit mining.

Practical implications. Use of the method of selective surface formation in terms of a dozer dump, taking into consideration overburden suitability for reclamation, helps intensify reclamation of the soils disturbed during field development.

Keywords: *soil disturbance, overburden, open-pit mining, reclamation, dump, rock*

1. Introduction

In terms of open-pit mining, substantiation of reclamation tendencies should involve analysis of the efficient use of land and formation of natural-technogenic landscape corresponding to ecologic, socioeconomic, and hygienic requirements of the area where the development of earth interior takes place. Expedient operation schedules to form external dump, developed with the consideration of further surface reclamation, favour the determination of efficient tendencies for the disturbed soil reclamation. The purpose should involve the methods of selective overburden dumping that correspond to its parameters and topography. Thus, the design operation dumping schedule has to be in accordance with the selective overburden allocation within a dump body following its reclamation suitability [1]-[3].

Use of land plots for mineral mining results in their disturbance, pollution, and productivity loss of the adjacent areas. Hence, avoidance of the negative sequences should involve implementation of a set of measures for environmental protection, enhancement of the area, and efficient use of the land and water resources [4]-[7]. Thus, determination of the methods of early reclamation of soils, disturbed during mineral extraction, is the most important task of the open-pit mining processes.

When the earth interior is developed with the help of open-pit mining, substantiation of both tendency and appropriate use of land under reclamation should involve consideration as well as analysis of the factors effecting the targeted economical production activities of such reclaimed areas. Then, the basic conditions include natural physical and geographical territorial conditions as well as basic characteristics of the disturbed lands and overburden suitability for biological development. Additionally, attention should be paid to the mining conditions of such reclamation activities, environmental conditions of the territory, and social importance of the disturbed land reclamation within the technogenic territory.

The paper substantiates recommendations concerning the creation of favourable conditions for the accelerated self-regeneration of forest ecosystem by means of mining reclamation [8]. The process may be favoured by a procedure of the field development as well as by the mandatory mining reclamation intended to improve environment within the opencasting area.

Various reclamation procedures have been developed for the disturbed territories. The procedures differ in the allotment land objective and in the natural and climatic conditions of the deposit [9]. Principles of mining reclamation involve: substantiation of the final landscape shaping, a sys-

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tem of the potentially fertile soil layer formation; planting and seeding techniques within the reclamation area. The abovementioned needs confirmation of such reclamation intensification when survival rate supports such success criteria. The effect requires handling of the plants and their monitoring (i.e. post watering of grasses and mowing).

High productivity of dump land and reduced reclamation costs may be achieved owing to the soil layer application on its surface. The layer has been formed in the context of mining land reclamation by means of fertile soil layer concentration [10]. In this connection, a power-shovel stope of an upper overburden bench should be mined selectively; moreover, locations of temporary warehouses for fertile soil layer within the open-pit field boundaries have to be substantiated as a part of the layer-by-layer dumping.

Natural revegetation within the disturbed Northern territories takes different periods of time depending upon the lithological composition, soil structure, terrain, moisture conditions, and specific character of the disturbances. Experiments and industrial activities as well as analysis and generalization of the disturbed land reclamation confirm considerable complexity of such activities and their specificity [11]. Under the conditions of a permafrost zone, environmental safety, land protection and its reclamation should be supported by such an important factor as the limitation of technogenic impact on the permanently frozen ground.

Basically, the assumed tendency of the disturbed land reclamation has to take into consideration the efficient use of natural resources involving minimum human interference in the environment and a process of land degradation as well as compensation of negative anthropogenic influence and inflicted damage. Under the mentioned circumstances, open-pit mining in such a situation is formed when it is necessary to validate the requirements concerning the improvement of the efficiency of external dump shaping. Thus, analysis of the situation aimed at the substantiation of reclamation intensification of the dump surface is focused on the early restoration of the disturbed land in the process of open-pit mining.

2. Analysis of the methods intensifying dump reclamation

Transition to the current land-use model, based on the simultaneous land reclamation and recultivation activities, differs in the number of considerable advantages to compare with the available traditional approaches to the restoration of lands disturbed as a result of opencast in the context of coal-mining regions [12]. Land reclamation procedures should take into consideration the complexity of the problem since vegetation restoration only cannot improve substantially the environmental situation within the disturbed territories. Improvement of the ecological setting in the industrial areas is possible if fundamental reclamation is substantiated with the generation of soil media able to support natural restoration of such disturbed ecosystems.

Currently, industrial activities, being manifested in the areas of mineral mining, preparation, and processing, are rather stressful for the nature [13]. Development of gold placers, occurring in floodplains and river valleys, is one of the most ecologically destructive branches of mining industry since the activities disturb landscape fundamentally. Consequently, information support of the research intended to restore the land timely is the key component of the problem solving.

Laboratory experiments and plot trials to control physicochemical as well as biological properties of rocks of the analyzed dumps were carried out by means of one rock adding to another [14]. Adding of a waste pile rock improved physical characteristics of coal-preparation dump; neutralization increased its fertile properties. Before planting, seeds were treated by lignite ammonium humate; plants were treated during their vegetation period. Use of the humic compounds provided optimum starting environment as well as adaptation of the plants to dump conditions while bettering the root formation and plant growth. Implementation potential of the innovative approaches to the disturbed land reclamation has been demonstrated in terms of a coal-preparation dump and a waste pile.

Nonhomogeneity of mining and geological, edaphic, environmental, technical and engineering as well as economic conditions, formed in the process of mineral deposit development on the Kola Peninsula, stipulate the necessity to analyze thoroughly the conditions while substantiating the expediency of the disturbed land reclamation and selecting its tendencies [15]. Contribution to natural planting of the disturbed soils should be considered as the main treatment method in terms of the disturbed vegetative ground cover under the severe natural and climatic conditions as well as the complicated mining and geological environment of Kola North.

From the viewpoint of landscape ecology, when mineral mining is over, terrain formation needs planning of melioration measures. There is no need to be limited by the areas which restoration resulted from a recultivation process; its connection with the environment should be taken into consideration [16]. However, the represented principles to form ecological structure in mining regions are integral parts of the inimitable code for the substantiation of land reclamation. Restoration of the disturbed lands after mineral mining completion is the official commitment for a mining enterprise which should provide means for the disturbed land reclamation.

A methodology to calculate parameters and indices of the operation schedules of a direct waste dumping, to identify methods which help increase capacity of internal dumps and enhance safety and to restore a surface, has been proposed in an open-pit coal mine [17]. End surface of the mine as well as its dumping surface involves modeling of the basic parameters of the dumping method and determination of common angles of the internal dumps to prevent from landslides and to control safety. The analysis helps conclude the following: common slope angles of multilayer dumps, floored by soft rocks, should not be more than 24-29º and 40-60 m in terms of their height; moreover, if natural slope height is 37° then slope height of level one should not exceed 20-25 m.

Fertile soils experience their decrease in the process of mineral stock mining. However, its efficient planning and controlling may help use the technogenic disturbed lands for other purposes. It should be noted that the aftereffects of mineral extraction are of long-term nature as for their impact on the environment [18]. At the stage of the production shut down, mining companies have to scale down both ore extracting and processing, deactivate mining enterprises as well as processing ones, and reclaim the disturbed lands and restore them. Hence, the conditions need long-term planning of ore mining starting from the earliest stages of the mineral stock extraction.

External dumping requires large areas; thus, environmental problems occur due to the increased expenditures for the

surface reclamation [19]. Consequently, internal dumping is more preferable owing to the decrease in expenditures connected with the restoration activities. The paper represents analysis of slope stability of 80 m height internal dump in a surface mine. If mining depth reaches 100 m, slope stability of the internal dump becomes critical. Moreover, adding of overburden results in the dangerous situation within the slope.

Rapid economic growth along with the deposit development factors into greater amount of lands disturbed by construction activities and coal mining. Hence, China stimulates land reclamation in coal-mining regions [20]. Disturbances in land characteristics vary from a region to a region depending upon the natural as well as geological conditions of the coal-mining areas. Land reclamation has been divided into three zones: eastern, western, and southern. The improvement strategies are focused on the primary protection of arable areas within the eastern zone and ecological restoration within the western and southern zones respectively. In this context, innovative methods over the past decade have been applied as well as land reclamation theories inclusive of coal mining, land reclamation, backfilling, and self-restoration of a surface soil in open pits.

Study of the factors of ecological disasters, stipulated by mineral mining, helps carry out a systematic analysis of their impact on lands, and geologic and ecologic environment. Among other things, it especially concerns the impact on the environment and on ecological system [21]. The key factors, influencing the environmental ecology, mining scope, its methods and techniques have been specified. Efficient measures, aimed at land reclamation and environmental protection, have been substantiated relying upon the control effects resulting from the research.

System approach has been applied as a research method while solving eco-economic problems of the restoration of waste dumps of a coal field. The approach made it possible to mitigate environmental damage and to obtain substantial economic effect from the implemented environmental measures [22]. The proposed method of waste dump recultivation has been used to calculate the prevented economic harm the environment. In future, such recultivated waste dumps will be applied for the agricultural purposes; moreover, use of the waste by a metallurgical plant will release the enterprise from the waste placement payments.

Paper [23] proposes technological solutions for a complex of land reclamation activities of a mining stage taking into consideration specific features of steeply deeping ore deposit opencasting, requirements for the determination of land reclamation tendencies, and rapid restoration of the disturbed areas. Implementation of the recultivation decisions will help intensify the process of the disturbed soil rehabilitation corresponding to the legislative requirements concerning environmental protection.

Findings of the research have made it possible to develop an innovative method to reclaim lands disturbed by a discharge of acid mine water; local industrial wastes were used as reagents and additives [24]. In such a case, use of the industrial wastes results in several-time cheapening of the environmental measures. Full-scale experiments were carried out at a surface of previous discharge of the acid water. Stable vegetation cover has been obtained. Concentrations of the chemical agents within the flora are not hazardous from ecological viewpoint since in the majority of cases their content stay within the natural background ones. Massive pilot tests of the method have been conducted; its implementation will remedy negative coal-mining aftereffects as for the land.

Application of organic substances in the basis of the parent rocks results in the intensified soil genesis and recultivation; nevertheless, development tendencies of any organic substance vary depending upon the differences in soil types as well as in the application techniques [25]. Humus within the surface layers demonstrates its accumulation tendencies and increase in a humification degree. The tendencies are stipulated by the intensification of a regeneration process as well as by the increase in biological productivity in the process of the disturbed land reclamation.

To intensify dump recultivation in the neighbourhood of settlements, it is necessary to plant seeds of permanent grasses and annual grasses after preliminary preparation of slope and bench surfaces [26]. Under the conditions, the environment of human occupancy district will meet the ecological requirements intended to improve a situation with the lands disturbed technogenically.

Mining activities result in soil disturbance, changes in microbial communities and vegetation factoring into destruction of huge areas [27]. Land restoration is a process when ecological integrity of the soil, disturbed by mining operations, is rehabilitated. If soil pH, fertility, microbial community, and various nutrients are controlled then the disturbed land becomes productive. Revegetation at the surface of the disturbed soils is the most popular and useful method to minimize erosion and protect land from its degradation during recultivation.

3. Substantiating intensification of the dozer dump recultivation

Progress of soil-building process at the surface being recultivated favours gradual transformation and formation of a land cover and rehabilitation of soil layer and grasses at the dump surface while characterizing edaphic and ecological conditions of the improved lands as well as natural soil genesis process [28]-[30]. Substantiation of the disturbed land reclamation method should be based upon the field soil studies, laboratory analysis of the soil samples, and purposeful survey of the object conditions to obtain qualitative result while determining the rehabilitation tendency for the technogenically disturbed territory.

In the context of open-pit mining, surface rehabilitation tendency of the formed external dozer dump depends upon a tendency of the restored land use for the national economy needs [31]. Thus, the selection should be focused on the creation of favourable conditions to restore stable ecosystem within the disturbed territories in terms of maximum limitation of negative aftereffects and to bring back their commercial, ecological, and recreational importance. The energized rehabilitation needs such an operation schedule for an external dump formation which takes into consideration selective placement of the overburden rocks inside the dump depending upon their suitability for the recultivation purpose. Further, deposit geometry analysis will help determine overburden rock conformance to the required conditions of the disturbed soil reclamation. Hence, overburden analysis helps identify volume of nonsuitable rocks, potentially fertile rocks, and fertile soil layer. Further, calendar period for their use in the rehabilitation process is identified in accordance with a mining procedure accepted for the deposit.

In the context of the proposed operation schedule, potentially fertile rocks are discharged to a slope surface and horizontal surface (b_w is the terrace width) of dump levels within a peripheral share; nonsuitable for land reclamation rocks are discharged to a dump body. When the projected height (H) is achieved, a layer of potentially fertile rocks ($h_{p.f.r}$) and a fertile layer ($h_{f.l}$) also cover its horizontal surface. Angles α and β correspond to a slope angle of the level as well as to a resultant angle of the dump slope reclamation; h_1, h_2, and h_3 correspond to heights of the levels. Figure 1 explains a scheme of selective formation of the rounded external three-level dozer dump in section.

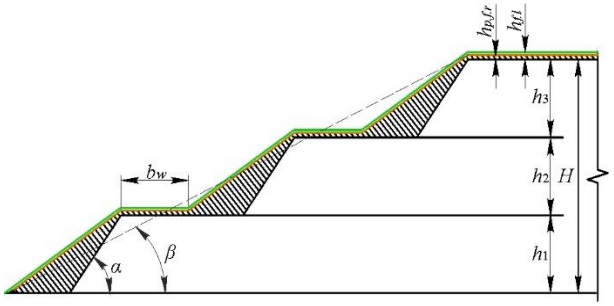


Figure 1. Scheme of the selective shaping of a peripheral share of a three-level dump

The recommended scheme of the external dumping helps accelerate its surface rehabilitation owing to the overburden discharge in terms of their suitability for land reclamation. In this context, the specified average height of the dumped levels is 3 m. Figure 2 represents following dumping procedure. After a pilot embankment is discharged, dumping is developed along a boundary of the discharged dump both from the right side and the left side up to their meeting. Then, the entrance into a level two is dumped at a level one with following formation of dumping level two being parallel to the level one. In the similar way, dumping level is shaped to accelerate reclamation of an external dozer dump. When the sufficient area is available, potentially fertile rock layers are placed at the horizontal surface of a peripheral share of the dumped levels (terraces); then fertile soil level is placed upon its availability.

Digital terrain model (DTM) of a future dump is recommended to be produced with the help of the current information resources for the efficient use of a fertile soil level, available within the boundaries of land allotment and the volumes of the potentially fertile rocks within the open pit (Fig. 3). In this context, requirements for biological reclamation of the dump surface are involved. Its formation is performed selectively. The model makes it possible to take into consideration volumes of the potentially fertile rocks from the open pit as well as the unsuitable ones from the moment when the first volume of rocks is dumped up to its final formation. Moreover, it helps determine dumping areas while intensifying the disturbed land reclamation in the process of dump formation [32].

The digital terrain model of a dump and its sections has been produced using AutoCAD and GeoviaSurpac programs. Following parameters were specified for the dump: number of levels – 3; level height – 3 m; slope angle – 37°; berm (terrace) width – 10 m; road width – 6 m; and entrance slope – 80°.

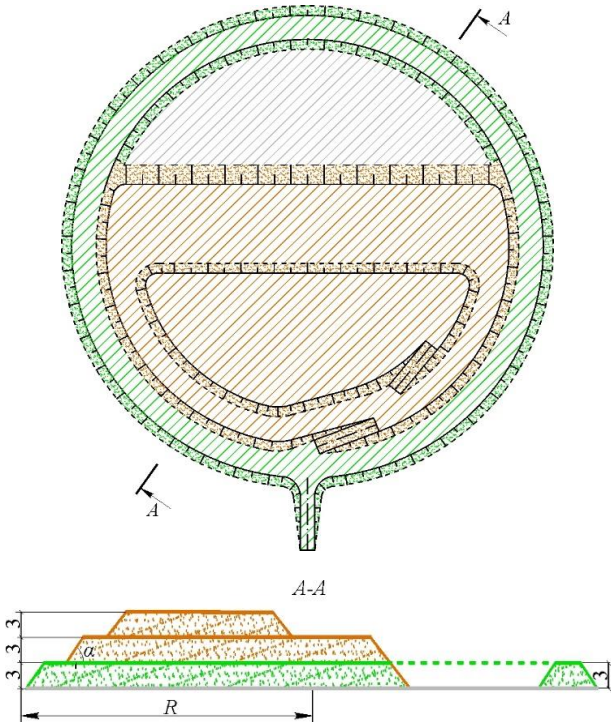
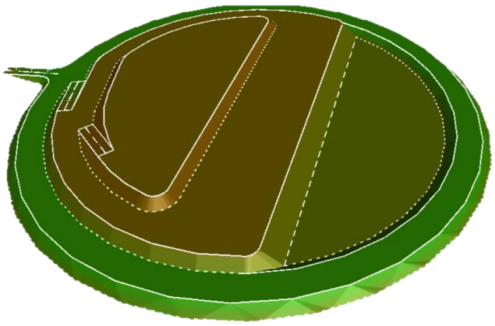


Figure 2. Operation schedule of the dumped area filling by dead rock taking into consideration the rehabilitation requirements (R is the radius of the dumped area)

(a)



(b)

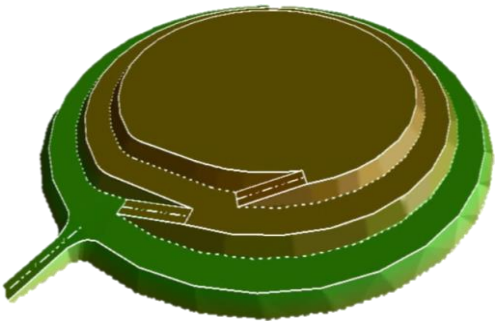


Figure 3. Digital terrain model: (a) a dump in the process of its formation; (b) a dump formed selectively

4. Algorithm to calculate parameters of dozer dumps

In terms of selective formation, parameters of the external three-layer rounded dozer dump (S_r) are specified as follows. Depending upon the dumped overburden volume, height, and resultant angle of the dump slope, area of the rounded dump is determined according to formula [33]:

$$S_r = \pi\left(\sqrt{\frac{VK_f}{\pi H}} - \frac{Hctg\beta}{2}\right)^2, \quad (1)$$

where:

V – volume of overburden rocks piled in the dump, m^3;

H – dump height, m;

β – resultant angle of the dump slope, degrees;

K_f – fragmentation coefficient of the overburden rocks.

Area of the upper horizontal surface of the dump ($S_{h.r}$ is determined using following expression:

$$S_{h.r} = \pi\left(\sqrt{\frac{VK_f}{\pi H}} - \frac{Hctg\beta}{2}\right)^2. \quad (2)$$

In terms of the known linear parameters of the rounded dump (V_r), its volume is identified on the formula:

$$V_r = \frac{\pi H\left(2R - HCtg\beta\right)^2}{4K_f}. \quad (3)$$

In terms of the known parameters, radius of the dumped area (R) is determined according to the formula:

$$R = \sqrt{\frac{VK_f}{\pi H}} + \frac{HCtg\beta}{2}. \quad (4)$$

The required volume of the potentially fertile rocks ($V_{p.f.r}$) for the rounded external dump recultivation is determined using the formula:

$$V_{kp} = \pi\left(\sqrt{\frac{VK_f}{\pi H}} - \frac{Hctg\beta}{2}\right)^2 h_{p.f.r}, \quad (5)$$

where:

$h_{p.f.r}$ – thickness of the applied potentially fertile rocks, m.

Volume of fertile soil layer ($V_{f.s.l}$), placed on the surface of external dozer dump, is determined on the formula:

$$V_{f.s.l} = \pi\left(\sqrt{\frac{VK_p}{\pi H}} - \frac{Hctg\beta}{2}\right)^2 h_{f.s.l}, \quad (6)$$

where:

$h_{f.s}$ – thickness of the placed fertile soil level, m.

The abovementioned calculation algorithms are intended to identify rather accurately the parameters of the area allocated for the external dozer dump, its upper horizontal surface, the dump volume, and radius of the dumped area. Use of the listed dependences is especially important to substantiate the efficient parameters of the external dump in terms of different values of a resultant angle of its slope.

In the context of the proposed schedule, piling of the dump levels starts on a peripheral share of the external dozer dump making it possible to place rocks, suitable for reclamation, at the horizontal surface to accelerate its rehabilitation. Selective dump of the potentially fertile rocks on the peripheral surface of each dump level favours intensification of the external dump reclamation. Potentially fertile rocks at the surface of the dump level slopes helps prevent from their flattening while improving land use indices in the context of the external dump formation. Efficient use of the potentially fertile rocks, extracted from an open pit at the initial stages of the deposit development, for their selective placement to accelerate the surface reclamation is among the key advantages of a method of the external dozer dump formation.

The recommended operation schedule of selective formation of the external dozer dump differs from the available ones in the simultaneous level dumping to intensify surface rehabilitation of its dumped share. In terms of overburden suitability for reclamation, substantiation of its selective placement at a dump surface helps accelerate rehabilitation of the dumped share in the process of its formation and mitigate the negative consequences of open-pit mining on the environment. Use of the represented method of a selective formation of three-level dozer external dump helps intensify its surface reclamation in the process of open-pit mining.

Following methods are planned for future to combine dump and overburden operating with reclamation of the disturbed areas:

– 3D modeling (using a drone, surface laser scanning, and GIS) starting from a mining enterprise design up to the compete recultivation of the disturbed land;

– IT with the use of the global positioning systems to dispatch support service vehicles, monitoring of the disturbed land.

5. Conclusions

The improved efficiency of the external dump reclamation helps return timely the rehabilitated land for the national economy needs while favouring environmental security in the process of open-pit mining. Vegetation of the disturbed territory during reclamation after mining to harmonize the natural environment is the necessity of ecological orientation of any nation. In the context of open-pit mining, internal dump formation is the most economical and environmentally friendly method of waste removal. Hence, the internal overburden dumping, matching the requirements to accelerate reclamation of the disturbed land and having the greatest technical and economic performance, is the optimum method for overburden dumping.

In the context of economic growth, the improvement of land use will remain one of the most important tasks of the mining industry; more efforts and facilities are expected to be channelized to the substantiation of the accelerated reclamation of the disturbed land areas. Deposit development should involve efficient mining methods as well as the methods of the disturbed land rehabilitation while considering it as the important link in the process of mining. In the context of reclamation operations, recycling of organic substance is the key soil-forming factor; moreover, it intensifies fundamentally the disturbed surface rehabilitation.

Digital terrain model helps demonstrate selectivity of the external dump formation as well as its reclamation intensity. The recommended selective dozer dumping differs from the available ones in the simultaneous formation of dump levels to intensify surface reclamation of its already formed share. Selective placement of the overburden rocks as well as efficient tendency to restore technogenically disturbed land favours rehabilitation of the mining district; it will produce positive effect as for the efficient solution of the problem impacting ecologically the environment.

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Обґрунтування інтенсифікації рекультивації відвалів у період освоєння родовищ

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Мета. Обґрунтування можливості інтенсифікації рекультивації поверхонь бульдозерних відвалів при відкритій розробці родовищ.

Методика. Застосовано аналіз способів інтенсифікації рекультиваційних робіт при відкритому видобутку корисних копалин у різних гірничо-геологічних умовах. На підставі критичного аналізу і власних аналітичних досліджень розроблена нова технологічна схема рекультивації відвалу.

Результати. Обґрунтовано технологічну схема формування бульдозерного відвалу з урахуванням придатності порід для цілей рекультивації, що дозволяє знизити негативний вплив гірничих робіт на навколишнє середовище. Розроблено алгоритм розрахунку параметрів бульдозерних відвалів і створена цифрова топографічна модель селективного формування відвалу.

Наукова новизна. Розроблена нова технологічна схема селективного формування зовнішнього бульдозерного відвалу відрізняється від існуючих одночасним відсипанням відвальних ярусів для інтенсифікації рекультивації поверхні його відсипаної частини в період експлуатації родовища відкритим способом.

Практична значимість. Застосування технології селективного формування поверхні на прикладі бульдозерного відвалу з урахуванням придатності розкривних порід для рекультивації дає можливість інтенсифікувати рекультивацію порушених земель у процесі експлуатації родовищ.

Ключові слова: *порушення земель, вскриша, відкрита розробка, рекультивація, відвал, порода*

Обоснование интенсификации рекультивации отвалов в период освоения месторождений

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Цель. Обоснование возможности интенсификации рекультивации поверхностей бульдозерных отвалов при открытой разработке месторождений.

Методика. Применен анализ способов интенсификации рекультивационных работ при открытой добыче полезных ископаемых в различных горно-геологических условиях. На основании критического анализа и собственных аналитических исследований разработана новая технологическая схема рекультивации отвала.

Результаты. Обоснована технологическая схема формирования бульдозерного отвала с учетом пригодности пород для целей рекультивации, позволяющая снизить отрицательное влияние горных работ на окружающую среду. Разработан алгоритм расчета параметров бульдозерных отвалов и создана цифровая топографическая модель селективного формирования отвала.

Научная новизна. Разработанная новая технологическая схема селективного формирования внешнего бульдозерного отвала отличается от существующих одновременной отсыпкой отвальных ярусов для интенсификации рекультивации поверхности его отсыпанной части в период эксплуатации месторождения открытым способом.

Практическая значимость. Применение технологии селективного формирования поверхности на примере бульдозерного отвала с учетом пригодности вскрышных пород для рекультивации дает возможность интенсифицировать рекультивацию нарушенных земель в процессе эксплуатации месторождений.

Ключевые слова: *нарушение земель, вскрыша, открытая разработка, рекультивация, отвал, порода*

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