Land reclamation technologies for direct dumping

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Abstract. The article describes features of the direct dumping method and analyzes various profiles of group dumps that meet land reclamation requirements. Main provisions of technological overburden and dumping schemes using draglines were analyzed. Three groups of technological schemes of overburden and dumping works were analyzed. They differ in methods of filling of intermediate dumps when forming a group dump and land reclamation objectives. Technical and economic assessment of mining options using draglines for overburden and dumping works was carried out. Technical, economic and ecological results of mining operations were identified and analyzed.

1. Introduction
The annual growth of consumption and production of natural resources makes the problem of environmental management relevant and crucial. To solve it, measures aimed at using environmentally friendly natural resources should be developed and implemented. Mining operations have a strong impact on natural landscapes; mines and dumps modify the original topography. To ensure safe conditions for the natural and man-made system, the structure of modified landscapes should correspond to future economic activities. Mining enterprises should carry out reclamation works aimed at reproducing the lost economic value of lands disturbed by mining operations. Reclamation works can be carried out simultaneously with mining operations or after their completion. Technologies of land reclamation include surface planning and slope flattening by excavators, dumpers, bulldozers, scrapers and other mining or special equipment. Land reclamation may be carried out by forming a certain profile of mining slopes and surfaces suitable for agriculture and forestry, construction, etc. in accordance with regulatory documents. In remote areas, the surface profile should ensure its resistance to environmental impacts and not deteriorate.

Resource-saving and resource-reproducing technologies of open-pit mining are crucial for Russia and foreign countries extracting minerals in different climatic conditions [1, 2, 5, 8, 9, 12, 14]. They use direct dumping methods involving a combination of construction, dumping and technical reclamation works. When creating dump embankments suitable for forestry and agriculture, the slopes are flattened by draglines [10, 11]. During the dumping, it is possible to form a surface and create a relief that fully meet mining reclamation requirements. It is possible to use draglines for multiple transportation of rocks to the dumps of a certain height and dumping piles by dispersing rocks when unloading the dipper, flattening slopes, etc. During the overburden works, when the degree of preparation of reserves determines quarry performance, the use of equipment for auxiliary operations is not always possible. When developing placers using draglines, it is necessary to remove overburden from the pit contour to the outer dumps with a width of 80-300 m. When using draglines for
overburden operations, this can increase the number of transshipments of rocks into dumps and losses of working time for moving the excavator. It will violate equipment use requirements and worsen placer development indicators.

When developing mineral deposits, it is necessary to find the best combination of volumes of works performed by stripping equipment in the main production cycle in order to prepare the site for reclamation using machines for land surface reclamation. For direct technologies, it is necessary to assess possibilities and feasibility of overburden and dumping works using draglines with partial preparation of the surface for subsequent reclamation.

2. Materials and methods
The direct external dumping technology is used for the development of placers, coal and construction materials deposits characterized by horizontal and low-dipping strata [3, 4, 6, 7, 13]. In addition to technical solutions, the efficiency of deposit development is influenced by the sequence of execution and distribution of rocks during the reclamation works.

The overburden technology involving external dumping by one dragline includes excavation of rocks and dumping them into the interim and final (group) dumps. To develop technological schemes of overburden and dumping works, a number of provisions can be used. If the height of dumps does not exceed the height of the dragline unloading, the excavator is installed on the working platform surface. When filling high intermediate dump, the excavator installation horizon is changed by preliminary stockpile filling or trapezoidal stockpile filling. To create a high group dump, a belt-level dump is used and the dragline is installed both on the surface of the deposit and on the first tier dumps.

Cross-section excavator overburdens can have the same or widths. Therefore, intermediate and final dumps have different heights and profiles. Dump parameters are controlled by changing the width of overburden and dumping. The trapezoidal dump can be expanded by changing the angle of rotation of the dragline when dumping rocks.

The final dump profiling during the reclamation, including backfilling of the intercostal space, slope flattening and subsequent lowering of the dump height, can be carried out by excavators and bulldozers. When forming a relief for the desired reclamation direction, a horizontal or inclined surface is formed along the entire dump with stable slopes along the perimeter of the dump system. Under favorable conditions, this profile will meet the requirements of self-restoration of the natural environment.

The following factors influence the productivity of excavators: climatic and geological conditions; technological (pit excavation parameters, width of the dumping area, location and height of the excavator, excavation conditions, dragline movement step, rotation angle, quality of rock preparation, etc.), technical (type of the excavator, availability of repair facilities, availability of spare parts and materials), and organizational (operation mode, time alignment of technological processes, emergency downtime, etc.) parameters. The design of the technological scheme and its parameters affect the performance of draglines through the loss of working time.

In the technological schemes, in filling the group dump, the surfaces are characterized by vertex elevation differences constituting intermediate dumps and distances between them.

Let us consider several technological schemes of overburden and dumping works with external dumping using an ESH 10.70 dragline and applying the direct dumping method (Fig. 1). To determine their parameters, we used a graphical modeling method. When developing the deposit, works of the mining stage of reclamation are performed: slope flattening, surface planning and other auxiliary works. After the deposit development has been completed, the land surface is used for afforestation and cultivation of crops.

In addition to the main production purpose, involving the extraction of minerals and profit, these schemes differ in associated objectives.

Option 1, Figure 1(a). Associated production objective: the technological scheme of overburden and dump works should ensure formation of a compact high external dump, i.e. the minimum area of
dumps. The overburden is carried out during two longitudinal penetrations. The first intermediate dumps are filled beyond the quarry contour.

Figure 1. Technological scheme of overburden and dumping operations: a) – high dump; b) – dispersed dump of intermediate dumps of the same height; c) – dispersed dump of intermediate dumps of different heights.
During the second run, the excavator working level is changed. For this purpose, along the track axis, the dump is formed by the same dragline. The rocks are filled into the outer dump behind the first dump. Rocks from the dump where the excavator was installed are filled into the same dump.

**Option 2, Figure 1(b). Associated production objective:** to carry out the initial profiling of the dump system using the dragline with various degrees of surface preparation for subsequent mining reclamation. In this case, a single-tier dumping method with several intermediate dumps of the same height is used. Overburden includes serial longitudinal penetrations of the dragline, dumping of intermediate piles, moving them to the site of dumping and forming a group dump.

Overburden operations are performed with a different number of penetrations and formation of a group dump from 2, 3, 4 and 5 intermediate dumps with a decrease in their height.

**Option 3, Figure 1(b) Associated production objective:** during the pre-profiling of the dump surface by the dragline, it is necessary to create a group dump with a surface slope. For this purpose, both single-tier dumping and pre-dumping methods (Figure 1(b)) can be used. Rocks are mined by draglines whose longitudinal penetrations are of different widths, and the group dump is formed from intermediate dumps having different heights. The width of penetrations in the sequence from the first to the adjacent one is 10 – 14 – 18 – 22 – 16 m. On the outside of the dump field, a dump of a lower height is formed. Subsequent intermediate dumps are dumped into the quarry with an increasing height. Near the quarry contour, a high dump is formed. This design of the group dump helps create a profile of the dump surface with a reverse slope which can reduce the volume of planning works when restoring the surface with permissible deviations.

After the external group dump has been formed (options 1, 2 and 3), surface profiles corresponding to the target reclamation direction can be created (Figure 2). The validity of a decision is determined on the basis of its objectives, technical and economic feasibility.

**Figure 2.** Diagram of dump profile formation after reclamation: a) the dump profile with a predominant horizontal surface; b) the dump profile combining sloping and horizontal surfaces; c) the dump profile with an inclined surface.
Figure 2 (a) shows the dump design profile which meets the overburden technology (option 2). The dump is filled with rocks from five intermediate dumps and profiled with parameters more appropriate to the agricultural reclamation. The slopes are acceptable for the forestry reclamation and self-organized vegetation.

The group dump is designed by its height. It includes intercostal cavities. Intermediate dumps are filled to the same height. To increase their volume, they are partially expanded. Thus, they are trapezoidal. The rocks from the adjacent penetration are placed in the intermediate dump near the pit contour, and the rocks from the first penetration are placed on the opposite side of the group dump. The dumping step depends on the penetration width, the dump height and the number of dragline moves required to place the rocks into the group dump.

Dump profiles combining different reclamation directions are shown in Figures 2 (b) and 2 (c).

3. Results and analysis

When assessing the overburden and dumping options, it is assumed that overburden and dumping works are performed by one dragline; the period of reclamation is two years more than the deposit development period; the area of reclaimed lands is the same (64.4 hectares). The volume of re-excavation works is considered as the volume of preparation works for subsequent reclamation works. The parameters of technological schemes and volumetric indicators were determined by the calculation and graphic method. The results are presented in Table 1.

Table 1. Parameters of overburden and dumping works.

| Parameters                                      | Option 1 | Option 2 | Option 3 |
|------------------------------------------------|----------|----------|----------|
| Number of intermediate dumps, pcs              | 1        | 2        | 3        |
| Average height of the group dump, m            | 28.4     | 25.0     | 20.4     |
| Land area occupied by dumps before reclamation, thousand m³ | 292      | 366      | 411      |
| Annual volume of overburden, thousand m³       | 1609     | 1160     | 1203     |
| Annual volume of re-excavation, thousand m³    | 80       | 537      | 469      |
| Volume of re-excavation per 1 m² of the reclaimed area, m³/m² | 38.7     | 25.1     | 21.3     |
| Current land capacity, m³/m²                   | 1.5      | 2.4      | 2.5      |
| The ratio of the reclaimed land area to the previously occupied dumps | 2.2      | 1.8      | 1.6      |

As a rule, efficiency of the mining technology is characterized by different indicators. For example, technical results are assessed by the performance of equipment, the amount of works, the area of disturbed land. The environmental impacts are mostly negative causing changes in the landscape. Evaluation criteria include land capacity and fertility of resources (e.g., the area and structure of lands). Economic results include current and integrated assessments of works using different types of profit, profitability, productivity, etc.

Assessment results according to the operational technical criteria.

Analysis of the results of studies on technological schemes involving formation of the dump surface for forestry and agriculture showed that the highest annual productivity (Option 1) can be achieved for a compact dump.

In schemes involving surface preparation for subsequent mining reclamation when filling intermediate dumps of the same height (Option 2), the best technical indicators (overburden performance and reduction of the number of transshipments) can be obtained for dumps with a height of 20.4 m. It makes it possible to form a group of three intermediate dumps.

A group dump including intermediate dumps of different heights (Option 3) allows us to reduce the number of transshipments by using the pre-dump; when forming inclined surfaces, it reduces the volume
of preparation works. The annual volume of overburden works is larger than in the schemes involving dumps of the same height, while the share of dump works is lower and does not exceed 19 %.

Environmental assessment (environmental management efficiency).

It is obvious that the area of land occupied by external dumps is larger when filling scattered dumps; smaller values correspond to a high group dump (29.3 ha) and a dump filled by excavator penetrations of different widths (35.4 ha).

When planning low dumps, it is necessary to use bulldozers. In the dump surface reclamation scheme with a decreasing height of the dump from 15.8 m to 10 m, the volume of preparation works will be 40% in relation to the volume of mining works and 79% in relation to re-excavation works. Depending on the dump height, the volume of preparation works varies in the range of 7.3 – 8.3 m³/ha.

At the end of deposit development, specific land capacity will be the same for all Options. The current land capacity is better for high dumps. However, if we take into account that it characterizes the use of land during the mining process, such environmental benefits will not be sufficient.

Economic assessment.

In the schemes with dumps of the same height, the share of cost of preparation works is 28 – 30 % of the total cost of excavation works; in the schemes with dumps with inclined surfaces, it is 23 %. Therefore, specific capital investment in these schemes will be lower. For scattered dumps (Option 2), specific capital investment is lower than for dumps 15.8 m. in height due to the reduced number of bulldozers.

4. Discussion

According to the general trends, one can observe a decrease in the annual productivity of draglines and an increase in the dump site area. Overburden and dump works, including the dispersion of intermediate dumps forming a group one, can reduce the volume of preparation works. Re-excavation works account for 22.9 – 31.6 % of the mining works.

Environmental performance indicators should be taken into account. The lower current land capacity achieved by filling high group dumps (1.5 m³/m³) does not allow us to assess efficiency of environmental works. In performing mining and reclamation works, this indicator will be 2.5 m³/m³; 3.5 m³/m³ and 3.7 m³/m³ for Options 1, 2 and 3 for high and scattered dumps. But if we evaluate the surface area after reclamation, the indicator will be better for the dumps with different slope angles (Option 3). The design of the final dump with different slope angles allows for the use of the reclaimed area for agricultural and forestry purposes. Successful reclamation will bring commercial benefits to the territories.

When justifying and choosing mining and reclamation technologies, basic and associated production objectives, involving achievement of positive social, ecological and economic results, should be taken into account. It is necessary to use a set of assessment criteria where efficiency and safety will be boundary parameters.

Let us analyze Options 1 and 2 as examples of decision justification. If you aim to achieve the best operational performance of the overburden and mining equipment, and the associated objective is to reduce a dump area, Option 1 is more preferable. It can be implemented for a short period. An increase in the reclaimed land area in relation to the dump area is 2.2 times. It can be achieved by increasing capital costs.

When the reduced volume of annual production of minerals and capital costs increase profitability, Option 2 can be more preferable. If we take into account that at the end of deposit development the area of reproduced land resources is the same and there is a small difference in the lifetime of the quarry and a significant decrease in capital investment in equipment, the income will increase.

5. Conclusion

Thus, when justifying overburden operations with external dumping by draglines, it is useful to study the dumping and the group dump designtaking into account possible partial performance of reclamation works.
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