SELECTION OF ENVIRONMENTALLY SAFE OPEN-PIT TECHNOLOGY FOR MINING WATER-BEARING DEPOSITS

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ВИБІР ЕКОЛОГІЧНО БЕЗПЕЧНОЇ ТЕХНОЛОГІЇ ВІДКРИТОЇ РОЗРОБКИ ОБВОДНЕНИХ РОДОВИЩ

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ABSTRACT

Purpose. Substantiation of environmentally acceptable technologies for surface mining of water-bearing placer deposits, taking into account the parameters of mining systems elements and areas damaged during mining of mineral deposits.

Methods. Selection of the most environmentally safe technology of surface mining is carried out with the help of technical analytical method by way of establishing parameters of mine workings and determining the instant area of workings for each technological scheme.

Findings. To conduct the research, we proposed to use index Δ which compares the actual position of inter-ramp angles and the inside dump angles with the maximum permitted values. The dependences of concentration degree K_K and area of workings Str on index Δ allow to infer that the technological scheme with a rotary excavator is more environmentally sound than the scheme with hydraulic excavators. Application of the former technological scheme makes it possible to reduce the area of disturbed lands by 8%. In the proposed scheme of mining Motronivske placer deposit, the concentration degree K_K reaches the maximum value 0.7, which corresponds to the minimum area of workings.

Originality. The most environmentally efficient technological scheme of surface mining deposits is the scheme with the highest mining concentration factor.

Practical implications. The results of the conducted research are of considerable practical value for the companies engaged in mining horizontal water-bearing deposits, which leads to disturbance of large land areas. In selecting a rational technological scheme for the surface mining of mineral deposits, it is proposed to consider not only economic indicators, but also the possibility of the disturbed land areas reduction.

Keywords: surface mining, mining technology, environmentally safe technology, water-bearing deposit, dredge

1. INTRODUCTION

A considerable amount of mineral resources is concentrated in deposits located in water-saturated soils. However, from year to year mining conditions become more difficult and environmental requirements get stronger. Therefore, mining companies should pay more attention to all economic, environmental, social, and legislative aspects of mining (Drebenstedt & Schmieder, 2005).

There are many factors affecting mining methods due to which the procedure of making a decision about technology to use is rather difficult (Gumenik, Lozhnikov, & Panasenko, 2013). These researches are aimed at the selection of a surface mining method in terms of environmental aspects for the case when mineral deposits are located in water-saturated soils. The choice of available mining technologies is based on the environmental impact, as well as economic and social aspects. Its implementation will enable to improve decision-making mechanism, providing the best solutions for a mining region.

Nowadays the problem of mining technology in water-saturated deposits in Ukraine is related to titanium ores exploration. The total reserves and resources of

titanium ores exceed the world's reserves of ilmenite. More than 40 deposits of titanium-zirconium ores were discovered in Ukraine, including the unique Malyshevske deposit. Up to 20 deposits of ilmenite and complex ores have been explored in the Volyn Region. They are confined to the northwestern part of Ukrainian crystalline shield within the Volodar-Volyn rocks massif.

The Motronivske-Annovske placer deposit (MAP) is the part of Malyshevske deposit with huge mineral resources and significant advantages of geological and technological parameters in comparison with other ilmenite deposits – it concerns particularly the thickness of the ore deposit in terms of proven reserves and ore minerals grain size. The main feature of MAP is the fact that the ore seam is located below the groundwater level in the Neogene aquifer. Therefore, in conditions of placer deposit, implementation of technological schemes that are used on actual pits of Vilnohirsk mining processing plant (MPP) is complicated by the current ore properties and water-bearing rocks.

It should be noted that hydrogeological conditions of the watered part of the Motronivske deposit are not fully studied. In this regard, all calculations of water in the future pit and the proposed drainage systems previously carried out by various organizations were not well-grounded.

The conducted research departs from the main methodological principles of the theory and practice of deposits surface mining, taking into account the water-saturated rocks, as reflected in the scientific works of G. Nurok, M. Abzalov, J. Jansen, B. Weinrib and others (Weinrib, 2015; Abzalov, 2016; Jansen, 2016).

Having analyzed mining methods of placer and water-bearing deposits described in these scientific works, we came to the conclusion that underwater ore mining is rather widely implemented in mining industry while the mechanical mining of overburden rocks does not affect underwater technology of ore mining.

At the same time, currently there are no specific recommendations for the use of hydro mechanization facilities for exploration of water-bearing deposits of titanium-zirconium ores characterized by specific water saturation and low water level. During the underwater mining, when ore is lying below the aquifer, it is necessary to study in detail how hydrogeological conditions change at different stages of the deposit development which is related to the problem of water-bearing deposits mining impact on the environment. That is why those pits should also be the subject of thorough research.

The topicality of this problem arises from the necessity to achieve cost efficiency of the titanium deposits development, given mining industry produces an essential influence on GDP in Ukraine. However, the profit from the water-bearing deposit development should not be the only factor to consider when selecting a technological mining scheme. The second criterion is to choose the environmental indicator of the technological scheme of placer deposit development, which takes into account the impact of mining on the environment.

In this concern, it is important to use the experience of mining industry in Germany that is established as a leader in the safety and environmental standards worldwide.

2. THE MAIN PART OF THE ARTICLE

In the process of selecting a mining technological scheme in terms of environmental evaluation of water-bearing deposits, the objective will be achieved by solving the following tasks: determination of mining technologies suitable for the development of water-saturated soils which include mechanical and hydromechanical methods of mining; determination of mechanical and hydromechanical mining methods efficiency by the CAPEX and OPEX; selection of theoretical methods for determination of technological, hydrogeological, and environmental parameters for conducting environmental and economical evaluation of mining in water-saturated soils; development of a comparative method integrating factors associated with the most rational mining scheme with minimum negative impact on the environment and maximum feasibility of mining; comparison of economic and environmental efficiency of the existing technological schemes of water-bearing deposits mining.

Estimation of environmental risks and lands damage while mining water-saturated soils will be done via development of a method for the complex analysis of mining influence on the qualitative characteristics of groundwater, stability of overall slope angles, areas of lands damaged by surface mining taking into account mining and geological conditions, as well as mining technology (Golovach & Volovik, 2008).

The choice of the environmentally friendly mining method for deposits in water-saturated soils must be based on: hydrogeological evaluation of the deposit, stability of the overall pit and dump slopes, the area of land disturbed by workings, the possibility of storing overburden rocks in the gob, using of modern mining equipment, etc.

We compared several schemes of mining deposits in water-saturated soils with available mechanical and hydromechanical mining (dredging) equipment. The assessment of environmentally-friendly mining machinery takes into account environmental effects, economic/commercial and social aspects. These aspects are closely interrelated, as the lower environmental impact, the cleaner and healthier the workplace, and the fewer complaints from neighbors (Elsayed, 2013).

As of today, there is no method for environmental evaluation of schemes for mining deposits in water-saturated soils. For the first time ever, the water-saturated soils will be considered as the main object for conducting complex technological, environmental, economic, and social assessment of mining (Pivniak, Gumenik, Drebenshtedt, & Panasenko, 2011). Implementation of the research results will allow to develop the choice method, which provides rational solutions in mining technology on the basis of input-output data analysis of the obtained models, taking into account mining and hydrogeological conditions of the deposit.

During the research we estimated ecological efficiency of two most common titanium-zirconium ores mining technologies in water-saturated soils. Such water-bearing deposits can be mined by well-known methods: using mechanical with dewatering wells (dragline) and trucks haulage or hydromechanical mining equipment (dredge) with hydraulic haulage (Fig. 1).

(a)

(b)
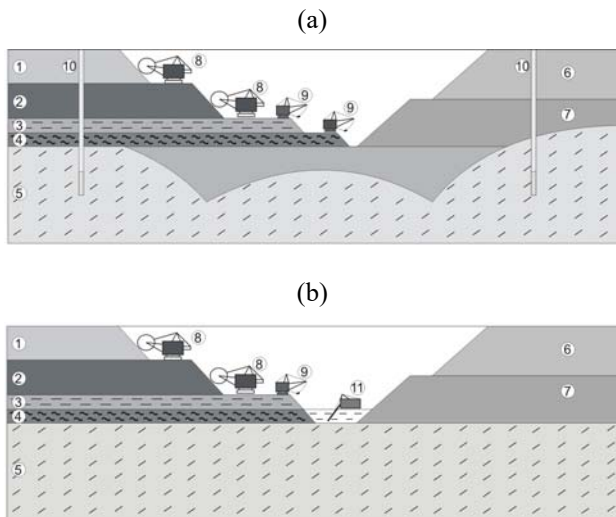
Figure 1. Schemes of mining in water-saturated soils: (a) mechanical mining method; (b) hydromechanical (combined) mining method; 1, 2 – overburden rocks; 3 – rocks with aquifer; 4 – mineral deposit; 5 – aquifer; 6, 7 – inpit dumps; 8 – rotary excavator; 9 – dragline; 10 – pumping well; 11 – dredge

Each of them has its own advantages and disadvantages in terms of economic and environmental impacts, so while choosing between two mining schemes it is necessary to conduct a detailed analysis.

To justify the mining schemes (Fig. 1) and technologies of water-bearing deposits mining using hydromechanical mining method, technological parameters of the following operations were determined:

– working of the dry part of the soil massif by means of mechanical method;

– working of the water-bearing part of the soil massif by means of hydromechanical method;

– mining of mineral resources by means of hydromechanical method;

– dumping of waste and clay slimes into the tailing pond;

– dumping of sandy waste into the working;

– formation of dumps in the working.

For the purpose of the research we have used the following equipment: suction dredges, bucket dredges, and other floating or land mounted mining machinery. The obtained results and calculation of capital and exploitation costs formed the basis for working out recommendations on the use of hydromechanical mining method.

Mining technology is justified by the results of studying geotechnical conditions for the case of the traditional opencast scheme of mining water-bearing deposits. On the basis of the data obtained, the influence of water on the opencast bench stability as well as the available method of quarry drainage can be estimated.

Mining technology analysis is used as the basic component of the method for environmental evaluation of mining in water-saturated soils. This component will enable to conduct further environmental impact analysis (working parameters, surface land disturbance, etc.), and to establish economic indicators of mining (productivity, energy consumption, costs, etc.).

Changes in qualitative characteristics of water body during mining are estimated on the basis of simulating

water inflow, taking into account characteristics of the deposit (mining and hydrogeological conditions, formation flow characteristics, chemical content of soils, etc.) and mining technology (Sobko, Lozhnikov, Haidin, & Laznikov, 2016). Changes in surface and ground water conditions can influence the climate, deformation of the surface which sustains vitality of vegetation, yield performance, biodiversity.

The assessment of an environmentally-friendly mining technique should take into account not only environmental effects, but also economic/commercial and social aspects.

It should be also considered to what degree minimization takes into account social requirements to costs and environmental aspects, because an environmentally-friendly and cost-effective technique should be socially acceptable as well. Environmental, economic/commercial and social aspects are closely interrelated, because the lower the environmental impact, the cleaner and healthier the workplace, and the fewer complaints from the neighborhood. That is why cost efficiency is not the only criteria for surface mining.

Evaluating environmental efficiency of technology for mining water-bearing deposits according to the listed criteria is a complex process and requires a large number of theoretical studies. However, it is irrefutable that the volume and extent of pollution caused by gobs are directly proportional to the area of workings or active area of the quarry.

The preliminary research made it clear that mining of deposits in water-saturated soils implementing technological scheme based on the mechanical method of mineral extraction is not economically feasible. In addition to significant pit drainage costs, operating costs for minerals haulage are several times higher than in the case of hydraulic haulage.

The present research showed that net present value (NPV) for the technological scheme (Fig. 1b) with hydromechanical mining method is 4.02 times lower than NPV in the scheme where ore and lower rocks are excavated by draglines and trucks.

We have conducted not only comparative technical and economic assessment of the technological schemes of mining operations efficiency but also calculated general discounted economic technical and economic indicators during the development of MAP. Comparison of the capital investments efficiency indicators in the process of selecting implementation technological scheme showed that schemes with hydromechanical method are the most effective for mining on the ore bench.

To specify and determine a more efficient scheme for the development of the water-bearing deposit, the existent scheme with the use of hydraulic excavators on overburden benches was also considered. The advantage of this scheme is that the use of hydraulic excavators can significantly reduce capital costs, but the use of truck haulage significantly increases operating costs. Therefore, it is necessary to carry out additional technical and economic studies to select the most effective scheme.

Two technological schemes for mining deposits in water-saturated soils were suggested. The first scheme is presented in Figure 1b, and the second scheme with hydromechanization method on ore bench and mechanical mining on overburden benches with hydraulic excavators is shown in Figure 2.
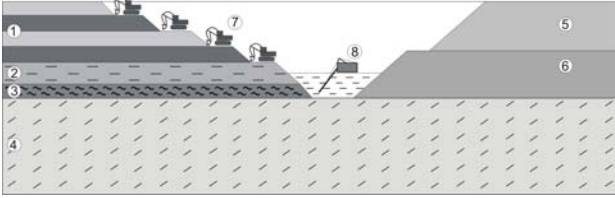
Figure 2. Scheme of mining in water-saturated soils by hydro-mechanical (combined) mining method: 1 – overburden rocks are mined by the shovel excavator; 2 – overburden rocks with aquifer are mined by the dredge; 3 – mineral deposit; 4 – aquifer; 5, 6 – inpit dumps; 7 – hydraulic excavators; 8 – dredge

The conducted research testified that operating costs for the scheme with rotary excavators and the dredge are 1.63 times lower than for the scheme with hydraulic excavators and the dredge.

After determination of the two most cost-effective technological schemes for the development of Motronivske pit, we analyzed the environmental effect produced by each of them, taking into account the disturbance of the land area caused by mining operations.

Hence, while studying the impact of mining on the ecological condition of the mining region, it is proposed to determine the total mining working area for each mining system with different equipment.

For the purpose of comparing the first (Fig. 1b) and second schemes (Fig. 2) of mining in Motronivske pit according to the criterion of the quarry area, it is proposed to use the concentration degree index of mining operations (Sobko, 2008). This indicator represents the ratio of the minimum permissible area of the pit working space according to the index of maximum overall slope stability to the actual, and comparing the area of pit working.

This criterion has the advantage of taking into account the main parameters of the pit working area. Change of those parameters influences the technological indicators, which are directly related to the economic evaluation of technological solutions.

Concentration degree index is calculated by the formula:

$$K_K = \frac{S_{MA}}{S_F}, \qquad (1)$$

where:

S_{MA} – minimum permissible area of the pit workings at the condition of the slope stability, ha;

S_F – actual area of pit workings under condition of pit slope stability, ha.

In order to calculate this index, it is necessary to establish the minimum permissible angles of safety, dumps and pit slopes for the rotary and hydraulic excavator based technological schemes of mining.

S_{MA} area is calculated according to the formula:

$$S_{MA} = L_P \cdot \left((H+h) \cdot (ctg\varphi + ctg\beta) + a\right), \text{ha}, \qquad (2)$$

where:

L_P – length of the working trench on the surface, m;

H – thickness of overburden rocks, m;

h – thickness of the mineral deposit, m;

φ – overall pit slope angle, degrees;

β – overall slope angle of the inner dump, degrees;

a – width of the pit floor, m.

S_F area is calculated according to the formula:

$$S_F = L_F \cdot \left((H+h) \cdot (ctg\varphi_S + ctg\beta_S) + a\right), \text{ha}, \qquad (3)$$

where:

L_F – minimum permissible length of the working trench on the surface, m;

φ_S – maximum steady overall pit slope angle, degrees;

β_S – maximum steady overall dump slope angle, degrees.

The overall inter-ramp angle of the first and second schemes is calculated by the formula:

$$\varphi = arctg \frac{H_P + h}{\sum_{i=1}^{n} h_i ctg\alpha_i + \sum_{i=1}^{n} H_P ctg\gamma_i + \sum_{i=1}^{n} W_{P_i}}, \text{degrees}, \qquad (4)$$

where:

n – number of benches;

i – serial number of a bench;

H_P – height of the overburden bench, m;

h – thickness of mineral deposit, m;

α – inter-ramp angle, degrees;

γ – dump slope angle, degrees;

W_P – road and ramp width, m.

The overall slope angle of the internal dump for each technological scheme is calculated according to the following formula:

$$\beta = arctg \frac{H_B \cdot K_P}{\sum_{i=1}^{n} H_{B_i} ctg\beta_i + W_{B2} + W_{B3}}, \text{degrees}, \qquad (5)$$

where:

n – number of benches in the dumps;

i – serial number of the dump;

H_B – height of the dump, m;

K_P – coefficient of overlying rocks loosening;

β – dump bench slope angle, degrees;
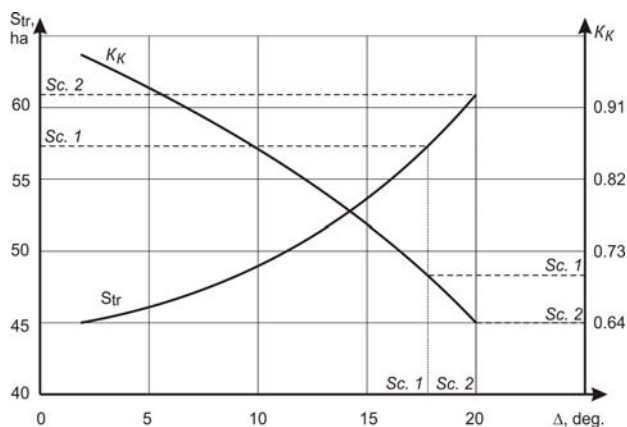
W_B – width of the dump bench working area, m.

According to the results of the present research, it was determined that the maximum stable overall inter-ramp angle in conditions of Motronivske pit is 31.36° and overall dump slope angle – 18.37°.

For the first technological scheme with the rotary excavator on overburden benches, the overall slope angle of the pit working is 16.0° and for the dump – 14.8°. For the second scheme with hydraulic excavator on the overburden benches, the overall pit slope angle is 13.5° and the dump slope angle – 15.0°.

In order to evaluate the considered technological schemes, it was proposed to use index Δ which compares the existent overall slopes of the pit working and internal dump with the maximum permissible angles. Those angles were determined by calculating concentration degree index of mining operations:

$$\Delta = (\varphi_S + \beta_S) - (\varphi + \beta). \qquad (6)$$

Figure 3 shows the research results related to determination of the dependence of the concentration degree index K_K and the area of mining working S_{tr} on the index Δ for the two technological schemes.

8%. При цій технологічній схемі розробки Мотронівського родовища ступінь концентрації K_K досягає максимального значення 0.7, що відповідає мінімальній площі гірничих виробок.

Наукова новизна. Найбільш екологічно ефективною технологічною схемою відкритої розробки родовища є схема із застосуванням гідромеханічного способу розробки корисної копалини та з найбільшим коефіцієнтом концентрації гірничих робіт.

Практична значимість. Результати виконаних досліджень мають важливе практичне значення для підприємств, які виконують розробку горизонтальних обводнених родовищ з порушенням великих площ землі. При виборі раціональної технологічної схеми розробки корисної копалини відкритим способом пропонується розраховувати не тільки економічні показники, а також враховувати можливість скорочення площ порушених земель.

Ключові слова: відкриті гірничі роботи, технологія видобування, екологічно-безпечні технології, обводнені родовища, драга

ABSTRACT (IN RUSSIAN)

Цель. Обоснование экологически приемлемых технологий открытой разработки обводненных россыпных месторождений с учетом параметров элементов систем разработки и площадей земель, нарушаемых при добыче полезного ископаемого.

Методика. Выбор наиболее экологически безопасной технологии открытых горных работ выполняется с использованием метода технико-аналитического анализа путем установления параметров горных выработок и определения непосредственной площади горных выработок для каждой из технологических схем.

Результаты. При выполнении исследований предложен показатель Δ, который сравнивает существующее положение углов откосов рабочего борта и внутреннего отвала с максимально допустимыми значениями. Зависимость показателей степени концентрации K_K и площади горных выработок Str от индекса Δ позволяет определить, что технологическая схема с применением роторного экскаватора более экологически безопасна, чем схема с гидравлическими экскаваторами. Применение данной схемы позволяет уменьшить площадь нарушенных земель открытыми работами на 8%. При этой технологической схеме разработки Мотроновского месторождения степень концентрации K_K достигает максимального значения 0.7, что соответствует минимальной площади горных выработок.

Научная новизна. Наиболее экологически эффективной технологической схемой открытой разработки обводненного месторождения является схема с применением гидромеханического способа разработки и наибольшим коэффициентом концентрации горных работ.

Практическая значимость. Результаты выполненных исследований имеют важное практическое значение для предприятий, выполняющих разработку горизонтальных обводненных месторождений с нарушением больших площадей земель. При выборе рациональной технологической схемы разработки полезного ископаемого открытым способом предлагается рассчитывать не только экономические показатели разработки, а также учитывать возможности сокращения площадей нарушенных земель.

Ключевые слова: открытые горные работы, технология добычи, экологически безопасные технологии, обводненное месторождение, драга

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