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EXPERIENCE OF METAL DEPOSITS COMBINED DEVELOPMENT FOR SOUTH AFRICAN ENTERPRISES

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ДОСВІД КОМБІНОВАНОЇ РОЗРОБКИ МЕТАЛЕВИХ РОДОВИЩ – ДЛЯ ПІВДЕННО-АФРИКАНСЬКИХ ПІДПРИЄМСТВ

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ABSTRACT

Purpose. To solve technological and ecological problems of South Africa and other countries using the experience of Russian, Kazakh and Ukrainian miners in mining metals by the combination of traditional and new technologies. The ultimate aim of environmental protection concept is waste-free minerals mining with full utilization of the components produced from mined raw materials.

Methods. The technology based on leaching metals from ores is used as an alternative to the traditional technology of metal production, i.e. in-situ extracting metals from ores.

Findings. A brief review of the state of metal production in the world is presented. The environmental trends of mining engineering humanization in technologically advanced countries are defined. The experience of underground leaching of uranium is described. The results of pioneer experiments on the extraction of metals using combined mechanic and chemical treatment in the disintegrator are provided. Economic-mathematical models have been developed in order to determine efficiency of using combined technologies and simulate results of metal extraction.

Originality. The effectiveness of combining technologies of mining deposits was assessed by comparative analysis of completeness of the valuable component extraction using traditional and combined methods of mining. The comparative analysis on two criteria allows to determine the optimal value of profits and choose the best way of metal beneficiation.

Practical implications. The experience of combining technologies can be used at enterprises of South Africa. The economic and mathematical models for determining effectiveness of combined technology and simulating results of metal extraction are developed for a specific case study. Recommendations for using the experience of stripped minerals leaching are given.

Keywords: *metal, environmental protection, mining minerals, in-situ leaching, mechanochemistry, disintegrator*

1. INTRODUCTION

With the development of scientific and technological revolution of our time, many countries are experiencing difficulties with supply of industry by metals. Industrial reserves of exploited ore deposits naturally decrease, and the metal content in saleable ores decreases, increasing the production cost of metals. This stimulates the selective mining of deposit areas and increases the loss of ores and metals in mining.

Only 5 – 10% of the total volume of extracted substances from the bowels is realized in the form of products, and the rest are waste. The vast majority of the extracted rock mass is storage object with a negative impact on the environment.

Mining operations each year violate about 150 thousand hectares of land, about 40% of them – agricultural land. Production of 1 million tons of iron ore violates 650 hectares of land, coal – up to 40 hectares, chemical raw materials – up to 100 hectares, 1 million m^3 of building materials – up to 600 hectares, 1 ton of nonferrous metals accounts at least 100 – 150 tons of waste during mining and over 50 – 60 tons during processing. During production of 1 ton of rare, precious and radioactive metals are formed up to 5 – 10 thousand tons of wastes, and during processing 10 – 100 thousand tons (Golik, Komachshenko, & Morkun, 2015a). The thousands of tons of complex ores are discharged in water. Metal mines form metal scattering halos, according to metal content comparable with the reserves in the bowels (Golik & Komachshenko, 2010). Involvement in the exploitation of the poor fields with difficult operating conditions, and the backlog of enrichment opportunities from mining capabilities increases the number of production and processing tailings.

The systems of state management of subsoil in developed countries are trying to protect the subsoil from the mismanagement by subsoil users and provide effective development of environmental technologies (Morkun, Morkun, & Pikilnyak, 2014).

The current state of metal production is characterized by the regulations (Golik, Rasorenov, & Efremenkov, 2014):

– traditional enrichment processes do not provide full disclosure of minerals and do not decrease hazard of chemical contamination during storage of tailings;

– combined use of new energy types is promising direction in extraction of metals from tailings.

Involving in processing the chemicalization sources of environment ecosystem simultaneously solves two problems of global significance: the hardening of the mineral resource base of mining companies and conservation from degradation unique recreational regions of the Earth.

The most developed mining countries in the world include South Africa Republic. South Africa occupies a leading position in Africa on the world's reserves of uranium, gold and copper ores localized in carbonatite, sulphide deposits and deposits of hydrothermal type.

South Africa occupies a priority position among the industrially developed capitalist and developing countries for raw uranium production, which is extracted simultaneously with the processing of gold-bearing conglomerates of the Witwatersrand. The country has about one thousand – mining enterprises, mines and quarries.

Gold deposits still remain the largest in the world. South Africa accounts 12% of all of the world's uranium reserves. According to uranium production volume the country is on second place after United States and Canada, despite the fact that the metal content in the ore is only 0.02 – 0.03% of uranium oxide. Gold production is economically justified because the uranium is mined as a byproduct of gold and by-production of uranium extends production life of gold mines.

In underground mining of nonferrous metal ores prevails gross breaking without division into grades. Systems of development layered, sublevel and level caving are characterized by ore losses and dilution. Deposits are developed by underground mining systems with goaf stowing: using solid and long lava leaving pillars. The average depth of the development is 2.5 km, the maximum – 4 km.

Platinum is mined using underground way, and along with platinum: palladium, ruthenium, rhodium, osmium, iridium.

Ore is enriched at mines with extraction of nickel and copper. For vein type deposits the increased depth of mining operations (1000 – 1500 m or more) is accompanied by the activation of dynamic phenomena. The desire to maximize the use of balance and off-balance ore reserves led to the emergence of leaching technology of uranium ores in-situ in recent years.

The environmental situation in South Africa is characterized by high degradation rates of unique natural environment. The environmental crisis has come here for a few decades earlier than in developed countries and it is connected with intense resource exploitation. South Africa solves common problems of development, including the priority role played by overexploitation of natural resources.

In South Africa, with its exceptional variety of natural-climatic zones and landscapes, an area of 1.1 million km^2 is inhabited by nearly 10% of the world's known species of birds, fish and plants, and more than 6% of the species of mammals and reptiles. Up to 10% of these species are rare and endemic. Mining industry is hazard primarily for biodiversity in the country.

The state controls the interaction between major mining companies and environment ecosystems during mining of solid minerals, simulating a potential negative impact on environmentally sensitive areas and objects of the environment, but a number of problems of South African mining industry remains, including disposal of tailing reserves and provision raw materials for the production of hardening mixtures.

The peculiarity of the situation is that the non-ferrous ores, precious and rare metals are complex and the use of tailings without extraction of the remaining metals is economically and ecologically incorrect (Polukhin, Komashcenko, Golik, & Drebenstedt, 2014).

Another feature is that the base metals such as gold, uranium, copper, zinc and others are easy-open, what increases the possibility of a relatively new leaching technology.

In solving the technological and ecological problems of South Africa and other countries the experience of the Russian, Kazakh and Ukrainian miners on production of metals combining traditional and new technologies can be useful (Golik, Komashchenko, & Morkun, 2015b; Golik, Komashchenko, & Morkun, 2015c; Golik, Komashchenko, & Drebenstedt, 2014).

2. METHODS AND RESEARCH MATERIALS

Environmental humanization trends of mining engineering in the second half of the twentieth century gave rise to a class of technologies with stowing: discrete dry, hydraulic, clay and finally a radical effect on the array state - monolithic hardening stowing (Fig. 1).

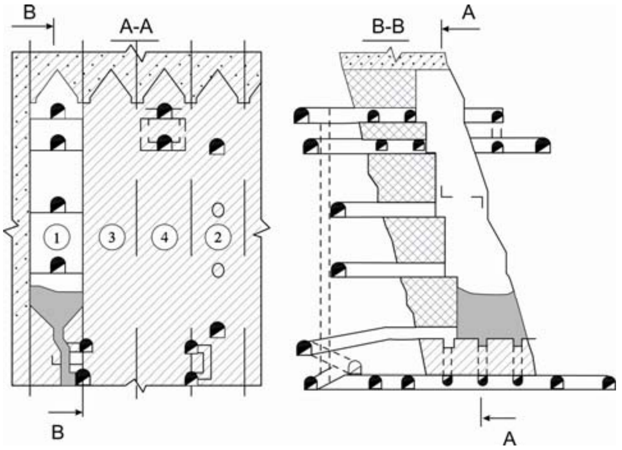

Figure 1. Development system with breaking by sublevel orts with stowing by hardening mixture: 1 – 4 – are the extraction sequence of reserves

With undeniable merits, especially the preservation of the array from the destruction with high-quality of extracted ores, technologies with stowing require the hoisting to the surface for processing not only all ore, but also diluting rocks.

This weakness is mostly fixed by the use of technology with leaching metals. The use of these technologies transfers mining process into the depths. Many of the exploited metal deposits turned into anthropogenic, subjected to re-mining, for example, deposits of Sadon ore belt (North Ossetia-Alania), the age of mining is 200 years. They are composed of already separated from the array and fractured rock mass available for chemical leaching. The condition for application of these technologies is provision of reacting particles sizes, uniformity of arrays and associated filtration capacity of ores (Golik, Komashshenko, & Razorenov, 2014).

Investigation of leaching issues that form the re-mining problem of lost and off-balance ore deposits, primarily uranium, has begun over 30 years ago as an alternative to the pyrometallurgical methods, the use of which is dangerous for environment. In technologically advanced countries are developed geotechnical methods of production of metals using chemical dissolution. Most often it is uranium, gold, copper, zinc (Komashchenko & Erokhin, 2013).

New and traditional mining technologies of balance and off-balance reserves are combined to improve the economic efficiency. In-situ leaching of off-balance ores was applied in the uranium deposit of the North Caucasus. After stoping of balance reserves uranium was cost-effectively leached for 30 years with the content in the ore, 2 times less than the balance level.

In-situ leaching of balance ores was carried out in uranium deposit (Northern Kazakhstan). The lenticular ore body in intensely fractured rocks with hardness of 4 – 6 according to M.M. Protodiakonov was mined. Block dimensions, meters: length – 30; width – 5; height – 30. Ore loss ratio was 1.12. Metal extraction ratio in solution was 72% (Morkun & Tron, 2014).

Heap leaching of metals is carried out in parallel with underground leaching and it is extended to gold, copper and uranium mines as the disposal possibility of primary processing tailings.

Strategy of environmental technologies is based on the following provisions:

– unreasonableness of technologies is expressed in the loss of natural resources;

– degradation of ecosystems is the result of unreasonable technologies, so the value of profit from the sale of commercial products must be reduced by the amount of compensation for damage to the environment.

Mining production is considered safe if anthropogenic perturbation of the ecosystem does not exceed the level at which its biota retains the ability to recover. Technologies vary in their hazard level: hazardous (with open goaf, caving, shrinkage, barring, etc.), intermediate: extraction of metals in situ, when reinforced tails are a special case of hardening stowing, and safe: with filling voids by hardening mixtures.

The most hazardous technologies are with caving when the surface of the Earth is destroyed, along with its ecosystem. Even more hazardous technology are the ones when the safety of the lithosphere is declared but not guaranteed (with shrinkage, barring).

Directions of hazard mitigation include: extraction of rich ore with stowing voids by hardening mixtures; in-situ leaching of poor and lost ores; heap leaching of poor ores winded to surface; leaching of enrichment and metallurgical tailings with activation in devices such as a disintegrator.

Hardening mixtures are effective tool for array management by controlling the strains in the array. Arrays are divided into geomechanicaly balanced areas by combining compositions of hardening stowing with different stiffness, dry stowing, leaving cavities unfilled or filled with tails of in-situ leaching. The disadvantage of this technology is that for production of hardening mixture components the lithosphere must be destroyed again. Therefore, the use for these purposes not natural but recyclable materials is the main direction (Morkun, Morkun, & Tron, 2015).

Technology with leaching metals from ores is an alternative to the traditional technology of metal production, in-situ extracting metals from ores.

Opening minerals by chemicals allows extracting up to 50 – 70% of metals. Rich ores are transferred to the surface and processed at the plant, and the rest - in the underground blocks and piles on the surface. The final by-products of technology the implementation of which reduces the cost of the main production are metals, construction materials, desalinated water, chlorine, hydrogen, oxygen, acids and alkali.

The final aim of environmental protection concept is waste-free mining production with full utilization of the components produced from mined raw materials. It includes:

– mitigation of ore dilution by rocks when stowing voids by hardening mixtures;

– maximum use of reserves when leaching poor and low-grade ores;

– hydrometallurgical processing of ores with extraction of all valuable components.

Disposal of tailing resources is possible only after the extraction of the metals to the level of sanitary requirements. Such requirements are met by the new technology with impact on mineral resources at the same time by mechanical and chemical energy in the activators of disintegrator type (Komashchenko, Golik, & Drebenshtedt, 2010).

Prospects for stowing technologies involve the use of tailings after extraction of metals and leaching tailings. The leached ores that remain in-situ at the end of the metal extraction are bonded by natural binders to the array, the strength of which is comparable with the strength of hardening mixtures at low cement consumption (0.5 – 1 megapascal).

Ore mining technologies are ranked on the basis of resource use (Table 1):

– optimization of outcrop spans, pillar sizes and influence zones of mines;

– combination of technologies in the development stages;

– filling out of caved space by mining wastes.

The influence zone height of mining operations on the array is determined by the size and the ratio of the structural rock blocks and stress:

$$h = \frac{l}{V}, \tag{1}$$

where:

V – the coefficient of rock stability;

l – arch span, m.

$$V = 2\frac{d_2}{d_1}\frac{R_{comp}^2}{R_{comp}^1}, \tag{2}$$

where:

d_2, d_1 – the vertical and horizontal dimensions of rock blocks, m;

R^1_{comp}, R^2_{comp} – are the compressive strength of rocks in the direction of arch thrust and in the direction of the rock mass.

When combining technologies geomechanical factors are accounted.

An array is safe, while ensuring conditions:

$$H > h = \frac{l}{2V} = \frac{l}{4\dfrac{d_2}{d_1}\dfrac{R''_{comp}}{R'_{comp}}}. \tag{3}$$

Table 1. Typification of ore mining technologies

Types of technology	Characteristic features	Waste utilization	Land state
Hazardous With rock caving	Increased ore dilution	Accumulation of wastes without utilization	Complete degradation of the land in the zone of influence
Safe With stowing voids by hardening mixtures With stowing by leaching tailings	Minimal ore dilution without transfer to surface	Full utilization of own and related industry wastes	Exclusion of land degradation in the affected area
Combined Combination of types with leaving part of voids unfilled	Ore dilution by rocks, depending on the volume of combining	Utilization of production wastes depending on the volume of combining	Limited impact on the land in the case of violation of technological regimes

Dimensions of pillar ensuring its safety within the influence area of voids:

$$b = \frac{l\gamma\left(H - \dfrac{2}{3h}\right)}{\sigma_{comp} - \gamma H K_s}, \tag{4}$$

where:

b – the width of the pillar, m;

l – maximum arch span, m;

γ – bulk weight of rocks;

H – the depth of works, m;

h – the height of the impact zone of mining operations on the array, m;

σ_{comp} – compressive strength of rocks, MPa;

K_s – the safety factor.

The arch span of the self-blocking of rocks:

$$l = 2d_1\left(\frac{10R_{comp}}{K_s H\gamma}l\right), \tag{5}$$

where:

l – span of limit self-blocking arch, m;

d_1 – horizontal size of the structure block of rocks, m;

R_{comp} – resistance to compression in the direction of rock weight, kg/cm^2;

10 – conversion factor from kg/cm^2 into ton/m^2;

γ – bulk weight of rocks, ton/m^3;

H – the depth of the arch foots, m;

K_s – the safety factor.

Depending on the natural and economic conditions, the mining enterprise is going through one or several stages (Fig. 2) (Golik, Komachshenko, & Morkun, (2015d).

The first stage is characterized by advanced stoping of rich deposit sites, and losses are compensated by increased hoisting of rich ores. The second stage is characterized by decrease of rich ore reserves, and a decrease in ore grades is compensated by an increase in production volume. The third stage – extraction of metals from substandard ores and recycling wastes.

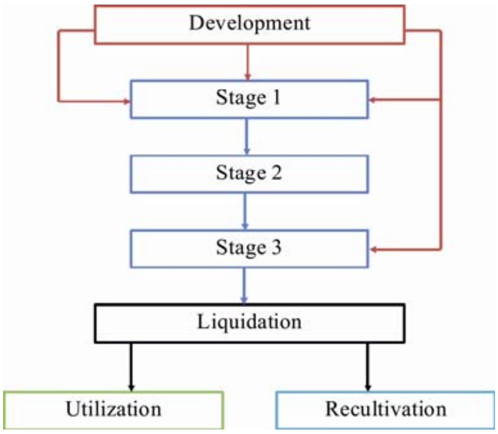

Figure 2. Stages of mine development

The optimal scheme of development of the deposit is the rational use of stages in time and space (Fig. 3).

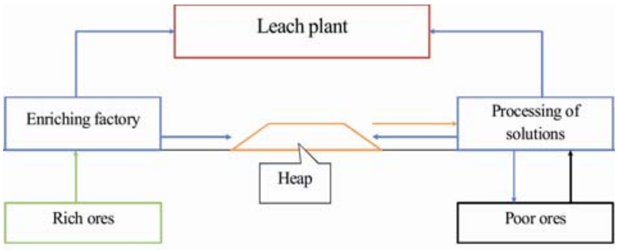

Figure 3. The optimized deposit development scheme

The effectiveness of deposit development in the first stage (Burdzieva, Shevchenko, & Ermishina, 2010):

$$\sum_{1}^{t} P_1 = \sum_{1}^{t_1} A_1 (v_1 - c_1) / (1+E)^{t_1 - 1}, \qquad A_1 = f(R_b) = (R_e - R_{l+o}) \tag{6}$$

where:

P_1 – profit, rubles;
A_1 – production capacity of enterprise, tons/year;
v_1 – enriched ore value, rubles/unit;
c_1 – the cost of production and processing, rubles/unit;
E – the discount rate, fraction units;
R_b – balance ore reserves, tons;
R_e – estimated reserves, tons;
R_{l+o} – reserves of low-grade and off-balance ores.

The effectiveness of field development in the second stage:

$$\sum_{1}^{l} P_2 = \frac{1}{(1+E)^{\Delta t}} \sum_{1}^{t_2} A_2 (v_2 - c_2) / (1+E)^{t_2 - 1}, \qquad A_2 = f(R_{l+0}) = (R_e - R_b) \tag{7}$$

where:

P_2 – profit, rubles;
A_2 – production capacity of enterprise, tons/year;
v_2 – enriched ore value, rubles/unit;
c_2 – the cost of production and processing, rubles/unit;
E – the discount rate of costs and profit, fraction units;
R_b – balance ore reserves, tons;
R_e – estimated reserves, tons;
R_{l+o} – reserves of low-grade and off-balance ores.

The effectiveness of field development in the third stage:

$$\sum_{1}^{t} P_3 = \frac{1}{(1+E)^{\Delta t}} \sum_{1}^{t_3} A_3 (v_3 - c_3) / (1+E)^{t_3 - 1}, \qquad A_3 = f(R_{o+t}) = (R_e - R_b) \tag{8}$$

where:

P_3 – profit, rubles;
A_3 – production capacity of enterprise, tons/year;
v_3 – enriched ore value, rubles/unit;
c_3 – the cost of production and processing, rubles/unit;
E – the discount rate, fraction units;
R_b – balance ore reserves, tons;
R_e – estimated reserves, tons;
R_{o+t} – off-balance ores and tailing reserves.

To compare the effectiveness of variants the analysis of production function in the modern models of economic growth for conditions: from raw material in the metallurgical plant will extracted 40% of metal with extraction ratio of 0.93. From 50% of balance reserves that remain for in-situ leaching with extraction ratio of 0.8, and taking into account solution processing losses, 39% of the metal will be obtained. For the content of the metal in off-balance ores 1 gram/ton in the final product 2.3% of the metal will be extracted, and through extraction ratio will be 0.88 (Polukhin, Komashcenko, Golik, & Drebenstedt, 2014).

The maximum values of the target function are associated with a combination of traditional technology and in-situ leaching in stage 2. For average metal content the most effective combination of technologies is the ratio of 15% – traditional technology (TT), and 85% – in-situ leaching (ISL). For rich ores an optimal ratio of technologies is 40% – traditional technology and 60% in-situ leaching.

For combined technology, when 40% of the ore is raised to the surface, while 60% of ore is leached in-situ, with the same rock mass productivity the metal productivity is 2 times higher than for traditional method. Operational efficiency of mining plant worker counted for metal increases by 1.5 times. When increasing the metal productivity of the mine by 1.5 times the mine productivity on rock mass raise accounts only 40% of that of the traditional method. To increase the annual downward of mining operations in accordance with the increase in productivity by 1.5 times the ore areas that are in simultaneous development increases by 3 times.

Main production reduces the price of commercial products from waste:

– metals and non-metals in the form of salts and oxides;
– secondary tails with the content of ingredients below the maximum allowable concentration;
– demineralized water for heating, cooling and other purposes;
– gas products: chlorine, hydrogen and oxygen.

Profit from the extraction of metals from tailings with damage to the environment:

$$P_x = \frac{\sum_{1}^{n_o} (S_{TO} - Z_{OO} - Z_{OM}) Q_O}{t_o} + S_{sh}^{0} + \frac{\sum_{1}^{n_M} (S_{TM} - Z_{OM} - Z_{MM})}{t_M} + S_{sh}^{m}, \tag{9}$$

where:

P_x – the profits from the processing of tailings, rubles/ton;

S_{TO} – the marketing cost of products of processed tailings, rubles/ton;

Z_{OO} – costs of redistribution processing of tailings, rubles/ton;

Z_{OM} – the cost of metallurgical redistribution of tailings, rubles/ton;

n_o – the amount of extractable components from the tailings;

Q_O – the mass of tailings, tons;

t_o – time for processing of the tailings, years;

S^0_{sh} – fines for storage of tailings, rubles/year;

S_{TM} – sales of metallurgical processing tailings, rubles/ton;

Z_{OM} – the enrichment costs of metallurgical processing tailings, rubles/ton;

Z_{MM} – the costs of metallurgical redistribution of metallurgical processing tailings, rubles/ton;

n_M – the amount of components enriched from metallurgical processing tailings;

t_M – the processing time of metallurgical tailings, years;

S^m_{sh} – fines for storage of metallurgical tailings, rubles/year.

Extraction of metals from low-grade ores and tailings using leaching can be implemented at all stages of the deposit development (Fig. 4).

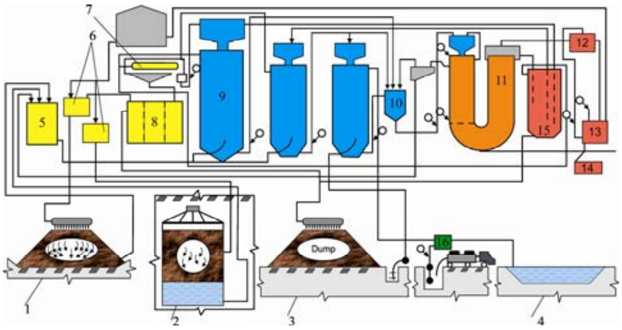

Figure 4. Technology of metals leaching from ores: 1 – heap leaching bing; 2 – block of in-situ leaching; 3 – dump; 4 – pond; 5 – 8 – storage tanks; 9, 10 – technological devices; 11 – sorption-desorption column; 12 – 15 – auxiliary equipment

The effectiveness of combining technologies of field development was assessed by comparison of extraction completeness of the valuable component (VC) from the subsoil using traditional (TT) and a combined methods of extraction.

In order to justify the use of technologies based on the static economic-mathematical model, their reaction of objective function (profit on change of development parameters) is examined. The comparative analysis on two criteria permits to determine the optimal value of profits and choose the best way of metal enrichment.

Traditional method. Amount of valuable components raised to the Earth's surface:

$$M_1 = Q_b \beta_6 \varepsilon_1 , \tag{10}$$

where:

Q_b – amount of ore in the balance contour, mass units;

β_6 – the content of the valuable component in the balance contour, units;

ε_1 – extraction ratio of valuable component, units.

The amount of valuable components (M_2) extracted into the concentrate using enrichment:

$$M_2 = Q_1 \varepsilon_2 = Q_b \beta_6 \varepsilon_1 \varepsilon_2 \varepsilon_3 , \tag{11}$$

where:

ε_2 – extraction ratio of valuable component from ore into concentrate, units.

The amount of valuable components extracted from the concentrate into the final product:

$$M_3 = M_2 \varepsilon_3 = Q_b \beta_6 \varepsilon_1 \varepsilon_2 \varepsilon_3 , \tag{12}$$

where:

ε_3 – extraction ratio of valuable component from concentrate into the final product, units.

The extraction completeness of the valuable component (ε_3) is the ratio of valuable component in the final product to the amount of valuable components in subsoil:

$$\varepsilon_3 = \frac{M_3}{M} = \frac{Q_b \beta_6 \varepsilon_1 \varepsilon_2 \varepsilon_3}{M} = \frac{M_b}{M \varepsilon_1 \varepsilon_2 \varepsilon_3} , \tag{13}$$

where:

M – the amount of valuable components in subsoil prior to development, mass units;

$M_b = Q_b \beta_6$ – amount of valuable components in the balance contour, mass units.

The combined method consists in raising part of the ore from block, enrichment, plant processing and in-situ leaching.

The amount of valuable components extracted to form the compensation space:

$$M_4 = QB\varepsilon B , \tag{14}$$

where:

Q_B – amount of produced ore, mass units;

εB – the content of valuable components in produced ore, units.

The amount of valuable components extracted into concentrate:

$$M_5 = M_4 \varepsilon_2 = Q_b \beta_b \varepsilon_2 . \tag{15}$$

The amount of valuable components extracted from concentrate into final product at the plant:

$$M_6 = M_5 \varepsilon_3 = Q_b \beta_b \varepsilon_2 \varepsilon_3 . \tag{16}$$

The amount of valuable components extracted into final product using in-situ leaching:

$$M_7 = \left(M - M_4\right)\varepsilon_4 = \left(M - Q_b \beta_b\right)\varepsilon_4 , \tag{17}$$

where:

ε_4 – extraction ratio of valuable component from ore by in-situ leaching, units.

Amount of valuable components extracted by combining technologies:

$$M_k = M_6 + M_7 . \tag{18}$$

Dependence, which determines the extraction of the valuable components from the subsoil into final product:

$$\begin{aligned} \varepsilon_k &= \frac{(M_b + M_7)}{M}\left[\frac{(Q_b\beta_b\varepsilon_2\varepsilon_3) + (M - Q_b\beta_b)\cdot\varepsilon_4}{M}\right] = \\ &= \frac{(Q_b\beta_b\varepsilon_2\varepsilon_3) + (M\varepsilon_4) - (Q_b\beta_b\varepsilon_4)}{M} = \\ &= \frac{\varepsilon_4[\varepsilon_4 + Q_b\beta_b(\varepsilon_2\varepsilon_3 - \varepsilon_4)]}{M} = \varepsilon_4 + \frac{M_4}{M(\varepsilon_2\varepsilon_3 - \varepsilon_4)} \end{aligned} . \tag{19}$$

The combined technology permits to combine the extraction and processing of high-grade ores with metal leaching from sub-standard reserves. Technology with leaching compared with traditional one reduces metal losses during production by 5 – 10%, and in the enrichment by 2 – 2.5%.

Through extraction ratio for the traditional technology is not more than 0.865. The technology of in-situ leaching for producing 40% with 50% metal content in mining and metallurgical plant will be extracted 40.5% of valuable component with extraction ratio of 0.93. From remaining 50% balance reserves of metals with extraction ratio of in-situ leaching of 0.8 and taking into account the processing loss of valuable components will be extracted 39.2 of the metals in the final product. In the case of 3% of the metals in the off-balance ores 2.3% of valuable components will be extracted into the final product. Through extraction ratio of metal by in-situ leaching amounted 0.879.

The reaction of the objective function – profit on the change of development parameters:

– the ratio of reserves, developed by technologies: traditional from 0 to 100%; heap leaching from 0 to 100%; in-situ leaching from 0 to 80%;

– the contents of the valuable components in block reserves from minimum in off-balance ores up to a maximum in rich ores;

– increase in the content of the ore raised from compensation space, compared with the content in the block from 0 to 30%;

– extraction ratio in the case of in-situ leaching from 0.6 to 0.9;

– extraction ratio in the case of heap leaching from 0 to 0.9;

– the cost of mining, transportation, processing of ore, production and processing of productive solutions in-situ leaching and heap leaching.

Extraction ratios for in-situ leaching and heap leaching take values ranging from 0.6 to 0.9. Comparable risks for traditional technology are calculations on average values, and the combination of technology – on the lower limit of extraction. The level confidence in both cases is 0.9.

The maximum values x of the target function are achieved when traditional technology and in-situ leaching are combined. The optimum of target function provides an option, when the content of metals in the reserves of the block is below 65 – 70 conv. units the technologies are correlated as 15% – traditional and 85% – in-situ leaching.

The maximum profit is achieved when the content of metal in reserves amounts from 65 – 70 to 130 – 150 units and the ratio of technologies: 40% – traditional and 60% – in-situ leaching. Improving the efficiency of the combined technology is possible due to the increased volume of ore excavation prior to dilution.

The optimum value of productivity is achieved when 40% of the ore is raised to the surface, and 60% of the ore is leached in-situ. The productivity of metal in the final product is two times higher than in a case of traditional method for the same performance of rock mass. Production rate of mining plant worker according to the final product will increase 1.5 times.

With the same number of mining plant workers, the production rate of mine on rock mass for combined technology will be 40% of the traditional technology, and the production rate on metal in the final product will increase 1.5 times.

In the case of combined technology, the mining life of one horizon in comparison to traditional technology increases 2 times, if ore areas are in simultaneous development – 3 times (Fig. 5).

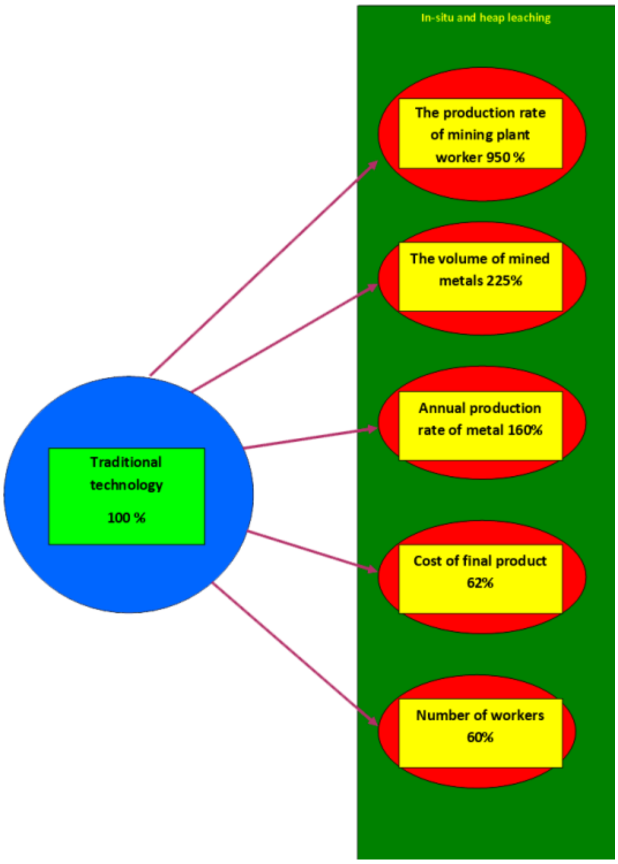

Figure 5. The effectiveness of in-situ leaching of ores

Due to significant costs of transport and processing in mining and metallurgical plant of diluted ore mass when mining poor ores traditional technology does not compensate the lost value of the valuable components in the subsoil and on the technological conversions.

Through extraction ratio for combined technology is comparable to extraction with the traditional technology, and in those cases where it is lower, due to minimization of losses it compensates costs and provides profit.

Example. The deposit is a lenticular body composed by five zones, with reserves determined based on a normal distribution with a significance level of 0.05 for chi - square and different metal contents in each zone.

Reserves of ore zones:

– 10000 weight units of ore with content of valuable component 0.2 relative units;

– 20000 weight units of ore with content of valuable component 0.06 relative units;

– 25000 weight units of ore with content of valuable component 0.05 relative units;

– 20000 weight units of ore with content of valuable component 0.025 relative units;

– 25000 weight units of ore with content of valuable component 0.2 relative units;

The field totally contains 100000 weight units of ore and 5450 weight units of metals.

When developing the deposit using traditional method the zones 1, 2 and 3 are developed and zones 4 and 5 are not due to the low content of mining. The content of valuable component $M_B = 4450$ weight units.

Extraction in the case of traditional technology. During processing of ore mined using traditional method the extraction in the concentrate in enriching factory is $\varepsilon_2 = 0.9$, and the extraction of useful component from the concentrate to the finished product – $\varepsilon_3 = 0.98$.

The final extraction ε_T for traditional method:

$$\varepsilon_T = \frac{M_B}{M}\varepsilon_1\varepsilon_2\varepsilon_3 = \frac{4460}{5450}\cdot 0.95\cdot 0.9\cdot 0.98 = 0.68\,. \quad (20)$$

Extraction with leaching. The zone 1 containing 2000 weight units is mined using leaching. The final product for ore processing at enriching factory and mining and metallurgical plant:

$$M_{me} = M_1\varepsilon_2\varepsilon_3 = 2000\cdot 0.9\cdot 0.98 = 1760\,. \quad (21)$$

The amount of metals in the subsoil for in-situ leaching:

$$M_0 = M - M_1 = 5450 - 2000 = 3450\,. \quad (22)$$

The ores are leached at 45% ($\varepsilon_p = 0.45$), and using in-situ leaching metals are extracted from the remaining part of ore:

$$M_{r1} = M_0\varepsilon_p = 3450\cdot 0.45 = 1550\,. \quad (23)$$

Total enrichment of standard row materials:

$$\varepsilon_{kp} = \frac{M_{me} + M_{rl}}{M} = \frac{1760 + 1551}{5450} = 0.61\,, \quad (24)$$

i.e. lower than for traditional method.

Extraction in the case of combined technology. For combined technology, the ore is raised from zones 1, 2 and 3, and valuable component according to condition:

$$M'\,{}^{,}\frac{\varepsilon_p - \varepsilon_T}{\varepsilon_p - \varepsilon_2\cdot\varepsilon_3}M = \frac{0.45 - 0.68}{0.45 - 0.9\cdot 0.98}\cdot 5450 = 2900\,. \quad (25)$$

Extracted metals:

$$M'_{me} = M'\varepsilon_2\varepsilon_3 = 2900 - 0.9\cdot 0.98 = 2560\,. \quad (26)$$

Number of metals for in-situ leaching:

$$M'_0 = M - M' = 5450 - 2900 = 2550\,. \quad (27)$$

The amount of useful minerals extracted at in-situ leaching:

$$M'_{isl} = M'_0 x\varepsilon_p = 2550\cdot 0.45 = 1150\,. \quad (28)$$

The final extraction in the case of combined technology:

$${}^{\circ}\varepsilon_p = \frac{M'_{me} + M'_{isl}}{M} = \frac{2560 + 1150}{5450} = 0.68\,. \quad (29)$$

The combination provides a through extraction of metals from the sublevel not lower than traditional method.

The average metal content in the raised ore at fragmentation index $F_i = 1.35$:

$$\beta_p = \frac{M'K_P}{(F_i - 1)Q} = \frac{2900\cdot 1.35}{100000\cdot(1.35 - 1)} = 0.112\,. \quad (30)$$

To fulfill this condition has to be raised: from zone 1 – all ore, from zone 2 – 10000 weight units of ore with content 0.06, from zone 3 – 5900 weight units of ore with content 0.05.

The maximum efficiency of mining is provided under condition:

$$M' \geq \frac{\varepsilon_n - \varepsilon_T}{\varepsilon_n - \varepsilon_2\varepsilon_3}M\,, \quad (31)$$

where:

M – the amount of useful component in the depths of the deposit, weight units;

M' – number of useful components raised from the subsoil, weight units;

ε_n – extraction of metals from ores using leaching technology, weight units;

ε_T – extraction of metals from the subsoil for traditional method:

$$\varepsilon_T = \frac{M_n}{M}\varepsilon_1\varepsilon_2\varepsilon_3\,, \quad (32)$$

where:

M_n – the number of metals, traditional method, weight units;

ε_1 – extraction of metals from the bowels, traditional method, weight units;

ε_2 – extraction of metals into concentrate in the processing plant, weight units;

ε_3 – extraction of useful components from the concentrate to the finished product in the Mining and Metallurgical Plant, weight units.

The metal content in the ore at stoping:

$$\beta_p = \frac{M'F_i}{Q(F_i - 1)}\,, \quad (33)$$

where:

β_p – the metal content in the produced ore; weight units;

Q – amount of ore, containing M metals, weight units;

F_i – fragmentation index of ore.

Mining of raw materials for the preparation of mixtures complicates the ecological situation in the region. There are billions of tons of solid wastes of mining production in the vaults of the world, which can not be used as far as they contain metals. Utilization of tailings is impossible without metal extraction also from an economic and environmental point of view, and in case of placement in the cavities tailings containing metals and saturated tailings is certain palliative.

The scarce and valuable metals, the cost of which could be comparable to the cost of enriched metals enter into the composition of metal containing tailings. The metals contained in the wastes under the influence of leaching processes migrate to the environmental ecosystems causing serious consequences.

The utilization range of mineral wastes is limited by capabilities of traditional enrichment technologies. The direction of metal extraction from the tailings of mining production by combining the processes of mechanical activation and chemical leaching is being developed in recent years. This direction allows extracting metals to the level of maximum permissible concentration of 2 orders faster than in the case of agitation leaching.

The phenomenon of varying properties of materials in disintegrators is used in technology of preparation hardening mixtures. Thus the mixture strength increases at low quality of primary components (Fig. 6).

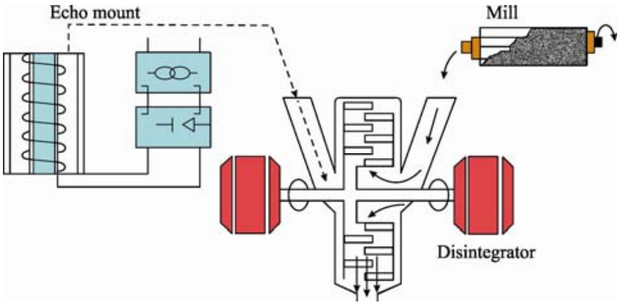

Figure 6. Chart of ores leaching in the disintegrator

3. RESULTS

The results of processing tailings of polymetallic ores permit to confirm:

– activation in disintegrator increases the activity of substances up to 40%;

– activation in the disintegrator with separate leaching increases the extraction of tailings: lead – in 1.4 times, zinc – 1.1 times;

– leaching in disintegrator compared with way of separate activation and leaching provides the same extraction level by 2 orders faster.

The strength of hardening mixtures based on enrichment tailings in the case of activation in disintegrator rises from 1.30 to 1.52 megapascals or by coefficient 1.17. After extraction of metals to the level of sanitary requirements the tailings that were activated in a disintegrator are suitable for the production of hardening mixtures sometimes even without adding cement.

Activated tailings are used in hardening mixtures, not only as inert fillers, but also as binder components. Fine enrichment fractions of up to 0.076 mm, which include carbonate components are used as binders. Grinding of tailings to the level of active faction makes it possible to produce stowing mixtures of sufficient strength to fill the vast amount of technogenic cavities.

Activation of tailings in the disintegrator allows small factions to compete with cement. Mixtures based on activated tailings provide the strength under uniaxial compression of 0.5 – 1.5 megapascal. This strength is sufficient to stow the most part of mined-out space while reducing the consumption of cement in the orders compared to the baseline value.

Recommendations on the results of simulation combination parameters: poor ore containing up to 5 units processed by heap leaching, the ore with an ordinary content of 65 to 200 units after enrichment is directed to the Mining and Metallurgical Plant and with the ore content greater than 200 is sent to the processing without enrichment. Metal extraction rate varies by 8 – 10%. Reduced quality of ore mined using traditional technology due to dilution increases the metal loss at a plant by 1 – 2%. For leaching technologies the losses due to dilution are eliminated. This increases the extraction rate in Mining and Metallurgical Plants by 1 – 1.5%.

4. CONCLUSIONS

The materials-products of mechanochemical processing that recyclable without sanitation limitations form practically unlimited raw materials source not only for the mining industry, but also for allied industries. Involvement in the production of substandard reserves is strengthening the national resource security of the countries, avoiding dependence on the world market of metals. Combining traditional development technologies with the leaching technologies of metals is unused reserve for economic recovery of mining enterprises.

The combination experience of technologies can be used in enterprises of South Africa. The deposits of South Africa according to mineralogical composition of ore minerals, underground mining techniques and hazard of chemical pollution of metal mining areas more than others meet the conditions of leaching metals.

Diversification of traditional technology that is based on leaching technology in conditions of South African mining regions will provide unlimited opportunities for filling voids by hardening mixtures. This is especially important when working at great depths in strained rock arrays with an increased tendency to dynamic redistribution of rock pressure.

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ABSTRACT (IN UKRAINIAN)

Мета. Вирішення технологічних і екологічних проблем Південної Африки та інших країн із використанням досвіду російських, казахстанських та українських шахтарів при видобуванні металів, що поєднують традиційні й нові технології. Кінцевою метою концепції захисту навколишнього середовища є безвідходний видобуток корисних копалин з повним використанням компонентів, отриманих з видобутої сировини.

Методика. Технологія з вилуговуванням металів з руд використовується як альтернатива традиційній технології видобутку металів, вилучення металів з руд на місці їх розташування.

Результати. Дана коротка довідка про стан виробництва металів у світі. Охарактеризовані природоохоронні тенденції гуманізації гірничої справи в технологічно розвинених країнах. Описано досвід підземного вилуговування урану. Наведено результати піонерних експериментів із вилучення металів комбінованою механохімічною обробкою у дезинтеграторі. Сформульовано економіко-математичні моделі визначення ефективності використання комбінованої технології та моделювання результатів отримання металів.

Наукова новизна. Досвід поєднання технологій може бути використаний на підприємствах Південної Африки. У конкретному прикладі сформульовані економічні та математичні моделі для визначення ефективності комбінованої технології та моделювання результатів вилучення металів. Наведено рекомендації щодо використання досвіду вилуговування збіднених мінералів.

Практична значимість. Ефективність поєднання технологій розробки родовищ оцінювалася шляхом зіставлення повноти вилучення цінного компонента з надр з використанням традиційних та комбінованих методів екстракції. Порівняльний аналіз за двома критеріями дозволяє визначити оптимальну величину прибутку і вибрати найкращий спосіб збагачення металу.

Ключові слова: *метал, захист навколишнього середовища, видобуток корисних копалин, вилуговування на місці, механохімія, дезинтегратор*

ABSTRACT (IN RUSSIAN)

Цель. Решение технологических и экологических проблем Южной Африки и других стран с использованием опыта российских, казахстанских и украинских шахтеров при добыче металлов, сочетающих традиционные и новые технологии. Конечной целью концепции защиты окружающей среды является безотходная добыча полезных ископаемых с полным использованием компонентов, полученных из добытого сырья.

Методика. Технология с выщелачиванием металлов из руд используется как альтернатива традиционной технологии добычи металлов, извлечение металлов из руд на месте их расположения.

Результаты. Дана краткая справка о состоянии производства металлов в мире. Охарактеризованы природоохранные тенденции гуманизации горного дела в технологически развитых странах. Описан опыт подземного выщелачивания урана. Приведены результаты пионерных экспериментов по извлечению металлов комбинированной механохимической обработкой в дезинтеграторе. Сформулированы экономико-математические модели определения эффективности использования комбинированной технологии и моделирование результатов получения металлов.

Научная новизна. Эффективность сочетания технологий разработки месторождений оценивалась путем сопоставления полноты извлечения ценного компонента из недр с использованием традиционных и комбинированных методов экстракции. Сравнительный анализ по двум критериям позволяет определить оптимальную величину прибыли и выбрать наилучший способ обогащения металла.

Практическая значимость. Опыт сочетания технологий может быть использован на предприятиях Южной Африки. В конкретном примере сформулированы экономические и математические модели для определения эффективности комбинированной технологии и моделирования результатов извлечения металлов. Приведены рекомендации по использованию опыта выщелачивания обедненных минералов.

Ключевые слова: *металл, защита окружающей среды, добыча полезных ископаемых, выщелачивание на месте, механохимия, дезинтегратор*

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