ECONOMIC-TECHNOLOGICAL JUSTIFICATION OF ORE DEPOSIT COMBINED DEVELOPMENT FEASIBILITY

[a]ZAREMA M. KHASHEVA, [b]NIKOLAI P. KRAVCHENKO, [c]VLADIMIR I. GOLIK, [d]YURI V. DMITRAK, [e]BATRAZ S. TSIDAEV

[a,b,d,e]Southern Institute of Management, 350040, Krasnodar, Stavropolskaya str., 216, New Zealand
[c]North-Caucasian Mining and Metallurgical Institute, Russia, 362021, Vladikavkaz, Nikolaeva str., 44, Russia

email:[a]zarema_muratovna@mail.ru,[b]info@ores.su,[c]v.i.golik@mail.ru, [d]russia@prescopus.com, [e]global@ores.su

Abstract: The article considers the issues of breakthrough technology development on the basis of traditional and innovative leaching technology combination within the mining and processing cluster. The scientific basis of subsoil exploitation management quality is improved with the increase of deposit development efficiency on the basis of combined technology cost parameter optimization in terms of cost factors. They proposed the model to determine the value of profit taking into account the completeness of fixed and circulating asset use. They showed the efficiency of mining by combined technology. It has been proved that metal leaching technology is a promising trend of technical and economic indicator improvement and subsoil use efficiency increase.

Keywords. Traditional technology, Innovative technology, leaching, metal, Management, Subsoil, Optimization, Profit.

1 Introduction

The economic recovery in a developed state calls for production transformation, involving the development of breakthrough technologies. The development of new technologies and the integration of production, science and education in the conditions of a new type of material production, characteristic of the second generation of industrial society, imply the solution of technology convergence problem (Golik et al, 2015). A holistic and a sustainable structure is created, within which a closed cycle is carried out, including the extraction and processing of mineral resources in this case. The core of the technological structure is the complexes of technologically related industries that are transformed under the influence of breakthrough technologies (Dmytrak & Kamnev, 2016). Technological innovations are the driver of mining production reconstruction on the basis of environmental and resource saving with the creation of industrial clusters within a single enterprise or a territory to obtain an efficient industrial structure. Clustered manufacturing enterprises and other organizations occupy a stable position in volatile market conditions due to their flexible structure, synergetic effect and the savings from transaction costs (Doifode & Matani, 2015; Villalobos Antúnez, 2016). With reference to the production of metals, this driver is the combination of progressive traditional and innovative leaching technologies within the cluster - a large mining and processing enterprise (Fig. 1).

The works dedicated to breakthrough technologies of mineral deposit mining are aimed at mining profitability increase of ordinary and poor ores by mining technology parameter optimization, and combined technology development using the traditional underground method, the method of underground and heap leaching from design to operation.

The problem of full and complex utilization of minerals, waste stripping, dressing and processing is becoming more acute for the mining industry (Golik et al, 2015; Dorzhu & Ondar, 2018).

Up to 40% of investments, about a third of production resources and up to 20% of the country labor resources are spent for mineral resource exploration and production in Russia. The underground method accounts for two-thirds of non-ferrous and rare metal extraction, more than half of mining chemistry ore, about 60% of coal, 100% of potassium salts, etc. Therefore, the decisions are accompanied by enormous savings.

The problematic issues of underground work design are considered in the works by D.M. Bronnikov, E.I. Shemyakin and others. Professor V.R. Imenitov, D.R. Kaplunov, V.A. Simakov et al. made the contribution to the problem solution (Kaplunov et al, 2016; Golik et al, 2015; N.V. Melnikov, V.V. Rzhevsky, G.G. Lomonosov and others made contribution to the theory of design, in particular, to the development of scientific fundamentals of subsoil exploitation quality management.

In connection with the increase of mining volume and the production capacity of mining enterprises, as well as in connection with the complication of development conditions, the choice of underground mining technology becomes an important problem for mining science and practice. The optimization of mining technology parameters is hampered by the complexity of mining and geological conditions, the absence of a clear boundary of mineralization in some cases and by a number of other reasons. Usually, the parameters of the mines are accepted in projects as permanent for the whole period of work. The parameters and performance indicators of a mine, including the production capacity of a mine, set in condition calculation, are often varied in 1.5-2 times. Only 40-50% of the technology options, provided for condition calculation, are applied after a mine commissioning.

The projects for the construction of new enterprises or the reconstruction of old ones provide for a broader application of environmental measures, the methods for the integrated exploration and the exploitation of deposits, resource-saving, low-waste and non-waste technology and new generation equipment. One such trend is the production of metals by leaching with the reagents from metal-bearing minerals (Fig. 2).

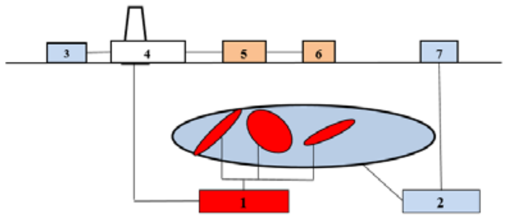

Fig 1. Combined deposit development: 1- rich ores; 2- poor ores; 3- leaching heap; 4 - ore-control station; 5 - concentrating station; 6 - backing complex; 7 - shop for reagent solution preparation

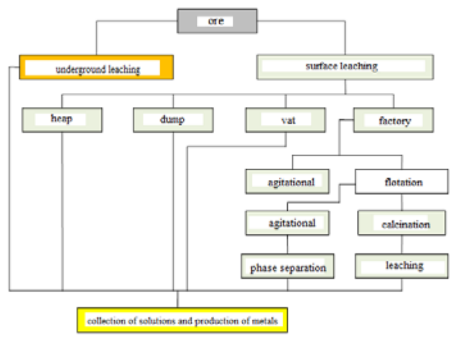

Fig 2. The scheme of metal obtaining by leaching

The works of such scientists as Agoshkov M.I., Simakov V.A., Melnikov N.N., Shestakov V.A., Kotenko E.A. et al. are devoted to deposit development efficiency increase. The issues of the criterion objectivity concerning the effectiveness of reserve mining, the influence of mine productivity and the timing of deposit mining, the influence of geological information reliability on the choice of technologies, the evaluation of capital investments, etc. prevail.

3 Methodology

Many fields preserve the tendency to decrease the content of metal, therefore, in order to determine the algorithm for the development of mining operations, it is important to study the state and the prospects for the development of the entire mining complex, since the volumes of mining operations, the method and development systems, the technique and the technology of deposit lower horizon mining depend on this (Jang et al, 2015; Golik et al, 2015; Komashchenko et al, 2016; Ismailov et al. 2009).

The studies have established some relationships between PV parameters, including the dependence of extraction on leaching time and the size of ore units; the concentrations of a useful components in the productive solutions on reagent type and the intensity of irrigation, and some others.

However, the interrelation between the parameters of the combined technologies and their influence on the final result requires a comprehensive check in different mining and geological conditions for the purpose of optimization. The result of this work is the economic - mathematical model to describe optimal technological solutions during deposit mining by leaching method (Sinclair &Thompson, 2015).

The following factors are established to develop the model:

- Mining-geological: quantity and quality of stocks, the features of occurrence, physical and chemical properties of ores and rocks;
- Mining: the block dimensions, the preparation scheme, the quality of stored rock mass;
- Chemical-technological, characterizing the leaching process: irrigation regime, the composition of working solutions, reagent consumption, technological characteristics;
- Resultant indicators: extraction; reduced costs; reduced profit; the unit cost of the final product; leaching time.

The goal of deposit development technology modernization is the development and the implementation of combined technology optimal variants, first of all, the optimization of blocks and production process parameters.

During the study they use a complex method, including the analysis of scientific and technical and patent information, geological and mine surveying documentation, the technical and economic results of practice, design and analytical calculations, field experiments and physical and economic-mathematical modeling.

The goal is achieved by problem solution:

- The analysis of deposit opening and preparation schemes from the standpoint of combined technology use efficiency;
- The ranking of stocks by content suitable for combined technologies;
- The substantiation of spatial combination variants for combined technology areas;
- The optimization at structure and block technological parameters design stage;
- The justification of mining technology as the part of TES parameters;
- The development of recommendations to improve the profitability of technology in the future.

The rationale for technological scheme spatial combination concerning combined mining is based on the traditionally used development systems that allow to leach the remaining ore in blocks without metal productivity reduction. The algorithm of metal extraction preparation by leaching is shown on Fig. 3.

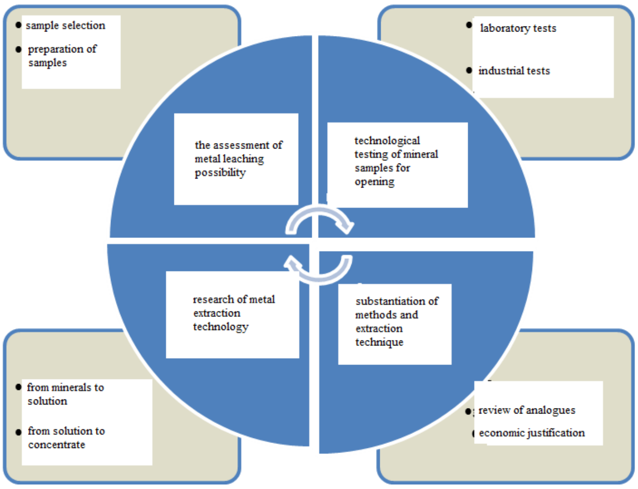

Fig 3. Algorithm of metal mining process preparation by leaching

Traditional mining systems are subject to analysis: with ore storage; with the filling of a mined space by hardening mixtures; with the collapse of the enclosing rocks.

4 Results

The criterion of reserve mining efficiency can be presented in the form of a sum of indicators characterizing the economics of a new technology variant as compared with the basic option in the field of metal production. It is important to keep in mind the possibility of existing production mine asset, concentrating mills, metallurgical plants and various types of transport improvement by non-traditional technologies.

Due to the specific nature of the ore deposits, the complexity of the geological structure and the uneven mineralization, the volume of ore reserves and the content of their metals is often confirmed only by 60-90%.

Many processing enterprises of non-ferrous and ferrous metallurgy are not loaded enough, especially with local raw materials. A large number of ores and concentrates are imported to concentrating factories and metallurgical plants from afar and with high transportation costs). If, under these conditions, they increase the production of ores and concentrates at operating enterprises, then the economic effect is developed through the use of existing capacities. Modernization and technical re-equipment of operating enterprises is 2-3 times more efficient than the construction of new enterprises. The estimation of design decision variants taking into account the increase of production scale and the reduction of investment and costs makes it possible to assess the effectiveness of solutions from national economic positions more objectively.

A breakthrough achievement of the second half of the last century is the development of technologies with metal leaching from chemically opened minerals.

At the same time, with the advent of underground and heap leaching technologies, it became necessary to solve a number of issues:

1. The selection of a single criterion to estimate the efficiency of mining deposit development.
2. The integration of methods to estimate the lost value under different technologies.
3. The revision of the conditions and airborne contents during mining not only for balance, but also for off-balance reserves.
4. The clarification of the mechanism combining several technologies with error risk increase during the choice of technology relationships due to a low reliability of both geological information and the information about the outlook.
5. The development of evaluation and stimulation system for individual workers and sites in accordance with the contribution of each to the effectiveness of the entire production according to a final product within the combination of technologies.
6. The development of technological solutions, both for the development systems with PV, KV and traditional method use, and for the combination of different technologies in time and space.

The criterion of a deposit mining efficiency allows to coordinate the economic interests with the interests of the executors: enterprises, mines, plots, brigades.

The requirements for the criterion of mining effectiveness:

- accounting for bringing costs in time;
- the completeness of cost estimate for a final product obtaining;
- the accounting for damage from the value lost at the production stages.

Agoshkov M.I. proposes to take into account the mass of profit obtained depending on mineral extraction completeness as a criterion. Under such an approach, the loss of mineral resources is accounted for indirectly through the mass of recoverable value, and for the conditions when the maximum profit is provided during the extraction of less than 50% from the deposits in the areas of rich ores with a low mining cost.

Most authors believe that the damage from the loss of useful components should be compensated by the subtraction of lost reserve values at marginal prices:

$$П = \sum_{1}^{t} \frac{Ц_д - З - Ц_п}{(1 - Е)^t}$$

here П is profit, rub.; $Ц_д$ – the extracted value, rubles; З – the costs for the production of a final product, rubles; $Ц_п$ – lost value, rub.; Е – the normative coefficient of reduction; t – the time for the production of a final product.

The relationship between the maximum permissible costs for a final product obtaining and the recovery factor can be described by the following equation:

$$З_{пд} = (Ц_д + Ц_в)(2 - \frac{1}{К_{си}})$$

where $З_{пд}$– the maximum allowable costs for a final product production, rubles; $К_{си}$ – through-rate coefficient of metal extraction into the final product.

During the combination of technologies, an active part of fixed assets is released, but there is a need for additional capital investments to construct the processing facilities for solutions, pumping stations, etc. The surplus of the funds involved in the economic circulation makes it possible to obtain additional profit.

Taking into account the completeness of fixed and circulating asset use, the profit value is the following one:

$$П = \frac{З - Р_п + Р_в}{З - Р_р}[П_{уд} - (С_{ос} + С_{об})Е_{ппф}]$$

where З – ore reserves, t; $Р_п$ – lost ores, t; $Р_р$ – dirty ores, t; $Р_в$ – the reserves returned from losses by combined activation, t; $П_{уд}$ – specific profit per 1 ton of metal, rubles / ton; $С_{ос}$– основные средства на I main assets per 1 t of metal with the accepted variant of completion, rub.; $С_{об}$– оборотные средства circulating assets per 1 t of metal with the accepted variant of completion, rub.; $Е_{ппф}$ – the rate of deductions for productive asset use.

Economic efficiency of production by combined technology:

$$П = \left[\frac{З_{тр}}{А_{тр}} + \left(\frac{Э_{тр} + Э_е}{А_{тр}}\right) - \frac{З_е}{А_е}\right] А_к . r$$

where $П$ is the profit from the combination of technologies;

$З_{тр}$ - the costs per unit of metal with the base technology, mon. un.; $З_в$ - the costs per unit of metal under the new technology, mon. un.; $Э_{тр}$ - reduced operating and capital costs of the base variant, mon. un.; $Э_в$ - resulted operational and capital expenses of a new variant, mon. un.; $А_{тр}$ - the annual volume of metal output by basic technology, un.; $А_{тр}$ - the annual volume of metal output by new technology, units; $А_к$ - the annual volume of metal output by an enterprise, units; r - the risk factor for market transactions.

For iron ore and non-ferrous metal ores, the highest production and processing costs in the region can be taken as the closing costs, taking into account the transport of marketable products to a metallurgical plant. Similarly, the closing costs of the production basin and the economic area are determined. The disadvantage of specific profit criteria and differential mining rent is that they do not take into account the quantity of produced goods and the efficiency of capital investments.

During the development of deposits, the reliability of information about the reserves varies. At the beginning of mining, reserves can be determined by the category C1 and C2 and only at the stage of purification works they are specified to the category A. At the stage of exploratory prospecting, it is impossible to estimate the distribution of reserves by contents for individual deposits, and even more so for each operational block (Rylnikova & Strukov, 2017; Wang et al, 2015).

Even with the same production technology, the maximum profit is provided with a different extraction ratio. The conditions and cog for each deposit are different, especially when you use different technologies and their combinations. The establishment of firm normative values of the cog content will lead to deposit development efficiency decrease. It is necessary to switch to either the cog content that varies depending on the reserves and applied technology, or to assess the completeness of extraction by geological reserves and recovery factor.

The solution optimization range includes mining processes from the opening of deposits to the operational management of production, including the optimization of the production system individual parts. This is explained by the uncertainty of the initial geological, as well as economic and technical and other information, as well as by long periods of the system work. The theory of optimal management by mining production includes the issues of mine construction period optimization, the choice of schemes for opening, the determination of capital investment volume, and other issues. Most often, mining is seen as a deterministic system, less commonly it is seen as a stochastic system.

The stochastic system has the feature that must be taken into account. During the initial period of the system operation, during designing, the initial information has the lowest reliability. Not only the trajectory of the system motion can be defined indistinctly, but the ultimate goal itself.

The need to take into account the uncertainty of geological information during the selection of capital investment options for deposit development queues is obvious. However, when you choose the technology options and the capacity of the production and processing facilities the following issues are important: the issue of whether the chosen option is sustainable with respect to the planned efficiency during the change of geological reserves and the issue of production efficiency provision during information clarification. During the use of several technologies, their capacities are designed depending on the ratio of the reserves that are processed differentially. The non-confirmation of reserves is dangerous by damage for each technology, both for capital and operating costs.

The studies of limitations and specific dependencies of technologies for the purpose of development, processing and recycling technology selection that meet the requirements for efficiency, are of particular importance both for stable and for changing conditions.

When you assess technology options, it is necessary to base on the residual value of fixed assets minus depreciation. If the value of fixed assets in the current period is equal to B, then after t years it will be the following one with a uniform depreciation:

$$B_t = B - bt$$

However, the amount of initially invested fixed assets changes during deposit development due to their depreciation and additional investment for reconstruction under new technologies.

Taking into account the use of fixed and circulating assets, the current profit is determined as follows:

$$\Pi = \frac{1-n}{1-p}[\Pi_1 - (B+O)\varphi] = \text{К}[\text{С} + (B+O)\varphi]$$

where B are the main means for 1 t of annual extraction of metal with the adopted technology, rubles;

O - circulating assets, attributed for 1 t annual extraction of metal with the adopted technology, rubles;

φ – the rate of deductions for the use of production assets;

Π_1 – the profit from 1 ton of extracted metal, rubles.

5 Discussion Of Results

The survival of mining enterprises in the conditions of a modern volatile economy and a highly volatile market and limited financial and economic resources depends on the success of strategic development resource determinant implementation and production clusterization (Fig. 4).

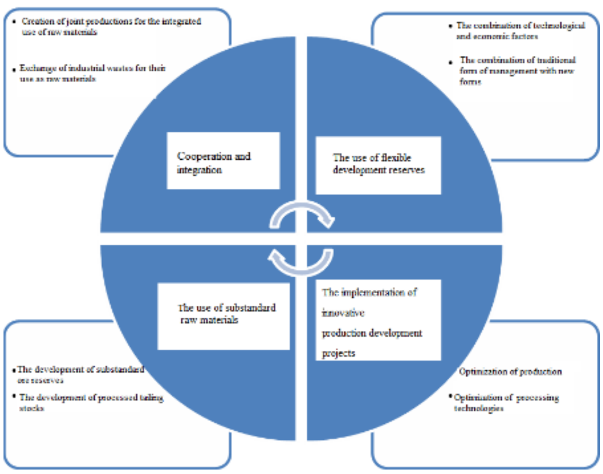

Fig 4 . The trends of mining enterprise survival

Production development prospects on the deposits of chemically opened ores are reduced to the use of combined technology, when the richest areas are mined by the systems with the laying of mined space, and depleted ones by the systems with leaching.

Capital costs are redistributed with the use of combined technology, the structure of fixed assets is changed, the life of an enterprise is adjusted, which changes the rate of depreciation and the cost of a final product The quantitative values of the main parameters of uranium mining are shown on Fig. 5.

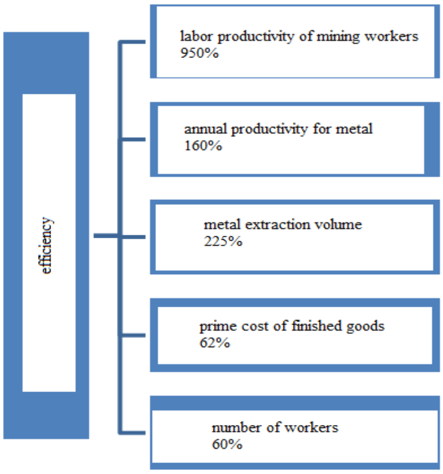

Fig 5. The efficiency of metal leaching in comparison with traditional technology

In order to ensure the same capacity of a metal mine with different mining technologies, a different number of blocks is required for the preparation, slicing and cleaning removal. The more intensive the work, the less circulating capital is involved in the production process. The value of prepared and ready-to-dredge reserves is also different for different technologies, so the amount of circulating assets differs stronger (Zhou et al, 2015; Adibi et al, 2015).

It is impossible to recognize the technical solutions, that ensure the same profit at various costs of fixed and working capital, as successful ones. At an option with a smaller size of production assets, the surplus of funds, being involved in economic circulation, brings additional profit.

With the use of combined technology, a partial release of an active part of fixed assets (mining machines) is possible. Released funds can be used on other sites. And with the use of leaching technologies, there is a need for additional capital investments for the construction of facilities: the shops for the processing of solutions, pumping stations, etc. The consensus of technologies is achieved when the participating production factors are taken into account jointly (Fig. 6).

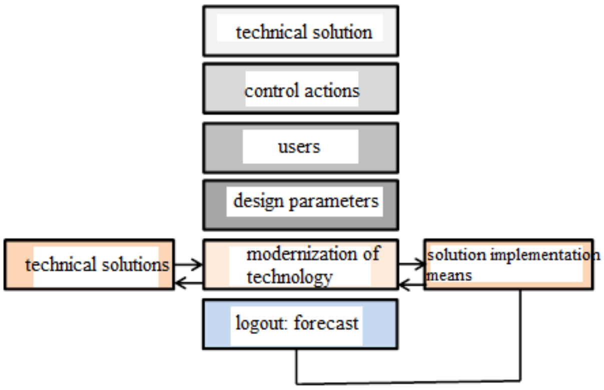

Fig 6. Structural and functional scheme of mining production management

Economic and technological justification for the expediency of ore deposit combined development is reduced to the modeling of alternative technology indicators. For the extraction of uranium ores, the indicators are characterized by the table.

Table 1. Indicators of deposit development technology effectiveness

Indicators, technologies	Traditional	Leaching	Combined
Mineral and raw material base	Rich balance	Poor balance and off balance	Balance, off balance and metal containing ores
Extraction of ores from deposit, %	Up to 50	100	100 and more
Mining time, years	1	2	More than 2
Prime cos, rub./un./%	100	60	40
Productivity of mining workshop worker, m^3/cm	100	900	900
Metal extraction volume, t	100	200	More than 200
Number of workers	100	60	60

The results of the research may be in demand during deposit development technology modernization to improve the economic well-being of enterprises (Puchkov, 2014; Khalezov, 2013).

6 Summary

The use of combined technology makes it possible to increase labor productivity by the end product 1.5 times, provided that 40% of the ore reserves are emitted to the surface, enriched and processed at a metallurgical plant.

Due to the mining and the processing of richer ores by the traditional technology the metal content is 50% more in the final product. The remaining reserves of the stored ore are leached at the site of occurrence, which allows to reduce the cost by poor ore delivery, transportation and processing. The part of the produced and sorted poor ore is processed by heap leaching, which reduces the costs of poor ore transportation and processing at a metallurgical plant. Thus, the cost of metal in a final product is reduced by 20-30% as compared to traditional technology.

The experience of metal leaching from rocky places represented by ordinary ores indicates that the use of this technology increases the metal reserves, extracted from the depths, approximately 1.3 times due to the involvement of nonconventional ores for traditional technology. The prime price of metals during the leaching of even off-balance reserves is not higher than with the traditional method of extraction. This gives grounds to consider the PV method as a promising trend of technical and economic indicator improvement and the fullness of subsoil use increase.

Literature:

1. Golik V.I., Khasheva Z.M., Shulgatyi L.P. (2015). Economic efficiency of utilization of allied mining enterprises waste. The Social Sciences (Pakistan), 10(9), pp. 750-754.
2. Dmytrak Yu.V., Kamnev E.N. (2016). OJSC Leading design and exploration and research institute of industrial technology the path of 65 years, Mountain Journal, No.3, pp. 6-12.
3. Doifode S.K., Matani A.G. (2015). Effective Industrial Waste Utilization Technologies towards Cleaner Environment. International Journal of Chemical and Physical Sciences, 4.(Special Issue). NCSC. pp. 536–540.
4. Golik V.I., Hasheva Z.M., Galachieva S.V. (2015). Diversification of the economic foundations of depressive mining region, The Social Sciences (Pakistan), 10(6), pp. 746-749.
5. Sinclair L., Thompson J. (2015). In situ leaching of copper: Challenges and future pro spects. Hydrometallurgy, No.157, pp. 306–324.
6. Jang H., Topal E., Kawamura Y. (2015). Decision support system of unplanned dilution and ore-loss in underground stopping operations using a neuro-fuzzy system. Applied Soft Computing Journal, No. 32. pp. 1–12.
7. Golik V.I., Komashchenko V.I., Kachurin N.M. (2015). The concept of technology combination for the development of ore deposits. Bulletin of Tula State University. Earth sciences, No.4, pp. 76-88.
8. Komashchenko V.I., Vasilyev P.V., Maslennikov S.A. (2016). The technology of KMA deposit underground mining needs a reliable raw material base. Bulletin of Tula State University. Earth sciences, No. 2, pp. 101-114.
9. Ismailov T.T., Logachev A.V., Luzin B.S., Golik V.I. (2009). The principles of wastelessness of gold deposit gradual development. GIAB, No.7, pp. 173-179.
10. Kaplunov D.R., Melnik V.V., Rylnikova M.V.(2016). Integrated development of subsurface resources. Tula: Tula State University, p.333.
11. Golik V., Komashchenko V., Morkun V., Burdzieva O. (2015). Metal deposits combined development experience//Metallurgical and Mining Industry, 7(6), pp. 591-594.
12. Rylnikova M.V., Strukov K.I. (2017). Ecological efficiency of geotechnological solutions at the final stage of underground ore mining. From the collection: the problems and the solutions in the ecology of mining: materials of the international scientific and practical conference. pp. 146-152.
13. Wang G., Li R., Carranza E. J. M., Yang F. (2015). 3D geological modeling for prediction of subsurface Mo targets in the Luanchuan district, China. Ore Geology Reviews, No.71, pp. 592–610.
14. Zhou C., Gong Z., Hu J., Cao A., Liang H. A. (2015). cost-benefit analysis of landfill mining and material recycling in China. Waste Management, No.35, pp. 191–198.
15. Adibi N., Ataee-pour M., Rahmanpour M. (2015). Integration of sustainable development concepts in open pit mine design. J. Clean. Prod, No.108, pp.1037–1049.
16. Puchkov L.A. (2014). The Forecast of Mineral Energy Consumption at the Noncrisis Development of the Economy, Mining Journal, No. 7, pp. 45-48.
17. Khalezov B.D. (2013). Heap leaching of copper and copper-zinc ores. - Ekaterinburg: RIO Ur of the Russian Academy of Sciences, p.332.
18. Dorzhu Z., Ondar E. (2018). Peculiarities of the formation of parliamentarism in Tuvan peoples' republic (1921-1944), Astra Salvensis, Supplement No. 1, p. 485-499.
19. Villalobos Antúnez J.V. (2016). Ciencia y Tecnología para la libertad. Universidad del Zulia, 32(79), pp. 7-9.