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Economic Preconditions of Optimum Iron Ore Reserves Extraction at Contemporary Mining Enterprises

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Abstract: The research considers key issues of economic optimization of the extraction parameters in compliance with peculiarity of underground mining and present-day market relations. A set of technical and economic indicators is offered in order to define optimum conditions and the line of iron ore reserves. It is offered to define optimum reserves delineation by comparison of different variants of ore contour and selection one with best economic benefits. Economic revaluation and defining of conditions can be done in the process of the mining and efficiency assessment of the whole deposit or its part. Attention is focused on issues of partial revaluation of unconditioned reserves. The fundamental stages of economic efficiency evaluation of iron ore reserves are described. An actual problem of conditions estimation of iron ore reserves is solved according to peculiarity of underground mining economy. Thereto research offers special coefficient characterizing the level of conditioning reserves at contemporary mining enterprise.

Key words: Mining enterprise · Economic efficiency · Iron ore reserves evaluation · Delineation of reserves · Underground mining

INTRODUCTION

Essential task of mining enterprises lies in optimization of production volumes of ore and finished metal products, support of the stable production capacity of mines, efficient use of deposit reserves regarding social and economic, production and technological, organizational, ecological, legal and other factors.

Under such conditions the main factor of the stable economic growth of mining enterprises is a provision of a raw material base, which is characterized by the availability of the needed amounts of mineral reserves. Sufficiency of a raw material base defines economic value of a deposit and industrial potential of the enterprise.

The classification of iron ore reserves is based on defining the condition parameters and corresponding resource delineation of a deposit according to the mine technical, mining and geological parameters of the deposit, technological possibilities of the mining and economic efficiency [1]. Reasonable choice of the line is determined by the amount of iron ore reserves suitable for mining which eventually influences economic indicators of mining.

Due to the dynamics of market conditions, change of technical and economic possibilities of the enterprise, the determination of conditions and choice of the reserve line must be carried out on the basis of a feasibility study and performance of corresponding economic assessments.

Research Tasks: The authors have set the task to define key economic aspects of determination of conditions at classification and selection of the optimum reserves line of a deposit in the modern operational environment of a mining enterprise with underground mining method.

The salvation of the mentioned task presupposes:

- firstly, the description of fundamental stages of economic efficiency evaluation of iron ore reserves;
- secondly, the formation of a system of indicators for calculation of condition parameters and selection of the reserves line regarding economic indicators of mining.

Reviews of Publications: Scientific research in the sphere of mining and economical assessment of mineral deposit reserves is performed in the number of works of national

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and foreign scientists; this gives us a possibility to generalize the existing experience in this matter.

According to studies [2], the minerals conditions are the totality of marginal requirements to the quality and quantity of minerals in the subsurface recourses, mine technical, mining and geological and other conditions of mining, adherence to which ensures the fullest and economically effective mining of the available deposit reserves.

One should distinguish indicators and parameters of conditions.

The condition indicators include natural characteristics of a deposit that determine the choice of schematic system of ore mining and processing as well as characterize technical and economical efficiency of production and realization of mining products.

Condition parameters show the marginal values of condition indicators, which are determined for a definite mining site or block on the basis of technical and economic calculations, valid standards, technical specifications, tasks of subsurface recourses users and experience of deposit exploitation.

Some authors [3-5] single out the following fundamental criteria for appropriate assessment of ore reserves conditions and performance of resource delineation: minimal grade of commercial components; cut-off grade; depth of an ore body; depth of deposit occurrence that determines the difficulty or inaccessibility of mining; assessment of rigidity of rock in excavations, which is determined by engineering and geological research that foresee the determination of physical and mechanical properties of ores and ore-bearing solids and deposits; characteristics of ore solidity; engineering and geological features of rock massifs such as anisotropy, composition, natural fraction pattern, tectonic structure, textural peculiarities, dilapidation in the weathered layer; and other processes that can complicate the mining of the deposit.

In order to make an assessment of the condition, one should choose only some of the mentioned parameters depending on the geological structure of the deposit, mining and geological conditions of mining, industrial requirements, etc.

According to [6-8], the economic assessment of conditions should be done according to the following principles of investment projects evaluation, which are acknowledged in the world practice.

First, economic efficiency of the ore mining is determined for the full cycle of production activity of a mining enterprise. Future (comparing to the date of assessment) monetary flows are taken into account in the calculation of indices of effectiveness. The calculations are done with the application of the method of discounting the future monetary flows [9].

Second, simulation of costs and incomings that form the monetary flows is performed in full regarding all production processes of commercial mining, taking into account investments made by years.

Third, the calculation of the effect has to include the period starting from geological survey, excavation and mining, recultivation of the environment and nature saving to the moment of product realization [10].

It must be observed that the determination of a certain mineral resource as a conditional one is provisional and rather flexible regarding the time of assessment, enterprise strategy and other factors [11]. First of all it is due to the fact that the criteria of availability and efficiency are changed with the development of scientific and technical progress and general economic situation.

The named aspect determines the necessity of periodical revision of condition parameters and choice of the line of iron ore reserves, which requires the determination of totality of indicators for feasibility assessment of deposit reserves in the current economic operational environment of a mining enterprise.

RESULTS

Due to peculiarity of mining enterprise, iron ore conditions are the complex of requirements to the quality and mining, geological conditions of occurrence and exploitation of a deposit. They ensure the possibility to delineate the deposit and divide its reserves into balance and out-of-balance ones. Conditions are defined for a definite period and are revised periodically due to the change of mining, geological and economic conditions [12]. Clarification and defining of conditions can be done in the process of the mining and economical assessment of the whole deposit or its part (block, panel, mining site).

Economic evaluation of conditions has the following stages:

- Analysis and generalization of materials of geological, mining and technical and technological assessment of the deposit or a separate mining site.
- Justification of the annual productivity of the mine, system of deposits, volumes of losses and depletion.
- Determination of indicators and parameters of conditions necessary for selection of the line and calculation of reserves.
- Fulfillment of logistic evaluation of provision of the enterprise with necessary resources and equipment, analysis of the external economic environment, level of prices on products and resources, level of taxes and obligatory payments, possibilities of the enterprise to organize mining and further ore processing.

- Determination of optimal delineation and corresponding parameters of conditions on the basis of comparative analysis of technical and economic indicators of exploitation at different variants of the reserves line.

As a result, a comprehensive system of indicators for economic evaluation and selection of optimal path the calculation should include the following elements:

- Amount of reserves in a particular path;
- Company's annual performance;
- Labour capacity by ore and the resulting products;
- Operating costs for ore extraction and processing;
- Total costs for mining and processing;
- Price of commodity products per unit;
- Removed economic value of stocks;
- Annual income from the production of the mining enterprises;
- Capital investments volume;
- Net income for the period of operation of a deposit by choosing a particular path;
- Internal rate of return;
- Profitability of production activity of mining enterprises.

Actually, the choice of an optimum conditions and line of iron ore reserves is based on comparison of economic and technical indicators which are received for different variants of reserves delineation.

Taking into account the generalization of the existing experience of geological and economic assessment of reserves, one of the most important condition parameter is indicator of the minimal grade of commercial components.

The indicator of the minimal grade of commercial components means such a grade of commercial components in the ore below which the ore of the given deposit becomes noncommercial, i.e. non-profitable for mining and processing. It is defined for every mining block and allows to evaluate the appropriateness of mining the reserves. The value of the minimal grade of commercial components has to ensure such an extraction of commercial components from the ore, which would exceed total costs for mining and processing [2]. As a rule, the minimal grade of commercial components is lower than the average grade of metals in the reserves.

Minimum industrial content for single-component ore is determined by the condition of equality between costs and withdrawn value following generally accepted formula

$$C_{\min} = Emp \cdot 100 / \left[P \cdot \varepsilon \cdot (1-r)\right] \quad (1)$$

where C_{min}-minimal industrial contents;

E_{mp}-expenses for mining and processing of iron ores, USD/t;

P-wholesale price of a useful component in commodity products, USD;

ε-coefficient of extraction by mining;

r-coefficient of dilution.

In some cases while lowering the minimum industrial content, one may help not only reducing the effectiveness of facilitation of the deposits and enterprise profitability, but also to increase it significantly. By reducing the minimum industrial content the increase both in ore and metal supplies, extension of scale of work by application of high technologies may be achieved that eventually gives a significant reduction of production costs and increase of economic efficiency.

For implementation of this approach the conditions for ore should be based on a comparison of several variants corresponding to different outlines of the deposit and thereby varying the average content of metals in the ore. The calculations are performed with different values of the onboard content.

It must be noted that the conventional division of iron ore reserves into balance and out-of-balance ones shows their economic value at the moment of assessment. Balance reserves are characterized by the fact that their mining is economically effective and that they correspond to the defined conditions completely. Out-of-balance reserves may have insufficient content of commercial components, small depth of the deposit and inaccessibility for mining.

However, attributing reserves to the group of balance ones is relative. The change in needs of the amount of iron ore mining, technology of mining or concentration may evoke the necessity of their economic revaluation and selection of a more reasonable line.

In this aspect the out-of-balance reserves may be deemed as "potentially economical" due to the fact that the feasibility study of conditions proves the possibility of their preservation in the subsurface recourses for accompanying mining together with the balance ones or their mining, storage and preservation for the future use.

In conditions of simple structures of the deposits the difference between the balanced and unconditioned ores is based on the estimation of their degree of conditionality.

The economic component of conditionality is based on comparison of withdrawn industrial values from 1 t of ore reserves and the cost of ore extraction and processing

$$R_v \cdot (1-v)/(1-r) \geq (E_m + E_p) \cdot (1-v)/(1-r)$$

thus
$$C_C = R_V / E_{mp} = \begin{cases} 0..1, & unconditioned; \\ >1, & conditioned. \end{cases} \quad (2)$$

where C_C-coefficient characterizing the level of conditioning reserves;

E_m, E_p-expenditures on mining, USD/t;
E_p-expenditures on processing of iron ores, USD/t;
E_{mp}-full expenditures on mining and processing of ores, USD/t;
R_V-withdrawn value, USD/t;
r-coefficient of dilution;
v-coefficient of ore losses.

Due to (2) there can be following situations:

- In case the costs for extraction and processing exceed the withdrawn value, the coefficient of conditionality $C_C < 1$ and ore reserves are unbalanced (unconditioned).
- When $C_C > 1$, the reserves are related to the balanced. The larger value of C_C, the higher level of ore conditionality and its value.

In the conditions of a complex structure with uneven extent of mineralization the task of assessment of conditionality becomes complicated due to the fact that in different areas and blocks of metal content and other parameters may vary significantly. Under such circumstances, it is advisable to apply a differentiated approach to establishment of standards and select multiple paths.

The most complete economic evaluation of deposits is only possible while addressing the task of selecting the optimal path of stocks and optimal production of mine capacity [13]. By varying paths of the deposit extraction the different performance of mine is secured and hence the operating term, which causes the necessity of taking into account the time factor.

By assessing of the deposits and distribution of stock in the balance sheet and off-balance sheet for each path one need to determine the optimum operating conditions and performance of the enterprise. It should be noted that as the contours of the deposit increase, the common stocks grow, but the average metal content reduces. The production capacity of enterprises by ore mass and in most cases-by final product-increases.

Reduction of metal in the ore reduces the value of the extracted ore mass, but by increasing the scale of deposit, the unit costs of enterprise on extraction and processing of iron ore are reduced. In addition, by increasing of the deposit and the enterprise, the productivity of labour increases by ore mass.

However, by reducing the contents of metals in the ore at the expense of joining a certain path and the attraction of unconditioned stocks, the productivity of the end product is reduced, that at some point may lead to lower productivity for metal, despite its growth over the ore mass.

When comparing outlines of the deposits it should be noted that as the iron ore reserves increase, the enterprise capacity may be significantly increased not only by ore mass, but also by the end product and therefore reduce the unit capital investments (USD /t).

With the increase of path of iron ore stocks the performance of mine and processing plant increases and the extraction and processing costs somewhat reduce [14].

Operating costs for ore extraction and processing (USD /t) depending on the annual performance of enterprises may be stated as

$$C_{EP} = C_{\text{var}} + \left(C_{fix}/P\right) \tag{3}$$

where C_{EP}-the cost of ore extraction and processing, USD /t; C_{var}-conventionally-variable costs in the ore mass mining and processing, USD/t;
C_{fix}-the amount of conditionally fixed costs, USD/t;
P-annual production capacity of enterprises by ore mass, thousand tons/year.

Thus, when increasing the productivity of enterprise within $P_á$ to P the unit operating costs (USD t) are reduced by the amount

$$\Delta C_{EP} = C_{fix} \cdot (1 - P_6 / P) \tag{4}$$

Cost reduction (4) may be quite significant, considering that the share in semi-constant component varies from 40 to 80% and makes 50-60% of the cost price at an average.

Reducing the cost of extraction and processing by reduction of depreciation of capital investments and semi-constant current expenses significantly compensates the decreased value of the commissioned paths with poorer ores.

The total profit for the operation period of a deposit when approving a specific path, is determined by the formula

$$\Pi = \sum_{i=1}^{T} Q_i \left(R_V - E_{MPi}\right) \times k_v / k_r \tag{5}$$

where Q is the reserves amount by a certain path field, which is extracted in the i-year of exploitation, t;
E_{MP}-expenditure on ore mining and processing in the i-year USD/t;
R_V-removed value in the i-year, USD/t;
k_r-coefficient characterizing the level of dilution (k_r=1-r);
k_v-coefficient characterizing the level of ore loss (k_v=1-v);
T-working term of the deposit by choosing a path of stocks, years.

Taking into account the time factor in the formula (5) is necessary when comparing the values at different paths that can be characterized by terms variety.

On the basis of the calculations the stocks may be designed to meet the most favourable outline (onboard) content and take into account the trend towards further involvement in the operation of unconditioned ores.

CONCLUSIONS

There are following conclusions and directions for further research.

It should be noted that by improvement of methods and technologies for iron ore extraction and processing, as well as the development of rich ore deposits, a steady trend towards involving into operation the less conditioned ores and metals. Also the change in needs of the amount of iron ore mining, technology of mining or concentration may evoke the necessity of their economic revaluation and selection of a more reasonable line.

Therefore, it is important to envisage the use of ores that were evaluated such as off-balanced ores, but may be involved into the production process within the period of the mine existence.

Setting the parameters of conditions and choice the optimum line of iron ore reserves ensure an optimal amount of ore extraction and allows to establish a stable enterprise productivity by iron ore mass and mining-metallurgical products, which is particularly actual for enterprises. In the issue it allows to increase economic efficiency and comprehensiveness of reserve extraction.

According to the economic efficiency evaluation of different ore reserves, mining enterprise gets an actual opportunity:

- to define key economic indicators which describe a particular mining environment;
- to determine cost-beneficial conditions and thus optimum reserve delineation;
- to extend and optimize raw material base in accordance with the specified parameters of the conditions;
- to reduce unit expenditures on mining and processing of iron ores.

The actual direction of the authors' further research lies in the development and justification of economic mechanism of determination of the effectiveness of unconditioned iron ore extraction at contemporary mining enterprises.

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