Quality of mineral wealth as a factor affecting the formation of refuse of ore mining and processing enterprises

Svetlana Chrykhalova[1*]

[1]The Federal State Educational Institution of the Higher Education National University of Science and Technology MISiS, Moscow, Russia.

Abstract. Studies are carried out to estimate the amount of refuse generated in mining operations in conditions of deteriorating ore quality. The introduction of static material efficiency is suggested, which shows how much of the extracted rock mass is the finished product (concentrate) and the refuse production factor at mining and processing enterprises.

1. Introduction

The level of product quality and its prime cost largely determine the survival and success of the enterprise in a market environment. Quantitative characteristics of the properties of products that make up its quality are called indicators of product quality.

In mining, the quality of mined ore (mining complex: mines, quarries) has a significant influence on the products of the following processing industries (crushing, sorting, concentrating), responsible for the output of finished products (concentrates, etc.). This impact is made on the technological, economic and environmental performance of enrichment units, determining the material composition of the concentrate, the degree of extraction of minerals from raw ore, the yield of concentrates (commercial ore), their cost, and the number of tailings, their toxicity and residual content of useful components in them [1].

The problem of changing the indicators of product quality in the mining industry has its own peculiarities. By now, people have already used a significant part of minerals, mostly of the best quality.

The most intensive deterioration of the mineral resource base is noted for iron, tungsten-molybdenum, copper, aluminum, etc. ores. A similar situation is observed for mining chemical raw materials: with a very intensive growth in production, there is a decrease in the quality indicators of mined chemical raw materials, which was noted back in the 1970s [2, 3].

Mining is a natural-technical system, which more complicates its study. The main technological process is connected with the extraction of minerals from the bowels, i.e. impact on the bowels of the Earth with the help of various engineering facilities and

* Corresponding author: tchmy@mail.ru

technologies. For the sustainable development of enterprises and society, further improvement of the technological process of extracting minerals is necessary [4, 5].

2. Modeling an object. Choice and justification of the model. Study of the model

By modeling the author means the method of cognition, which involves building and studying a model, and then transferring the obtained data to a modeled object - the original, in this case - a mining processing enterprise [6]. From this definition it follows that the models of the object can be quite a lot, because each of these models can be proposed to identify certain properties of the object.

Inputs receive raw materials - the main material resource that is the subject of processing, additional material and energy resources consumed during the process. Outputs are used for production and refuse disposal.

In this paper, the author uses a schematic macromodel of the mining enrichment enterprise, shown in Fig. 1.

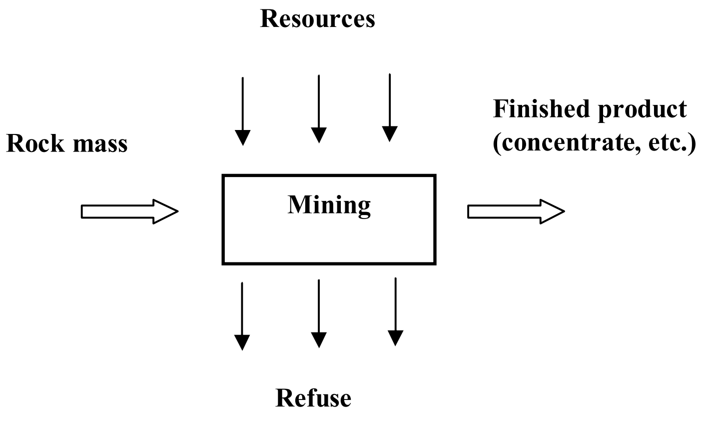

Fig. 1. Macromodel of mining

The main input is specially marked at the scheme - the subject of treatment (raw rock mass) and the main output is the product of processing (concentrate of a mineral). The scheme also reflects the refuse of the main transformation process, which includes overburden and enclosing rocks.

Additional inputs include material - natural and man-made resources, the consumption of which is caused by the technology of production chosen and the engineering facilities used, and additional outputs include the refuse of the production process, resulting from the transformation of additional resources.

The content of the useful component in the ore and the content of ore in the rock mass should be such that it is technologically and economically expedient to extract ore and then convert it to the plant's products. These tasks are solved at the mining and processing plant by mining and processing facilities.

The macromodel of the rock mass is shown in Fig. 2, it reflects the material balance: the distribution of mined rock into mineral resources and waste rock. Minerals can also be represented as a concentrate (finished products) and enclosing rocks, which are an integral part of the mineral. In this study, under enclosing rocks, the author means the part of the mineral resource that does not contain a useful component.

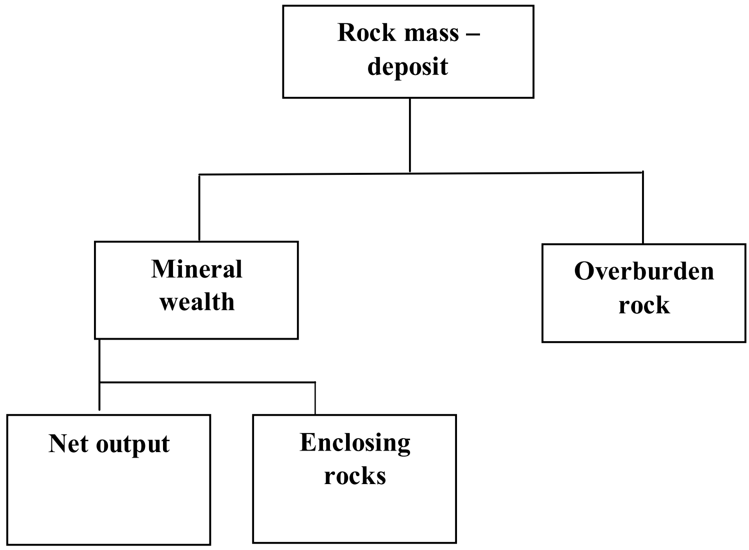

Fig. 2. Macromodel of rock mass

This model is described in some detail in [7].

The formula for calculating the weight coefficient of overburden K_{ovb} is:

$$K_{ovb} = M_{ovb} / M_{min}, \quad (1)$$

where M_{ovb} and M_{min} – the amount (mass) of overburden and minerals recovered from the deposit.

By analogy with the coefficient of overburden, introducing a new indicator - the coefficient of enclosing rocks. Under the coefficient of enclosing rocks, K_{enc} is meant the ratio of the number of enclosing rocks in tonnes or cubic meters to the amount of minerals in tonnes or cubic meters. The coefficient of enclosing rocks, calculated in tons of such rocks per ton of mineral, will be called weight.

The weight coefficient of enclosing rocks K_{enc} is calculated by the formula:

$$K_{enc} = M_{enc} / M_{min}, \quad (2)$$

where M_{enc} and M_{min} – the amount (mass) of enclosing rocks and minerals recovered from the deposit.

The content of new components in the initial rock mass and in the initial useful mineral can be expressed in fractions or percentages.

Based on the structural model of a complex of rocks that form the rock mass of a deposit of ore minerals (Figure 1), writing the following equations:

$$M_{rm} = M_{min} + M_{ovb} \text{ and } M_{min} = M_{conc} + M_{enc}, \quad (3)$$

where M_{conc} – the amount (mass) of concentrate of the useful component.

Dividing the right and left parts of the equations by M_{rm} and M_{min}, obtaining the expressions for the fractional coefficients characterizing the composition of the rocks in question:

$$\mu_{min} = M_{min} / M_{rm} = M_{min} /(M_{min} + M_{ovb}) = 1 / (1+ K_{ovb}); \quad (4)$$

$$\mu_{ovb} = M_{ovb} / M_{rm} = M_{ovb} /(M_{min} + M_{ovb}) = 1 / (1+ 1/K_{ovb}); \quad (5)$$

$$\mu_{conc} = M_{conc} / M_{min} = 1– K_{enc}; \quad (6)$$

$$\mu_{enc} = M_{enc} / M_{min} = K_{enc}. \quad (7)$$

It is obvious that

$$\mu_{min} + \mu_{ovb} = 1 \text{ and } \mu_{conc} + \mu_{enc} = 1. \quad (8)$$

Introducing the indicator of mining production, characterizing the quality of rock mass - static material efficiency $\zeta_{st.m.}$, calculated by the formula:

$$\zeta_{\text{st.m.}} = \frac{M_{conc}}{M_{rm}} = \frac{M_{conc}}{M_{min}+M_{ovb}} = \frac{M_{conc}}{M_{conc}+M_{enc}+M_{ovb}}. \quad (9)$$

This indicator characterizes the quality of the mineral deposit and provides an estimate of the amount of the finished product that can be obtained from the rock mass being developed.

To identify the amount of refuse, introducing the coefficient $\eta_{\text{st.m.}}$ – the static coefficient of refuse production, characterizing the amount of generated refuse, depending on the quality of the deposit.

$$\eta_{st.m.} = \frac{M_{enc}+M_{ovb}}{M_{conc}+M_{enc}+M_{ovb}}. \quad (10)$$

3. Implementation of the model in the mining processing industry

Assuming that the macro-indicators characterizing the quality of the mineral are as follows:

α_d - mineral content in the deposit;
α_{om} - useful component content in the extracted ore mass;
β – useful component content in finished product;
θ – useful component content in tailings;
R – dilution coefficient, %;
P – ore loss coefficient, %;
M_{rm} – extracted rock mass, t (thousand tons, million tons);
M_{ovb} – weight of overburden, t (thousand tons, million tons);
M_{ore} – mass of extracted ore, t (thousand tons, million tons);
M_{pr} – weight of processed ore, t (thousand tons, million tons);
M_{enc} – mass of enclosing rocks, t (thousand tons, million tons);
M_{fp} – weight of finished products, t (thousand tons, million tons).

Considering the values of these coefficients for real mining operations according to the data of OAO "APATIT", given in the table 1[8]:

Table 1. Dynamics of changes in the quality of balance and mined ores

Indicator	Year									
	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
P_2O_5 content in balance ores (at cutoff grade 4%)	15.18	15.1	14.95	14.86	14.68	14.55	14.65	14.34	14.32	14.36
Extraction of ore, million t	28.4	27.9	26.1	27.0	28.2	29.3	29.5	28.6	28.6	26..1
P_2O_5 content in extracted ore, %	14.14	13.96	13.63	13.77	13.63	13.32	13.12	12.91	12.87	12.93
Ore consumption per ton of concentrate, t	3.13	3.16	3.25	3.22	3.25	3.32	3.38	3.44	3.45	3.43
Operational loss, %	8.5	8.0	8.8	9.2	10.5	9.7	10.8	10.1	11.0	11.2
Dilution, %	6.9	6.7	7.0	7.5	7.3	8.3	9.1	10.0	9.9	9.8

Calculating the average indicators for 1999 to 2008. For this period:

- operational losses are on average per year $P = 9.78$ %;
- dilution on average per year $R = 8.25$ %;
- $\alpha_d = 14.70$ %;
- $\alpha_{rm} = 13.43$ %.

Content of the useful component P_2O_5 in extracted ore according to formula [9]

If the content of the component in the volume of balance reserves of ore to be extracted is α_d, the ore loss is P, and the dilution (contamination) with enclosing rocks is R, then the metal content in the extracted ore mass can be found from the relationship [4]:

$$\alpha_{rm} = \alpha_d \frac{1-P}{1+R}. \quad (11)$$

$$\alpha_{rm} = 14.7\frac{1-0.0978}{1+0.0825} = 14.7 \cdot \frac{0.9}{1.08} = 12.23\%. \quad (12)$$

This result is somewhat lower than that presented in the table, which is explained by the variable composition of the ore mass deposit.

Part of this expression, $\frac{1-P}{1+R} = K_\alpha$, determines the degree of change (decrease) in the content of the useful component in the ore mass in the process of ore extraction under the influence of losses and dilution. Therefore, it can be assumed that K_α is an indicator of the quality of mining in terms of ensuring the absolute level of the content of the useful component in extracted ore [9].

4. Discussion

Over the 80-year period of production, by 2009, the P_2O_5 cutoff grade decreased from 25% to 4%, and the content in the processed ore from 29% to 13.6% [3].

In the period from 2014 to 2017, the P_2O_5 content of the flotation concentrate is actually in the range of 12-13%, however, its variability is considerable.

From this study, it can be seen that the extraction of minerals in terms of its natural conditions implies the formation of a huge amount of refuse that can significantly exceed the extracted useful component. Therefore, the management of refuse in mining is an integral part of the technological mining process.

It can be seen from the table that an average of 3.3 tons of ore is consumed per 1 ton of concentrate. This means that 2.3 tons of ore are refuse (tailings of enrichment).

In 2005, the rock mass produced was 101,624 thousand tons, and the production of apatite concentrate was 8,756 thousand tons. Static material efficiency of the enterprise $\zeta_{st.m.} = 8.6\%$ for the apatite concentrate. The refuse production coefficient $\eta_{st.m.} = 91.4\%$.

5. Conclusions

Thus, it can be concluded from the above study that the extraction of minerals has a low static material efficiency and a large refuse production coefficient. Increasing the efficiency of mining operations is very difficult. The management of the quality of mining should begin in the extraction complex. However, established traditions, significant variability in the properties of the rock mass [10, 11], little information, complexity of production conditions, significant volumes of mining, transportation and loading operations greatly complicate quality management in mining. Currently, there are some recommendations for improving the mining process, but their introduction into production requires significant financial costs [12].

Taking into account what has been said at the first stage, it is necessary to revise the existing Technical Conditions for extracted ore and improve the technological regulations, which leads to the modernization of the extracting complex of mining enterprises.

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