ANALYSIS OF THE ORE RECOVERY AND ORE DILUTION IN THE UNDERGROUND MINE FOR LEAD AND ZINC „SASA“ - M. KAMENICA

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ABSTRACT. Ore recovery and ore dilution are very important parameters in all mining exploitation methods, butespecially in the sublevel caving mining method. In this exploitation method there is a functional dependence between the ore recovery and ore dilution, and for this reason it is very important to determine the optimal values for these parameters.
The paper presentsthe methodology for monitoring and analysis of the ore recovery and ore dilution in the underground mine for lead and zinc „SASA“ - M.Kamenica, by applying geodetic surveying measurements of the volume of excavated and unexcavated ore for each workplace.

Keywords: ore, recovery, dilution, sublevel caving, underground exploitation

АНАЛИЗ НА ИЗЗЕМВАНЕТО И ОБЕДНЯВАНЕТО НА РУДА В ПОДЗЕМЕН РУДНИК ЗА ОЛОВО И ЦИНК „САСА“ – М. КАМЕНИЦА

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РЕЗЮМЕ. Изземването и обедняването на руда са много важни параметри за всички минно-добивни методи, особено за системата на разработване с подетажно обрушаване. При този метод на разработване има функционална зависимост между изземването на рудата и нейното обедняване и поради тази причина е особено важно да се определят оптималните стойности на тези параметри.
В настоящия доклад е представена методология за мониторинг и анализ на изземването и обедняването на руда в подземен рудник за олово и цинк „САСА“ – М. Каменица чрез прилагането на геодезични маркшайдерски измервания на обемите иззета и неиззета руда за всяко работно място.

Ключови думи: руда, изземване, обедняване, подетажно обрушаване, подземен добив

Introduction

The sublevel caving mining method is applied in the underground mine for lead and zinc „SASA“ (Гоцевски и Мијалковски, 2008). In this exploitation method, the coefficients of ore recovery and ore dilution are in mutual functional dependence, that is, by increasing the ore recovery the ore dilution is also increased and vice versa. For this reason, it is necessary to calculate the optimal values for ore recovery and ore dilution (Mijalkovski et al., 2017; Mijalkovski, 2015).

When calculating the coefficient for recovery of geological reserves from the ore deposit, the ratio of the unexcavated ore and ore masses contained in the geological ore reserves is of high importance (Мијалковски, 2013). Classical methods (measuring surfaces with plan-meters, calculating volumes by approximating curved surfaces with a set of regular geometric bodies, etc.) to determine these masses were used in the past, which were not sufficiently accurate and therefore certain errors occurred, which indirectly affected the accuracy of calculating the coefficient for ore recovery. As a drawback, we can add the engagement of a large number of consultants and the increased number of working hours for performing this kind of analysis.

Due to the above-mentioned negative factors, today, computer graphics are used for faster and more accurate calculation of the excavated surfaces and volumes. This method is very favorable for 3D visual representation of ore bodies and mining objects, where the spatial distribution of all objects in the mine can be perceived (Mijalkovski et al., 2013). For this purpose, the software packages "Promine" and "Vulcan" were introduced in the underground mine „SASA“ (Mijalkovski et al., 2016).

Ore recovery and ore dilution in sublevel caving mining method

The sublevel caving mining method is characterized by a mutual connection between ore recovery and ore dilution, which in this case is such that by increasing the values of one parameter there is an increase in the values of the other parameter. In underground mining deposits with low thickness, ore recovery can be caused by the inability to monitor the contour of the deposit, which may be result in ore losses. When analysing the exploitation of ore deposits with big thickness, ore recovery and ore dilution arise primarily in the process of leached or caved ore (Mijalkovski et al., 2015).

In the leaching process of the mined ore, first the clean ore is leached, and then there is interference with the fragmented waste rock, which is in contact with the belt of the crushed ore. If an ore leak is stopped early, the ore dilution will be less, but the ore losses will be bigger. In order to have bigger ore recovery and at the same time reducing the ore losses, the leak continues, and as consequence of this the ore dilution is increasing according to the exponential dependence. This is the essence of the previously stated functional dependence of the ore recovery and ore dilution (Mijalkovski, 2015), where our goal is to obtain a high ore recovery for the purpose of small ore dilution.

These changes are particularly pronounced in the sublevel caving mining method with face loading. In the magnitude of the ore dilution the thickness of the blasting belt and its height have the biggest influence, also certain influence has the method of ore loading, i.e. the depth of engagement with the loading basket along the slope of the ore in the production drifts (Milicevic, 2008).

Ore dilution also occurs during exploitation. From this point of view, there are two types of ore dilution, planned and unplanned, shown schematically in Fig. 1 (Soyer, 2006; Stewart, 2012).

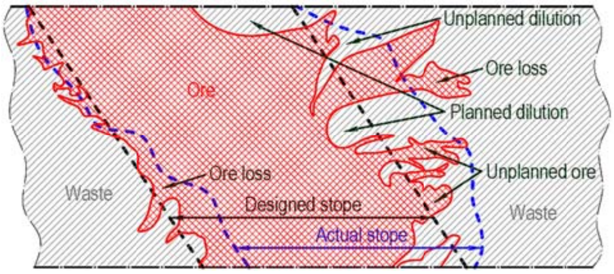

Fig. 1. Planned and unplanned dilution

Ore recovery is largely dependent on the human factor, that is, on the person managing the mining operations, but with disciplined work this influence can be reduced to a minimum.

Ore recovery (losses) of the reserves has an impact on the mine's exploitation period, and therefore on the size of the total revenue. While ore dilution, which is in direct functional dependence with ore recovery, has the greatest influence on the value of one ton of produced ore, that is, the value of a ton of produced concentrate, and thus on the size of the total revenues. Also, ore dilution has big impact both on the size of production costs and on the value of flotation utilization of metals in the technological processing (Mijalkovski, 2015).

Optimization of ore recovery and ore dilution in sublevel caving mining method

Taking into account the above-mentioned arguments, there is a necessity to determine the optimal values for the coefficients of ore recovery and ore dilution.

In order to optimize ore recovery and ore dilution when applying a sublevel caving mining method, the following steps have to be defined (Mijalkovski et al., 2017; Mijalkovski, 2015):

- Defining the geological parameters of the ore deposit (ore reserves, metal content, boundary content of metals);
- Defining the technological parameters for exploitation of the ore deposit (optimal annual production capacity, age of exploitation, content of metals in the ore, ore recovery during excavation, ore dilution during excavation, flotation utilization, metallurgical utilization of metals);
- Calculation of economic parameters (costs, revenues, net present value-NPV, internal rate of return of capital-IRR).

The last step is the decision making, whereby, by maximizing the net present value, the optimum values of the coefficient for ore recovery are reached (Mijalkovski et al., 2017; Mijalkovski, 2015). Net present value is obtained as the difference between total revenues and total cost of ore production.

Scientific research (Mijalkovski, 2015) has been carried out in order to calculate the optimal values for the coefficient of ore recovery and ore dilution for the sublevel caving mining method (Mijalkovski et al., 2017), applied for the conditions in mine „SASA". On the basis of experimental tests of similarity models, the functional dependence between the coefficient of ore recovery and ore dilution was determined and also the optimization area for these two technical-economic parameters of the excavation (Fig. 2). The values for the coefficient of ore recovery are ranged from 70% to 90%, while the values of the coefficient of ore dilution are ranged from 10% to 30%. The optimization results showed that the optimal value for the coefficient of ore recovery for the conditions in mine „SASA" is ir=80%, and for the coefficient of ore dilution is Or=20% (Mijalkovski, 2015).

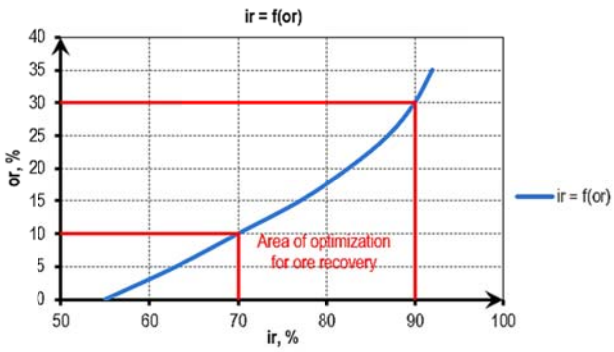

Fig. 2. Functional dependence between the coefficient of ore recovery and ore dilution with a display area of optimization

Monitoring of ore recovery and ore dilution in workplace areas in the mine „SASA"

Monitoring and calculation of the ore recovery and ore dilution are carried out by applying geodetic surveying measurements for the volume of excavated and unexcavated ore for each workplace (Mijalkovski et al., 2013; Mijalkovski et al., 2016; Mijalkovski et al., 2015). After calculating the coefficient of ore recovery and ore dilution for each workplace individually, the next step is to calculate the average coefficient for ore recovery and ore dilution for each ore block and then for each horizon. At the end, the average coefficient for ore recovery and ore dilution for each month and for a whole year is calculated (Mijalkovski et al., 2015; Mijalkovski, 2015).

Measurement of the volume of excavated and unexcavated ore for each workplace is done with modern geodetic instruments which in themselves are mini computers and with their speed, accuracy and output data allow acceleration of many steps leading to the final product of the whole procedure, i.e. maps and plans (Mijalkovski et al., 2013; Mijalkovski et al., 2016).

The „SASA" mine has the Total Station Leica Flex Line TS02/TS06/TS09/, which fully meets all the needs of the geometer when performing geodetic measurements in the pit. The advantage of this geodetic tool is that it does not need any trigonometric form template for recording the measured values (angles, lengths), because they store, process and output coordinates and elevation for all measured points. Furthermore, the measured data is very quickly and simply transferred to a computer and processed through the drawing program AutoCAD (Mijalkovski et al., 2016).

With the electronic mapping of mine maps, i.e. plans, high accuracy and precision is achieved, which in the past was complicated due to the size, type of paper, the way of storing the maps, the geodetic drawing tool, etc.

The maps and plans in the mining industry are of varying content, because the situation of the performed works is changed daily, and especially in the excavation zone, so that they have to be constantly updated, which is actually done in the „SASA" mine.

If safety conditions permit, after excavation of a certain production drift, a final measurement needs to be made for the safe production of some future mining facilities near the excavated part. In this way, the amount of excavated ore from the production drift is calculated and is compared with the value of the geologically projected quantity of ore, which calculates the ore recovery and ore dilution at that certain production drift (Mijalkovski et al., 2015; Mijalkovski, 2015).

The three geological profiles shown on Fig. 3 and in Fig. 4 display a plan for the given location between these three geological profiles. On the situation plan, as well as on the geological profiles, the forecast geological contours for the ore zone and the results of the geodetic survey of the mining workplace area are given, i.e., graphically we have the geological data before and after the excavation of that part in the ore zone.

Geodetic surveying of mining operations is carried out during excavation and in this way the monitoring of ore recovery and ore dilution is constantly done. According to the mining project, when ore dilution has increased above the planned, then the excavation of that part is stopped.

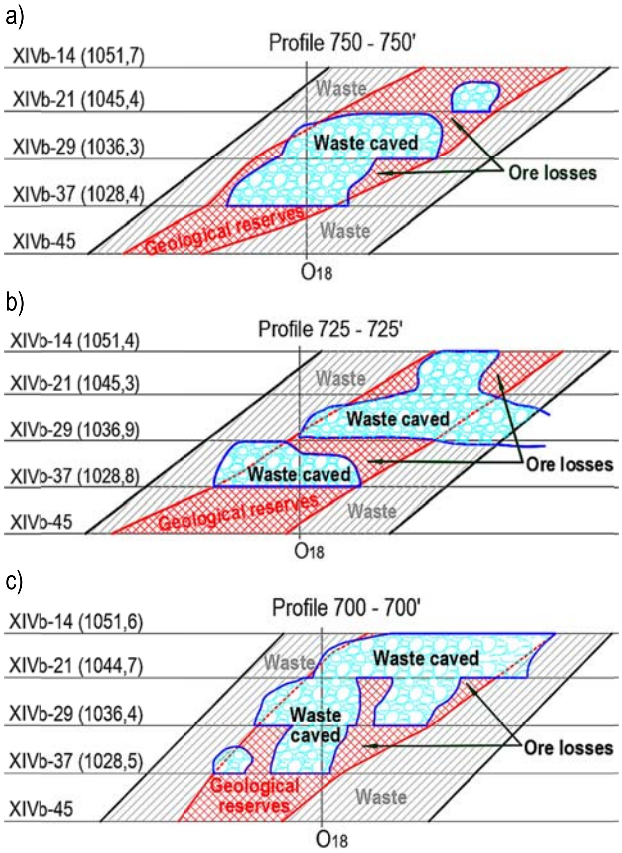

Fig. 3. Profiles for completed mining for theworking place: Level XIVb, Block 1, Level XIVb-37 footwall, Between profiles 750-700

When the excavation is completed at one workplace, then a final surveying is performed for that area, i.e., the final recording for the completed mining operations. From Fig. 3 and Fig. 4 (geological profiles and plan), the surface can be calculated, i.e. the volume of the excavated parts, as well as the parts where the ore is not excavated due to certain technical reasons (leaving the protective pillars, etc.) By comparing the quantities of geological reserves and quantities of excavated ore, the ore losses are calculated and compared with the planned losses according to the mining project. It is possible to calculate how much ore has been excavated without ore dilution and with ore dilution, i.e. with waste rock. In this way, the total ore dilution at the considered workplace can be calculated and then it can be compared with the planned ore dilution according to the mining project. In this way, it can be verified if there is a growth in geological ore reserves and its value, i.e. whether some unconfirmed geological reserves are involved (Mijalkovski et al., 2015; Mijalkovski, 2015). Then a report for each workplace is prepared and the values for the excavated parameters for each workplace are entered in a common table (Table 1), to make a record for the entire ore block or horizon.

Analysis of ore recovery and ore dilution for a specific workplace

An example for calculating the coefficient of ore recovery and ore dilution (Миланов, 2018) for the following workplace locations in the„SASA" mine is presented further on:

- Level XIVb;
- Mining Block 1;

Table 1.
Data for excavation parameters of some workplaces on level XV, mining block 3 in the "Sasa" mine

Workplace	Profile	Read geological reserves, (Q_{geol}) t	Total excavated ore without dilution, (Q_1) t	Total excavated ore with dilution, (Q_2) t	Total excavated rock waste, (Q_j) t	Dilution, (o_r) %	Ore in safety pillars, (Q_{zs}) t	Total excavate run of mine ore, (Q_v) t	Increment of geological reserves, (Q_{pr}) t
XV B3-0 f	1550-1500	10.2	9	9.4	0.4	4.3	1.8	10.8	0.6
XV B3-0 f	1500-1450	9.2	9.8	10.2	0.4	3.9	2.3	12.1	2.9
XV B3-0 f	1450-1400	13.3	8.6	10.4	1.8	17.3	5.2	13.8	0.5
XV B3-0 f	1400-1350	19.4	9.4	13.7	2.3	16.8	2.6	12	0
XV B3-0 f	1350-1300	12	10.7	13	2.3	17.7	2.6	13.3	1.3
XV B3+7 f	1550-1500	6.4	9.8	10.7	0.9	8.4	0.4	10.2	3.8
XV B3+7 f	1500-1450	12.1	16	16.9	0.9	5.3	3.6	19.6	7.5
XV B3+7 f	1450-1400	14.5	15.5	17.1	1.6	9.4	1.7	17.2	2.7
XV B3+7 f	1400-1350	18.1	15.8	17	1.2	7.1	2.7	18.5	0.6
XV B3+7 f	1350-1275	30.9	23	25	2	8	4	27	0
XV B3+7 f	1275-1225	10.5	8.3	9.3	1	10.8	2	10.3	0
XV B3-7 f	1550-1500	14.9	12.6	14.8	2.2	14.9	2.2	14.8	0
XV B3-7 f	1500-1450	26.8	21.2	23.2	2	8.6	5.6	26.8	0
XV B3-7 f	1450-1400	25.3	21.2	23.1	1.9	8.2	3.9	25.1	0
XV B3-7 f	1400-1350	19.5	17.6	19.7	2.1	10.7	2.3	19.9	0.4
XV B3-7 f	1350-1300		16.6	16.6		0		16.6	16.6
XV B3-7 f	1300-1250	7.8	5.1	5.6	0.5	8.9	2.7	7.8	0
XV B3-14 f	1525-1450	20.2	14	15.2	1.2	7.9	6.2	20.2	0
XV B3-14 f	1450-1400	21.8	18.2	19.9	1.7	8.5	3.8	22	0.2

- Sublevel XIVb – 37 (footwall ore body – north);
- Horizontal distance: L=50 m (from geological profile 700 to geological profile 750);
- Vertical distance: h = 8 m (from sublevel -37 to sublevel -29);
- Thickness of ore zone: variable (from 10 m to 20 m).

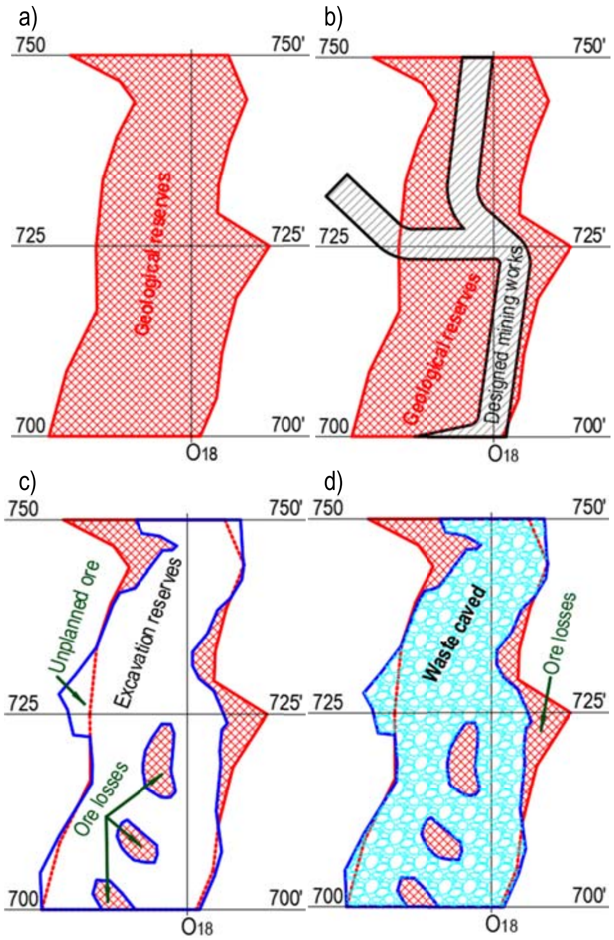

Fig. 4. Situation of the working place: Level XIVb, Block 1, Level XIVb-37 footwall, Between profiles 750-700, with excavation layout

On the basis of the geological data and the results of the geodetic surveying measurements of the mining works (Fig. 4 - *a*), it was stated that in the beginning, before , the preparatory mining works and the excavation of the ore, real geological reserves for excavation have been read for $Q_{geol.}$=18,9 t.

After the mining works, i.e. the excavation of the ore (Fig. 4 - *b* and *c*), the situation was as follows:

- quantity of excavated ore reserves without ore dilution Q_1=13,3t (from which 1,0 t is unconfined ore);
- quantity of excavated ore reserves with ore dilution Q_2=16,6t (from which 3,3 t is waste rock).

On the basis of the predetermined quantities of excavated ore reserves, the coefficient of ore dilution can be calculated (Mijalkovski et al., 2015), as follows:

$$o_r = \frac{Q_2 - Q_1}{Q_2} \cdot 100 = \frac{16,6 - 13,3}{16,6} \cdot 100 = 19,87\ \%$$

The planned average coefficient of ore dilution according to the mining project, which is actually the optimal coefficient, is: $o_{r,rp.} = 20$ %.

On the basis of volumetric measurements, the quantities of the remaining ore in the temporary protective pillars are determined (Fig. 4 - *c* and *d*) and their amount is Q_{zs} = 2,9 t. Knowing the geological reserves and the ore losses in the pillars, we can calculate the coefficient of ore losses:

$$z_{zs} = \frac{Q_{zs}}{Q_{geol.}} \cdot 100 = \frac{2,9}{18,9} \cdot 100 = 15,3\ \%$$

The planned average coefficient of ore losses according to the mining project, which is in fact the optimal coefficient, is: $z_{zs,rp.} = 20$ %.

The coefficient of ore recovery at excavation is:

$$i_r = 1 - z_{zs} = 1 - 0,153 = 0,847\ or\ 84,7\%$$

The total quantity of unexcavated ore and ore remaining in the protection pillars for this workplace is:

$$Q_{vk} = Q_1 + Q_{zs} = 16,6 + 2,9 = 19,5\ t$$

Now the ratio of total excavated ore with the ore in the geological reserves for this workplace can be calculated, expressed in percentages:

$$\frac{Q_{vk}}{Q_{geol.}} \cdot 100 = \frac{19,5}{18,9} \cdot 100 = 103,1\ \%$$

The explanation for the high ratio of the excavated ore for this workplace is proved by the following arguments:

- increment of geological reserves:

$Q_{pr} = Q_{vk}$- $Q_{geol.} = 19,5 - 18,9 = 0,6\ t$ or 3,1 %,

- unconfirmed geological reserves: 0 t or 0%,
- unexcavated ore for technical reasons: 0 t or 0%,

which can be seen from Fig. 3 and Fig. 4.

Conclusion

In the sublevel and block caving mining method the increasing of ore losses causes a reduction in ore recovery and ore dilution. Calculation of the parameters that have an impact on the ore recovery and ore dilution, can be carried out practically or through laboratory analyses.

In mining practice, the coefficients of ore recovery and ore dilution can be calculated with satisfactory accuracy using the already existing mathematical formulations with previously made detailed geodetic surveying measurements of the volume for excavated and unexcavated ore for each workplace.

The occurrence of losses or the utilization of the ore lead to significant economic consequences, which can be expressed in terms of value indicators. It must be kept in mind that the ore losses cannot be entirely avoided in practice, and therefore, as the main task, the question arises as how to minimize, i.e., how to achieve greater ore recovery, having in mind the fact that ore wealth is a non-renewable natural resource.

The „SASA“ mine constantly monitors the coefficients of ore recovery and ore dilution to provide optimum values for them, obtained on the basis of scientific research backed up by practical experiences.

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