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CONTENS

SADRŽAJ

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STRESS AND STRAIN ANALYSIS IN THE ROCK MASSIF DURING COAL EXPLOITATION WITH LARGE DIAMETER BOREHOLES IN EAST FIELD PIT RMU BOGOVINA

Abstract

This paper presents stress and strain analysis in massif during exploitation of out-of-balance coal layers in the BCM Bogovina. Behavior of the surrounding rock mass was tested during application of large diameter boreholes exploitation. Based on the proposed solutions for stope geometry and known geological conditions in deposit, physical and mechanical properties of coal and surrounding massif, the numerical analysis of the stress and strain of excavation area and surrounding massif was done. Numerical modeling of excavation area behavior was done using the software package Phase2, whose calculations are based on the finite element method. The analysis, conducted in this paper, has shown that there is a possibility for applying this kind of excavation in terms of stability the rock mass.

Keywords: *large diameter boreholes, coal, Bogovina, Phase2*

INTRODUCTION

BCM Bogovina is going through a difficult period as a consequence of a number of related factors. In order to overcome these problems, the possibility of exploitation the off-balance coal seams of coal is consider dusing mechanized mining methods - large diameter boreholes.

The high-quality brown coal is mined in the mine Bogovina by the traditional column method. Due to the underlying stratum of clay prone to swelling, the excavated raise is often reconstructed repeatedly and invested great effort in order to maintain the designed room dimensions. Therefore, it is necessary to change the exploitation method and increase coal production. Since there are no requirements for high investments, as the cheapest applicable model to increase the production solution is proposed the mechanized mining of off-balance reserves in the hanging wall and foot layer by drilling machine. This method would cause an increase in the production capacity of the mine, increase the total excavation reserves of thin seams in the deposit, and contribute to better working conditions and greater safety at work. Coal reserves of small thickness in the deposit East Field are shown in Table 1.

In order to study the possibility of applying the proposed method it is necessary to analyze the stress state.

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Table 1 *Calculation the total amount of reserves of small thickness in the East Field deposit [1]*

Serial number (n)	Blok K- roof P- floor	Block area S (m^2)	Average thickness (m)	Exploitation thickness d_{eks} (m)	Exploited coal reserves in block $Q_{eks}= S \cdot d_{eks} \cdot \gamma_{sr}$ (t)
1	B-3P	197 261	1.36	0.780	200 023
2	B-2P	79 428	1.10	0.780	80 540
3	B-1P	274 402	1.14	0.780	278 244
4	B-1K	182 441	1.10	0.780	184 995
5	B-3K	205 080	1.86(1.20)	0.780	207 951
6	B-4K	85 358	1.24	0.780	86 553
Σ		1023970			**1,038,306**

γ_{sr} *- average specific density*

The analysis is performed to determine the behavior of surrounding rock mass during excavation by the adopted geometry. Calculation of roofing and shelf deformation was carried out as well as study the possibility of caving mining drill holes as well as the behavior of underlying swelling clay. Checking the stress state of surrounding rock mass in preparing the excavation of drill holes, and the preparation was done with the help of software package Phase2. Tests were carried out on the basis of data taken from physical - mechanical properties of rock mass [1, 7] and adopted geometry of excavation panel.

Possibility of exploitation of off-balance deposits in parts of the BCM Bogovina so far has not been considered, but detailed tests were carried out of physical and mechanical characteristics the underlying stratum of clay and accompanied rocks and geological investigation. The resulting download data [1, 7] were used as the input parameters in the analysis program Phase2.

The method of excavation the drill holes of large diameter is used for the exploitation of small thickness seams ranging from coal mines in Poland, the Czech Republic (Paskov), China (Xinwen), USA (Appalachian), the Ukraine (Donbas), North Africa (Manto mine). Drilling machine VS 625 - Seal created as a prototype machines BŠK 2M Ukrainian producers, is proposed for the exploitation of thin coal seams in Bogovina [10]. Stability testing of drill holes at suggested geometry was considered the needs of mines in Poland. The obtained positive results were processed in the program FLAC 3D [5]. Analysis the effects of drilling machines BUA 600 mines Manto for seam thicknesses of 1.00 to 1.80 m showed that the machine can be successfully used in the underground mining [3]. This system of obtaining coal is characterized by a high degree of security and safety at work. The applicability of the method and effects depend primarily on the geological characteristics of seams and stability of the surrounding massifs. Frequent problem is demolishing of drill holes of great length in progress. To prevent the demolishing protective pillars of greater width should be left. Stability Analysis of the rooms in the underground construction and mining are often tested by the software packages that include in their calculations the finite element method. Depending on the parameters of the surrounding rock mass obtained results show whether the room is necessary to be supported or not. In coal mines, all development rooms have to be supported as a rule, except stope, so the condition of stress and strain was analyzed in terms of support durability [2, 3, 4, 5, 6, 8, 9].

1 EXCAVATION OF THIN SEAMS OF COAL DEPOSIT IN THE EAST FIELD BY DRILLING

An important area of application this technology of coal mining is in coal deposits of small thickness that are not tectonically disturbed (deposits without occurrence of micro faults). Principle of mining technology by drilling is that coal obtained directly by drilling the drill holes of large diameter that is smaller than the thickness of coal seam in order to achieve maximum utilization and waste web to minimum. In order to the ensure stability, depending on the intensity of stress and mechanical properties of coal and overlying sediments, between individual drill holes, the protective coal pillars, width of 0.2 - 1.0, have to be left m and for the case analysis were adopted pillars, width of 0.9 m. Losses during excavations can reach 38 - 45%, which is not rational, but it is acceptable because the excavation of these seams by conventional methods is not profitable, i.e. possibility for recovery is 0%. In favorable operating conditions in the coal seam thickness ranging from 0.6 to 0.7 m, the achieved production is 140 tons/day, while the effects on the excavation are 11.7 t/day [2].

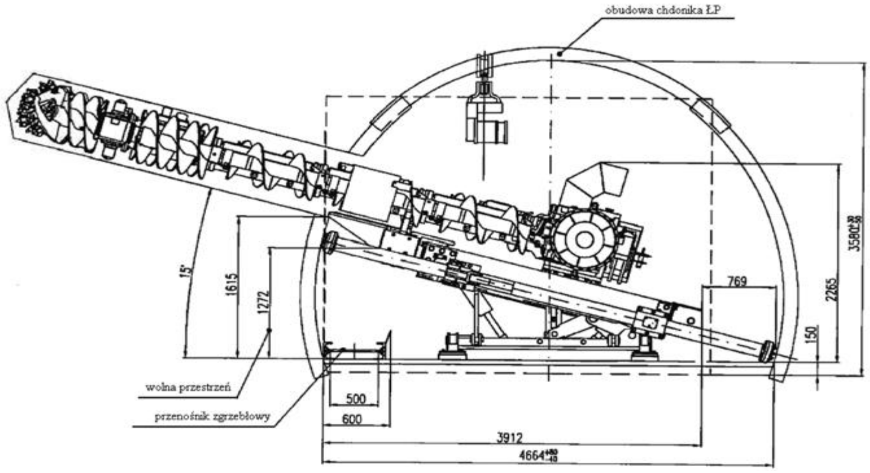

Figure 1 *Cross section of the underground rooms with dimensions of drilling machine VS 625 -Seal P2 [3]*

Mining methods with drilling machine is simple and depends on characteristics and capacity of the applied machines. Selected VS SEAL-625 P2 drilling machine is shown in Figure 1, which makes excavation with height of 0.625 to 0.825 m, width of 2.005 to 2.105 m, with resistance of coal to 350 kN/m [7]. In the event that the seam has the appearance of methane, machine has a system of ventilation and degassing led worksite capacity of 30 l/min.

The adopted excavation geometry involves making the basic premises prepared on the charcoal seam. Two parallel inclines will be located in the central part of the block. At every 200 meters length of in cline, the transverse corridors will be developed that allow flow ventilation and share panels on excavation fields. Excavation field is wide 200 m plus width of two protective pillars of 10 m. Among mining drill holes in the field column width of 0.9 m will be left. Geometry excavation field is shown in Figure 2. It is foreseen that the inclines exploited bilaterally on the left and right and pulls the room with the progress of excavation. The proposed profile room preparation needed to be settled. Drilling machine is shown in Figure 1. The room will be supported by permeable steel roof support, and the sides and ceiling will be pledged wooden pawns.

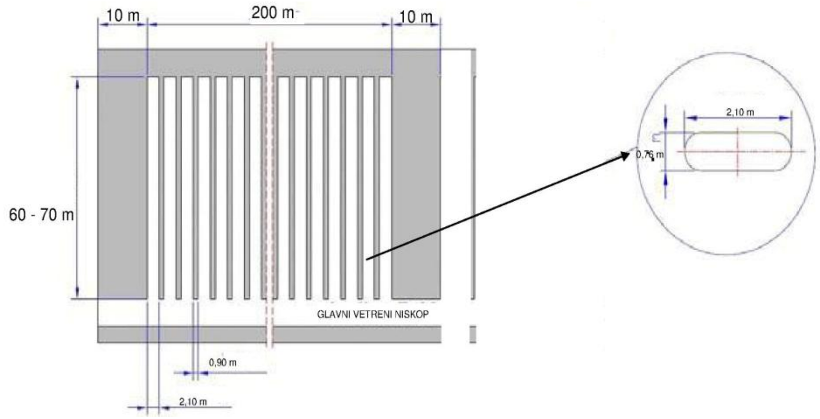

Figure 2 *View of excavation field geometry in exploitation with drilling machines in the BCM Bogovina*

As the advantages of selection this kind of exploitation of coal in the coal mine Bogovina, the following could be indicated:

- mechanized excavation,
- involvement of a small number of workers and the excavation and transportation of coal,
- low initial investments,
- excavation of reserves that cannot be exploited by the traditional methods,
- shorter transport of coal,
- depth of exploitation and up to 80 m,
- possibility of exploitation of small seam thickness below 1 m,
- stable production,
- small volume of preparatory work,
- direct sales of coal to the power plants, there is no additional cost of deposits and transportation of coal, and
- high level of security and safety at work.

2 ANALYSIS OF STRESS AND STRAIN IN THE ROCK MASS USING THE PROGRAM PHASE2

The analysis covered the preparing room for excavation of the panel, as well as the analysis of stress and strain in excavated drill holes that occur as a consequence of use the method of extraction the drill holes of large diameter. Input parameters relating to a given model are defined by the position of excavation panels in massive, thick supporting wall, thickness of coal seam and type of rock material beneath and above, position of the rooms to the surface of the field, which primarily depends on the thickness of rock mass above the excavation.

Panel, width of 251 m, is adopted as a calculation model, representing a vertical section of the rock mass, is shown in Figure 3. Two cross halls are made in this panel in the upper coal seam (PTn1 and PTN2) (Figure 3) and two identical corridors in the foot wall coal seam (PTN3 and PTN4) (Figure 3), which allow the transport of coal, transport of raw materials and ventilation work site. Excavation drill holes, width of 2.10 m, height of 0.8 m, are made in the coal seam them in a single excavation panel has under 65 (the top and bottom coal seam). A protective pillar is designed between the drill holes 0.9 m in width as shown in Figure 2. After making the excavation drill hole, machine is moved to the undisturbed environment and exploiting of new drill holes have to be done at given dynamics.

The model is divided into ten phases that representatively describe the state in the massif at key moments:

1. The first stage is an undisturbed massif,
2. The second stage is the state of the massif after making the cross hall in the upper coal seam (PTn1 and PTN2)
3. The third phase represents the state after the supporting steel support (PTN 1 and 2)
4. The fourth phase state of the massif after the first twenty drill holes in the upper coal seam,
5. The fifth phase of the state after making forty wells in the upper coal seam,
6. The sixth stage is a state in the massif after making all sixty-five drill holes in the upper coal seam, i.e. exploitation of coal in the top layer,
7. The seventh stage is massive after making a transverse corridor in the foot wall carbon layer (PTN3 and PTN4)
8. The eighth stage is a condition for support after these two rooms a steel arch support,
9. The ninth stage after making the top ten drill holes in the foot wall coal seam, and
10. The tenth stage shows end exploitation in the foot wall carbon layer and the condition observed the model after coal mining in the observed block.

After determining the phases, the mesh generation and discrediting were made, which is determined by the total number of finite elements in the model with the specified parameters. The parameters are: type of mesh gradient factor, the node number (17294), the number of elements (8553) depending on the considered phase. On the basis of laboratory tests of rock mass [1, 7] geomechanical features of the model studied were determined. Tests have shown what kind of rocks they are, and their geomechanical features are shown in Table 2.

Table 2 *The physical and mechanical properties of rocks in the pit East Field RMU Bogovina [1, 7]*

Name of material	Colour	Unit weight [MN/m³]	Young's Moduls [MPa]	Poisson's Ratio	Failure criterion	Kind of a material	Shear strength [Mpa]	Angle of internal friction (°)	Angle of internal friction	Cohesion max. [MPa]	Cohesion reducted [Mpa]
SANDSTONE		0.03	31.966	0.16	Mohr Coulomb	Plastic	0.3	33	48	0.28	0.176
MARL		0.0206	80.43	0.36	Mohr Coulomb	Plastic	1.4	35	40	1.79	1.78
MARL 2		0.01904	45.77	0.36	Mohr Coulomb	Plastic	1.1	40	38	0.66	0.65
CLAY		0.022	0.5	0.35	Mohr Coulomb	Plastic	0.06	22	21	0.3	0.3
ROOF COAL		0.013	57.14	0.37	Mohr Coulomb	Plastic	0.76	57	56	1.75	1.74
FLOOR COAL		0.013	57.14	0.37	Mohr Coulomb	Plastic	0.76	57	56	1.75	1.74

The boundaries of the model are determined such as the observation of infinite areas set aside part of the real performance of excavation panels to scale up to the surface. Boundary conditions are specify that it is permitted to move only the ground surface while the other borders without moving (bottom, left and right).

RESULTS AND DISCUSSION

Figure 3 and 4 shows the contour of the axial stress (σ_1) in the massif. In order to get a representative view for analyzing contours of axial stress in the model were selected following phases: Phase 1 - undisturbed massif, Phase 2 - situation in the massif after making facilities PTn1 and PTN2, phase 6 presents contours axial stress after excavation of the entire upper coal seam and phase 10 contour axial stress upon termination of exploitation in the reporting panel.

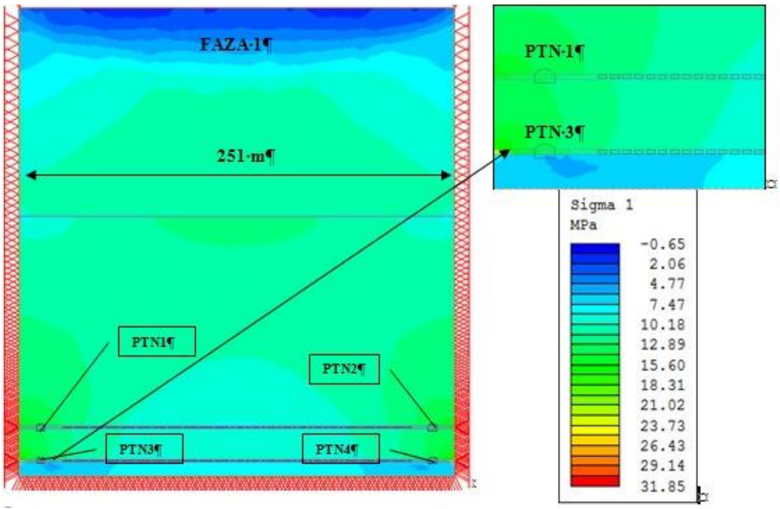

Figure 3 *Display of contours of axial stress σ1 in the model switching panels Phase 1*

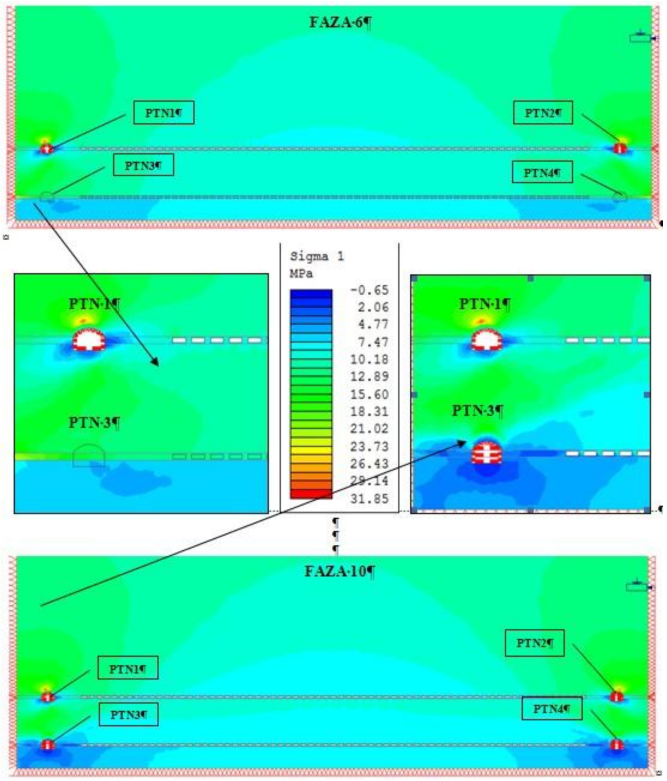

Figure 4 *Contour axial stress σ1 in the model of excavation panels in phases 6 and 10*

The highest intensity of axial stress in undisturbed massif is in vicinity of mining preparations in the upper and lower coal seam, and the lowest intensity is observed in the foot wall section of green clay, which opposes the action of axial stress of masses.

With the progress of excavation, contour reduced axial stress over the excavation of drill holes grows under the influence of stress underlying stratum of clay. In the vicinity of the room excavation preparation upper coal seam in safety pillars between the mining panels are concentrated axial stresses of greatest intensity.

Figure 5 shows the fracture zones in the vicinity of mining drill holes, reveals that the elements of fracture in all excavated drill holes and increasing the value of the axial stresses in the vicinity of drill holes as a result of the excavation progress. The elements on the edges of fracture drill holes in the upper indicating the possible collapse of coal to the border with marl roof.

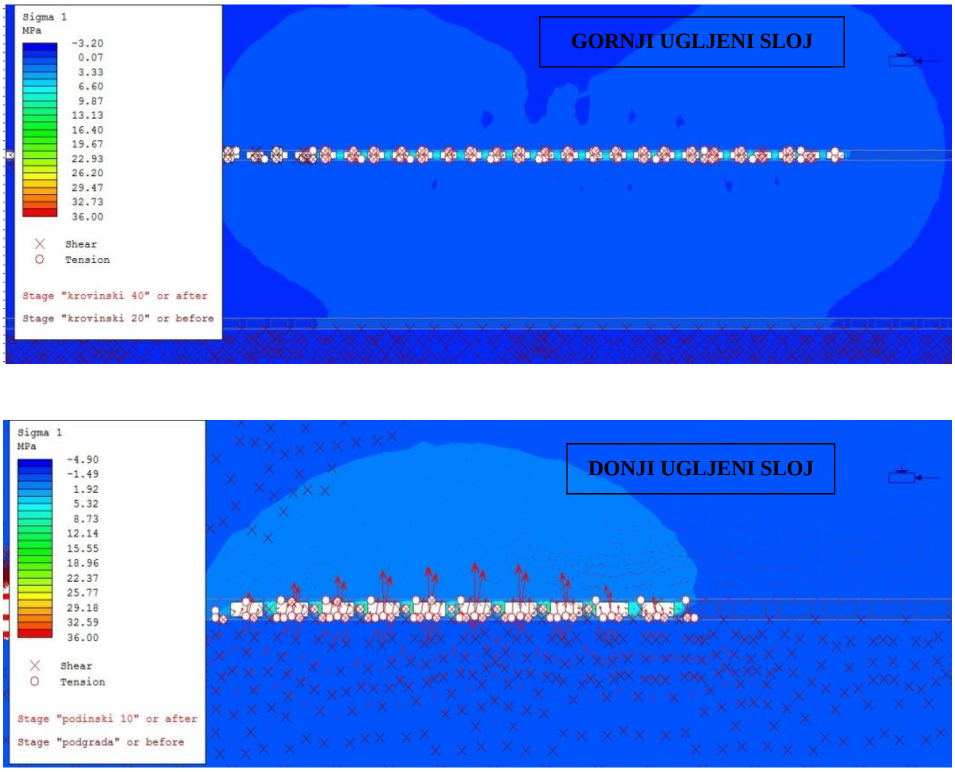

Figure 5 *Display of axial stress σ1, with elements of fracture in excavated drill holes upper and lower coal seam*

In the lower coal seam fracture elements are concentrated in the foot wall part and consequence of the proliferation of underlying stratum of clay, as indicated by displacement vectors. The surrounding rock mass no occurrence of elements fracture. Stress state is changing in terms of increasing the axial stress in the safety pillars between the drill holes because they now assume the new load.

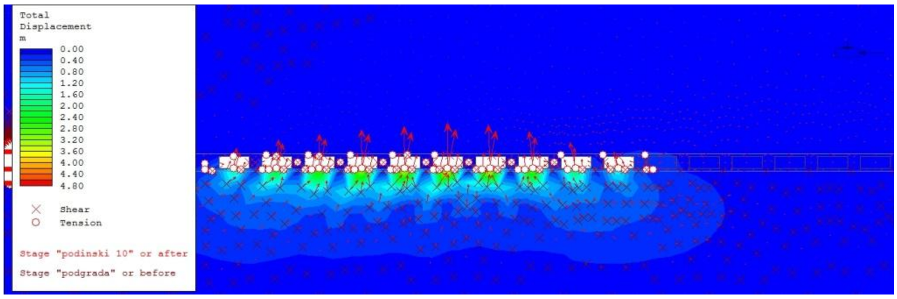

Figure 6 *Layout view of total movement in the lower coal seam after making the top 10 mining walked*

During excavations in the lower coal seam in the excavated drill holes due to proliferation of the foot wall of green clay comes to filling the open unsupported area. The direction and size of displacement in this part of the model is seen in Figure 6 where it shows the total displacements in lower seam after excavation. This shift amounts to 2.00 m, affect the increase in stability at further exploitation because it naturally fills the excavated space.

To analyze the stress strain state around the rooms excavated preparation upper coal seam in Figure 7 presents a comparative view of the total displacement after making facilities (Figure 7a) and the appearance of vector and contour of the total displacement after the supporting steel arch support (Figure 7b).

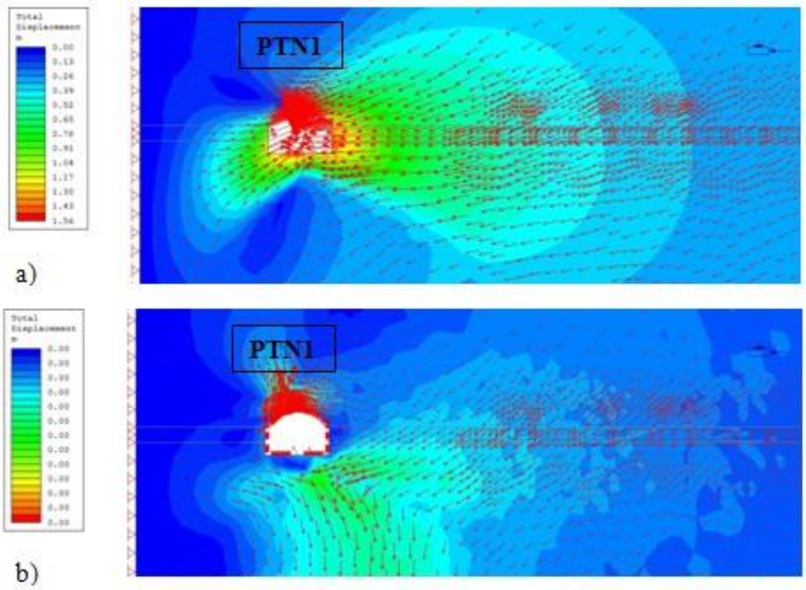

Figure 7 *Contour and Vectors total movement after a) making PTn1 b) the supporting steel support*

During creating of transverse corridors PTn1 in the top layer of carbon displacement vectors are concentrated in the ceiling of the room in the hips, where the values range from 0 to 1.30 m.

After installing the supporting overall shifts in relation to the previous phase have a value of 0.00 m, because the suburb assumed the burden of the surrounding massifs.

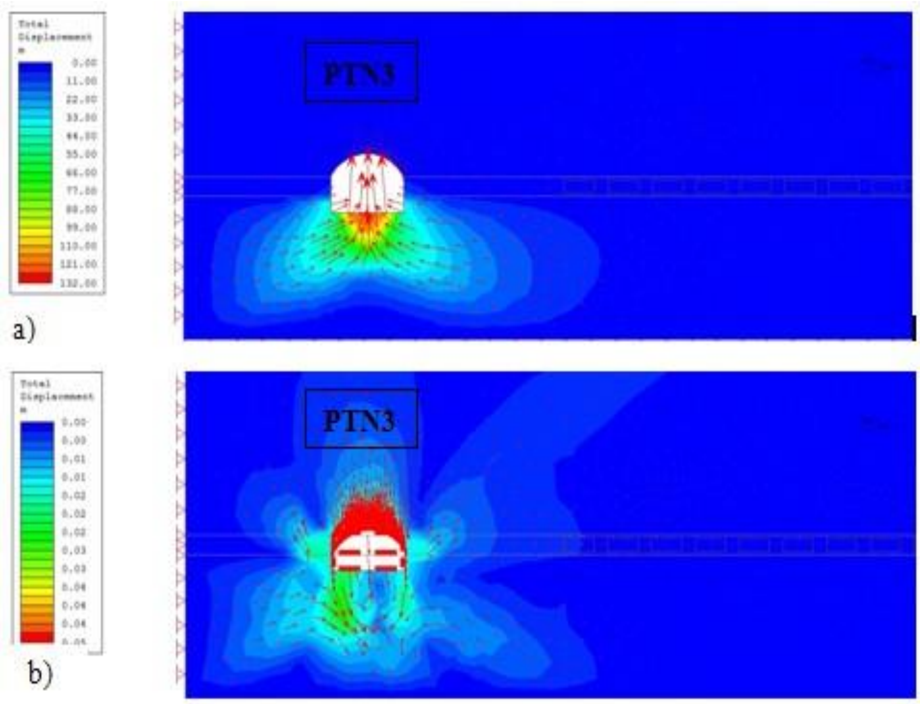

Figure 8 *Contour and Vectors total movement after a) making PTn1 b) the supporting steel support*

Analysis of movement during making room PTN3 points to the emergence of great pressure from the shelf as a consequence of a swelling green clay, figure 8 a), while the ceiling part of the room is almost does not suffer deformation. After the supporting facilities Figure 8 b), there is a reduction in the value of total displacement. At the foot wall section are observed less displacement distributed around observed the excavation which are in the range of 0.00 to 0.05 do not threaten the stability made the room. Preparation of room excavation for the significant amount of movement to contour around the excavation must stabilize the steel support to prevent collapses.

The stability of the panel excavation was presented by the contours of strength factor (SF) according to the stages in development of excavation. Caving excavation in with the progress of mining drill holes in the panel is not a problem in the coal exploitation using this method. It is important to avoid collapses during operation of the drill holes in order to avoid being stuck twist drills.

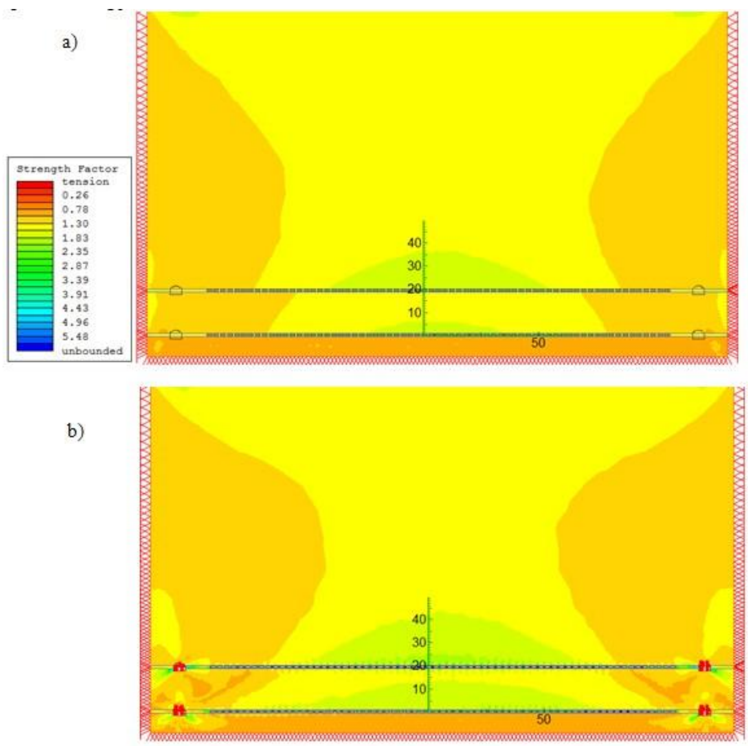

Figure 9 *Showing the strength factor contours a) undisturbed massif b) after excavation around the observed model*

The value of the strength factor in an area that is exploited is greater than one in all parts of the massif because the rock mass behaves plastically [8].

Green Zone (Figure 9) above the excavation of drill holesindicates an increase in the value of the strength factor in exploitation.

In order to explain the movement of factors of strength values are set checkpoints in security pillars of the room preparing the width of ten meters, Figure 10, item 1 and 3, and in security pillars between the drill holes in the upper and lower seams, Figure 10, item 2 and 4.

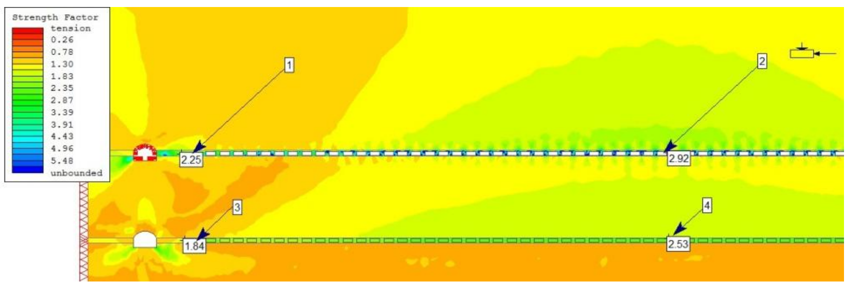

Figure 10 *Locations of sampling points of the strength factor in safety pillars*

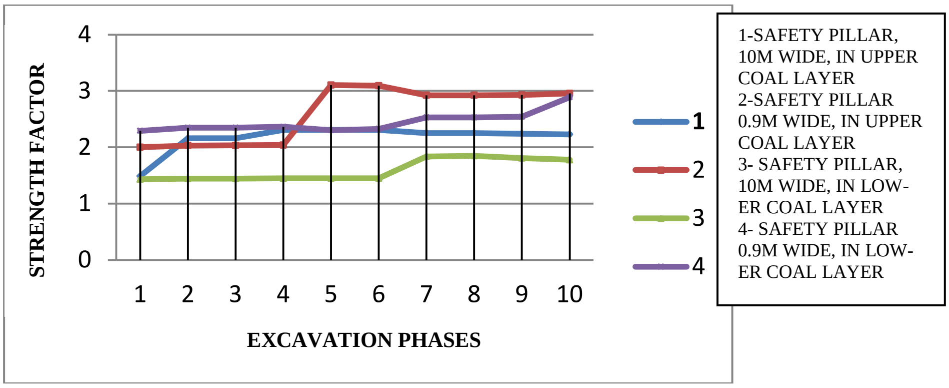

Figure 11 *Diagram of values strength factor according to the stage of excavation*

Graphic shows changes in value of the strength factor as a function of the excavation phase is shown in diagram (Figure 11). The factor of strength in the safety pillars at all control points with the progress of exploitation indicates growth.

Curve 1 from diagram for the upper coal seam, growth in value between the undisturbed massif (phase 1) and making room PTn1 (Phase 2), is the result of secondary redistribution of stress due to the creation of a new open area in the multi-rock environment. The value is still constant (between phases 2 and 3) because support is the new load. Excavation area on the other side of the seat pillar (Phase 3) comes to relaxation and growth factors of strength. After phase 4, further excavation has no significant effect on the value of strength factor in the security pillar of the upper coal seam.

Curve 2 from the diagram represents the value of the strength factor in the security pillar between the drill holes of the upper seam, width of 0.9 m. Since the beginning of coal exploitation in the top seam (phase 1-4) the value of the strength factor is not changed until the progress of excavation comes to the pole (phase 5), when the strength factor rises sharply. Further progress of excavation front and end of exploitation the upper seam (phase 6) lead to a slight fall in the strength factor value in the security pillar. This decline in value is the result of transfer the loads of rock mass lying on the pillars between the drill holes.

Constant values of strength factor (stage 7-10) Curve 1 and 2 with the diagrams show that works in the lower coal seam does not affect the strength factor in safety pillars of the upper coal seam, in terms of reducing its value.

Curves 3 and 4 in the diagram show the change of the strength factor value in the safety pillars during exploitation the lower coal seam. Works in the top coal seam have no impact on the strength factor value in the lower coal seam. This can be seen from the chart, where the curves 3 and 4 do not change the value until the end of exploitation in the upper seam (step 6). After excavation the upper seam, the strength factor in both safety pillars increases (step 7). Growth factor values of strength is the result of flourishing the underlying stratum of clay, which meets for digging wells and taking the load stabilizes the surrounding mountain range. Further excavation of the lower coal seam (stage 8-10) does not change the strength factor value in the security pillar between the panels, which shows the curve 3 with a diagram. The value is constant on curve 4 in stages 8 and 9. Excavation of drill holes in the vicinity of the security pillar (stage 10) leads to an increase in the value on curve 4 from diagram. The growth is a result of flourishing underlying stratum of clay that fills the drill holes and takes on the load of the surrounding rock mass.

Such high values of strength factors indicate that the caving will not be in massif in the coal exploitation of coal drilling machines with the excavation geometry.

CONCLUSION

Mechanized excavation of off-balance seams of small thickness ranging from the RMU Bogovina would provide a long-term increase in production, increased security and safety at work as well as increasing the total reserves in the deposit.

When analyzing the given model led to the conclusion that the described behavior of the rock mass about real events in seam, in particular of the analysis relating to the proliferation of clay and deformations that occur during the excavation. During the excavation of the lower coal, seam clay will soon be filled with exploitation drill holes and contribute to better stability of the observed part of panel. The excavated drill holes of the upper coal seam, demolishing small-scale, does not threaten the exploitation circumferential borehole to move marl. The analysis showed a high amount of movement around the room excavation preparation and this should be permissive steel roof supports to prevent deformation.

It can be concluded from the above that the BCM "Bogovina" may consider this type of excavation in the current situation, but it is necessary to do a series of geotechnical analyses to confirm the received data. It is also required to explore the possibility of exploitation the other parts of the deposit at lower excavation geometry, the one that would contribute to better recovery of the deposit.

REFERENCES

[1] Study on Coal Reserves of the Deposits BCM "Bogovina" - Bogovina, JP PEU "Resavica" in Restructuring, Bureau for Design and Development, Belgrade, 2011;

[2] Z. Milicevic, Methods of Underground Exploitation the Mineral Deposits, Technology of Devewlopment the Underground Rooms Using the Combined Machines, Working Script, Bor, 2008;

[3] I. L. Follington, R. Deeter, D. Share, C. Moolman, A New Underground Auger Mining System, The Journal of The South African Institute of Mining and Metallurgy 101, (2001), 25-32;

[4] F. Wang, S. Tu, Q. Bai, Practice and Prospects of Fully Mechanzed Mining Technology for Thin Coal Seams in China, The Journal of The Southern African Institute of Mining and Metallurgy 112, (2012), 161-170;

[5] Z. Luboski, Assessment of Auger Mining Application in Polish Hard Cool Deep Mines, Mining of Mineral Deposits, (2013),133–142, ISBN: 978-1-138-00108-4;

[6] Z. Rak, J. Stasica, K. Skrzypkowski, Eksploatacja Pokładów Cienkich Metodą Zwiercania, PRZEGLĄD GÓRNICZY, (2014), 18-24;

[7] Report on Performed Testing on Samples of Bentonite from BCM Bogovina from Bogovina, Copper Institute Bor, Bor, June 2002;

[8] Lj. Tadic, Analysis of Occurrence the Plastic Fracture in the Rock Mass along the Tunnel Opening, Proceedings of Faculty of Civil Engineering 19 (2010), 63-77,

[9] R.E. Hammah, T. Yacoub and B. Corkum, J. H. Curran, The Practical Modelling of Discontinuous Rock Masses with Finite Element Analysis, 42nd US Rock Mechanics Symposium and 2nd US-Canada Rock Mechanics Symposium, San Francisco, San Francisco June 29-July 2, 2008;

[10] M. Stoniš, V. Hudeček, Mining of Coal Pillars Using the Drilling Method, Acta Montanistica Slovaca Ročník 14 (2009), 241-249;

[11] Rocscience Inc. 2005 Phase2 v6.0 - Two Dimensional Finite Element Slope Stability Analysis.

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ANALIZA STANJA NAPONA I DEFORMACIJA U STENSKOM MASIVU PRILIKOM PRIMENE METODE EKSPLOATACIJE UGLJA BUŠOTINAMA VELIKOG PREČNIKA U JAMI ISTOČNO POLJE RMU BOGOVINA

Izvod

U radu se analizira stanje napona i deformacija u masivu prilikom eksploatacije vanbilasnih slojeva uglja u RMU Bogovina. Ispitivano je ponašanje okolnog stenskog masiva prilikom primene metode otkopavanja bušilicama velikog prečnika. Na osnovu predloženih rešenja geometrije otkopa, i poznatih geoloških uslova u ležištu, fizičko-mehaničkih osobina uglja i okolnog masiva, izvršena je numerička analiza stanja napona i deformacija otkopnog prostora i okolnog masiva. Numeričko modeliranje ponašanja otkopnog prostora urađena je primenom softverskog paketa Phase2, čiji se proračuni baziraju na metodi konačnih elemenata. Analiza sprovedena u ovom radu pokazala je da postoji mogućnost ovakvog načina otkopavanja sa aspekta stabilnosti stenske mase.

Ključne reči: *bušotine velikog prečnika, ugalj, Bogovina, Phase2*

UVOD

RMU Bogovina prolazi kroz težak period koji je posledica više povezanih faktora. U cilju prevazilaženja ovih problema razmatra se mogućnost eksploatacije vanbilasnih slojeva uglja primenom mehanizovane metode otkopavanja - bušotinama velikog prečnika.

U rudniku Bogovina otkopava se visoko kvalitetan mrki ugalj tradicionalnom stubnom metodom. Zbog podinske gline sklone bujanju otkopni uskopi se vrlo često rekonstruišu, podina se više puta pouzima i ulaže se veliki napor kako bi se prostorije održale na projektovane dimenzije. Zato je potrebno izmeniti način eksploatacije i povećati proizvodnju uglja. Obzirom da ne postoje uslovi za visoka investiciona ulaganja, kao najjeftiniji primenljiv model za povećanje proizvodnje predloženo je rešenje mehanizovanog otkopavanja vanbilansnih rezervi u krovinskom i podinskom sloju mašinama za bušenje. Ova metoda uslovila bi povećanje proizvodnih kapaciteta rudnika, uvećala bi ukupne rezerve otkopavanjem tankih slojeva u ležištu, i doprinela boljim uslovima rada kao i većoj bezbednosti pri radu. Rezerve uglja male moćnosti u ležištu Istočno polje prikazane su u tabeli 1.

Da bi se ispitala mogućnost primene predložene metode neophodno je izvršiti analizu naponsko deformacionog stanja.

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Tabela 1. *Proračun ukupne količine rezervi male moćnosti u ležištu Istočno polje [1]*

Redni broj (n)	Blok K- krovinski P- podinski	Površina bloka S (m^2)	Srednja debljina (m)	Eksploataciona debljina d_{eks} (m)	Eksploatacione rezerve uglja u bloku $Q_{eks}= S \cdot d_{eks} \cdot \gamma_{sr}$ (t)
1	B-3P	197 261	1,36	0,780	200 023
2	B-2P	79 428	1,10	0,780	80 540
3	B-1P	274 402	1,14	0,780	278 244
4	B-1K	182 441	1,10	0,780	184 995
5	B-3K	205 080	1,86(1,20)	0,780	207 951
6	B-4K	85 358	1,24	0,780	86 553
Σ		1023970			**1.038 306**

γ_{sr}srednja specifična težina

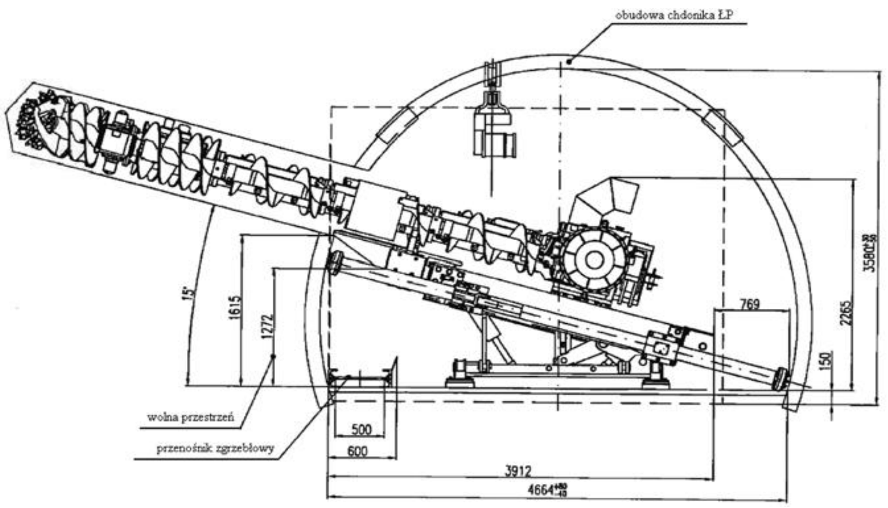
Analiza se vrši da bi se utvrdilo ponašanje okolnog stenskog masiva prilikom otkopavanja po usvojenoj geometriji. Izvršen je proračun deformacija krovine i podine, ispitana mogućnost zarušavanja otkopnih bušotina kao i ponašanje podinske bujave gline. Provera naponskog stanja okolnog stenskog masiva pri izradi otkopnih bušotina i prostorija pripreme urađena je uz pomoć programskog paketa Phase2. Ispitivanja su izvršena na osnovu preuzetih podataka fizičko- mehaničkih osobina stenskog masiva [1, 7] i usvojene geometrije otkopnog panela.

Mogućnost eksploatacije vanbilasnih delova ležišta u RMU Bogovina do sada nije razmatrana, već su vršena detaljna ispitivanja fizičko mehaničkih karakteristika podinske gline i pratećih stena, kao i geološka istraživanja ležišta. Dobijeni preuzeti podaci [1, 7] korišćeni su kao ulazni parametri analize u programu Phase2.

Metoda otkopavanja bušotinama velikog prečnika se primenjuje za eksploataciju slojeva male moćnosti u rudnicima u Poljskoj, Češkoj (Paskov), Kini (Xinwen), SAD (Appalachian), Ukrajni (Donbas), Severnoj Africi (Mantla mine). Bušaća mašina VS – SEAL 625 nastala kao prototip mašine BŠK 2M ukrajinskog proizvođača, predložena je za eksploataciju tankih slojeva uglja u Bogovini [10]. Ispitivanje stabilnosti bušotina po predloženoj geometriji razmatrano je za potrebe rudnika u Poljskoj. Dobijeni su pozitivni rezultati koji su obrađeni u programu FLAC 3D [5]. Analiza učinaka bušeće mašine BUA 600 u rudniku Mantla za slojeve debljine od 1,00 do 1,80 m pokazala su da se mašina može uspešno koristiti i u podzemnoj eksploataciji [3]. Ovaj sistem dobijanja uglja karakteriše se visokim stepenom sigurnosti i bezbednosti pri radu. Primenljivost metode i učinci prvenstveno zavise od geoloških karakteristika sloja i stabilnosti okolnog masiva. Učestali problem je zarušavanje bušotina velike dužine u napredovanju. Da bi se sprečilo zarušavanje ostavljaju se zaštitni stubovi veće širine. Analiza stabilnosti prostorija u podzemnoj gradnji i rudarstvu vrlo često se ispituje programskim paketima koje u svojim proračunima koriste metodu konačnih elemenata. U zavisnosti od parametara okolnog stenskog masiva dobijeni rezultati pokazuju dali je prostoriju potrebno podgrađivati ili ne. U rudnicima uglja se sve pripremne prostorije izuzev otkopa po pravilu podgrađuju, tako da je analizirano stanje napona i deformacija u smislu izdržljivosti podgrade [2, 3, 4, 5, 6 i 8, 9].

1. OTKOPAVANJA TANKIH SLOJEVA LEŽIŠTA UGLJA ISTOČNO POLJE BUŠENJEM

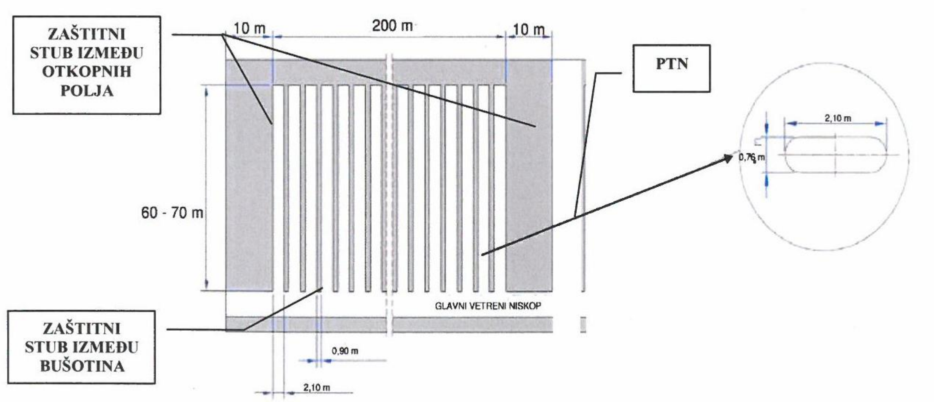
Značajna oblast primene ove tehnologije eksploatacije uglja je u ležištima uglja male moćnosti koja nisu tektonski poremećena (ležišta koja nemaju pojave mikro raseda). Princip tehnologije otkopavanja bušenjem je da se ugalj direktno dobija bušenjem bušotina velikog prečnika koji je manji od debljine ugljenog sloja, kako bi se ostvarilo maksimalno iskorišćenje a zahvat jalovine sveo na minimum. U cilju obezbeđenja stabilnosti, u zavisnosti od intenziteta napona i mehaničkih karakteristika uglja i krovinskih naslaga, između pojedinih bušotina ostavljaju se zaštitni stubovi uglja širine 0,2 - 1,0 m, a za konkretan slučaj analize usvojen su stubovi širine 0,9 m. Gubici prilikom otkopavanja mogu dostići 38 - 45 %, što nije racionalno, ali je prihvatljivo pošto otkopavanje ovakvih slojeva konvencionalnim metodama nije rentabilno tj. mogućnost iskorišćenja je 0 %. Pri povoljnim radnim uslovima, u sloju uglja moćnosti 0,6 – 0,7 m, postiže se proizvodnja od 140 t/dan, pri učincima na otkopavanju 11,7 t/nad [2].



Sl. 1. *Poprečni profil prostorija sa dimanzijama bušeće mašine VS –SEAL 625 P2 [3]*

Metoda otkopavanja mašinama za bušenje je jednostavna i zavisi od karakteristika i kapaciteta primenjene mašine. Odabrana je VS SEAL-625 P2 bušaća mašina prikazana na slici 1 koja izrađuje otkope visine od 0,625 do 0,825 m, širine od 2,005 do 2,105 m, pri otpornosti uglja do 350 kN/m [7]. U slučaju da u sloju ima pojave metana mašina poseduje sistem za ventilaciju i otplinjavanje na čelu radilišta kapaciteta 30 l/min.

Usvojena otkopna geometrija podrazumeva izradu prostorije osnovne pripreme po ugljenom sloju. Dva paralelna niskopa biće locirana u središnjem delu bloka. Na svakih 200 metara dužine niskopa izrađivaće se prečni hodnici koji omogućavaju protočno provetravanje i dele panele na otkopna polja. Otkopno polje je široko 200 m plus širina dva zaštitna stuba od 10 m. Između otkopnih bušotina u polju biće ostavljen stub širine 0,9 m. Geometrija otkopnog polja prikazana je na slici 2. Predviđeno je da se iz niskopa otkopava dvostrano na levu i desnu stranu i povlači prostorija sa napredovanjem otkopa. Predloženi profil prostorija pripreme potreban da bi se smestila bušeća mašina prikazan je na slici 1. Prostorija će se podgrađivati čeličnom popustljivom podgradom a bokovi i strop biće založeni drvenim zalagačima.



Sl. 2. *Izgled geometrije otkopnog polja pri eksploataciji bušaćim mašinama u RMU Bogovina*

Kao prednosti izbora ovakvog načina eksploatacije uglja u RMU Bogovina može se navesti:

- mehanizovano otkopavanje,
- angažovanje malog broja radnika i na otkopavanju i na transportu uglja,
- niska početna investiciona ulaganja,
- otkopavanje rezervi koje se ne mogu eksploatisati tradicionalnim metodama,
- kraći transport uglja,
- dubina eksploatacije i do 80 m,
- mogućnost eksploatacije sloja male debljine ispod 1 m,
- stabilna proizvodnja,
- mali obim pripremnih radova,
- direktni plasman uglja toplanama, nema dodatnih troškova deponovanja i prevoza uglja, i
- visok nivo bezbednost i sigurnosti pri radu.

2. ANALIZA STANJA NAPONA I DEFORMACIJA U STENSKOM MASIVU PRIMENOM PROGRAMA PHASE2

Analizom su obuhvaćene prostorije pripreme otkopnog panela, kao i analiza napona i deformacija u otkopnim bušotinama koji se javljaju kao posledica primene metode otkopavanja bušotinama velikog prečnika. Ulazni parametri koji se odnose na zadati model, definisani su položajem otkopnog panela u masivu, debljinom pratećih stena, debljinom samog ugljenog sloja i vrstom stenskog materijala podine i krovine, položajem prostorija u odnosu na površinu terena, koji u prvom redu zavise od debljine stenske mase iznad iskopa.

Kao proračunski model usvojen je deo panela širine 251 m koji predstavlja vertikalni presek stenskog masiva prikazan na slici 3. U panelu su izrađena dva poprečna hodnika u gornjem ugljenom sloju (PTN1 i PTN2) (slika 3) i dva indentična hodnika u podinskom ugljenom sloju (PTN3 i PTN4) (slika 3), koja omogućavaju transport uglja, dopremu repromaterijala i ventilaciju radilišta. Otkopne bušotine širine 2,10 m, visine 0,8 m izrađuju se u samom ugljenom sloju i njih u jednom otkopnom panelu ima po 65 (u gornjem i donjem ugljenom sloju). Predviđen je zaštitni stub između bušotina širine 0,9 m kao što je prikazano na slici 2. Nakon izrade otkopne bušotine mašina se pomera prema neporemećenoj sredini i eksploatiše se nova bušotina po zadatoj dinamici.

Sam model podeljen je u ukupno deset faza koje reprezentativno opisuju stanje u masivu u ključnim momentima:

1. prva faza predstavlja neporemećeni masiv,
2. druga faza predstavlja stanje u masivu nakon izrade prečnih hodnika u gornjem ugljenom sloju (PTN1 i PTN2),
3. treća faza predstavlja stanje nakon podgrađivanja čeličnom podgradom (PTN 1 i 2),
4. četvrta faza stanje u masivu nakon prvih dvadeset bušotina u gornjem ugljenom sloju,
5. peta faza je stanje nakon izrade četrdeset bušotina u gornjem ugljenom sloju,
6. šesta faza je stanje u masivu nakon izrade svih šezdeset i pet bušotina u gornjem ugljenom sloju, tj. završetka eksploatacije uglja u gornjem sloju,
7. sedma faza je masiv nakon izrade prečnih hodnika u podinskom ugljenom sloju (PTN3 i PTN4),
8. osma faza predstavlja stanje nakon podgrađivanja ove dve prostorije čeličnom lučnom podgradom,
9. deveta faza nakon izrade prvih deset bušotina u podinskom ugljenom sloju, i
10. deseta faza prikazuje završetak eksploatacije u podinskom ugljenom sloju i stanje posmatranog modela nakon otkopavanja uglja u posmatranom bloku.

Nakon određivanja faza izvršeno je generisanje mreže i diskretizacija koja je je odredila ukupan broj konačnih elemenata u modelu po zadatim parametrima. Parametri su: tip mreže, faktor gradijenta, broj čvorova (17294), broj elemenata (8553) u zavisnosti od posmatrane faze. Na osnovu laboratorijskih ispitivanja stenske mase [1, 7] određene su geomehaničke karakteristike za ispitivani model. Ispitivanja su pokazala da su u pitanju stene sledećih geomehaničkih osobina prikazanih u tabeli 2.

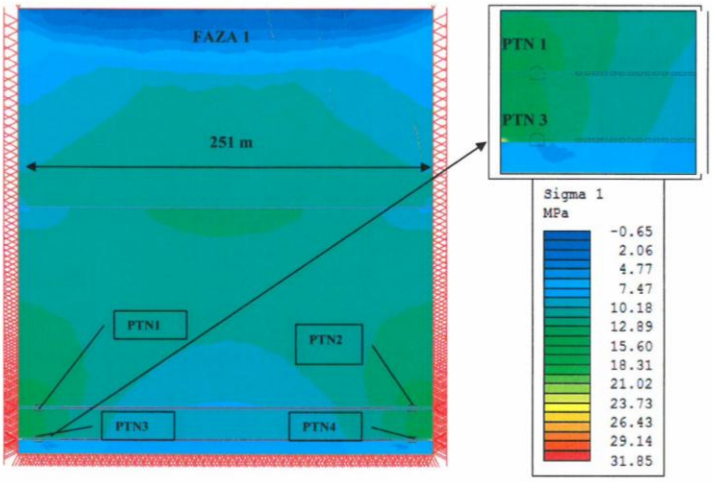
Tabela 2. *Fizičko-mehaničke karakteristike stena u jami Istočno polje RMU Bogovina [1, 7]*

Ime materijala	Boja	Jedinica težine [MN□m^3]	Young's Moduls [MPa]	Poisson's Ratio	Kriterijum loma	Vrsta materijala	Smičući napon [Mpa]	Ugao unutrašnjeg trenja (°)	Ugao unutrašnjeg trenja	Kohezija maks. [MPa]	Kohezija red. [Mpa]
PEŠČAR		0,03	31,966	0,16	Mohr Coulomb	Plastičan	0,3	33	48	0,28	0,176
LAPORAC		0,0206	80,43	0,36	Mohr Coulomb	Plastičan	1,4	35	40	1,79	1,78
LAPORAC 2		0,01904	45,77	0,36	Mohr Coulomb	Plastičan	1,1	40	38	0,66	0,65
GLINA		0,022	0,5	0,35	Mohr Coulomb	Plastičan	0,06	22	21	0,3	0,3
UGALJ KROVINSKI		0,013	57,14	0,37	Mohr Coulomb	Plastičan	0,76	57	56	1,75	1,74
UGALJ PODINSKI		0,013	57,14	0,37	Mohr Coulomb	Plastičan	0,76	57	56	1,75	1,74

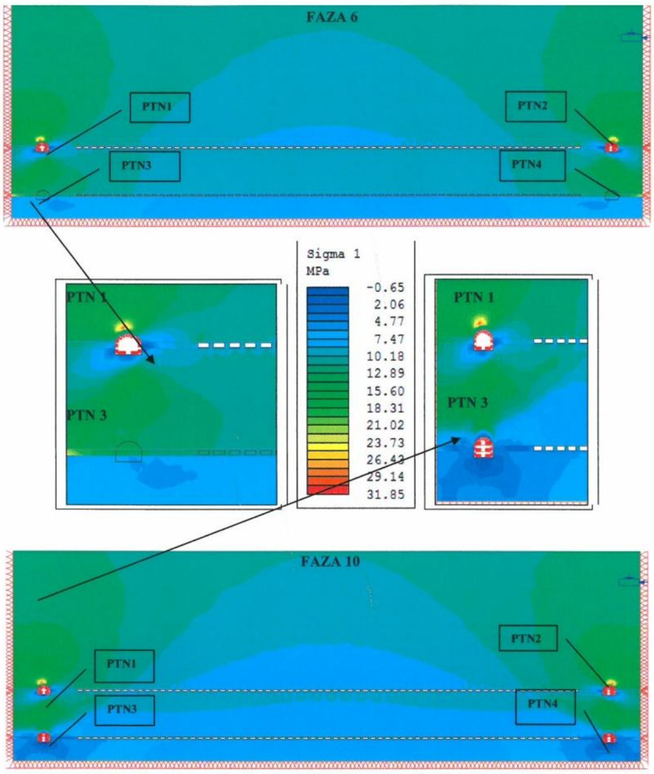
Granice modela određene su tako što je iz posmatranog beskonačnog područija izdvojen deo koji je realna predstava otkopnog panela u razmeri sve do površine terena. Granični uslovi su zadati tako da je dozvoljeno pomeranje samo prema površini terena dok su ostale granice bez pomeranja (donja, leva i desna).

REZULTATI I DISKUSIJA

Na slici 3 i 4 prikazana je kontura aksijalnog napona (σ_1) u masivu. Kako bi dobili reprezentativni prikaz za analizu konture aksijalnog napona u modelu izdvojene su sledeće faze: faza 1 - neporemećen masiv, faza 2 - stanje u masivu nakon izrade prostorija PTN1 i PTN2, faza 6 izgled konture aksijalnog napona nakon otkopanog cello-kupnog gornjeg ugljenog sloja i faza 10 kontura aksijalnog napona nakon završetaka eksploatacije u posmatranom panelu.



Sl. 3. *Prikaz konture aksijalnog napona σ_1 u modelu otkopnog panela faza 1*

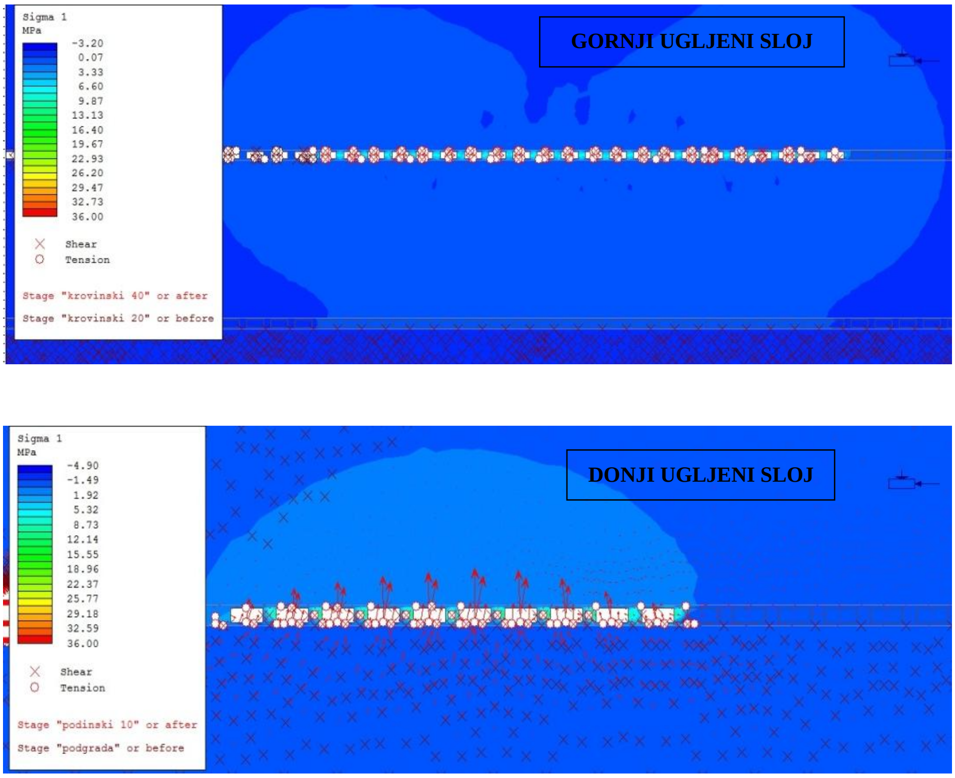


Sl. 4. *Prikaz konture aksijalnog napona σ_1 u modelu otkopnog panela po fazama 6 i 10*

Najveći intezitet aksijalnog napona u neporemećenom masivu je u okolini otkopnih priprema u gornjem i donjem ugljenom sloju, a najmanji intezitet se uočava u podinskom delu od zelene gline koja se suprotstavlja dejstvu aksijalnih naprezanja višeležećih masa.

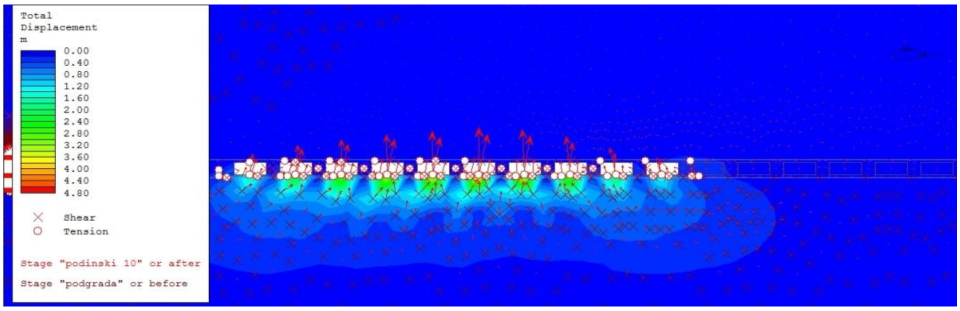
Sa napredovanjem otkopavanja, kontura smanjenih aksijalnih naprezanja iznad otkopnih bušotina raste pod uticajem naprezanja podinske gline. U okolini prostorije otkopne pripreme gornjeg ugljenog sloja i u zaštitnim stubovima između otkopnih panela koncentrisana su aksijalna naprezanja najvećeg inteziteta.

Na slici 5 prikazana je zona loma u okolini otkopnih bušotina, uočavaju se pojave elemenata loma u svim otkopanim bušotinama kao i povećanje vrednosti aksijalnog naprezanja u okolini bušotina kao posledica napredovanja otkopavanja. Elementi loma na obodima bušotina u gornjem sloju ukazuju na mogućnost obrušavanja uglja do granice sa loporovitom krovinom.



Sl. 5. *Prikaz aksijalnog napona σ_1 , sa elementima loma u otkopnim bušotinama gornjeg i donjeg ugljenog sloja*

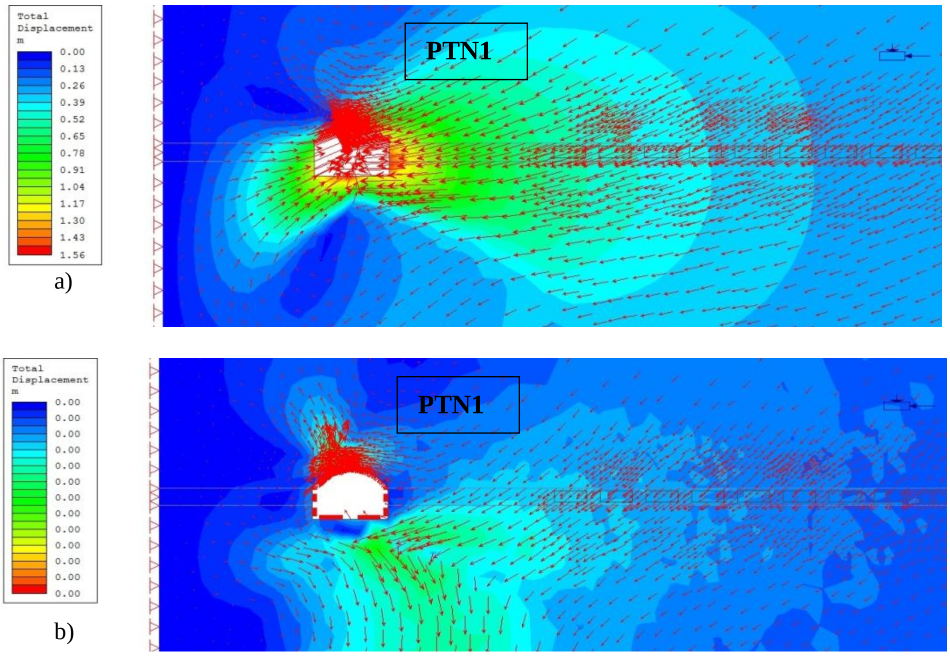
U donjem ugljenom sloju elementi loma su koncentrisani u podinskom delu i posledica su bujanja podinske gline na šta ukazuju i vektori pomeranja. U okolnom stenskom masivu nema pojave elemenata loma. Naponsko stanje se menja u smislu povećanja aksijalnog napona u sigurnosnim stubovima između bušotina jer oni sada preuzimaju novonastala opterećenja.



Sl. 6. *Prikaz izgleda totalnih pomeranja u donjem ugljenom sloju nakon izrade prvih 10 otkopnih prohoda*

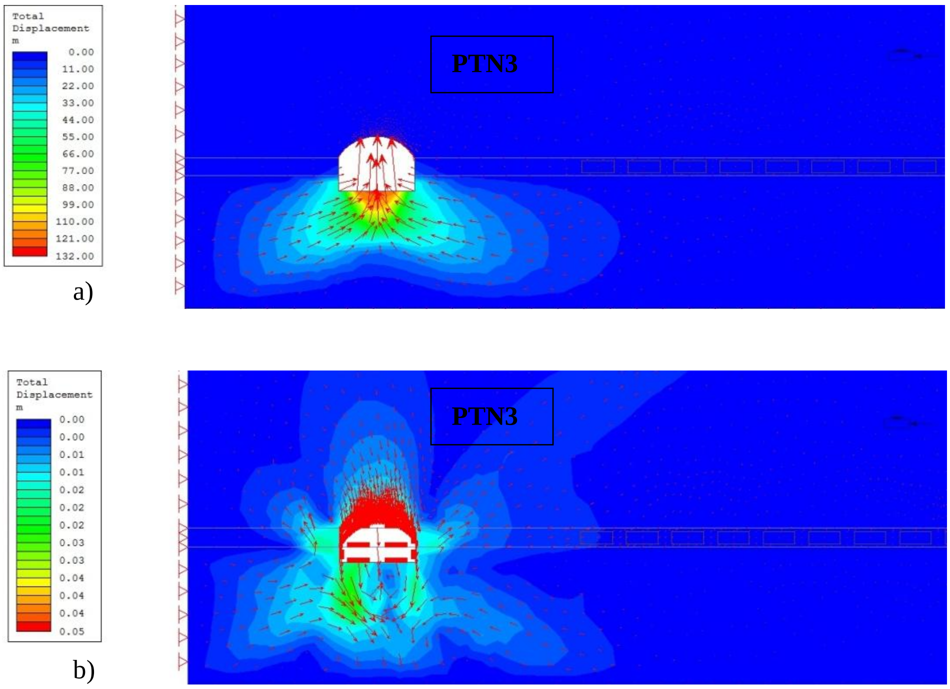
Prilikom otkopavanja u donjem ugljenom sloju u otkopnim bušotinama zbog bujanja podinske zelene gline dolazi do zapunjavanja otvorenog nepodgrađenog prostora. Smer kao i veličinu pomeranja u ovom delu modela uočavamo na slici 6 gde su prikazana ukupna pomeranja u donjem sloju nakon otkopavanja. Ova pomeranja iznose do 2,00 m i utiču na povećanje stabilnosti pri daljoj ekspoloataciji jer se prirodno zapunjava otkopani prostor.

Kako bi analizirali naponsko deformaciono stanje u okolini prostorija otkopne pripreme gornjeg ugljenog sloja na slici 7 dat je uporedni prikaz ukupnih pomeranja nakon izrade prostorije (slika 7a) i izgled vektora i kontura ukupnih pomeranja nakon podgrađivanja čeličnom lučnom podgradom (slika 7b).



Sl. 7. *Kontura i vektori ukupnih pomeranja nakon a) izrade PTN1 i b) podgrađivanja čeličnom podgradom*

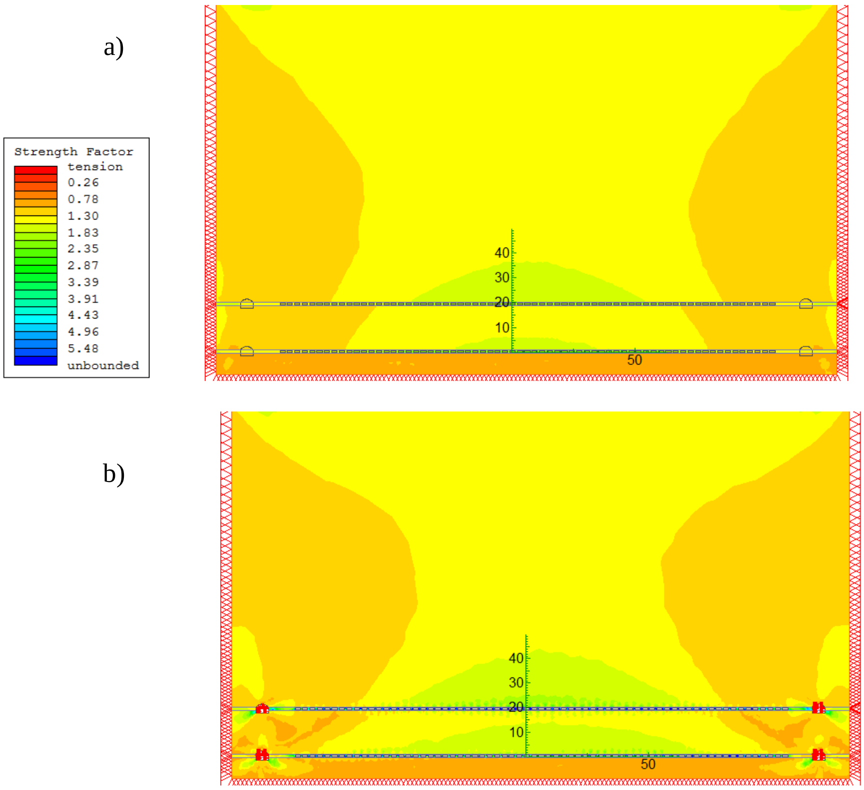
Prilikom izrade poprečnih hodnika PTN1 u gornjem ugljenom sloju vektori pomeranja koncentrišu se u stropnom delu prostorije i u bokovima, gde se vrednosti kreću od 0 do 1,30 m. Nakon ugradnje podgrade ukupna pomeranja u odnosu na prethodnu fazu imaju vrednost 0,00 m jer je podgrada preuzela opterećenje okolnog masiva.



Sl. 8. *Kontura i vektori ukupnih pomeranja nakon a)izrade PTN1 i b) podgrađivanja čeličnom podgradom*

Analiza pomeranja prilikom izrade prostorije PTN3 ukazuje na pojavu velikih pritisaka iz podine koji su posledica bujanja zelene gline slika 8 a), dok u stropnom delu prostorija skoro da ne trpi deformacije. Nakon podgrađivanja prostorije slika 8 b) dolazi do smanjenja vrednosti ukupnih pomeranja. U podinskom delu se uočavaju manja pomeranja raspoređena oko posmatranog iskopa koja se kreću u granicama od 0,00 do 0,05 m i ne ugrožavaju stabilnost izrađene prostorije. Prostorije otkopne pripreme se zbog značajnih vrednosti pomeranja na konturi oko iskopa moraju stabilizovati čeličnom podgradom kako bi se sprečilo zarušavanje.

Stabilnost otkopnog panela predstavljena je pomoću kontura faktora čvrstoće (SF) prema fazama u razvoju otkopavanja. Zarušavanje otkopa sa napredovanjem otkopnih bušotina u panelu ne predstavlja problem prilikom eksploatacije uglja ovom metodom. Važno je da ne dođe do zarušavanja u toku eksploatacije same bušotine kako ne bi dolazilo da zaglave spiralnih burgija.

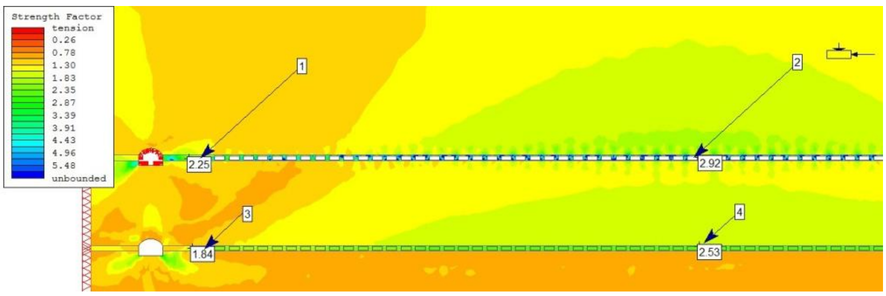


Sl. 9. *Prikaz kontura faktora čvrstoće a) neporemećenom masivu i b) nakon otkopavanja celog posmatranog modela*

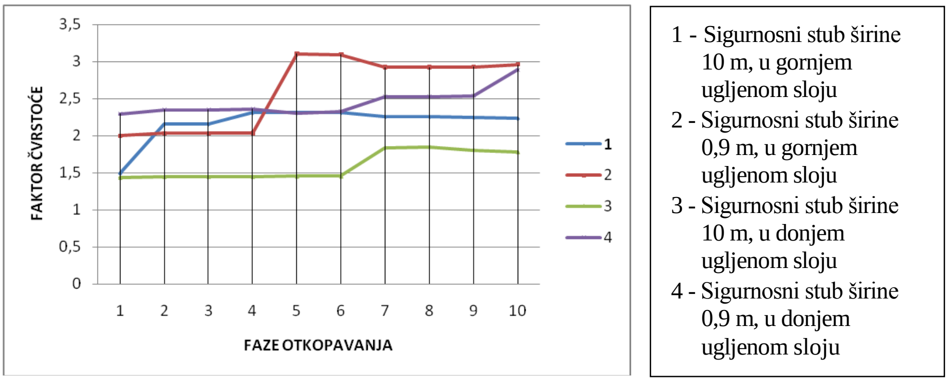
Vrednost faktora čvrstoće u oblasti koja se eksploatiše je veća od jedan u svim delovima masiva jer se stenska masa ponaša plastično [8].

Zelena zona (na slici 9) iznad otkopnih bušotina ukazuje na povećanje vrednosti faktora čvrstoće u toku eksploatacije.

Kako bi pojasnili kretanje vrednosti faktora čvrstoće postavljene su kontrolne tačke u sigurnosnim stubovima prostorije pripreme širine deset metara, slika 10. tačka 1 i 3, i u sigurnosnim stubovima između bušotina u gornjem i donjem sloju slika 10. tačka 2 i 4.



Sl. 10. *Prikaz lokacija tačaka ispitivanja faktora čvrstoće u zaštitnim stubovima*



Sl. 11. *Dijagram vrednosti faktora čvrstoće prema fazama otkopavanja*

Grafička predstava promene vrednosti faktora čvrstoće u funkciji od faze otkopavanja prikazana je na dijagramu (slika 11). Faktor čvrstoće u sigurnosnim stubovima na svim kontrolnim tačkama (Slika 10) sa napredovanjem eksploatacije pokazuje rast.

Na krivi 1 sa dijagrama za gornji ugljeni sloj, rast vrednosti između neporemećenog masiva (faza 1) i izrade prostorije PTN1 (faza 2), posledica je sekundarne preraspodele napona usled stvaranja nove otvorene površine u višestenskoj sredini. Vrednost je nadalje konstantna (između faze 2 i 3) jer podgrada preuzima novonastala opterećenja. Otkopavanjem površine sa druge strane sigurnosnog stuba (faza 3) dolazi do rasterećenja i rasta faktora čvrstoće. Nakon faze 4, dalje otkopavanje nema značajnijeg uticaja na vrednost faktora čvrstoće u sigurnosnom stubu gornjeg ugljenog sloja.

Kriva 2 sa dijagrama predstavlja vrednost faktora čvrstoće u sigurnosnom stubu između bušotina gornjeg sloja širine 0,9 m. Od početka eksploatacije u gornjem ugljenom sloju (faza 1-4) vrednost faktora čvrstoće se ne menja, sve dok se napredovanjem otkopavanja ne dođe do samog stuba (faza 5), kada faktor čvrstoće naglo raste. Daljim napredovanjem otkopnog fronta i završetkom eksploatacije gornjeg sloja (faza 6) dovodi do blagog pada vrednosti faktora čvrstoće u sigurnosnom stubu. Ovaj pad vrednosti posledica je prenosa opterećenja ležeće stenske mase na stubove između bušotina.

Konstantne vrednosti faktora čvrstoće (faze 7-10) za krive 1 i 2 sa dijagrama pokazuju da radovi u donjem ugljenom sloju ne utiču na faktor čvrstoće u sigurnosnim stubovima gornjeg ugljenog sloja, u smislu smanjenja njegove vrednosti.

Krive 3 i 4 na dijagramu prikazuju promenu vrednosti faktora čvrstoće u sigurnosnim stubovima pri eksploataciji donjeg ugljenog sloja. Radovi u gornjem ugljenom sloju nemaju uticaja na vrednost faktora čvrstoće u donjem ugljenom sloju. Na to ukazuju krive 3 i 4 koje sve do završetka eksploatacije u gornjem sloju (faza 6) ostaju sa istim vrednostima. Nakon otkopavanja gornjeg sloja faktor čvrstoće u oba sigurnosna stuba raste (faza 7). Rast vrednosti faktora čvrstoće je posledica bujanja podinske gline, koja ispunjava otkopne bušotine i preuzimajući opterećenje stabilizuje okolni masiv. Dalje otkopavanje u donjem ugljenom sloju (faze 8-10) ne menja vrednost faktora čvrstoće u sigurnosnom stubu između panela, što prikazuje kriva 3 sa dijagrama. Na krivi 4 faktor čvrstoće je konstantan u fazama 7-9. Otkopavanje bušotina u okolini samog sigurnosnog stuba (faza 10) dovodi do rasta vrednosti na krivi 4 sa dijagrama. Rast je posledica bujanja podinske gline koja zapunjava bušotine i preuzima opterećenje okolnog stenskog masiva.

Ovako visoke vrednosti faktora čvrstoće ukazuju da neće doći do zarušavanja u masivu pri eksploataciji uglja bušaćim mašinama sa ovom otkopnom geometrijom.

ZAKLJUČAK

Mehanizovano otkopavanje vanbilasnih slojeva male moćnosti u RMU Bogovina obezbedilo bi dugoročno povećanje proizvodnje, veću sigurnost i bezbednost pri radu kao i povećanje ukupnih rezervi u ležištu.

Prilikom analize zadatog modela došlo se do zaključka da je opisano ponašanje stenske mase približno realnim dešavanjima u sloju, posebno deo analize koji se odnosi na bujanje gline i deformacije koje pri otkopavanju nastaju. Prilikom otkopavanja donjeg ugljenog sloja glina će vrlo brzo zapuniti eksploatacione bušotine i doprineti boljoj stabilnosti posmatranog dela panela. U otkopnim bušotinama gornjeg ugljenog sloja, zarušavanje manjeg obima, ne ugrožava eksploataciju po obodu bušotine do podinskog laporca. Analiza je pokazala visoke vrednosti pomeranja u okolini prostorije otkopne pripreme pa je iste potrebno podgraditi čeličnom popustljivom podgradom kako bi se sprečile deformacije.

Iz svega navedenog može se zaključiti da RMU "Bogovina" može razmotriti ovakav vid otkopavanja u sadašnjim uslovima, ali je potrebno uraditi niz geomehaničkih analiza kako bi se potvrdili preuzeti podaci. Potrebno je takođe istražiti mogućnost eksploatacije drugih delova ležišta po povoljnijoj otkopnoj geometriji, onoj koja bi doprinela boljem iskorišćenju ležišta.

LITERATURA

[1] Elaborat o rezervama uglja ležišta „Bogovina“ RMU „Bogovina“ – Bogovina, JP PEU „Resavica“-u restrukturiranju, Biro za projektovanje i razvoj, Beograd, 2011. god.

[2] Ž. Milićević, Metode podzemnog otkopavanja ležišta mineralnih sirovina, Tehnologija izrade jamskih prostorija kombinovanim mašinama, radna skripta, Bor, 2008 god.

[3] I. L. Follington, R. Deeter, D. Share, C. Moolman, A new underground auger mining system, The Journal of The South African Institute of Mining and Metallurgy 101, (2001), 25-32.

[4] F. Wang, S. Tu, Q. Bai, Practice and prospects of fully mechanzed mining technology for thin coal seams in China, The Journal of The Southern African Institute of Mining and Metallurgy 112, (2012), 161-170.

[5] Z. Luboski, Assessment of auger mining application in Polish hard cool deep mines, Mining of Mineral Deposits, (2013), 133–142, ISBN: 978-1-138-00108-4.

[6] Z. Rak, J. Stasica, K. Skrzypkowski, Eksploatacja pokładów cienkich metodą zwiercania, PRZEGLĄD GÓRNICZY, (2014), 18-24.

[7] Izveštaj o obavljenim ispitivanjima na uzorcima bentonita iz RMU Bogovina iz Bogovine, Institut za bakar Bor, Bor, jun 2002. god.

[8] Lj. Tadić, Analiza pojave plastičnog loma u stenskoj masi uz tunelski otvor, Zbornik radova građevinskog fakulteta 19, (2010), 63-77.

[9] R. E. Hammah, T. Yacoub and B. Corkum, J.H. Curran, The Practical Modelling of Discontinuous Rock Masses with Finite Element Analysis, 42nd US Rock Mechanics Symposium and 2nd U.S.-Canada Rock Mechanics Symposium, San Francisco, San Francisco June 29-July 2, 2008.

[10] M. Stoniš, V. Hudeček, Mining of Coal Pillars Using the Drilling Method, Acta Montanistica Slovaca Ročník 14 (2009), 241-249.

[11] Rocscience Inc. 2005. Phase2 v6.0 – Two dimensional finite element slope stability analysis.

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POSSIBILITY OF Pb-Zn ORE EXPLORATION IN THE DISTRICT "CRNAC-EAST" OF THE MINE "CRNAC"**

Abstract

The aim of this work is to present what are the possibilities for providing Pb-Zn ore from the surrounding districts for exploitation the "CRNAC" mine. The amount of excavated ore, as well as a well-known fact that the ore reserves are not inexhaustible, generated the need for continuation od geological exploration. Enlargement of raw material base should be expected on the indicated locations close to the active deposits of Crnac. One of the identified sites in the Crnac ore zone and the eastern part of active deposit is also the so-called district of "CRNAC-EAST".This paper presents the results of geologically explored operations obtained by interpolation of data from exploratory wells and exploratory mining operations in the district of "CRNAC-EAST".

Keywords: *lead, zink, Crnac-East, exploratory operations, ore structures, exploration, geology of deposits*

1 INTRODUCTION

The deposit "CRNAC" was opened after ten years of intensive research by drilling from surface and mining exploration works in the period from 1957 to 1968 by the Geological Service of the Mine and Lead and Zinc Smelter "Trepca" in Zvečan. The opening of the mine "CRNAC" has contributed to the increase in raw material base of lead and zinc as the basic raw materials for metallurgical plants and newly constructed processing capacities of the combine of "Trepca" based on these metals. The opening of the mine "CRNAC" with a relatively high content of lead and zinc metal is a major incentive for the development of an underdeveloped area such as is the territory of Leposavic.

From the outset, respectively since 1968 the mine "CRNAC" is part of the OC Mines and Flotation "Kopaonik" - Leposavic. The current unfavorable situation of raw material base of the OC "Kopaonik", as well as Combine "Trepca" in general, and the increasing need to meet the processing capacities require further intensification of research work both in the deposit, including its wider area. At the same time with the introduction of exploration works are investing considerable material and financial funds in opening the new mines in order to increase production, income and standard of workers.

Geographical area of Rogozna is contoured with the flows of the rivers Ibar and Raska almost entirely limited to the west, east and south sides, and then close the northern mouth of the Raska-Ibar triangles that cover the hydrographic network of left tributaries of Ibar and right river Raska, almost entirely determined the area of the mountain massif Rogozna where in the central part of ore is the deposit "CRNAC".

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The traffic network of roads on Rogozna provides approach to most parts of the mine. In addition to the macadam road Banjska-Novi Pazar, are all recently built roads for exploitation the forests for rugged off-road vehicles for most of the year. Asphalt roads valleys of Ibar and Raska and partially paved with Josanicka and Banjska river provided approach to the peripheral and central parts of Rogozna. With the valley of Josanicka or the Crnacke River in the upper reaches, the mine "CRNAC" is associated with the facilities for processing ore in Leposavic with the asphalted road 15 km long. Till the Gnježdanski undermine a path is of 5 m wide, and the other 6 km is width of 3 m. Among major facilities in this way is a reinforced concrete bridge over the Ibar River, then the overpass over the railway line and connected to the main road of Raska-Kosovska Mitrovica.

In terms of relief, tertiary volcanoes most often make sharp points, while other creations make something milder forms, with an altitude above 600m. The area of deposit "CRNAC" - "Plakaonica" is hilly and crisscrossed by streams and deep ravines.

The mine "CRNAC" is at a relatively low altitude of about 600 to 900 m. It is located in the valley of the Crnacka River, left tributary of Ibar. It has a mild mountain climate. Heavy rainfall in the winter months does not cause major problems for ore transport.

Lead and zinc mine "CRNAC", more than two decades, did not conduct the geological exploration neither drilling of exploratory drill holes nor mining of exploratory works. During this time the exploitation was conducted in the scope of 50,000 t to 150,000 t ore annually. For these reasons, there was a reduction in the available ore reserves to a level that allows exploitation of ore for the next few years.

Looking at the current situation of ore reserves and the need to maintain continuity in the production of ore, it suggests to research in the shortest time the potential mineral structures.

The potential areas that could be caught exploratory mining operations and exploration of drill holes involves the "CRNAC-ISTOK".

Results from an earlier exploratory period which were obtained by exploration drilling from surface, as well as by drilling of exploration drill holes from the pit, indicate that, in this area may prove more ore wires, which in terms of quality and quantity of the metal content correspond to the existing mineral veins in the central part of the deposit "CRNAC".

Insufficient exploration of mineral veins in the central part of the deposit "CRNAC" which is now exploited ore is planned to drill veins by direction and laying.

2 DESCRIPTION OF DEPOSITS

“CRNAC” and “PLAKAONICA” represent a system of fault zones and veins, genetically and temporally identical, so that they have great similarity by the mineralization type. The ore is mostly deposited in amphibolites, while now in a serpentine quantitative and qualitative ore are of subordinated importance. The ore veins have lens thickening and wedge out per stretching and by the fall. Often, thin veins are met in some thicker veins, in order to diverge and wedge out. Individually thin and mineralized veins can be grouped into the ore zones, giving the ore bodies with thickness up to 10 m, with metal content within the limits of viability of exploitation. Smaller veins and tiny veins, as well as impregnation sometimes build a network and give mineralization of the stock work type [2].

The system of mineral veins is connected to the fault zones and cracks, striking NE - SW while the slopes are different, the ore veins sometimes divergently diverge at deeper levels, because one declines on the NW, and the other on the SE.

The ore zones connected to contact of amphibolites of serpentine or diabase – floral series, which has the fault zones and dacite dikes, they decline to the SE. There are ore strings (e.g., subsoil veins 3 and 4) with decline on the opposite side, or declining towards NW. A higher number of mineral ore veins as well as the ore veins in the Plakaonica district decline towards NW. The decline angles of ore veins are variable and range within the limits of between 60° and 90°.

In the ore association of the ore deposit “CRNAC”, the following essential minerals are identified: galena, sphalerite and pyrite, and subordinated chalcopyrite, arsenopyrite and pyrrhothine [1]. From the gangue minerals, mainly were found quartz and calcite, and rarely rhodochrosite. In subsequent tests of microelements were indicated the presence of iridium (2 – 114 g/t) and selenium (4.7 g/t) in individual sulphide minerals of lead and zinc. Scantily realized research of the mineral paragenesis in the deposit points out the absence of ore and non-ore minerals characteristic for the contact-metasomatic or transitional contact metasomatic-hydrothermal processes that preceded the main stage of hydrothermal processes in the formation of deposit. The absence of such phenomena and processes that preceded them show the conditions of formation the typical hydrothermal deposit of the mezothermal phase in which multi-stage was absent with characteristic successions that characterize the transition contact metasomatic-hydrothermal lead-zinc deposits of the Kopaonik ore region. Explanations, associated with different colored sphalerites as the evidence of presence the epithermal processes in the deposit are not sufficient and should be substantiated by more complete and versatile tests. Until now, the presence of two succession of hydrothermal area of deposition is macroscopically observed in deposit. First, processes of depositing huge silicate and less silicon-carbonate formations, formed mainly at the expense of serpentine in contact with their gabbro amphibolites and volcanic cover the cradle and Rogozna, correspond to the pre-ore stage. This association of rocks is mostly formed of opal-chalcedonian mass and amorphous silicon with higher or lower concentrations of pyrite, which in general can be considered sterile from an economic standpoint. The second main phase of depositing is represented by described ore minerals of mezothermal stage with economic mineralization of lead and zinc, whose concentration in the appropriate structures of silicon masses is manifested as the ore bodies with the economic content of useful metals [2].

Considering the established successions and mineral paragenesis, the positional relationship of deposit and ore bodies with volcanic breakthroughs of the tertiary age and clear hydrothermal processes, that approach to the conditions and deposits of the ore field Koporić – Jelakce, the deposit is classified as a type of hydrothermal deposits predominantly of mezothernal succession, genetically related to the process of tertiary [3].

3 OPENING THE CRNAC DEPOSIT

Opening the deposit CRNAC was carried out in two phases. The first phase was in the period from 1957 - 1968 and included level above 862 m and the second phase of opening from 1968 – 1980 from level 600 m – the Gnješdanski mine [3].

The ore deposit CRNAC above 862 m was opened by the system of undermine, which at the same time represent the levels of the mine horizons as follows [3]:

- 0 - horizon at level 1.062 m
- I - horizon at level 996.2 m
- II - horizon at level 944.7 m
- III - horizon at level 902 m
- IV - horizon at level 862 m

The first, second and fourth horizon were opened by undermines from the surface (given elevations related to the elevations of the entrance into undermines), while the third horizon was opened from the IV horizon by the system of raises as sub-level [3].

Next to the entrance of mine No. 4 (elevation 862), economically significant veins are labeled with ordinal numbers 1 - 17. As already mentioned, they have very sharply decline towards SE with decline angle of about 80°. They have the same morphological features as the other ore veins and remaining as the most important their ability to retain relatively good continuity, both by strike and by decline [3].

The fourth (IV) horizon has long been the main horizon, because the entire ore transport was done along ore, the ore haulage to the surface was done over this mine. In addition, the entire delivery of materials required for the work was performed from the IV horizon; the main power grid is now at the horizon (compressed air, technical water and electrical energy) [3].

Opening of deposit below the level of 862 m was done by a system of mining operations of capital importance for the whole mine with the aim of undertaking a deep part of the deposit. For this purpose, the mine Gnježdane, length 3,781 m, was made. The blind service shaft was made at the level of 600 m to the level of 862 m level which six filling stations were made, as follows [3]:

- IV - horizon (K. 867.00 m)
- V - horizon (K. 818.00 m)
- VI - horizon (K. 768.00 m)
- VII - horizon (K. 718.00 m)
- VIII - horizon (K. 668.00 m)
- IX - horizon (K. 609.89 m) pit bank at the level of adit

The haulage machine of the system "KEPE" is in the hall, which is located directly above the tower, and at 23.5 m above the filling station of the IV horizon [3].

The central ore rod – use for the ore lowering from the pit to the level of the IX horizon - to the level of the mine "Gnježdane" [3].

4 EXPLORATION DEGREE OF THE "CRNAC-EAST" DISTRICT

4.1 District "CRNAC-EAST"

Exploration the "CRNAC" ore structure to the east, started in 1979 with exploratory drill holes from surface in the structures of Mladjev do to Metalica. These operations involved the exploration of these structures of drill holes from the surface structure and were found the presence of more lead - zinc ore veins with the economic metal content of lead, zinc and silver in the gabbro-amphibolites and roof shale [4].

Drill holes B-33, B-30, B-34, B-35 and B-36 in the two profiles at distance of 200 m drilled several veins with a significant content of lead and zinc. Carried out volume of research works in the area of Metalica - Mladjev do does not meet the criteria for assessment the reserves of the C1 category. Therefore, it is necessary to do the re-categorization in order to perform the additional exploration works from the pit in the extension of corridor N°410 on the fourth horizon [4].

4.2 Description of carried out exploratory operations in the "CRNAC-EAST" district

With the performed drilings B-33and B-34 the structures of Metalica are directed to the zone of shales, serpentinite and gabbroamphibolites with the quartz latite breakthroughs.

- Drill holes B33 and B34 gave identical geological profiles, fully confirmed assumptions about the structure of deposit and extending the presence of lead-zinc mineralization in this part of the field. Both drill holes determined series contact with the inserts of serpentine shale with lenses and quartz latite breakthrough in the roof below the horizon IV [4].
- With the drill hole B33, five intervals of lead-zinc mineralization were drilled. The most powerful mineralization was deposited in gabbroamphibolites slightly in shale (gneiss and cornets), a higher number of very thin lead-zinc wire was registered without economic value. Below the level of horizon IV was drilled in hydrothermal alterations of gabbroamphibolites several intervals with weaker and stronger mineralization of lead and zinc, whose position coincides with direction of ore

veins 6, 7 and 8, open on the horizon 862 m (IV horizon). The rich lead-zinc ore is located at 30 m below the level of the horizon thickness ranging from 3.5 m with a lead content of 9.7%, 7.57% zinc, 0.39% copper, 0.005% bismuth, cadmium 0.05% of silver 89 g/t [4].

- With the drill hole B34, several intervals of lead-zinc mineralization were also drilled in roof shale and gabbro-amphibolites in their basement. The metal content in the ore drilled wires ranging from trace amounts to 9% of metals such as lead and zinc. Richer lead-zinc ore veins drilled at the contact of gabbroamphibolites and slate and 5m thickness at the level of horizon VI. Positional mineralization is located along the direction of the vein no. 8. The metal content in the sample from the drill hole is 12% lead and 1.82% zinc. [4].
- Drill holes B35 and B-36 are located northeast of the profile drill holes B-33 and B-34, in order to check the possible presence mineralization of lead and zinc ore at levels which correspond to the open structures of the ore in the deposit "CRNAC" [4].
- With the B35 drilling from the surface until below the level of the fourth horizon 30 m were drilled shale (gneisses and cornet) with breakthrough of quartz latite, diabase and serpentine at the level of the first to the third horizon. The data obtained from boreholes indicate that at this level a complex tectonic zone was drilled, which is clearly expressed on the surface with breakthrough of quartz latite as tectonic contact of gabbroamphibolites and serpentine. Below the level of the second horizon at height of 935 m at the contact shale and serpentine, a lead-zinc vein was drilled, thickness of 0.40 m with a very high content: 13.24% lead and 13.6% zinc, 0.38% copper and 105 g/t silver. Between the third and fourth horizon at height of 892 m, the mineralized zone of an apparent thickness ranging from 5 m was drilled, with a very small percentage of the extracted core, and therefore could not be sampled [4].
- Drill hole B-36 was placed in the same profile line with the drill hole B-5. Geological profiles of these two wells are almost identical. Besides being absent breakthroughs of serpentines and quartz latite in shale and level of determined tectonic zone. The shale is drilled over an interval of hydrothermal changes in lower lead-zinc mineralization. The exception is lead-zinc ore vein at height of 935 m below the level of a second horizon, whose apparent mightiness is 0.5 m with content of 5.74% lead, 13.85% zinc, 011% copper and 52 g/t silver. It is confirmed that mineralization in gabbro-amphibolites occurs in two ore veinsc that in positional lie in tectonic zone with serpentine and quartz latite of Dajka at 20-40 m below the horizon IV. The lead content in the samples taken are as follows: 3.30% lead, 4.02% zinc and 24 g/t silver. This positional subsoil structure is located on the axis of ore veins 2 and 3, already partially explored on the horizon IV [4].

Results from these exploration wells B-33, B-34, B-35 and B-36 confirm that in these structures are present the lead-zinc mineralization which are identical with an open ore bodies of the „CRNAC“ deposit in terms of modes of appearance and content of lead, zinc, silver, etc. [4].

From this ore structure Mladjev do - Metalica according to the previously specified data, based on data from boreholes B-33, B-34, B-35 and B-36 and B-43 (Table 19), can be safely concluded the presence of 140,000 t of ore of the C2 cate-gory with the average rate of 8.79% lead, 3.56% zinc and 97.5 g/t silver [5].

Table 1 *Tabular overview the C2 reserves of the "CRNAC –EAST"*

Category	Drill hole	Ore (t)	Mean metal content			Amount of metal		
			Pb(%)	Zn(%)	Ag(%)	Pb(t)	Zn(t)	Ag(t)
	B-33	30,000	9.70	7.59	89	2,910	2,227	2,670
	B-34	40,000	12.20	1.82	161	4,880	728	6,440
	B-36	10,000	3.13	4.02	21	313	402	210
	B-35	10,000	13.24	13.60	105	1,324	1,360	1,050
	B-43	50,000	5.79	0.44	66	2,895	220	3,300
Total C2		**140,000**	**8.79**	**3.56**	**97.5**	**12,322**	**4,937**	**13,670**

In order to further exploration and converting of these reserves in a higher category, it is necessary from the hall N°410 to construct the research hallway covering the length of 230 m toward the site of Mladjev do. At the end of the corridor to make a chamber of 16 m^2 of which are projected six drill holes or 2 fans by three drill hole, one fan is directed to the north, the other to the south, perpendicular to the direction of the ore wire.

After the undertaken drilling, the further elaboration would be planned of this locality related to the mining operations.

5 CONCEPTION OF FURTHER EXPLORATION OF THE "CRNAC - EAST" DISTRICT

The "CRNAC-EAST" district includes exploration the mineral structures in the east direction of the capital facilities of the pit CRNAC, respectively, from the service shaft and central ore bars. Studies of these areas were performed only with exploration drill holes from the surface. Exploratory drill holes are located in the two profiles at distance of 200 m profile from the profile, including the wells B-33; B-34; B-35 and B-36, which were drilled by the profiles 33 - 34 and 35-36. [5].

The conducted scope of work on the study of this area clearly indicates the presence of more lead-zinc ore veins, with the economic content of metals of lead, zinc and silver. Also, it is concluded that the scope of works conducted from exploration drill holes from the surface indicates the promising reserves of the C2 category. Based on these data, the reserves can be evaluated that will serve as a roadmap for further geological exploration, to convert the reserves into more categories. Taking into account the current level of exploration areas of „CRNAC - EAST" and the results of these studies, it's imposed as a priority, to carry out further research system development of mining operations and development of exploration wells. For this approach of research we committed on the basis of so far experience in the exploration of the other areas.

In accordance with the position of mining facilities of the active part of the pit, as well as the position of the results obtained with drill holes B-33; B-34; B-35 and B-36, the following solution is imposed for additional exploration of the "CRNAC-EAST" district.

At the end of the hall to predict a chamber 4 x 4 m and 3 m in height, from which are projected 6 exploration drill holes, respectively, in two (2) fans of 3 (three) drill holes.

With this scope of works, a re-categorization of mineral resources can be done from C2 to C1 category.

5.1 Exploratory corridor H-410

Exploratory corridor was made towards the stretching direction of ore vein no. 6 on the fourth horizon. Bearing in mind a rather modest metal content in the ore in the last 40 meters, the hall ceased to be built up. The exploratory corridor was made in the middle of that promised continuation of mineralization ore economically viable. However, in the meantime, considerably improved ore veins are found in the other areas and ore with a higher metal content and terminated with further work on corridor development.

The current position of corridor seems at the same time and the position of beginning of making the corridor H -410 to the east. The starting coordinates of this corridor would be:

x = 4.771 264

y = 7474 910

azimuth = 52°

Building up a new corridor with a length of 230 m with the given elements, there would be up to the position with the exploration drill holes to check data from the drill holes B-33; B-34; B-35 and B-36 in the depth prospecting. In addition to these data, it is possible to check the method of providing the ore blocks in this area.

Building up the exploratory corridors, without prior drilling and getting dense network data would not be rational.

5.2 Drilling of exploratory drill holes from the corridor410

Considering the great distance of geological profiles one of the other (about 200 m) on the district of "CRNAC-EAST", designned drill holes from the horizontal IV, or from the chamber hall SIH410, a denser network of geological data was obtained. Table 2 shows the elements of drill holes SIH410 from the corridor, in the direction of district "CRNAC-EAST".

Table 2 *Tabular overview of exploratory drill holes for the "CRNAC- EAST" district*

Drill hole name	Coordinates x y		Azimuth (v°)	Slope (±)	Length (m)	Height (z)
JB-1/2013	4 771 313	7 474 985	172	O	220	862
JB-2/2013	4 771 313	7474 985	140	-35	250	862
JB-3/2013	4771 313	7474 985	105	O	300	862
JB-4/2013	4 771 390	7475 090	340	O	300	862
JB-5/2013	4 771 390	7475 090	310	-30	200	862
JB-6/2013	4 771 390	7475 090	275	O	200	862

The pit drill hole 1/2013 with the given elements is designed and directed so to cut all mining structures from the drill hole B-43 at the level IV of the horizon profile (I-II).

The pit drill hole 2/2013 with the given elements is designed between the profiled lines (I-II) and (II-III) with the aim of proving the mineral structure of the wells B-33, B-34 and B-43 below the level of horizon IV, or the spreading of these structure in depth at the site Metalica.

The pit drill holes 3/2013 is designed to define the ore structures from the profile (III-IIII) respectively from the drill holes B-33 and B-34 and their spreading towards the east.

By making all three of pit drill holes 1, 2 and 3/2013 that range from chamber no. 1, get a clearer picture of the mineral structures of Metalica can be obtained as per stretching also and by the fall.

The pit drill holes B-4/2013.5/2013 and 6/2013will give for these drill holed from chamber no. 2 a clearer picture of the mineral structures of Mladjev do by stretching, strengthening and depth of laying.

After drilling of six drill holes with a total length of 1470 and proving of economically significant mineralization, a further elaboration of this locality would be planned for mining exploration works.

The ore reserves shown in Table 1, including elaboration of researched works in this district "CRNAC - EAST" as per width of the deposit and at depth, as well as the interpolation data can be transferred into a higher category B + C1 categories, shown in Table 3.

Table 3 *Reserves of B + C1 categories of the "CRNAC- EAST" district*

Category	Ore (t)	Content of metal		
		PB (%)	Zn (%)	Ag (g/t)
B + C1	399,000	8.25	2.33	93.5

CONCLUSION

For this conceptual presentation the exploration of the "CRNAC-EAST", the following reasonsare taken into consideration: development and opening the mine Crnac, as well as the district of Plakaonica 1 created the preconditions for the continuation of exploration towards the new areas in this case the "CRNAC-EAST". Stretching and falls of individual ore veins and their parallelism and location of pane and the central ore bars in the slopes of the ore deposits imposed for this district making the main mining facilities that will interconnect all future mining veins while connecting the districts of "CRNAC-EAST" with the central mining areas of "CRNAC". So, in later stage of processing and exploitation of ore from this area the exploratory facilities before all corridors and excavations to turn into development facilities, transportation, transient and ventilation pathways. According to the geology of the "CRNAC-EAST" deposit was made the most favorable site selection of the exploratory hallway N 410 of which will be confirmed the results of drill holes B-33, B-34, B-35, B-36 and B-40 by exploratory geological drill holes. Based on the existing data and the expected data there has been made the connection of results from exploration wells and more insight is obtained into the parallel structures of the ore that will be confirmed by the mining exploratory works. So far, in the "CRNAC-EAST" district, three ore structures were identified at depths below 862 meters at some distance from the existing active works of the Crnac mine about 300 meters. The direction of these mineral structures and spreading of depth, primarily will be studied by exploratory drill holes and then by mining exploratory works. The length of development the mining exploratory works define data from drill holes and they are on the limit of spreading to the footwall deposits with what have to be taken into account in the organic connection of the "CRNAC-EAST" district and the central district of the Crnac mine.

REFERENCES

[1] G. O. Milentijević, Fundamental of Geology and Engineering Geology, University in Priština, Faculty of Technical Sciences, 2011, pp. 385-412 (in Serbian);

[2] Technical Documentation of Geological Department of the Mine and Flotation - Kopaonik Leposavić (in Serbian);

[3] G. O. Milentijević, B. Lj. Nedeljković, M. Jakšić, Possibilities of Exploration the Pb-Zn Ore in the District Plakaonica II of the Mine Crnac, Mining and Metallurgy Engineering Bor, 4/2014;

[4] B. Lj. Nedeljković, G. O. Milentijević, Technical Mining Design of Development the Mining Exploratory Works for the District „PLAKAONICA II", 2013 (in Serbian);

[5] Report on Exploration the lead-Zinc Ore in the Period 1983 to 1994 on Rogozna, Rapporteur: Geozavod Belgrade (in Serbian).

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MOGUĆNOSTI ISTRAŽIVANJA Pb-Zn RUDE NA REVIRU „CRNAC-ISTOK“ RUDNIKA „CRNAC“**

Izvod

Cilj rada je da predstavi koje su mogućnosti za obezbeđivanje rude Pb-Zn sa okolnih revira za eksploataciju u rudniku „CRNAC“. Količina otkopane rude, kao i opšte poznata činjenica, da rudne rezerve nisu neiscrpne, uslovile su potrebu za nastavkom geoloških istraživanja. Proširenje sirovinske baze, trebalo bi očekivati na indiciranim lokalitetima u blizini aktivnog ležišta Crnac. Jedan od identifikovanih lokaliteta u crnačkoj rudnoj zoni je i istocni deo od aktivnog ležišta tzv. revir „CRNAC-ISTOK“.

U ovom radu se prikazani rezultati geoloških istražnih radova dobijenih interpolacijom podataka sa istražnih bušotina i istražnih rudarskih radova na reviru „CRNAC-ISTOK“.

Ključne reči: *olovo, cink, crnac-istok, istražni radovi, rudne strukture, istraživanje, geologija ležišta*

1. UVOD

Ležište "CRNAC" otvoreno je nakon intenzivnog desetogodišnjeg istraživanja bušenjem sa površine i rudarskim istražnim radovima u periodu od 1957. do 1968. godine, od strane geološke službe rudnika i topionice olova i cinka "Trepča"-Zvečan. Otvaranje rudnika "CRNAC" doprinelo je povećanju sirovinske baze olova i cinka kao osnovnih sirovina za potrebe metalurških postrojenja i novoizgrađenih prerađivačkih kapaciteta Kombinata "Trepča" na bazi ovih metala. Otvaranjem rudnika "CRNAC" sa relativno visokim sadržajem metala olova i cinka veliki je podsticaj razvoju jednog nerazvijenog područja kao što je teritorija opštine Leposavić.

Od početka rada, odnosno od 1968. godine rudnik "CRNAC" nalazi se u sastavu OC Rudnici i flotacija "Kopaonik" - Leposavić. Sadašnje nepovoljno stanje sirovinske baze OC "Kopaonik" kao i kombinata "Trepča" u celini i sve veće potrebe za zadovoljavanje prerađivačkih kapaciteta zahtevaju dalje intenziviranje istražnih radova kako u samom ležištu, tako i njegovom širem području. Istovremeno se uvođenjem istražnih radova ulažu znatna materijalna i finansijska sredstva u otvaranju novih rudnika u cilju povećanja proizvodnje, dohotka i standarda radnika.

Geografski područje Rogozne okontureno je tokovima reke Ibar i Raške koje skoro u celini ograničavaju sa zapadne, istočne i južne strane, a potom severne zatvaraju ušćem u Rašku-Ibar, trouglom kojim pokrivaju hidrografske mreže levih pritoka Ibra i desnih reke Raške, skoro u potpunosti određeno je područje planinskog masiva Rogozne u čijem se centralnom delu nalazi rudno ležište "CRNAC".

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Saobraćajna mreža puteva na Rogozni obezbeđuje pristup većem delu područja rudnika. Osim makadamskog puta Banjska - Novi Pazar, sve su to u novije vreme izgrađeni putevi za eksploataciju šuma prohodnih za terenska vozila tokom većeg dela godine. Asfaltnim putevima dolinama Ibra i Raške i delimično asfaltiranim uz Jošaničku i Banjsku reku, obezbeđen je pristup u obodne i centralne delove Rogozne. Dolinom Jošaničke, odnosno Crnačke reke u gornjem toku, rudnik "CRNAC" povezan je sa objektima za preradu rude u Leposaviću asfaltnim putem dugim 15 km. Do Gnježdanskog potkopa put je širine 5 m, a ostalih 6 km je širine 3 m. Od većih objekata na ovom putu se nalazi armirano-betonski most na Ibru, zatim nadvožnjak preko železničke pruge i priključen na magistralni put Raška - Kosovska Mitrovica.

U pogledu reljefa, tercijarni vulkaniti najčešće grade oštre vrhove, dok ostale tvorevine čine nešto blaže oblike, sa nadmorskom visinom iznad 600 m. Područje ležišta „CRNAC" – „PLAKAONICA" je brdovito i ispresecano dubokim potocima i jarugama.

Rudnik „CRNAC" je na relativno maloj nadmorskoj visini od oko 600 do 900 m. Nalazi se u dolini Crnačke reke, leve pritoke Ibra. Ima blagu planinsku klimu. Obilne padavine, u zimskim mesecima ne pričinjavaju veće teškoće prilikom transporta rude.

Rudnik olova i cinka „CRNAC", više od dve decenije nije vršio geološka istraživanja, ni bušenjem istražnih bušotina ni rudarskim istražnim radovima. Za to vreme je vršena eksploatacija rude u obimu od 50.000 t do 150.000 t rude godišnje. Iz ovih razloga došlo je do smanjenja raspoloživih rudnih rezervi na nivo koji omogućuje eksploataciju rude za nekoliko narednih godina.

Sagledavajući postojeće stanje rudnih rezervi kao i potrebu za održavanjem kontinuiteta u proizvodnji rude, predlaže se istraživanje u najkraćem vremenskom roku potencijalnih rudnih struktura.

U potencijalne prostore koji bi se obuhvatili istražnim rudarskim radovima i istražnim bušotinama spada, "CRNAC-ISTOK".

Rezultati iz ranijih perioda istraživanja koji su dobijeni istražnim bušenjem sa površine, kao i bušenjem istražnim bušotinama iz jame, upućuju na to, da se, u tom prostoru mogu dokazati više rudnih žica, koje po kvalitetu sadržaja metala i količini odgovaraju postojećim rudnim žicama u centralnom delu ležišta „CRNAC".

Nedovoljna istraženost rudnih žica u centralnom delu ležišta „CRNAC" gde se sada vrši eksploatacija rude predviđeno je bušenje istražnih bušotina dužine do 100 m. Ovim bušotinama će se razrešiti pitanje kontinuiteta rudnih žica po pravcu pružanja i zaleganja.

2. OPIS LEŽIŠTA

„CRNAC" i „PLAKAONICA" predstavljaju sistem rasednih zona i žica, genetski i vremenski istovetnih, tako da i po vrsti mineralizacije imaju veliku sličnost. Većim delom ruda je odložena u amfibolitima, dok je za sada u serpentinu kvantitativni i kvalitativno ruda podređenog značaja. Rudne žice imaju sočivasta zadebljanja i isklinjavaju kako po pružanju tako i po padu. Često se tanje žice sastaju u nešto deblje žice, da bi se opet razilazile i isklinjavale. Pojedinačno tanke i rudom bogate žice mogu se grupisati u rudne zone, dajući rudna tela moćnosti i do 10 m, sa sadržajem metala u granicama rentabilnosti eksploatacije. Sitnije žice i žičice kao i impregnacije kad kad grade mrežu i daju mineralizaciju štokverhnog tipa [2].

Sistem rudnih žica vezan je za rasedne zone i pukotine, pružanja SI-JZ dok su padovi različiti, rudne žice se nekad divergentno razilaze u dubljim nivoima, jer jedne padaju na SZ, a druge na JI.

Rudna zona vezana za kontakt amfibolita serpentinita ili dijabazrožne serije, gde ima i rasednih zona, kao i dacitskih dajkova, imaju pad ka JI. Postoje i rudne žice **(primer, rudna žica 3 i 4)** koje imaju pad na suprotnu stranu, odnosno padaju prema SZ. Veći broj rudnih žica kao i rudne žice u plakaoničkom reviru imaju pad prema JI. Padni uglovi rudnih žica su promenljivi i kreću se u granicama između 60° i 90°.

U rudnoj asocijaciji ležišta „CRNAC" identifikovani su kao bitni minerali galenit, sferelit i pirit, a podređeno halkopirit, arsenopirit i pirhotin [1]. Od minerala jalovine konstatovane su pretežno kvarc i kalcit, ređe rodohrozit. Pri naknadnim ispitivanjima mikroelemenata indicirano je prisustvo iridijuma (2-114 g/t), selena (4,7 g/t) u pojedinačnim sulfidnim mineralima olova i cinka. Oskudno vršena ispitivanja mineralne parageneze u ležištu pokazuju na osudstvo rudnih i nerudnih minerala karakterističnih za kontaktno-metasomatske ili prelazne kontaktno-metasomatsko-hidrotermalne procese koji su predhodili glavnoj fazi hidrotermalnih procesa u formiranju ležišta. Odsustvo takvih fenomena i procesa koji bi im predhodili pokazuje na uslove stvaranja tipskog hidrotermalnog ležišta mezotermalne faze u kome je odsustvovala višefaznost sa karakterističnim sukcesijama koje karakterišu prelazno konztaktno-metasomatsko hidrotermalna olovo-cinkova ležišta kopaoničkog rudnog reona. Objašnjenja koja se vezuju za raznobojne sfalerite kao dokaz prisutnosti epitermalnih procesa u ležištu nisu dovoljna i trebalo bi ih potkrepiti potpunijim i svestranijim ispitivanjima. Do sada je u ležištu makroskopski sigirno uočeno prisustvo dve sukcesije hidrotermalnog područja deponovanja. Prvo, prerudnoj, odgovaraju procesi deponovanja ogromnih silicitskih i manje silicijsko - karbonatnih tvorevina formiranih mahom na račun serpentinita u njihovom kontaktu sa gabro-amfibolitima i vulkanskim pokrovom u ležištu i na Rogozni. Ovu asocijaciju stena izrađuju pretežno opalsko-kalcedonske mase i amorfije silicije sa većim ili manjim koncentracijama pirita, koja se u celini može smatrati sterilnom sa ekonomskog stanovišta. Drugu glavnu fazu deponovanja reprezentuju opisani rudni minerali mezotermalne faze sa ekonomskim orudenjima olova i cinka čija se koncentracija u pogodnim strukturama silicijskih masa manifestuju kao rudna tela sa ekonomskim sadržajima korisnih metala.

Obzirom na utvrđene sukcesije i mineralnu paragenezu, pozicionu vezu ležišta i rudnih tela sa vulkanskim probojima tercijarne starosti i jasne hidrotermalne procese koji se približavaju uslovima i ležištima rudnog polja Koporić - Jelakce ležište je svrstano u tip hidrotermalnih ležišta dominantno mezotermalne sukcesije genetski vezano za proces tercijarne metalogenije [3].

3. OTVARANJE LEŽIŠTA CRNAC

Otvaranje ležišta CRNAC je vršeno u dve faze. Prva faza u period od 1957 - 1968. god. i obuhvata nivo iznad 862 m i druga feaza otvaranja od 1968 - 1980. god. od nivoa 600 m - Gnježdanskog potkopa [3].

Rudno ležište "CRNAC" iznad nivoa 862 m otvoreno je sistemom potkopa, koji u isto vreme predstavljaju i nivoe horizonata rudnika i to [3]:

- 0 - horizont na koti 1.062 m
- I - horizont na koti 996,2 m
- II - horizont na koti 944,7 m
- III - horizont na koti 902 m
- IV - horizont na koti 862 m

Prvi, drugi i četvrti horizont otvoreni su potkopima sa površine (date kote se odnose na kote ulaza u potkope), a dok je treći horizont otvoren sa IV horizonta sistemom uskopa kao međuhorizont [3].

Idući od ulaza potkopa br. 4 (kota 862) ekonomski značajnije žice su označene rednim brojevima od 1 - 17. Kao što je već rečeno, imaju pad ka JI vrlo strmo sa radnim uglom oko 80°. One imaju iste morfološke karakteristike kao i ostale rudne žice i ostaje kao najvažnije njihova osobina da relativno dobro zadržavaju kontinuitet, kako po pružanju tako i po padu [3].

Četvrti (IV) horizont je dugo vremena bio osnovni horizont, jer se po njemu obavljao celokupni transport rude, izvoz rude na površinu vršio se preko ovog potkopa. Pored toga, sa IV horizonta vršila se skoro celokupna dostava materijala potrebnog za rad, osnovna energetska mreža je i sada na ovom horizontu (komprimirani vazduh, tehnička voda i elektro energija) [3].

Otvaranje ležišta ispod nivoa 862 m urađeno je sistemom rudarskih radova kapitalnog značaja za ceo rudnik a u cilju poduhvatanja dubinskog dela ležišta. U tu svrhu urađen je potkop Gnježdane dužine 3.781 m. Slepo servis okno sa nivoa 600 m do nivoa 862 m iz kojeg su urađena šest navozišta i to [3] :

- IV - horizont (K. 867,00 m)
- V - horizont (K. 818,00 m)
- VI - horizont (K. 768,00 m)
- VII - horizont (K. 718,00 m)
- VIII - horizont (K. 668,00 m)
- IX - horizont (K. 609,89 m) odvozište na nivou potkopa

Izvozna mašina sistema "KEPE" nalazi se u hali koja se nalazi neposredno iznad tornja, a na 23,5 m iznad navozišta na IV horizontu [3].

Centralna rudna sipka - kojom se celokupna ruda iz jame spušta na nivo IX horizonta - na nivo potkopa "GNJEŽDANE".

4. STEPEN ISTRAŽENOSTI REVIRA „CRNAC-ISTOK“

4.1. Revir „CRNAC-ISTOK“

Istraživanje rudne strukture "CRNAC" u pravcu istoka, započet je 1979. godine istražnim bušotinama sa površine u strukturama Mlađev do i Metalica. Ovim radovima izvršeno je istraživanje ovih struktura bušotinama sa površine i utvrđeno prisustvo više olovo-cinkovih rudnih žica sa ekonomskim sadržajem metala olova, cinka i srebra u gabro - anfibolitima i povlatnim škriljcima [4].

Bušotina B-33, B-30, B-34,B-35 i B-36 u dva profila na rastojanju 200 m nabušeno je nekoliko žica sa značajnim sadržajem olova i cinka. Izvedeni obim istražnih radova na reviru Metalica - Mlađev do ne zadovoljava kriterijume za procenu rezervi C1 kategorije. Zbog toga je potrebno u cilju prekategorizacije obaviti dopunske istražne radove iz jame u produžetku hodnika N°410 na četvrtom horizontu [4].

4.2. Opis izvedenih istražnih radova u reviru "CRNAC-ISTOK"

Urađenim bušotinom B-33 i B-34 struktura Metalica usmerene na zonu kontakta škriljaca, serpentinita i gabroamfibolita sa kvarclatitskim probojima.

- Bušotine B-33 i B-34 dale su identične geološke profile, u potpunosti potvrdile predpostavke o produženju strukture ležišta i prisustvo olovo-cinkove mineralizacije u ovom delu terena. Obema bušotinama utvrđen je kontakt serije škriljaca sa umecima serpentinskih sočiva i proboja kvarclatita u povlati ispod nivoa IV horizonta [4].
- Bušotinom B-33 nabušeno je pet intervala olovo-cinkovih orudnjenja. Najmoćnije orudnjenje deponovano je u gabroanfibolitima, neznatno u škriljcima (gnajsevima i kornitima), gde je registrovan veći broj veoma tankih olovo-cinkovih žica, bez ekonomske vrednosti. Ispod nivoa IV horizonta nabušeno je u hidrotermalno promenjenim gabroanfibolitima više intervala sa slabijim i jačim orudnjenjima olova i cinka, čija se pozicija poklapa sa pravcem pružanja žice 6, 7 i 8, otvorenih na horizontu 862 m (IV horizont). Bogata olovo-cinkova ruda locirana je na 30 m ispod nivoa ovog horizonta moćnosti 3,5 m sa sadržajem olova od 9,7%, cinka 7,57%, bakra 0,39%, bizmuta 0,005%, kadmijuma 0,05%, srebra od 89 g/t [4].
- Bušotinom B-34 takođe je nabušeno više intervala olovo-cinkovih orudnjenja u povlatinim škriljcima i gabroanfibolitima u njihovoj podini. Sadržaj metala u nabušenim rudnim žicama kreće se od tragova do 9% metala olova i cinka. Bogatija olovo-cinkova rudna žica nabušena je na kontaktu gabroanfibolita i škriljaca

debljine oko 5 m na nivou VI horizonta. Poziciono orudnjenje se nalazi na pravcu žice br. 8. Sadržaj metala u uzorku iz bušotine je 12% olova i 1,82% cinka [4].

- Bušotinom B-35 i B-36 locirane su severoistočno od profila bušotina B-33 i B-34, sa ciljem da proveri moguće postojanje orudnjenja olova i cinka u nivoima koji odgovaraju otvorenim rudnim strukturama u ležištu "CRNAC“ [4].
- Bušotinom B-35 od površine do ispod nivoa četvrtog horizonta 30 m nabušeni su škriljci (gnajsevi i kornit) sa probojima kvarclatita, dijabaza i serpentinita u nivou prvog do trećeg horizonta. Dobijeni podaci iz bušotina ukazuju da je u ovom nivou nabušena složena tektonska zona, koja je na površini jasno izražena kvarclatitskim probojem kao i tektonskim kontaktom gabroanfibolita i serpentinita. Ispod nivoa drugog horizonta na koti 935 m na kontaktu škriljaca i serpentinita nabušena je olovo-cinkova žica debljine 0,40 m sa veoma visokom sadržajem: 13,24% olova, 13,6% cinka, 0,38% bakra i 105 g/t srebra. Između trećeg i četvrtog horizonta na koti 892 m nabušeno je orudnjena zona prividne moćnosti od 5 m, sa vrlo malim procentom izvađenog jezgra, pa samim tim nije mogla biti oprobavana [4].
- Bušotina B-36 postavljena je u istoj profilskoj liniji sa bušotinom B-5. Geološki profili ove dve bušotine gotovo su indentični. Osim što izostaju proboji serpentinita i kvarclatita u škriljcima i nivou utvrđene tektonske zone. U škriljcima je nabušeno više intervala sa hidrotermalnim promenama slabijom olovo-cinkovom mineralizacijom. Izuzetak čini olovo-cinkova rudna žica na koti 935 m ispod nivoa drugog horizonta, čija prividna moćnost iznosi 0,5 m sa sadržajem 5,74% olova, 13,85% cinka, 011% bakra i 52 g/t srebra. Konstatovana orudnjenja u gabroanfibolitima javljaju se dve rudne žice koje poziciono leže u tektonskoj zoni sa serpentinitom i kvarclatitskim dajkom na 20-40 m ispod IV horizonta. Sadržaj olova u uzetim probama iznose: 3,30% olovo, 4,02% cink i 24 g/t srebro. Poziciono ova rudna struktura nalazi se na pravcu rudne žice 2 i 3, već delimično istraženih na IV horizontu [4].

Rezultati iz ovih istražnih bušotina B-33, B-34, B-35 i B-36 potvrđuju da su u ovim strukturama prisutna olovo-cinkova orudnjenja koja su identična sa otvorenim rudnim telima ležišta „CRNAC“ u pogledu načina pojavljivanja i sadržaja olova, cinka, srebra i dr. [4].

Iz ove rudne strukture Mlađev do-Metalica prema dosad utvrđenim podacima, a na osnovu podataka iz bušotina B-33, B-34, B-35, B-36 i B-43 (Tabela 1.) sa sigurnošću se može konstatovati 140.000 t rude C2 kategorije sa srednjim sadržajem 8,79% olova, 3,56% cinka i 97,5 g/t srebra [5].

Tabela 1. *Tabelarni prikaz C2 rezerve „CRNAC –ISTOK“.*

Kategorija	Bušotina	Ruda (t)	Srednji sadržaj metala			Količina metala		
			Pb(%)	Zn(%)	Ag(%)	Pb(t)	Zn(t)	Ag(t)
	B-33	30,000	9,70	7,59	89	2910	2227	2670
	B-34	40,000	12,20	1,82	161	4880	728	6440
	B-36	10,000	3,13	4,02	21	313	402	210
	B-35	10,000	13,24	13,60	105	1324	1360	1050
	B-43	50,000	5,79	0,44	66	2895	220	3300
Ukupno C2		**140000**	**8,79**	**3,56**	**97,5**	**12322**	**4937**	**13670**

U cilju daljih istraživanja i prevođenja ovih rezervi u višu kategoriju neophodnoje iz hodnika N°410 uraditi 230 m istražnog hodnika prema lokalitetu Mlađev do. Na kraju hodnika uraditi komoru 16 m^2 iz koje su projektovane 6 bušotina odnosno 2 lepeze po tri bušotine, jedna lepeza usmerena na sever, druga na jug, upravno na pravac pružanja rudnih žica.

Posle izvedenog bušenja, planirala bi se dalja razrada ovog lokaliteta rudarskim radovima.

5. KONCEPCIJA DALJIH ISTRAŽIVANJA REVIRA "CRNAC - ISTOK"

Reviru „CRNAC-ISTOK" pripadaju istraživanja rudnih struktura u pravcu istočno od kapitalnih objekata jame CRNAC, odnosno, od servisnog okna i centralne rudne šipke. Istraživanja ovog revira su vršena samo sa istražnim bušotinama sa površine. Istražne bušotine su locirane u dva profila na rastojanju od 200 m profil od profila, i to sa bušotinama B-33; B-34; B-35 i B-36 koje su bušene po profilima 33-34 35-36 [5].

Izvedeni obim radova na istraživanju ovog revira, nesumnjivo ukazuje na prisustvo više olovo - cinkovih rudnih žica, sa ekonomskim sadržajem metala olova, cinka i srebra. Takođe, se zaključuje da izvedeni obim radova sa istražnim bušotinama sa površine ukazuje na perspektivne rezerve C2 kategorije. Na osnovu ovih podataka mogu se procenjivati rezerve koje će služiti kao putokaz za dalja geološka istraživanja, radi prevođenja rezervi u više kategorije. Imajući u vidu dosadašnji stepen istraženosti revira "CRNAC - ISTOK" kao i rezultate tih istraživanja, nameće se kao prioritetno, da se izvrši dodatno istraživanje sistemom izrade rudarskih radova i izradom istražnih bušotina. Za ovakav pristup istraživanju opredelili smo se na osnovu iskustva pri istraživanju ostalih revira.

Saglasno položaju rudarskih prostorija aktivnog dela jame, kao i položaju dobijenih rezultata sa bušotinama B-33; B-34; B-35 i B-36 nameće se sledeće rešenje za doistraživanje revira „CRNAC - ISTOK".

Na kraju hodnika predvideti komoru 4 x 4 m i i visine 3 m, iz koje su projektovane istražne bušotine iji količini od 6 bušotina, odnosno, u 2 (dve) lepeze po 3 (tri) bušotine.

Sa ovim obimom radova mogli bi smo izvršiti prekategorizaciju mineralnih sirovina iz C2 u C1 kategoriju.

5.1. Istražni hodnik H-410

Istražni hodnik je rađen po pravcu pružanja rudne žice br. 6 na IV horizontu. Imajući u vidu dosta skroman sadržaj metala u rudi na zadnjih 40 m, hodnik je prestao da se izrađuje. Istražni hodnik je rađen u sredini koja je obećavala nastavak orudnjenja ekonomski isplativim. Međutim, u međuvremenu došlo se do znatno boljih rudnih žica na drugim revirima kao i rude sa većim sadržajem metala i prestalo se sa daljim radovima na izradi hodnika.

Sadašnja pozicija kraja hodnika čini u isto vreme i poziciju početka izrade hodnika H -410 prema istoku. Polazne koordinate ovog hodnika bi bile:

x = 4.771 264
y = 7474 910
azimut = 52°

Izradom ovog hodnika u dužini od 230 m sa zadatim elementima, došlo bi se do pozicije da istražnim bušotinama proverimo podatke sa bušotina B-33; B-34; B-35 i B-36 po dubini ležišta. Osim ovih podataka moguće je i proveriti način pružanja rudnih blokova u ovom reviru.

Izrada istražnih hodnika, bez predhodnih bušenja i dobijanja gušće mreže podataka ne bi bilo racionalno.

5.2. Bušenje istražnih bušotina iz hodnika 410

Imajući u vidu veliku udaljenost geoloških profila jednog od drugog (oko 200 m) na reviru „CRNAC ISTOK", projektovanim bušotinama sa IV horizontal, odnosno iz komore hodnika SIH410 dobili bi smo gušću mrežu geoloških podataka. U tabeli 2dati su elementi bušotena iz hodnika SIH410, u pravcu revira „CRNAC - ISTOK".

Tabela 2. *Tabelarni prikaz istražnih bušotina za revir Crnac- istok*

Naz. bus.	**Kordinate x y**		**Azimut (v°)**	**Nagib (±)**	**Dužina (m)**	**Kota (z)**
JB-1/2013	4 771 313	7 474 985	172	O	220	862
JB-2/2013	4 771 313	7474 985	140	-35	250	862
JB-3/2013	4771 313	7474 985	105	O	300	862
JB-4/2013	4 771 390	7475 090	340	O	300	862
JB-5/2013	4 771 390	7475 090	310	-30	200	862
JB-6/2013	4 771 390	7475 090	275	O	200	862

Jamska bušotina 1/2013 sa zadatim elementima projektovana je i usmerena tako da preseče sve rudne strukture iz bušotine B-43 na nivou IV horizonta u profilu (I-II).

Jamska bušotina 2/2013 sa zadatim elementima projektovana je između profilskih linija (I-II) i (II-III) sa ciljem dokazivanja rudnih struktura iz bušotina B-33, B-34 i B-43 ispod nivoa IV horizonta, odnosno prostiranje ovih struktura po dubini na lokalitetu Metalica.

Jamska bušotina 3/2013 projektovana je tako da definiše rudne struktura iz profila (III-IIII) odnosno bušotina B-33 i B-34 i njihovo prostiranje prema istoku.

Izradom sve tri jamske bušotine 1, 2 i 3/2013 odnosno lepeze iz komore br. 1 dobićemo jasniju sliku o rudnim strukturama Metalice kako po pružanju tako i po padu.

Jamsklm bušotinama B-4/2013.5/2013 i 6/2013. izradom ove lepeze bušotina iz komore br. 2 dobićemo jasniju sliku o rudnim strukturama Mlađev do po pružanju, moćnosti i dubini zaleganja.

Posle izvedenog bušenja svih šest bušotina ukupne dužine od 1470 m i dokazivanja ekonomski značajnijih orudnjenja, planirala bi se dalja razrada ovog lokaliteta rudarskim istraznim radovima radovima.

Rudne rezerve prikazane u Tabeli 1, izradom istražnih radova u reviru „CRNAC – ISTOK" kako po širini ležista tako i po dubini, kao i interpolacijom podataka mogu se prevesti u višu kategoriju B + C1 kategorije prikazane u Tabeli 3.

Tabela 3. *Rezerve B + C1 kategorije revira „CRNAC- ISTOK"*

Kategorija	**Ruda (t)**	**Sadržaj metala**		
		Pb (%)	**Zn (%)**	**Ag (g/t)**
B + C1	399,000	8,25	2,33	93,5

6. ZAKLJUČAK

Za ovakav koncepcijski prikaz istraživanja revira „CRNAC-ISTROK" opredelili smo se iz sledećih razloga: razrada i otvaranja rudnika crnac kao i revira Plakaonica 1 stvorene su predpostavke za nastavak istraživanja u pravcu novih revira u ovom slućaju revira „CRNAC-ISTOK". Pružanje i padovi pojedinih runih žica kao i njihova paralelnoist, te lokacija okna i centralne rudne sipke u podine rudnog ležišta nameću i za ovaj revir izradu magistralnih rudarskih prostorija koji će međusobno povezati sve buduće rudne žice uz istovremeno spajanje revira „CRNAC-ISTOK“ sa centralnim rudarskim prostorijama „CRNAC“. Da se u kasnijoj fazi pri razradi i ekspoataciji rude sa ovog revira istražne prostorije pre svih hodnici i uskopi pretvoriti u objekte razrade, transporta, prolazne i ventilacione puteve. Saglasno geologiji ležista revira „CRNAC-ISTOK“ izvršen je najpovoljni izbor lokacije istržanog hodnika N 410 iz kojeg će se potvrditi rezultati bušotina B-33, B-34, B-35, B-36 i B-40 istražnim geološkim bušotinama. Na osnovu postojećih podataka i podataka koji se očekuju izvršeno je spajanje rezultata sa istražnih bušotina i time smo stekli uvid u više paralenih struktura rude koju treba potvrditi rudarskim istražnim radovima. Za sada su na reviru „CRNAC-ISTOK“ identifikovane tri rudne strukture na dubini ispod 862 metra koje su udaljene od postojećih aktivnih radova rudnika Crnac oko 300 metara. Pravac pružanja ovih rudnih struktura kao i zaleganje po dubini istražiće se prvo istražnim bušotinama a onda rudarskim istražnim radovima. Dužinu izrade rudarskih istražnih radova određuju podaci sa bušotina i oni su na granici prostiranja prema podini ležišta s tim što se ovde mora voditi računa o organskoj vezi revira „CNAC-ISTOK“ i centralnog revira rudnuka Crnac.

LITERATURA

[1] G. O. Milentijević, Osnove geologije i inženjerske geologije, Univerzitet u Prištini, Fakultet tehničkih nauka, 2011, str. 385-412.

[2] Tehnička dokumentacija geološke službe RIF – Kopaonik Leposavić

[3] G. O. Milentijević, B. Lj. Nedeljković, M. Jakšić, Mogućnosti istraživanja Pb-Zn rude na reviru Plakaonica II rudnika Crnac, Mining and metallurgy engineering Bor, 4/2014.

[4] B. Lj. Nedeljković, G. O. Milentijević, Tehnički rudarski projekat izrade rudarskih istražnih radova za revir „PLAKAONICA II“, 2013.

[5] Izveštaj o istraživanju olovno-cinkove rude u periodu 1983. do 1994. godine na Rogozni, Izvestioc Geozavod Beograd.

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SELECTION OF TRANSPORT SYSTEM FOR TRANSPORT OF ASH AND SLAG FROM THE TPP UGLJEVIK AT THE OP BOGUTOVO SELO UGLJEVIK***

Abstract

At the open pit "Bogutovo Selo" – Ugljevik, the coal mining is performed with a capacity of 1,750,000 tons annually of out-of-mine brown coal for the needs of the Thermal Power Plant "Ugljevik". Ash and slag are generated as product in operation of the power plant in the amounts of of 420,000 m^3 i 80,000 m^3, respectively. These amounts have to be disposed in the area of the open pit "Bogutovo Selo". This paper presents a selection of transport system for ash and slag for the next period.

Keywords: *Open Pit "Bogutovo Selo" – Ugljevik, ash and slag, transport system*

INTRODUCTION

The Mine and Thermal Power Plant Ugljevik ad Ugljevik is a subsidiary that operates within the Mixed Holding "Electric Power Industry of the Republic Srpska". The prevailing activity of the company is the production of thermoelectric energy and coal mining and selling. Mining of brown coal in this coal basin has been carried out since 1899, and until 2006 was excavated about 35 million tons of coal. By 1985, the coal production was intended for mass consumption, and since 1985, mostly to the needs of TPP Ugljevik 300 MW and about 3% for broad consumption. Geological coal reserves in this basin are 429.9 million tons.

Coal mining is carried out at the open pit "Bogutovo Selo". Mining at this open pit is carried out since 1978. Projected annual production of the open pit "Bogutovo Selo" is 1 750 000 tons of run-of-mine brown coal.

For continuous operation of the thermal power plant in the next 23 years, the location for disposal are selected, i.e. for dumping of ash and slag in the area of the open pit "Bogutovo Selo" [1]:

- Large west landfill of the North Mining District
- Interior landfill of the South Mining District.

It is also necessary to select the most economical method of transport and disposal - mass depositing by the amounts of ash and slag based on the operation of thermal power plant. These amount are 420 000 m^3/year for ash and 80 000 m^3/year of slag. For the next period of 23 years, the total amount that needs to be disposed are 9 m^3 of slag and 660 000 and 1 840 000 m^3 of ash [1]. In selecting the types of transport, three variants

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were analyzed with defined technological schemes of preparation, transport and disposal according to the required capacities:

- Transport with belt conveyors
- Hydraulic transport
- Truck transport.

TRANSPORT WITH BELT CONVEYORS

This transport system consists of three vibro feeders and belt feeders for ash and one vibro feeder and belt feeder for slag in the thermal power plant. Because of the mutual position of locations planned for disposal at the open pit regarding to the thermal power plant, as well as the terrain configuration, four stationary belt conveyors are provided. On the site of disposal, one disposal belt conveyor and belt conveyor are provided on arrow of conveyor. Technological scheme of preparation, transport and disposal of conveyor belts is shown in Figure 1.

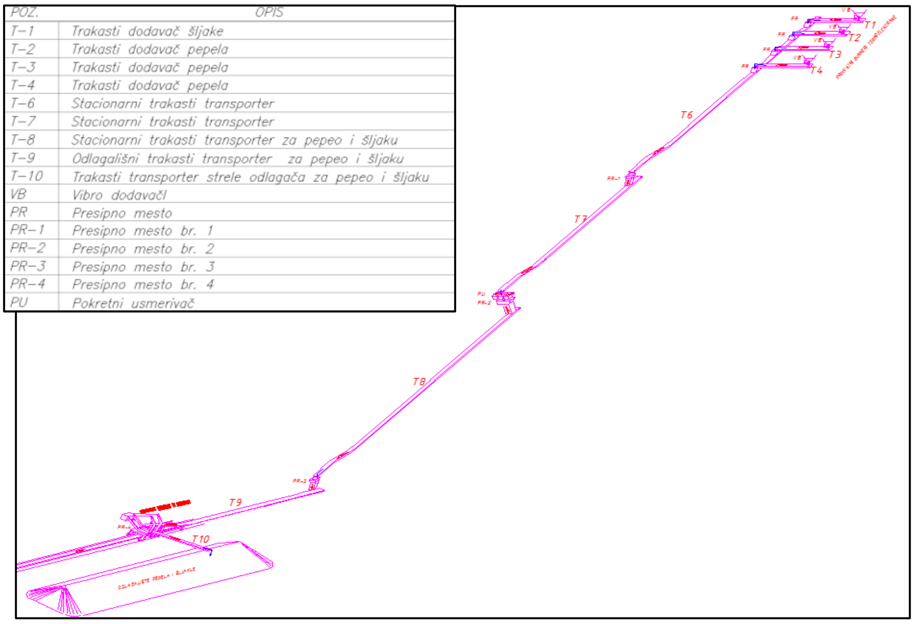

Figure 1 *Technological scheme of transport with belt conveyors*

Calculation of belt conveyors [7,9], disposer, construction facilities and works, as well as electrical installations was done for all elements of the system. The required investments for transport with belt conveyors are given in Table 1.

Table1 *Investments for transport with belt conveyors*

Item	Total, KM
Mechanical equipment	18 194 231
Construction works	2 170 950
Electrical equipment	1 034 017
Replacement of parts for a period of 23 years - 10% from the previous	2 139 920
Total	23 539 118

HYDRAULIC TRANSPORT

Plant for preparation and hydro transport of slag and ash transport will be located in a new built facility on the plateau below the existing silo. At this position, there are four already built concrete silos, three for ash and one for slag. The plant for preparation the hydro mixture will be located at this site and hydro transport to the landfill, i.e. a predicted landfill of slag and ash. A part of the plant for additional fragmentation of slag will be located in the circuit of thermal power plant, while a part of the plant for hydraulic transport with pumps for thick hydro mixture - pump station will be located in the extension of the basic plant for preparation of slurry and directly below the silo.

Formed slag, previously cooled with water is directed by gravel feeder into crusher for primary grinding and so fragmented falls on a belt conveyor. It is anticipated then that the slag is transported by belt conveyor to a reversible belt conveyor onto the crusher-mill for further comminution of slag. The cooling water which cools the slag in the slag remover boiler, together with suspended particles of slag, is collected in a drainage pit of boiler where the pumps pump it into the reservoir of thin hydro mixture of slag.

Additionally granulated slag in the device for additional comminution directly falls with the help of rinsing circulating water in the reservoir of thin hydro mixture of slag. Classification and thickening of thin hydro mixture of slag are developed. Sieve undersize, drained rinsing water and hydrocyclone overflow are directed into a concrete thickener. Overflow of thickener is relatively clean water that is collected in the tank of recirculation water, where it is distributed to all the necessary places.

Sieve oversize falls on a reversible feeder that such prepared slag directs alternately into two silos. Thick hydro mixture exits from two spiral horizontal mixers and enters the pump station of hydro transport system. The pump station can be found and

The additional pumping systems are situated into pump station for distribution the process and sealing water. Technological scheme of hydraulic transport for ash and slag is shown in Figure 2.

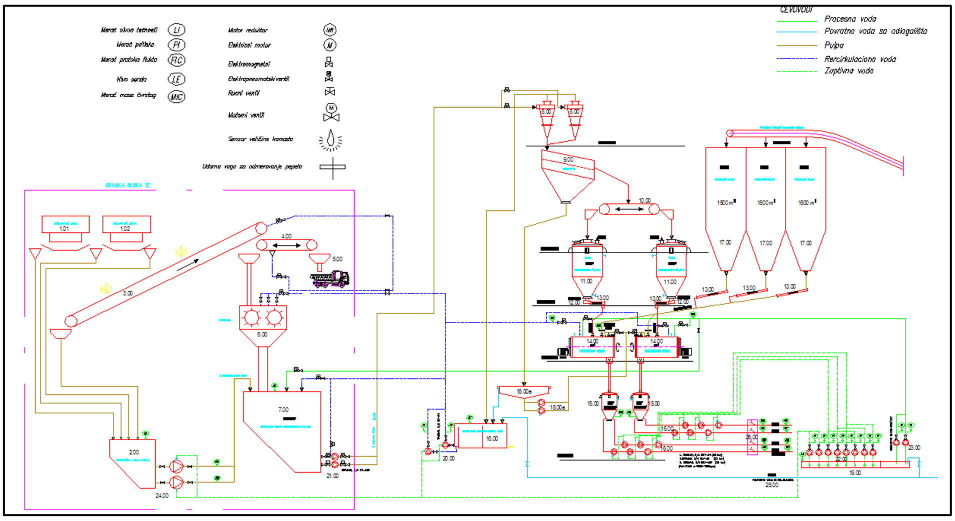

Figure 2 *Technological scheme of hydraulic transport for ash and slag*

Calculation of all elements of hydraulic transport, construction facilities and works as well as electrical installations for all elements of system was carried out. This transport system needs construction a water intake of fresh water as well as preparation of landfill [2, 3, 4] which includes the preparation of base, construction the circumferential dike as well as setting the waterproof foil, Figure 3.

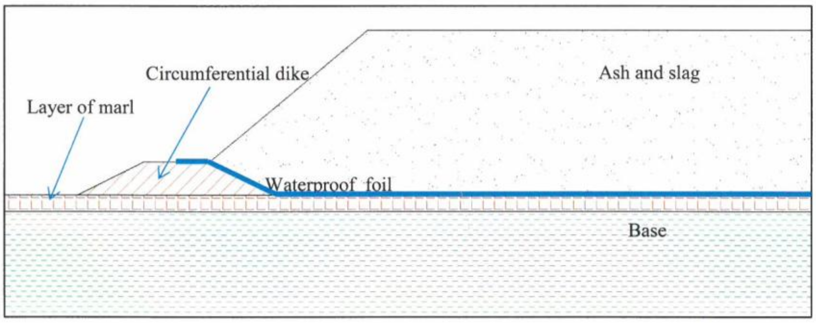

Figure 3 *Cross-section of landfill during hydraulic transport*

The investments required for transport by conveyor belts are given in Table 2.

Table 2 *Investments for hydraulic transport*

Item	Total, KM
Mechanical equipment	24 751 800
Construction works	1 949 165
Hydro-construction works	201 631
Electrical equipment	665 500
Replacement of parts for a period of 23 years - 10% from the previous	2 756 810
Base preparation	16 193 330
Total	46 518 236

TRUCK TRANSPORT

Truck transport of ash and slag [5, 6, 8, 9] would be conducted by the existing transport routes and does not require the special preparation works. Scheme of truck loading is shown in Figure 4, a diagram of transport route on the Inner land fill is shown in Figure 5. The required number of trucks was determined by a computer program Talpac with the replacement periods in 8 years. The investments required for truck transport are given in Table 3.

Table 3 *Investments for truck transport*

Item	Total, KM
Trucks Renault Kerax 430.35	4 800 000
Trucks Iveco AD/AT 720 T41T	7 200 000
Total	12 000 000

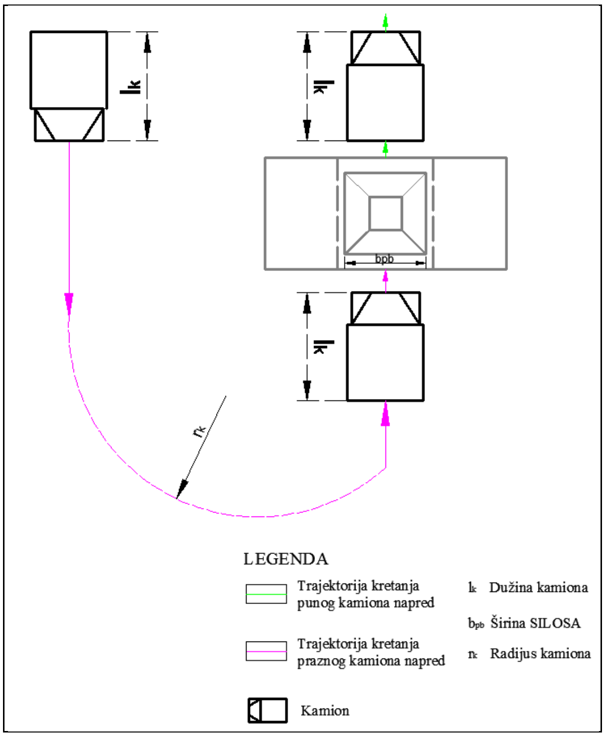

Figure 4 *Scheme of truck loading*

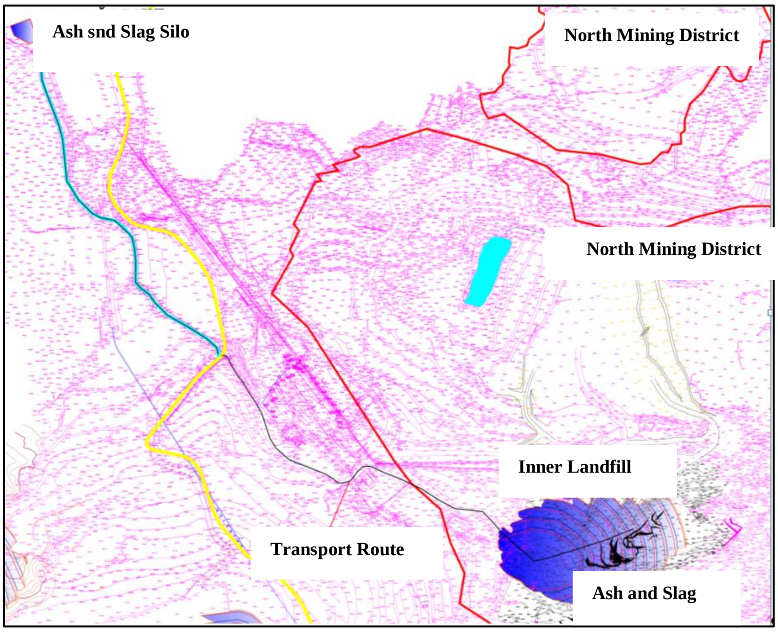

Figure 5 *Scheme of transport of ash and slag on the Inner landfill*

CONCLUSION

Based on technological schemes, the analysis of investments for each of the variants for a period of 23 years was carried out. The investments essential to select the type of transport are shown in Tables 1 - 3.

After the analysis, the conclusion is that the best economic effects are achieved by truck transport in terms of investments in the transport of ash and slag from the thermo power plant to the locations intended for disposal at the open pit.

Experiences from the open pit "Bogutovo Selo" – Ugljevik have to be used at the open pits of RTB Bor. Proper selection of transport system and maximum recovery the existing resources result into optimal solution in terms of investments, maintenance and energy consumption.

REFERENCES

[1] Additional Mining Design of Transport and Disposal of Slag, Ash and Gypsum of the TPP Ugljevik I at the Open Pit Bogutovo selo – Ugljevik; MMI Bor, 2015;

[2] R. Rajković, G. Angelov, B. Petrović, Lj. Obradović, D. Urošević, I. Jovanović, M. Mikić, B. Drobnjaković, Sr. Beatović, R. Milošević, N. Pušara: Construction the Cell No. III of the Phase 1 of the Ash Landfill of the TPP "Gacko" Using the New Technology of Construction the Landfill in Order to Reduce the Landfill Impact on the Environment; Decision of cientific Council of MMI on Adoption the Technical Solution No. XXIV/2.2 of 26.12.2014;

[3] M. Mikić, M. Ljubojev, R. Rajković, D. Kržanović, D. Urošević, I. Jovanović, L. Djurdjevac-Ignjatović, D. Ignjatović, Z. Vaduvesković; Technical Solution, New Technology of Preparation the Ash Landfill – Cell No. III of the Thermal Power Plant Gacko on the Internal Landfill of the Open Pit Gračanica in Order to Remediation; Decision of Scientific Council of MMI on Adoption the Technical Solution No. XXIII/7 of 02.12.2014;

[4] R. Rajković, Lj. Obradović, D. Kržanović, M. Mikić: Application the Software Packages Gemcom and Minex for Design the Waste Landfill – an Example of Construction the Cassette III Phase 3 of Ash and Slag Landfill of the Thermal Power Plant Gacko; Mining and Metallurgy Engineering Bor 4/2014; pp. 17-24;

[5] D. Kržanović, M. Žikić, R. Rajković: Determing the Real Minimum Width of Working Space for Trucks at the Open Pits; 10th International Conference Research and Development in Mechanical Industry“ RaDMI2010, pp. 801-804;

[6] M. Žikić, D. Kržanović, R. Rajković; Determing the Real Truck Turning Radius at the Open Pits; 42nd International October Conference on Mining and Metallurgy; Kladovo, 2010., pp. 146-149;

[7] R. Rajković, R. Lekovski, B. Rajković: Transportation Costs of Stationary Conveyor for Overburden Transportation System of Veliki Krivelj Open Pit in Relation to Inclination of Bearing Rollers; 39th International October Conference, Soko Banja, 07 – 10 October 2007; pp. 64-68;

[8] R. Rajković, D. Kržanović, Z. Vaduvesković: Optimization of Truck Transport Within the Combined TSJ V. Krivelj; 35th October Conference, Borsko jezero, October, 2003, pp. 152-156.

[9] R. Stanković, D. Pavlović, R. Rajković: Utilization the Transport System for Waste of Veliki Krivelj; V International Symposium on Transport and Haulage, Belgrade - Vrdnik, 25 - 27 September, 2002;

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IZBOR TRANSPORTNOG SISTEMA ZA TRANSPORT PEPELA I ŠLJAKE SA TE UGLJEVIK I NA PK BOGUTOVO SELO UGLJEVIK***

Izvod

Na površinskom kopu „Bogutovo Selo“ – Ugljevik eksploatacija uglja se izvodisa kapacitetom od 1.750.000 tona rovnog mrkog uglja godišnje za potrebe termoelektrane „Ugljevik“. Pri radu termoelektrane kao produkt nastaju pepeo i šljaka u količinama od 420.000 m^3 i 80.000 m^3 respektivno. Ove količine treba da se odlože u prostoru površinskog kopa „Bogutovo Selo“. Ovim radom prikazan je izbor transportnog sistema pepela i šljake za naredni period.

Ključne reči: *Površinski kop „Bogutovo Selo“ – Ugljevik, pepeo i šljaka, transportni sistem*

UVOD

„Rudnik i termoelektrana Ugljevik“ ad Ugljevik je zavisno preduzeće koje posluje u okviru Mješovitog holdinga „Elektroprivreda Republike Srpske“. Pretežna delatnost preduzeća je proizvodnja termoelektrične energije i eksploatacija i prodaja uglja. Eksploatacija mrkog uglja u ovom ugljenom basenu izvodi se od 1899. godine, i do 2006. godine otkopano je oko 35 miliona tona uglja. Do 1985. godine proizvodnja uglja je bila namenjena širokoj potrošnji, a od 1985. godine najvećim delom za potrebe TE Ugljevik snage 300 MW i oko 3% za široku potrošnju. Geološke rezerve uglja u ovom basenu iznose 429,9 miliona tona.

Eksploatacija uglja se vrši na površinskom kopu „Bogutovo Selo“. Eksploatacija na ovom kopu izvodi se od 1978. godine. Projektovana godišnja proizvodnja površinskog kopa „Bogutovo Selo“ je 1.750.000 tona rovnog mrkog uglja.

Kako bi se obezbedio kontiualan rad termoelektrane u sledeće 23 godine, izabrane su lokacije za odlaganje - deponovanje pepela i šljake u prostoru površinskog kopa „Bogutovo Selo“ [1]:

- Veliko zapadno odlagalište Severnog revira;
- Unutrašnje odlagalište Južnog revira.

Takođe, potrebno izabrati najekonomičniji način transporta i odlaganja – deponovanja masa prema količinama pepela i šljake, na bazi rada termoelektrane. Ove količine iznose 420.000 m^3/god za pepeo i 80.000 m^3/god za šljaku. Za naredni period od 23 godine ukupne količine koje treba da se odlože iznose 9.660.000 m^3 šljake i 1.840.000 m^3 pepela [1]. Prilikom odabira

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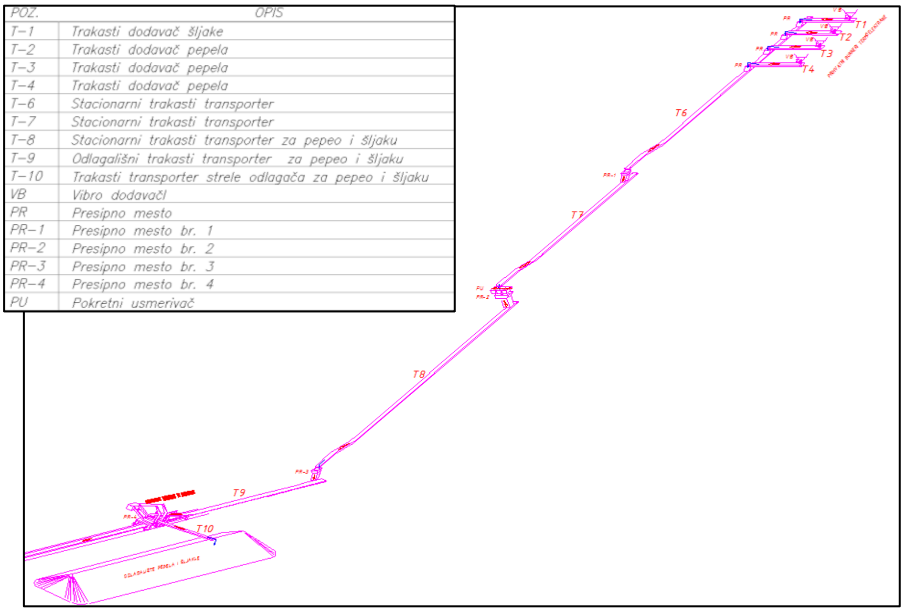
*** *Ovaj rad je jednim delom proistekao iz projekta TR37001 „Uticaj rudarskog otpada iz RTB Bor na zagadjenje vodotokova, sa predlogom mera i postupaka za smanjenje štetnog dejstva na životnu sredinu“, koji je finansiran sredstvima Ministarstva prosvete, nauke i tehnološkog razvoja Republike Srbije*

vrste transporta analizirane su tri varijante za koje su definisane tehnološke šeme pripreme, transporta i odlaganja prema potrebnim kapacitetima:

- Transport transporterima sa trakom;
- Hidraulički transport;
- Kamionski transport.

TRANSPORT TRANSPORTERIMA SA TRAKOM

Ovaj transportni sistem se sastoji od tri vibro dodavača i trakastih dodavača za pepeo i jednog vibro dodavača i trakastog dodavača za šljaku u termoelektrani. Zbog međusobnog položaja lokacija predviđenih za odlaganje na kopu u odnosu na termoelektranu, kao i konfiguracije terena, predviđena su četiri stacionarna trakasta transportera. Na lokaciji odlaganja predviđen je jedan odlagališni trakasti transporter i jedan trakasti transporterom na streli odlagača. Tehnološka šema pripreme, transporta i odlaganja transporterima sa trakom prikazana je na slici 1.



Sl. 1. *Tehnološka šema transporta transporterima sa trakom*

Izvršen je proračun trakastih transportera [7, 9]. odlagača, građevinskih objekata i radova, kao i elektroinstalacija za sve elemente sistema. Ulaganja potrebna za transport transporterima sa trakom data su tabelom 1.

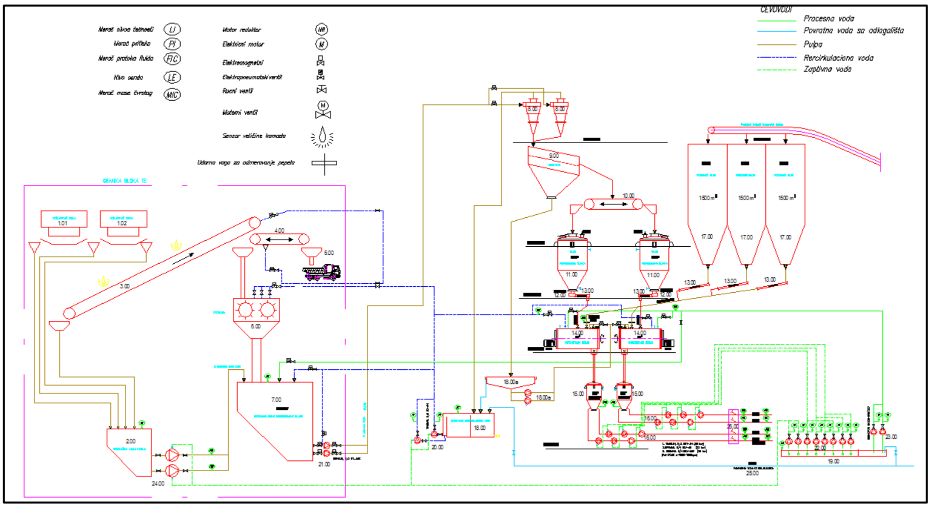
Tabela 1. *Ulaganja za transport transporterima sa trakom*

Stavka	Ukupno, KM
Mašinska oprema	18 194 231
Građevinski radovi	2 170 950
Elektro oprema	1 034 017
Zamena delova tokom perioda od 23 godine – 10% od prethodnog	2 139 920
Svega	23 539 118

HIDRAULIČKI TRANSPORT

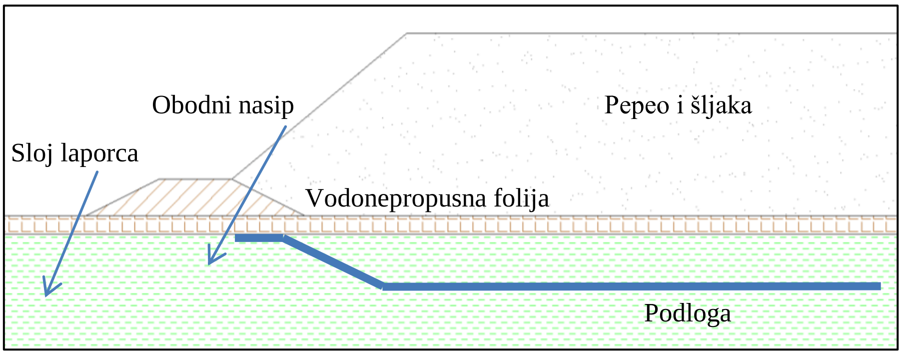
Postrojenje za pripremu i hidrotransport šljake i pepela nalaziće se u novoizgrađenom objektu na platou ispod postojećih silosa. Na toj poziciji, nalaze se četiri već izgrađena betonska silosa, tri za pepeo i jedan za šljaku. Na ovoj lokaciji će se locirati pogon za pripremu hidro mešavine i hidraulički transport do odlagališta tj. predviđene deponije šljake i pepela. Deo pogona za dodatno usitnjavanje šljake biće lociran u krugu termolelektrane, dok će deo pogona za hidraulički transport sapumpama za gustu hidromešavinu-pumpna stanica da se nalazi u produžetku osnovnog pogona za pripremu hidromešavine, a neposredno ispod silosa.

Stvorena šljaka, predhodno ohlađena vodom, se grabuljastim dodavačem usmerava u drobilicu za primarno usitnjavanje i tako usitnjena pada na trakasti transporter. Predviđeno je zatim, da se šljaka trakastim transporterom vozi do reverzibilnog trakastog transportera u drobilicu - mlin, za dodatno usitnjavanje šljake. Rashladna voda, kojom se šljaka hladi u odšljakivaču kotla, zajedno sa suspendovanim česticama šljake, sakuplja se u drenažnoj jami kotla gde se pumpama prepumpava u rezervoar retke hidromešavine šljake. Dodatno usitnjena šljaka u uređaju za dopunsko usitnjavanje direktno upada uz pomoć spirne recirkulacione vode, u rezervoar retke hidromešavine šljake. U hidrociklonima dolazi do klasiranja i zgušnjavanja retke hidromešavine šljake. Prosev sita, oceđena spirna voda kao i preliv hidrociklona se usmeravaju u betonski zgušnjivač. Preliv zgušnjivača predstavlja relativno čistu vodu koja se sakuplja u rezervoar recirkulacione vode, odakle distribuirana svim potrebnim mestima. Otsev sita pada na reverzibilni dodavač koji tako pripremljenu šljaku usmerava naizmenično u dva silosa. Iz horizontalnih dvospiralnih mešača izlazi gusta hidromešavina i ulazi u pumpnu stanicu hidrtransportnog sistema. U pumpnoj stanici nalaze se i dodatni pumpni sistemi za distribuciju procesne i zaptivne vode. Tehnološka šema hidrauličkog transporta pepela i šljake prikazana je na slici 2.



Sl. 2. *Tehnološka šema hidrauličkog transporta pepela i šljake*

Izvršen je proračun svih elemenata hidrauličkog transporta, građevinskih objekata i radova, kao i elektroinstalacija za sve elemente sistema. Kod ovog sistema transporta potrebna je i izrada vodozahvata sveže vode kao i priprema odlagališta [2, 3, 4] koja obuhvata pripremu podloge, izradu obodnog nasipa kao i postavljanje vodonepropusne folije, slika 3.



Sl. 3. *Poprečni presek odlagališta pri hidrauličkom transportu*

Ulaganja potrebna za transport transporterima sa trakom data su tabelom 2.

Tabela 2. *Ulaganja za hidraulički transport*

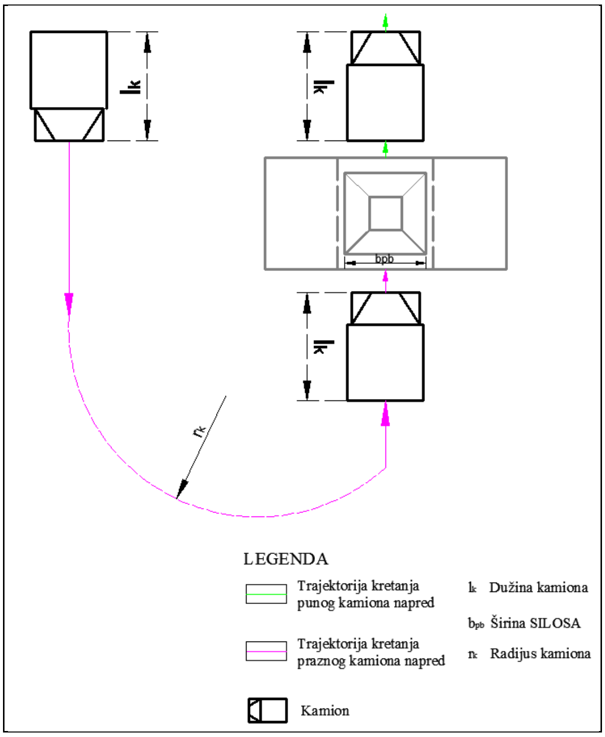
Stavka	Ukupno, KM
Mašinska oprema	24 751 800
Građevinski radovi	1 949 165
Hidrograđevinski radovi	201 631
Elektro oprema	665 500
Zamena delova tokom perioda od 23 godine – 10% od prethodnog	2 756 810
Priprema podloge	16 193 330
Svega	46 518 236

KAMIONSKI TRANSPORT

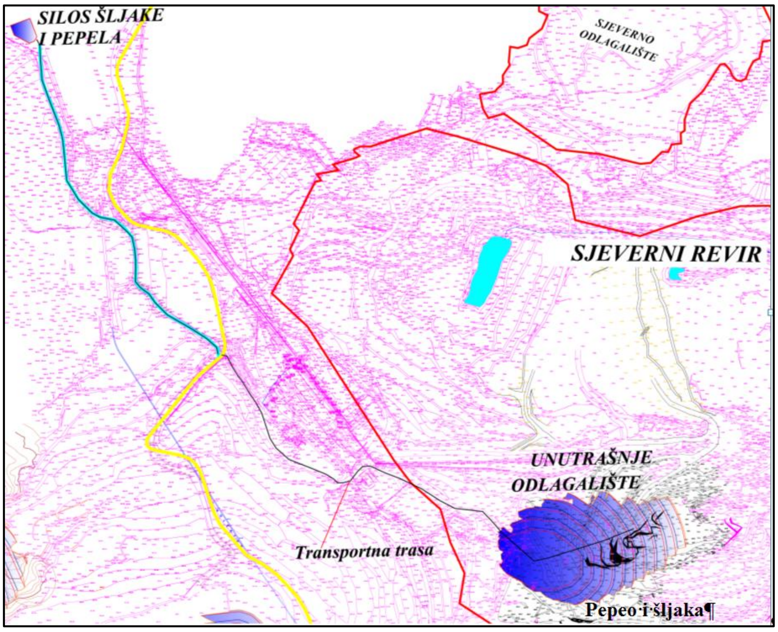
Kamionski transport pepela i šljake [5, 6, 8, 9] obavljao bi se postojećim transportnim putevima i ne zahteva posebne pripremne radove na pripremi. Šema utovara kamiona prikazana je na slici 4, a šema transportnog puta na Unutrašnje odlagalište prikazana je na slici 5. Potreban broj kamiona određen je računarskim programom Talpac sa periodom zamene na 8 godina. Ulaganja potrebna za kamionski transport data su tabelom 3.

Tabela 3. *Ulaganja za kamionski transport*

Stavka	Ukupno, KM
Kamioni Renault Kerax 430.35	4 800 000
Kamioni Iveco AD/AT 720 T41T	7 200 000
Svega	12 000 000



Sl. 4. *Šema utovara kamiona*



Sl. 5. *Šema transporta pepela i šljake na Unutrašnje odlagalište*

ZAKLJUČAK

Na osnovu tehnoloških šema izvršena je analiza investicionih ulaganja za svaku od varijanti za period od 23 godine. Ulaganja bitna za odabir vrste transporta prikazana su u tabelama 1 – 3.

Nakon analize zaključak je da se kamionskim transportom postižu najbolji ekonomski efekti sa aspekta ulaganja na transportu pepela i šljake od termoelektrane do lokacija predviđenih za odlaganje na površinskom kopu.

Iskustva sa površinskog kopa „Bogutovo Selo“ - Ugljevik, trebaju da se iskoriste i na površinskim kopovima RTB-a Bor. Pravilnim izborom sistema transporta i maksimalnim iskorišćenjem postojećih resursa, dobija se optimalno rešenje sa aspekta ulaganja, održavanja, i potrošnje energije.

LITERATURA

[1] Dopunski rudarski projekat transporta i odlaganja – deponovanja šljake, pepela i gipsa TE Ugljevik I na PK Bogutovo selo – Ugljevik; Institut za rudarstvo i metalurgiju Bor, 2015.

[2] R. Rajković, G. Angelov, B. Petrović, Lj. Obradović, D. Urošević, I. Jovanović, M. Mikić, B. Drobnjaković, S. Beatović, R. Milošević, N. Pušara: Izgradnja Kasete br. III faze 1 deponijepepela TE "Gacko" primenom nove tehnologije konstrukcije deponije, u cilju smanjenja negativnog uticaja deponije na životnu sredinu; Odluka Naučnog veća IRM-a o prihvatanju Tehničkog rešenja br. XXIV/2.2. od 26.12.2014

[3] M. Mikić, M. Ljubojev, R. Rajković, D. Kržanović, D. Urošević, I. Jovanović, L. Đurđevac-Ignjatović, D. Ignjatović, Z. Vaduvesković; Tehničko rešenje: Nova tehnologija pripreme deponije pepela – kaseta br. III termoelektrane Gacko na unutrašnjem odlagalištu površinskog kopa Gračanica u cilju rekultivacije; Odluka Naučnog veća IRM-a o prihvatanju Tehničkog rešenja br. XXIII/7. od 02.12.2014

[4] R. Rajković, Lj. Obradović, D. Kržanović, M. Mikić: Primena softverskih paketa Gemcom i Minex za projektovanje deponije otpada - primer konstrukcije kasete III faze 3 deponije pepela i šljake TE Gacko; Mining and Metallurgy Engineering Bor 4/2014; str. 25-32;

[5] D. Kržanović, M. Žikić, R. Rajković: Determing the Real Minimum Width of Working Space for Trucks on the Open Pits; 10. International Conference Research and Development in Mechanical Industry“ RaDMI2010, str. 801-804;

[6] M. Žikić, D. Kržanović, R. Rajković; Determing the Real Truck Turning Radius on the Open Pits; 42. Oktobarsko savetovanje rudara i metalurga; Kladovo, 2010., str. 146-149;

[7] R. Rajković, R. Lekovski, B. Rajković: Transportation Costs of Stationary Conveyor for Overburden Transportation System of Veliki Krivelj Open Pit in Relation to Inclination of Bearing Rollers; 39. Oktobarsko savetovanje, 07. – 10. oktobra 2007; str. 64-68;

[8] R. Rajković, D. Kržanović, Z. Vaduvesković: Optimizacija kamionskog transporta u okviru kombinovanog TSJ V. Krivelj; 35. Oktobarsko savetovanje rudara i metalurga, Borsko jezero, 2003. str. 152-156.

[9] R. Stanković, D. Pavlović, R. Rajković: Iskorišćenje transportnog sistema jalovine Veliki Krivelj; V internacionalni simpozijum o transportu i izvozu, Beograd - Vrdnik, 25 - 27. septembar, 2002. god.;

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THE USE OF SCRIPT IN THE SOFTWARE GEMCOM***

Abstract

Scripts are essentially the macros containing instructions for data manipulation in the form of mathematical and logical operations performed for the block model data.

In order to create the useful filters and key indices, it is important to have a good understanding of expressions and how to use them. Expressions are simple formulae that can be created to define selection criteria for data in the workspace. There are two types of expressions: math expressions, which always result in a numeric value, and logical expressions, which always result in a true or false condition.

Math expressions consist of up to three components: field specifiers, constants, and math operators.

Logical expressions are made up of two math expressions separated by a logical operator.

Keywords: *scripts, logical expressions, mathematical and logical operations, block model*

1 INTRODUCTION

The geological block model is a three-dimensional row of cubes (mini blocks) or matrixes, which are used for modeling the mineral deposits and other structures that are located beneath the ground surface. Those can be the amorphous ore bodies such as the mainly metallic ore deposits or layered for stratigraphic deposits.

Standard block model that is commonly used in geological modeling of deposit, consists of the following attributes (block models):

- *Rock Type*, or lithological block model
- *Density* model or specific mass model (weight)
- *Elevation* model or model of grids
- *Grade model* or model of content, which can be more than one, depending on the number of useful elements in the mineral raw material
- *Percentage* or partial model, if necessary
- Other attributes (models) as desired by the user

Block model geometry: Block model is spatially defined by three axes - X, Y, Z, and the start of the block model by point called the *"origin"* and is determined by the specified values x, y, z. If we accept conventionnally that the block model is a cube or parallelepiped composed of smaller elements, and the condition is that these elements - mini blocks have the same dimensions along the *z* axis, and observe it in space, the growing trends of rows, columns and levels from the origin that is located in the upper left corner of the block model, i.e. cube. Which space will be affected by the block model, depending on the size and number of mini-blocks.

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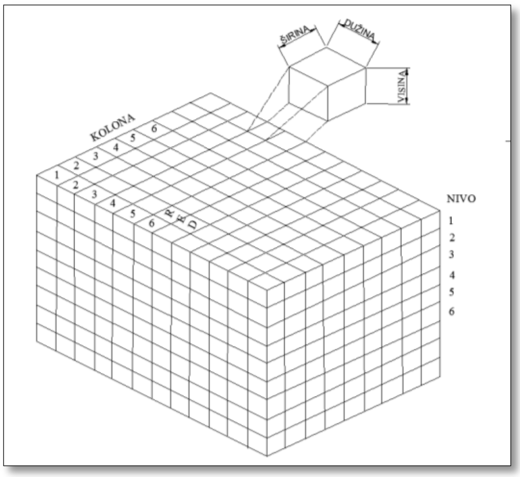


Figure 1 *Schematic view of a block model with elements*

1.1 Data manipulation in block models

It allows easy creation and evaluation of the new models as part of the existing one. Existing models such as the models of grade, rock types, density, etc., are often not sufficient, for example a detailed assessment of reserves. Purposes often occur in Gemcom:

- to create a model of equivalent grade for many metallic deposits or equivalent grade for determination the cut-off grade,
- to find relations between various elements (for example, Ca/Mg indicators) for various operations in the design of open pit,
- to develop the sophisticated *Rock Type* models, where codes of rock types depend on content in one or more of block models,
- to create the complex density models (if the density is assumed as a function of rock types and contents, etc.),
- to convert the block models from one set of units into another, etc.

Manipulation allows performing the global changes and rewriting the whole block model. Thewhole new models can be created as complex combinations of the existing models or selectively change the data in the model using the conditional logic. Manipulation of the block model is a powerful tool, but it must be used properly. Errors can permanently damage data in the block model.

1.2 Scripts

Scripts are essentially macros containing instructions for manipulation in the form of mathematical and logical operations that are performed for the specified block models. Scripts can be short and simple or very long duration and included, depending on the needs.

They are written using *GSI script language.*

2 EDITING PROCEDURE BY SCRIPTS

In the basic software - Gemcom, an additional attribute or *generic block model* is firstly created within the block model (CKB-BL). Data are stored in this block model that will be obtained by manipulation of the existing data in the block model attributes. For example, if in the block model there is an attribute blm of total copper (Cu), and also attribute blm of oxide copper (C_{uox}), created by interpolation of data from the exploration drill holes after certain procedure and geostatistical data processing, if the sulphide copper block model is needed with 10% oxide (Cu_S (10% OX), the same can be obtained by data manipulation using the script.

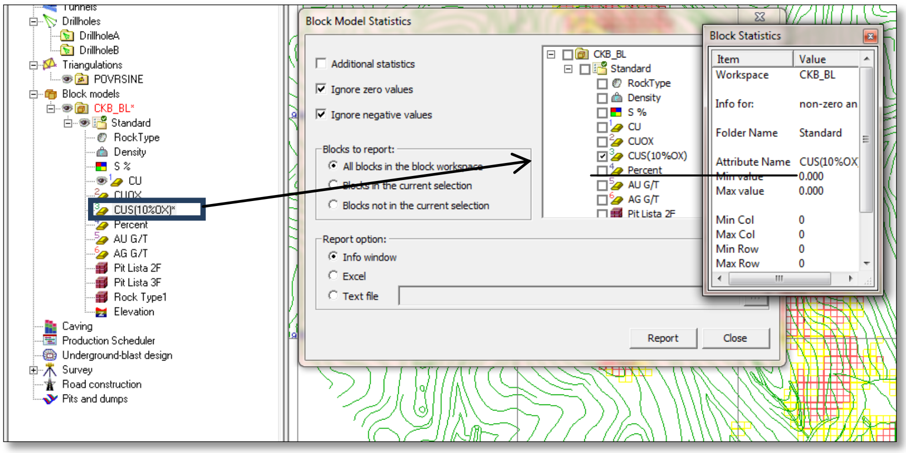


Figure 2 *Statistics of block model before editing by script, which shows that they are in the attribute, processed by the value "0"*

Commands in software for editing the block model are shown below:

Commands: **Block → Edit → Simple Manipulation / Advanced Manipulation**

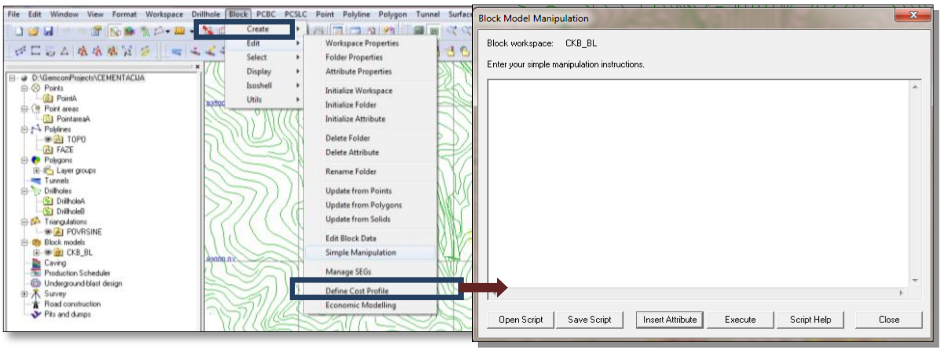


Figure 3 *Input into the block model manipulation editor*

The shown procedure opens the *manipulation editor*, where the attributes have to be inserted whose data will be used for manipulation and opening of prepared script, or macro, that is the system of mathematical and locial expressions:

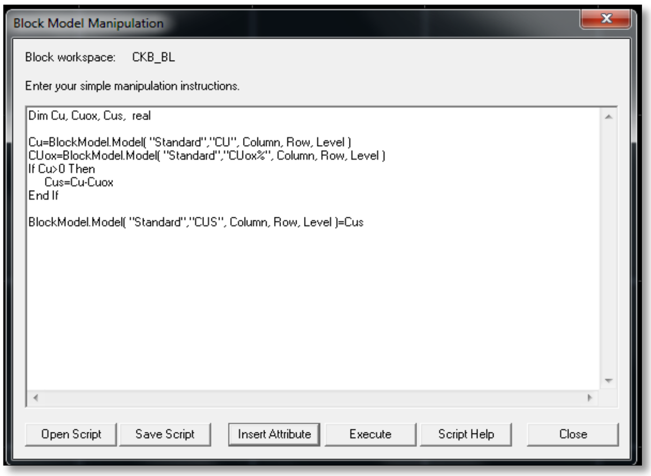


Figure 4 *Script opening – script input into the block model manipualation editor*

2.1 Some examples of script:

<u>Script 1 for Cus = Cu total – Cu ox</u>

```
Dim Cu, Cuox, Cus, real
Cu=BlockModel.Model("Standard","Cu % Grade", Column, Row, Level)
Cuox=BlockModel.Model("Standard"," Cuox % Grade", Column, Row, Level)
If Cu>0 Then
Cus=Cu-Cuox
End If
BlockModel.Model ("Standard", "Cus %", Column, Row, Level)=Cus
Dim Cu, Cuox, PrCUOX, real
```

<u>Script 2</u>

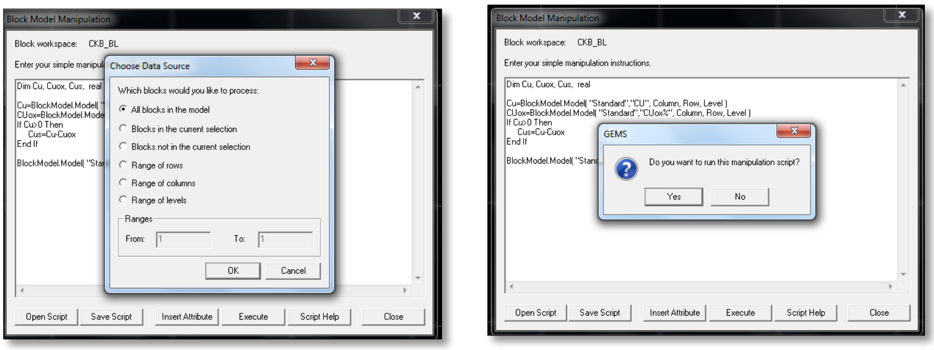
```
Cu=BlockModel.Model("Standard","CU %", Column, Row, Level)
Cuox=BlockModel.Model("Standard", "CUOX %", Column, Row, Level)
If Cu>0 Then
PrCUOX = 100*(Cuox/Cu)
End If
BlockModel.Model("Standard","PrCUOX", Column, Row, Level)=PrCUOX
```

<u>Script 3</u>

```
Dim Cu, Cuox, N, real
Cu=BlockModel.Model("Standard","Cu % Grade", Column, Row, Level)
Cuox=BlockModel.Model("Standard"," Cuox % Grade", Column, Row, Level)
If Cuox>Cu Then
  N=Cu
Else
  N=Cuox
End if
BlockModel.Model("Standard","Cuox % Grade", Column, Row, Level)=N
```

<u>Script 4 Cu eqivalent</u>

```
DIM Cu, Au, Ag
Cu=BlockModel.Model("Standard","Cu % Grade", Column, Row, Level)
Au=BlockModel.Model("Standard","Au g/t Grade", Column, Row, Level)
Ag=BlockModel.Model("Standard","Ag g/t Grade", Column, Row, Level)
If Cu>0.0999 Then
Cueq=Cu+0.375*Au+0.00206*Ag
Else
Cueq=0
End If
BlockModel.Model("Standard","Cueq % Grade", Column, Row, Level)=Cueq
```



1 2

Figure 5 *Further procedure of editing*

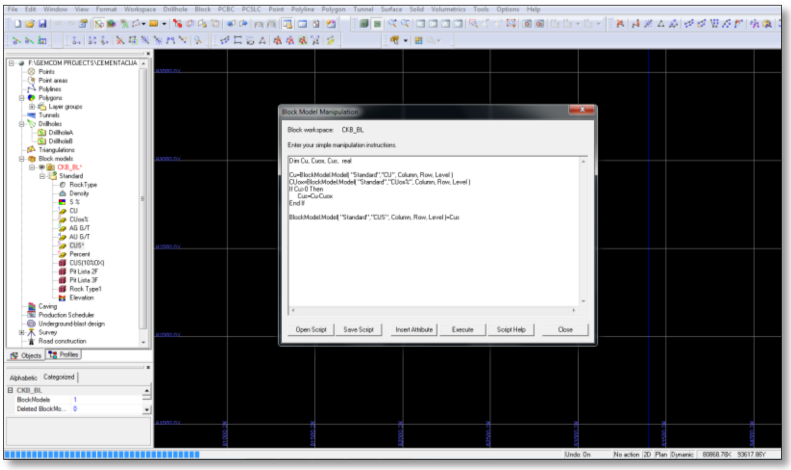


Figure 6 *Process of block model editing*

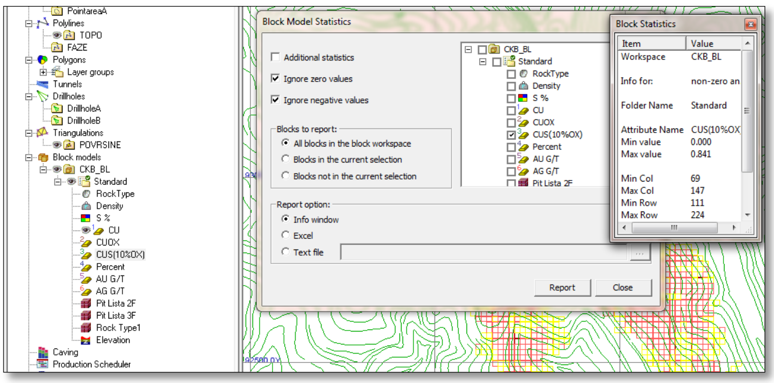


Figure 7 *Statistics of block model after editing by script; data are generated in the attribute that is processed*

2.1.1 Table of script types

Table 1 *Data types*

Data Types

Variable		Type Declaration	Size
Byte		Dim BVar As Byte	0 to 255
Boolean		Dim BoolVar As Boolean	True or False
String	$	Dim Str_Var As String	0 to 65,500 char
Integer	%	Dim Int_Var As Integer	2 bytes
Long	&	Dim Long_Var As Long	4 bytes
Single	!	Dim Sing_Var As Single	4 bytes
Double	#	Dim Dbl_Var As Double	8 bytes
Variant		Dim X As Any	
Currency		Dim Cvar As Currency	8 bytes
Object		Dim X As Object	4 bytes
Date		Dim D As Date	8 bytes
User Defined Types			size of each element

2.1.2 Mathematical operations used in scripts

Table 2 *Mathematical operators*

+	Addition.
–	Subtraction.
*	Multiplication.
/	Division.
^	Exponentiation.
LOG	Logarithm to base 10.
LN	Logarithm to base E.
( )	Parentheses for grouping.

2.2. Theoretical settings of data manipulation using mathematical and logical expressions

This type of data manipulation uses two sets of mathematical expressions to manipulate in records selected by logical expressions. Conditional manipulation has the following form:

If .>Logical expression> is TRUE
THEN Result = <math expression 1>
ELSE Result = <math expression 2>

In logical expression, if logical expression is:

- TRUE, then GEMS uses the first set of mathematical expressions.
- False, then GEMS uses the second set of mathematical expressions.

Mathematical expressions

They consist of combinations with one operator. The result of mathematical expression is always a numeric value.

Syntax

General syntax of mathematical expressions is in the following form:

<Descriptor> [<Operator><Descriptor>]

where:

<Descriptor> consists of specifiers of variables or constants field.

<Operator> consists of any mathematical or trigonometric operator.

Mathematical operators.

Mathematical operators perform simple mathematical operations in numeric fields (integer, real, double, coordinate, angle, date) and constants (integer number) and generate the numerical result. GEMS can interprete the following mathematical operators:

Logical expression. Always results in TRUE or FALSE conditions, and consists of two mathematical expressions separated by logical expression.

Logical operator.

Logical expressions consist of mathematical expressions and logical operators. The results of logical expression is either TRUE or FALSE. When it is used in data manipulation, the result TRUE means that the first mathematical expressions will be used, and FALSE means that the second mathematical expression will be used.

Syntax.

Generalized syntax of logical expression has the following form:

<Mathematical expression> <Operator> <Mathematical expression>

where:

< Mathematical expression > consists of mathematical equation as defined above

<Operator> consist of logical operator.

Examples.

Here are examples of logical expressions:

"ASSAYS:GOLD" LE 1.5

("ASSAYS:TO" - "ASSAYS:FROM") * COS ("ASSAYS:DIP") GT 10.0

Logical operators.

GEMS has the following logical operators that are used to compare two expressions:

1. **LT.** If the result of the first expression (equation) is smaller than the results of the second equation, logical operation is TRUE.
2. **LE.** If the results of the first equation is smaller or equal to the result of the second, logical operation is TRUE.
3. **GT.** If the results of the first equation is larger than the result of the second, logical operation is TRUE.
4. **GE.** If the results of the first equation is larger or equal to the result of the second equation, logical operation is TRUE.
5. **EQ.** If the results of the first equation is equal to the result of the second equation, logical operation is TRUE.
6. **NE**. If the results of the first equation is not equal to the result of the second equation, logical operation is TRUE.

There are other logical operators that can be used when one wants to compare more than two logical expressions simultaneously:

- **AND.** Combines the results of two logical expressions. The end result is TRUE if the result of both logical expressions is TRUE.
- **OR.** Combines the results of two logical expressions. The end result is true if none of the results of these two logical expressions is not TRUE.

When it is wanted to use more than one logical expression at one time, each set of logical expressions must be limited by parentheses:

("ASSAYS:GOLD" GE 1.0) AND ("ASSAYS:SILVER" GE 5.0)

In mathematical equations and logical expressions, Gems performs operations in a specific order.

3 CONCLUSION

Scripts are used for manipulation of geological and geodetic data in the software using such data, and that on the basis of known data sets, created subsets, according to the certain rules and procedures. This is a type of macro that has application in theother software that operate with mathematical expressions and data, and here is shown the usage in geological block model in the software Gemcom. Based on known data from two attributes that can be conditionally called the subsets of block model in the base of geological data, for example metal content, if it is a model of metallic deposit, a block model of *equivalent Cu content* can be created, if there are attributes of many metals (Au, Ag, Mo, etc.) in the model, or as in the example presented in the article - if the chemical analyses were carried out of core samples on total copper Cu and oxide (Cu ox), and it is necessary to calculate the sulphide Cus; using the script will solve this in a very elegant way.

Scripts are in fact short records of *linear programming* used for writing the instructions for data manipulation.

REFERENCES

[1] GEMS Block Modeling Manuel, ver. 6.1., Gemcom Software International Inc. Vancouwer, BC. Canada, June 2007;

[2] Gems Software "Help";

[3] B. Kolonja et al., "Modeling of Deposits Using the Modern Tools" Script for the Open Pit Designs, Faculty of Mining and Geology, Belgrade, 2012;

[4] Z. Vaduvesković and others, "A Review of Previous Exploratory Works in the Complex Cerovo Cementacija and Data Processing in the Software Gemcom", 43rd International October Conference on Mining and Metallurgy, Kladovo, Serbia, October 12-15, 2011, pp. 515-520;

[5] Z. Vaduvesković, N. Vušović, D. Kržanović: "Analysis the Possibility for Improvement the Economic Indexes for Mining the Deposit Cementacija – Kraku Bugaresku – Ore Field Cerovo", Mining and Metallurgy Institute Bor, 1/2014, pp. 13-24.

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KORIŠĆENJE SKRIPTA U SOFTVERU GEMCOM***

Izvod

Skripta su u suštini makroi koji sadrže uputstva u obliku matematičkih i logičkih operacija, za manipulacije podacima iz blok modela.

Da bi kreirali korisne filtere i ključne indikatore, važno je imati dobro razumevanje izraza i kako ih koristiti. Izrazi su jednostavne formule koje se mogu kreirati da bi se definisali kriterijumi za selekciju podataka u radnom prostoru - workspace-u ili radnoj bazi podataka. Postoje dve vrste izraza: matematički izrazi, koji uvek kao rezultat imaju brojčane vrednosti, i logični izraza, koji uvek rezultiraju istinito ili lažno stanje.

Matematički izrazi se sastoje od do tri komponente specifikatora polja, konstante, i matematičkog operatera.

Logički izrazi se sastoje od dva matematička izraza odvojenih logičkim operatorom.

***Ključne reči:** skripta, logički izrazi, matematički i logički operatori, blok model*

1. UVOD

Geološki blok model je trodimenzionalni niz kockica (mini blokova) ili i matrica, koje se koriste za modeliranje ležišta mineralnih sirovina i drugih struktura koje se nalaze ispod površine terena. To mogu biti amorfna rudna tela kao što su uglavnom metalična rudna ležišta ili slojevita za stratigrafska ležišta.

Standardni blok model koji se najčešće koristi kod geološkog modeliranja ležišta, sastoji se od sledećih atributa (blok modela):

- *Rock Type*, ili litološki blok model
- *Density* model ili model specifične mase (težine)
- *Elevation* model ili model gridova,
- *Grade model* ili model sadržaja, kojih može biti više od jednog, zavisno od broja korisnih elemenata u mineralnoj sirovini,
- *Procentualni* ili parcijalni model, ako je potreban,
- Drugi atributi (modeli) po želji korisnika.

Geometrija blok modela: Blok model je prostorno definisan trima osama – X, Y, Z, a početak blok modela tačkom koja se naziva „*origin*“ i određena je navedenim vrednostima x, y, z. Ako prihvatimo konvencionalno da je blok model kocka ili paralelopiped sastavljen od manjih elemenata, a uslov je da ti elementi - mini blokovi, imaju jednake dimenzije po *z* osi, i posmatramo ga u prostoru, rastući pravci redova, kolona i nivoa su od origina koji se nalazi u levom gornjem uglu blok modela, tj. kocke. Koji će prostor biti zahvaćen blok modelom, zavisi od dimenzija i broja mini blokova.

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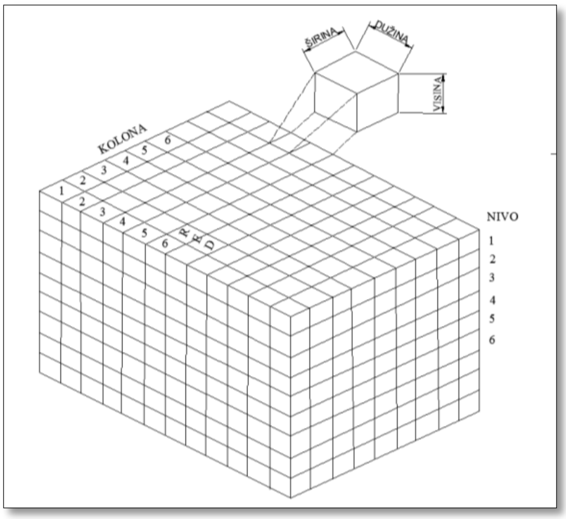


Sl. 1. *Šematski prikaz blok modela sa elementima*

1.1. Manipulacija podacima u blok modelima

Omogućava jednostavno kreiranje i evaluaciju novih modela u sklopu postojećeg. Postojeći modeli kao što su modeli sadržaja, tipova stena, gustine, i dr., često nisu dovoljni za npr. detaljnu procenu rezervi. U Gemcomu se često javljaju potrebe:

- da se kreira model ekvivalentnog sadržaja za više metalničnih depozita, ili ekvivalentni sadržaji za određivanje graničnog sadržaja (*cut-offgrade*),
- da se nadju odnosi različitih elemenata (na primer, Ca/Mg pokazatelji) za razne operacije u projektovanju kopova,
- da se izrade sofisticirani *Rock Type* modeli, gde kodovi vrste stena zavise od sadržaja u jednom ili više blok modela,
- da se kreiraju složeni modeli gustine (ako je gustina pretpostavljena kao funkcija tipova stena i sadržaja, i sl.),
- konvertuju blok modeli iz jednog skupa jedinica u drugu i dr.

Manipulacija omogućava da se izvrše globalne izmene i prepravi ceo blok model. Mogu da se kreiraju čitavi novi modeli kao kompleksne kombinacije postojećih modela ili selektivno promene podaci u modelu pomoću uslovne logike. Manipulacija Blok modelom je moćan alat, ali mora da se koristi pravilno. Greške mogu trajno da oštete podatke u blok modelu.

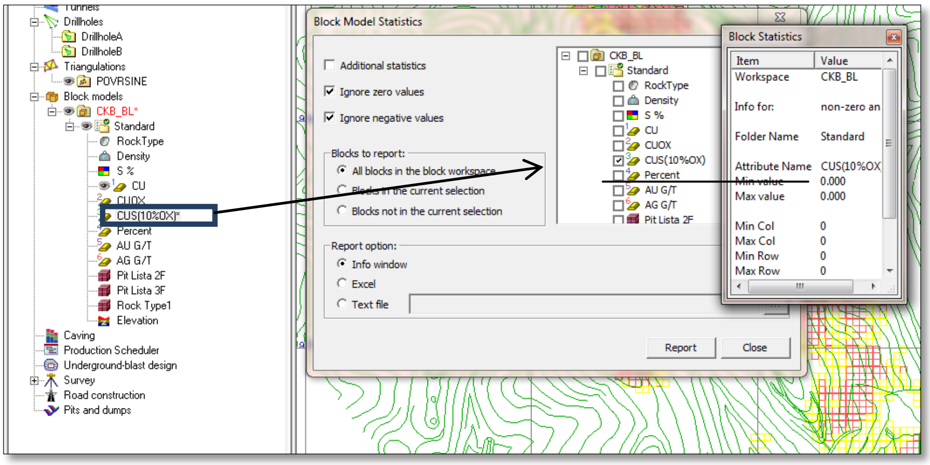
1.2. Skripte (Scripts)

Skripta su u suštini makroi koji sadrže uputstva za manipulacije u obliku matematičkih i logičkih operacija koje se obavljaju za navedene blok modele. Skripta mogu biti kratka i jednostavna ili veoma dugog trajanja i uključena, zavisno od potreba.

Pišu se koristeći GSI script language.

2. PROCEDURA EDITOVANJA SKRIPTAMA

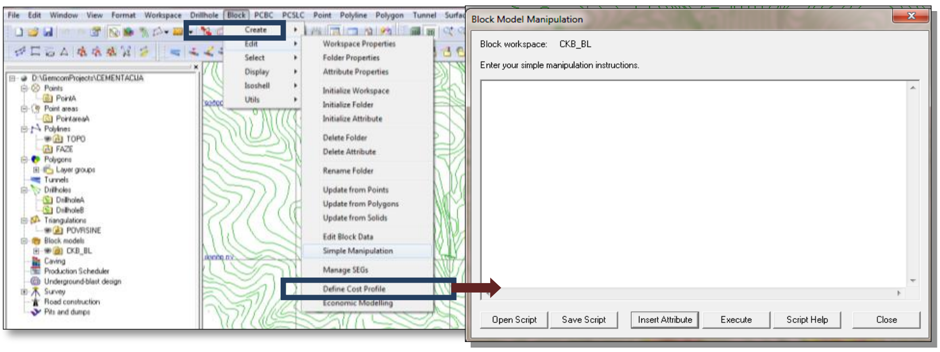
U osnovnom softveru – Gemcom-u, najpre se kreira dodatni atribut ili *generic blok model* u sklopu blok modela (CKB-BL). U tom blok modelu se smeštaju podaci koji će se dobiti manipulacijom postojećih podataka u atributima blok modela. Na primer, ako u blok modelu postoji atribut blm ukupnog bakra (Cu), takodje i atribut blm oksidnog bakra (C_{uox}), koji su kreirani interpolacijom podataka iz istražnih bušotina nakon određene procedure i geostatističke obrade podataka, ukoliko je potreban i blok model sulfidnog bakra sa 10% oksidnog (Cu_s(10%OX), isti se može dobiti manipulacijom podataka korišćenjems skripta.



Sl. 2. *Statistika blok modela pre editovanja skriptom, gde se vidi da su u atributu koji se obrađuje vrednosti "0"*

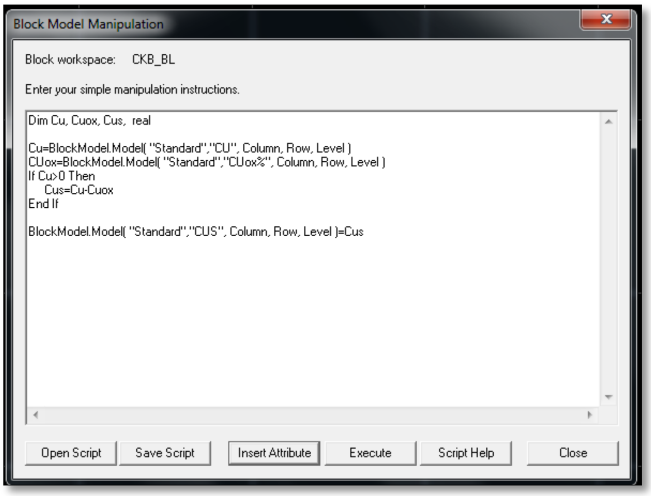
Komande u softveru kojima se vrši editovanje blok modela su prikazane u nastavku:

Komande: **Block → Edit → Simple Manipulation / Advanced Manipulation**



Sl. 3. *Ulazak u blok model manipulation editor*

Prikazana procedura otvara *editor za manipulaciju*, gde treba insertovati atribute čijim će se podacima manipulisati i otvoriti pripremljeni skript, ili makro, odnosno sistem matematičkih i logičkih izraza:



Sl. 4. *Otvaranje skripte – unos skripte u blok model manipualation editor*

2.1. Neki primeri skripta:

Skripta 1. za Cus = Cu ukupno – Cu ox

```
Dim Cu, Cuox, Cus, real
Cu=BlockModel.Model("Standard","Cu
%   Grade", Column, Row, Level)
Cuox=BlockModel.Model("Standard","
Cuox % Grade", Column, Row, Level)
If Cu>0 Then
Cus=Cu-Cuox
End If
BlockModel.Model ("Standard", "Cus
%", Column, Row, Level)=Cus
Dim Cu, Cuox, PrCUOX, real
```

Skripta 2

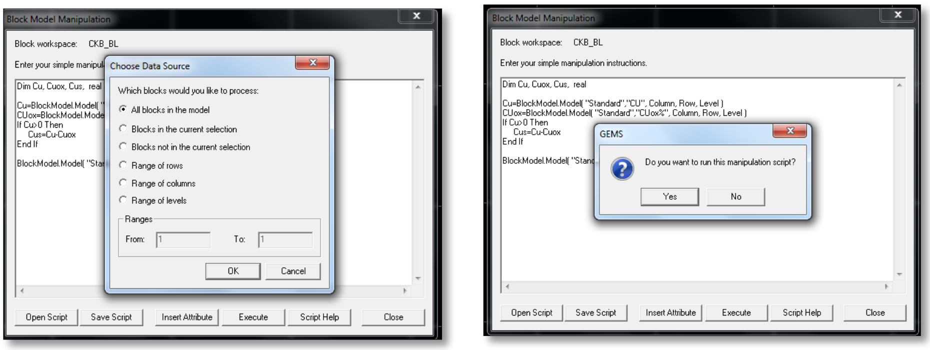
```
Cu=BlockModel.Model("Standard","C
U %", Column, Row, Level)
Cuox=BlockModel.Model("Standard",
"CUOX %", Column, Row, Level)
If Cu>0 Then
PrCUOX = 100*(Cuox/Cu)
End If
BlockModel.Model("Standard","PrCU
OX", Column, Row, Level)=PrCUOX
```

Skripta 3.

```
Dim Cu, Cuox, N, real
Cu=BlockModel.Model("Standard","Cu
%   Grade", Column, Row, Level)
Cuox=BlockModel.Model("Standard","
Cuox % Grade", Column, Row, Level)
If Cuox>Cu Then
  N=Cu
Else
  N=Cuox
End if
BlockModel.Model("Standard","Cuox %
Grade", Column, Row, Level)=N
```

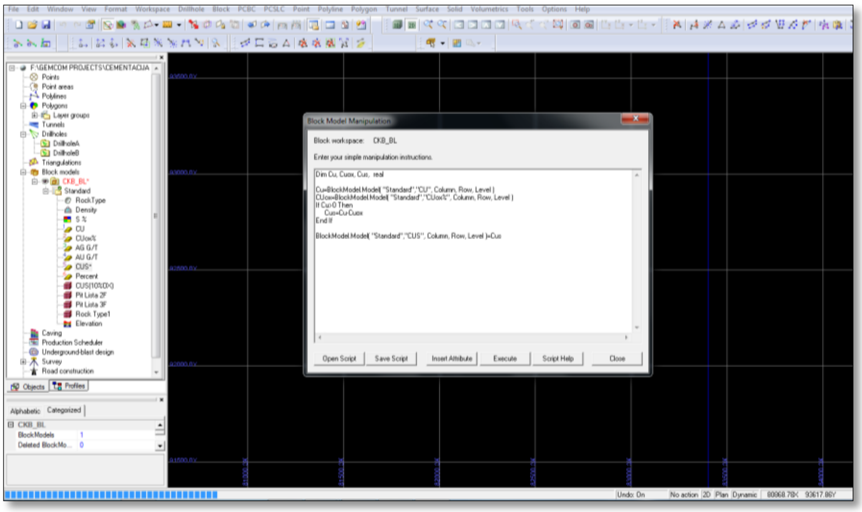
Skripta 4. Cu ekvivalent

```
DIM Cu, Au, Ag
Cu=BlockModel.Model("Standard","Cu
%   Grade", Column, Row, Level)
Au=BlockModel.Model("Standard","Au
g/t Grade", Column, Row, Level)
Ag=BlockModel.Model("Standard","Ag
g/t Grade", Column, Row, Level)
If Cu>0.0999 Then
Cueq=Cu+0.375*Au+0.00206*Ag
Else
Cueq=0
End If
BlockModel.Model("Standard","Cueq %
Grade", Column, Row, Level)=Cueq
```

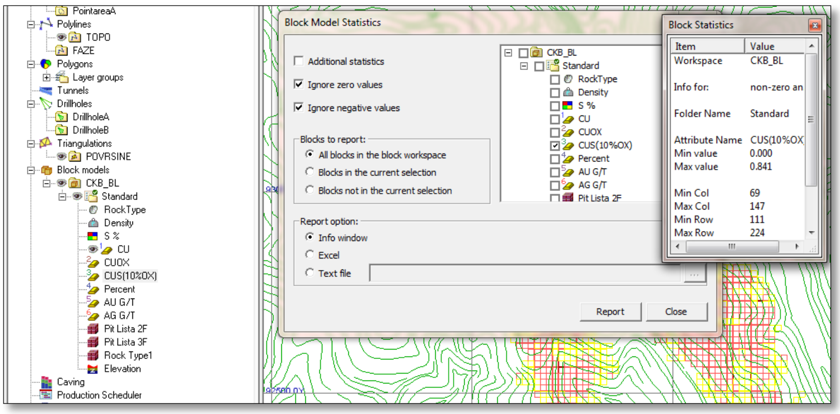


1 2

Sl. 5. *Dalji postupak editovanja*



Sl. 6. *Proces editovanja blok modela*



Sl. 7. *Statistika blok modela nakon editovanja skriptom, podaci su generisani u atributu koji se obrađuje*

2.1.1. Tablica tipova skripta

Tabela 1. *Tipovi podataka*

Data Types

Variable		Type Declaration	Size
Byte		Dim BVar As Byte	0 to 255
Boolean		Dim BoolVar As Boolean	True or False
String	$	Dim Str_Var As String	0 to 65,500 char
Integer	%	Dim Int_Var As Integer	2 bytes
Long	&	Dim Long_Var As Long	4 bytes
Single	!	Dim Sing_Var As Single	4 bytes
Double	#	Dim Dbl_Var As Double	8 bytes
Variant		Dim X As Any	
Currency		Dim Cvar As Currency	8 bytes
Object		Dim X As Object	4 bytes
Date		Dim D As Date	8 bytes
User Defined Types			size of each element

2.1.2. Matematičke operacije koje se koriste u skriptama

Tabela 2. *Matematički operatori*

+	Addition.
–	Subtraction.
*	Multiplication.
/	Division.
^	Exponentiation.
LOG	Logarithm to base 10.
LN	Logarithm to base E.
( )	Parentheses for grouping.

2.2. Teoretske postavke manipulacije podataka korišćenjem matematičkih i logičkih izraza

Ovaj tip manipulacije podacima koristi dva seta matematičkih izraza da manipuliše u zapisima koji su izabrani logičkim izrazima. Uslovna manipulacija ima sledeću formu:

If .>Logički izraz> je ISTIT (*TRUE*)
THEN Result = <math expression 1>
ELSE Result = <math expression 2>

U logičkom izrazu, ako je logički izraz:

Ististinit (TRUE), onda GEMS koristi prvi set matematičkih izraza.

- True, then GEMS uses the first set of mathematical expressions.
- False, onda GEMS koristi drugi set matematičkih izraza.

Matematički izrazi (*Mathematical expressions).*

Sastoje se od kombinacija sa jednim operatorom. Rezultat matematičkog izraza je uvek numerička vrednost.

Sintaksa (*Syntax)* .

Generalna sintaksa matematičkih izraza je u sledećoj formi:

<Descriptor> [<Operator><Descriptor>]

gde je:

<Descriptor> sastoji se specifikatora polja varijabli ili konstanti.

<Operator> sastoji se bilo kog matematičkog i trigonometrijskog operatora.

Matematički operatori (*Mathematical operators).*

Matematički operatori (Mathematical operators) izvršavaju jednostavne matematičke operacije u numeričkim poljima fields (integer, real, double, coordinate, angle, date) i constama (integer i broj) i generišu numerčki rezultat. GEMS može da interpretira sledeće matematičke operatore:

Logički izraz. Uvek rezultira TRUE ili FALSE uslovima, a sastoji se od dva matematička izraza odvojenih logičkim izrazom.

Logički operator.

Logički izrazi se sastoje od matematičkih izraza i logičkih operatora. Rezultat logičkog izraza je bilo TRUE ili FALSE. Kada se koristi u manipulaciji podacima, rezultat TRUE se koristiti prvi matematički izraz i FALSE se koristiti drugi matematički izraz.

Syntaxa.

Uopštena sintaksa logičkih izraza ima sledeću formu:

<Matematički izraz> <Operator> <Matematički izraz>

gde:

<Matematički izraz> se sastoji iz matematičke jednačine kako je gore definisano

<Operator> se sastoji od logičkog operatora.

Primeri.

Tu su navedeni primeri logičkih izraza

"ASSAYS:GOLD" LE 1.5

("ASSAYS:TO" - "ASSAYS:FROM") * COS ("ASSAYS:DIP") GT 10.0

Logički operatori.

GEMS poseduje sledeće logičke operatore koji se koriste radi upoređenja dva izraza:

1. **LT.** Ako je rezultat prvog izraza (j-ne) manji od rezultata druge j-ne, logička operacija je TRUE.
2. **LE.** Ako je rezultat prve jednačine manji ili jednak rezultatu druge, logička operacija je TRUE.
3. **GT.** Ako je rezultat prve jednačine veći od rezultata druge jednačine, logička operacija je TRUE.
4. **GE.** Ako je rezultat prve jednačine veći ili jednak rezultatu druge jednačine, logička operacija je TRUE.
5. **EQ.** Ako je rezultat prve jednačine jednak rezultatu druge jednačine, logička operacija je TRUE.
6. **NE.**. Ako je rezultat prve jednačine nije jednak rezultatu druge jednačine, logička operacija je TRUE.

Postoje i drugi logički operatori koji mogu da se koriste kad se želi da se uporedi više od dva logička izraza istovremeno:

- **AND.** Kombinuje rezultate dva logička izraza. Krajnji rezultat je TRUE ako je rezultat oba logička izraza TRUE.
- **OR.** kombinuje rezultate dva logička izraza. Krajnji rezultat je istina ako nijedan od rezultata ova dve logička izraza nije TRUE.

Kada se želi da se koristi više od jednog logičnog izraza u jednom trenutku, svaki set logičkih izraza mora biti ograničen zagradama:

("ASSAYS:GOLD" GE 1.0) AND ("ASSAYS:SILVER" GE 5.0)

U matematičkim jednačinama i logičkim izrazima, Gems obavlja operacije u određenom redosledu.

3. ZAKLJUČAK

Skripta se koriste za manipulaciju podacima, geološkim i geodetskim u softverima koji koriste takve podatke, i da se na osnovu poznatih skupova podataka, kreiraju pod skupovi, prema određenim pravilima i procedurama. To je vrsta makroa koji ima primenu i u drugim softverima koji operišu matematičkim izrazima i podacima, a ovde je prikazana upotreba u geološkom blok modelu u softveru Gemcom. Na osnovu poznatih podataka iz dva atributa koje uslovno možemo nazvati podskupovima blok modela u bazi geoloških podataka, npr. sadržaja metala, ako se radi o modelu metaličnog ležišta, može se kreirati blok model *ekvivalentnog sadržaja Cu* ukoliko u modelu postoje atributi više metala (Au, Ag, Mo, i dr), ili kao u primeru koji je obrađen u članku - ukoliko su urađene hemijske analiza na uzorcima jezgara na ukupan bakar Cu, i oksidni (Cu ox), a potrebno je sračunati i sulfidni Cus, upotrebom scripa se na vrlo elegantan način to rešava.

Scripta u u stvari kratki zapisi *linearnog programiranja* kojima se pišu instrukcije kojima se vrši manipulacija podacima.

LITERATURA

[1] GEMS Block Modeling Manuel, ver. 6.1., Gemcom software International Inc. Vancouwer, BC. Canada, Jun. 2007

[2] Gems software "Help"

[3] B. Kolonja i saradnici, "Modeliranje ležišta savremenim alatima", Skripta iz projektovanja površinskih kopova Rudarsko-geološki fakultet Beograd, 2012.

[4] Z. Vaduvesković and others, "A Review of Previous Exploratory Works in the Complex Cerovo Cementacija and Data Processing in the Software Gemcom", 43. Oktobarsko savetovanje rudara i metalurga, Kladovo, Srbija, 12.-15. oktobra 2011., str. 515-520.

[5] Z. Vaduvesković, N. Vušović, D. Kržanović: "Analiza mogućnosti poboljšanja ekonomskih pokazatelja eksploatacije ležišta cementacija Kraku Bugaresku - Rudno polje Cerovo", Mining and Metallurgy Institute Bor, 1/2014., str. 25-36.

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FLOTATION OF BLUE WATER**

Abstract

Flotation of ions and molecules represents a promising method of separating components from solution, or in our case, gelled copper salt from blue water. The method of flotation of ions and molecules is basically the flotation extraction process which produces different concentration gradients of multicomponent condensed phase system. Different concentration gradients in the flotation extraction are due to the driving forces of participating molecules driven by molecular interactions. Multicomponent condensed phase system, i.e. flotation pulp, consists of water molecules of solute, and a suitable reagent which has the role of connection the liquid and gaseous phases dispersed in a biphasic system. Such a system leads to the interaction of solute with reagent to the formation of coagulated component in water as solvent. Separation in the polyphased system is in accordance with the Van't Hoff equation, and spontaneously occurs in two-phase systems like gaseous-fluid, such as the system of flotation pulp. Using the osmotic pressure in a column flotation machine comes to separation of flotation pulp into heavy and light phase. This allows the water molecules to form their natural distances which are only valid for molecules of pure water or heavy phase. Also, the solute forms its light phase, copper – surfactant salt as insoluble product. For some polyphase systems such as colloidal systems like in the flotation process are sufficient atmospheric pressure conditions, and for others solutions should be applied overpressure while being aerated. This paper presents the results of research the flotation extraction of blue water, i.e. copper solution content of 0.2 g/l. It is concluded from results that there is a possibility of purifying the blue water from the copper mine tailing dump using the flotation extraction technology.

Keywords: *concentration gradient, condensed phase, coagulation, osmotic pressure, xerogel*

INTRODUCTION

Flotation was first applied in 1877 to enrich the graphite ore, but immediately afterwards it was abandoned. Since the first patented process (Elmore, 1898) [1], it was applied and constantly improved. The use of flotation in wastewater treatment is considered to be a revolutionary innovation because it runs 6-8 times faster than sedimentation and ends in 15-30 minutes [2]. In addition, it provides a very high degree of removal the suspended material, significantly reducing the concentration of surface active materials in waste water and increases the oxygen content, all in a great extent the later stages of processing. Today, the flotation process is applied in many areas of industry: in the enrichment, separation of various metals in ores and fuels, separation of valuable components from the solutions, while in the wastewater treatment it is used for removal the suspended and emulsified pollutants and biological sludge buildup. The solid particles, droplets, ions or mole

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cules from the liquid phase, "glued" to the air bubbles pumped to the liquid phase in various ways, are carried to the surface by the driving force of the osmotic pressure, and concentrated to a foam which is removed from there.

FLOTATION PROCESS

Flotation process is based on the fact that particles with hydrophobic surface in aqueous dispersions have the ability to stick with a gas bubble. During the process of mutual mixing the dispersion and bubbles, some particles are concentrated on the surface of bubbles, while particles without a hydro phobic surface remain in the volume of dispersion. Separation based on these natural capabilities of particles is used as an opportunity of getting separate particles based on their different abilities to concentrate on the surface of bubbles. Flotation is a process of molecular "attaching" of particulate materials on the boundary surface of phases, usually gas (usually air–water) Flotation is used as an alternative method to the other separation processes: sedimentation, centrifuge separation, filtration and similar, and it is often more efficient or economically justified [2]. Figure 1 illustrates differences between these processes, and Figure 2 shows the types of flotation process.

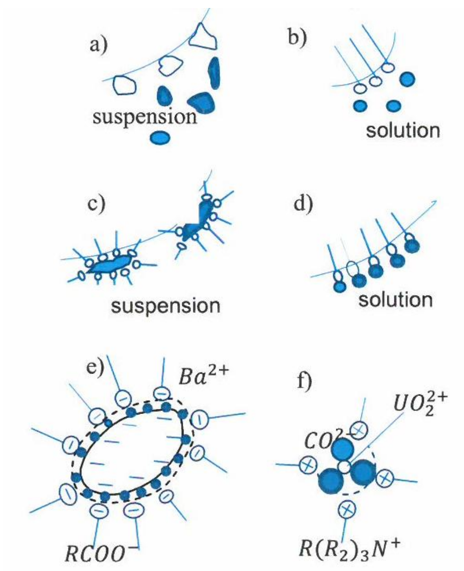

Figure 1 *Illustration the similarity of flotation of ions and molecules with the flotation of minerals*

a) Flotation active mineral particles are adsorbed on surface of bubbles while inactive mineral particles remain in the bulk;
b) Surface active components of solution are adsorbed on surface of bubbles, while other ones, eg. suface inactive, remain in the bulk;
c) Onto surface of bubbles are adsorbed mineral particles covered with collector;
d) On surface of bubbles is adsorbed sublat (individual chemical compound), which consists of colligend (indicates the ion to be removed) and the collector;
e) ions are attracted by fatty acid anion collector ( ) adsorbed on surface of quartz particles
f) ion is a binder between ion and four ions of alkyl ammonium collector( ).

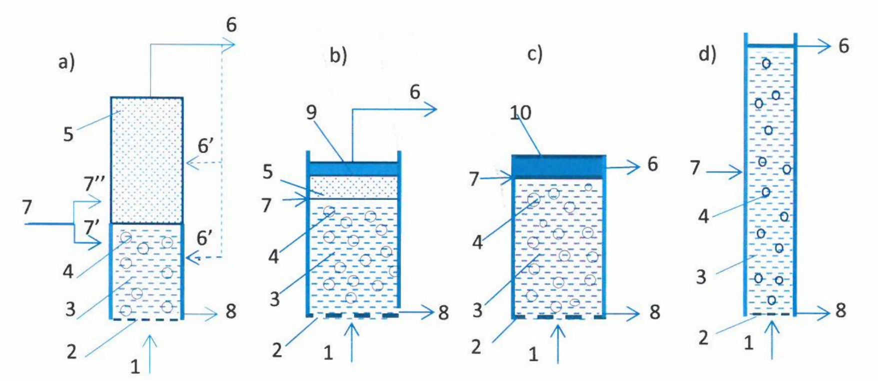

Figure 2 *Scheme of foam separation (a), ion flotation (b), flotation extraction (c) and nucleate fractionating (d)*

Where: 1. air, 2. bubbles prunger, 3. water solution, 4. surfacing bubbles, 5. foam layer, 6. upper product, 6' 6'' or the upper product which is returned to the wet foam and upper product which is returned under the foam, 7. starting solution, 7' i 7'' added to the starting solution, i.e. the initial solution added above and below the level of foam, 8. bottom product, 9. foam, 10. organic liquid phase

ADSORPTION ON SURFACE OF BUBBLE

Adsorption on surface of bubble is the basis of the flotation of ions and molecules [3].

Termodynamics of adsorption: The basic thermodynamic equation of interfacial boundaries liquid-gaseous was given by Gibbs:

(1)

Where:

σ - surface tension

η_s - excess entropy in the system

T - absolute temperature

- the excess weight of i-th component per unit of surface of interfacial area

μ_i - chemical potential

n - number of components

From the expression given in the form of equation 1, the adsorption isotherm equation is derived:

(2)

Or

— (3)

When

(4)

Where:

- standard chemical potential

- activity of the i-th component in solution

- universal gas constant

i (5)

—— (6)

In very dilute solution where , - concentracion of i-th component in the solution, instead of equation 6, there is:

—— (7)

or

—— (8)

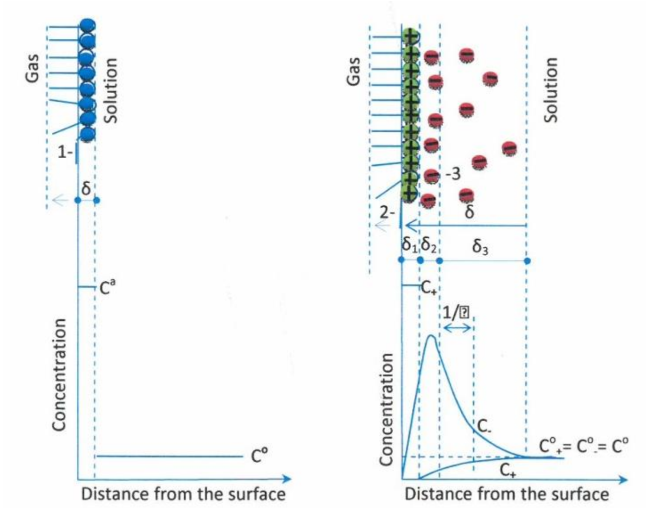

Figure 3 *Structure of adsorption layers at the interphase boundary liquid – gas, systems for water - dissolved surfactant*

From equation 8 it follows, if the components of the solution reduce the surface tension (—) then adsorption on the interphase boundary ( ) and vice versa. In the first case the substance is called surfactant, and contrary.

If the adsorption layer is considered as a single surface phase thickness δ, then for the i-th component of solution can be written:

(9)

If is adsorption extent, equilibrium concentracion in the solution, while concentration in the adsorption layer ( ) then from equations 8 and 9 it follows:

— —— (10)

Presented equation shows that in the case of highly active surface active substance — ratio can attain the value of 10^4 to 10^6 or more. Figure 3 illustrates the structure of adsorption layer.

a) nonionic surfactant;
b) ionic surfactant (symmetric binary electrolyte unassociated with surface-active cation);

- concentration in bulk
- concentration on adsorption layer

i - concentration of anions and cations

1 – surface active molecules
2 – surface active ions
3 – opposite charged ions

Based on the review of the structure of the adsorption layer is obvious that calculations based on equation 10 are illustrative only. More artificial is the notion of homogeneity thickness of adsorption layer in case of ionic surfactants

— —— ——

Driving forces and theoretical aspects of flotation extraction of ions and molecules

The osmotic pressure Π from the Van't Hoff equation is

(11)

In this equation, c is the molar concentration of solute, R is the gas constant and T is the absolute temperature at which they are dissolved. The chemical potential of water must be in equilibrium and the same on both sides of the semi permeable membrane

(12)

In case of the solution the following is applied:

(13)

Changes in chemical potential related to changes in pressure are given by the equation:

(14)

Combining equations 2, 3 and 4 assuming that the molar volume of water

1.80356E-05

varies very little at a given pressure range, the following is applied:

(15)

Therefore

(16)

Where k_p is piezoscopic constant (–),

When is low, the following approximation is:

(17)

and it is

(18)

For small values of

— (19)

Where n_s is the number of moles of solute n_w number of moles of water

(20)

Where —, is molar concentration of solution

At low osmotic pressure up to 0.5 MPa, the ideal colligative equation has the form:

—— (21)

V is volume (in liters) of solution containing one liter of water. [4]

Description of equipment and processes

Flotation extraction device consists of three functionally incorporated wholes [5]:

- Worm pump
- Injector or sprinklers
- Column container

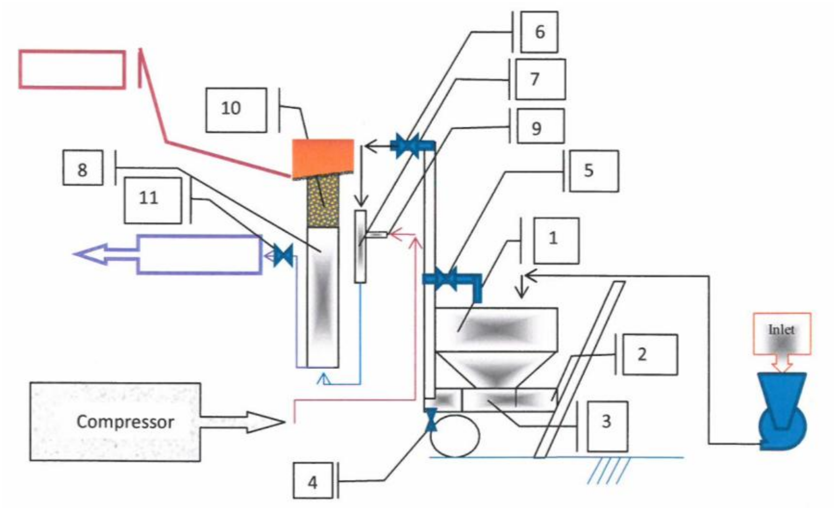

Figure 4 *Schematic view of the flotation extraction device*

Functional connection of the device is shown in Figure 1. The mobile worm pump (Mozly) has a basket (1) for the incoming pulp, engine (2), worm wheel (3) and three outlet orifices from valves (4) ,(5) and (6).In the pump basket the pulp is conditioned with reagent (usually a flocculant) so that the output from the pump is returned into the basket through the return line (5). At the moment when the prepared pulp is put into the column through the injector (7) discharge valve of clean water is closed (11) and valve of return line (5). Batch filling of the column (8) is carried out through injector element that sucks in the air (9) or to the air being blown through the compressor. In a higher part of column above the condensed phase (10) is formed a two-phase system characteristic for isobaric and isothermal macroscopic flow of the pulp. The two-phase system increases its volume by continuously full column injector, a meniscus condensed phase, which is actually a semi permeable membrane is moved upward. Dynamic equilibrium of the water molecule as a solvent is established on the semi permeable membrane or meniscus of condensed phases. Mass transfer of substance or flocculated gel in the case of larger quantaties of dispersion is found in the nature of osmotic pressure.

MATERIALS AND METHODS

Tailing dumps resulting in explotation of copper ore contain dissolved copper salt, i.e. the so-called blue water. In order to inhibit precipitation of copper salts, it is necessary to form a compound with sodium-stearate from soap. Sodium stearate is a salt of sodium and stearic acid. This is one is the basic raw material in the manufacture of soap. The process of obtaining has been known since the ancient times [5] obtained by reacting vegetable oils with sodium hydroxide. In addition to the manufacture of cleaning stuffs, it is also used as an emulsifier in various creams, shampoos and foodstuffs. It is obtained by saponifying the ester with sodium hydroxide, thus obtaining sodium stearate, and glycerol. In the reaction of sodium stearate and cooper from blue water in the process of flotation extraction, is formed a gel-like structure, i.e. copper stearate, which is collected on surface and removed mechanically.

Osmosis is a colligative property and depends on the amount of solute particles [6]. This feature is used to calculate the required weight of soap as a reagent, for the successful flotation extraction of blue water. The osmotic potential of pure water is defined as zero. Osmotic potential of solution has a negative value in units of pressure. At low concentrations of solution, the osmotic potential is expressed by the Van't Hoff' equation:

(22)

Table 1 *Values for calculation the osmotic pressure of blue water, and soap as a collector which was added to the flotation extraction process*

1	2	3	4	5	6	7	8
n, mol	R, $Jmol^{-1}K^{-1}$	T, K	P, Pa	V, m^3	M, $gmol^{-1}$	m, g	h, m
Blue water, solution of copper sulphate							
Amount of salt in solution	**Molar gas constant**	**Tempe-rature**	**Osmotic pressure**	**Volume of dissolved salt**	**Molar mass of $CuSO_4$**	**Weight of dissolved salt**	**Foam height**
0.00414	8.314	293.0	10073.0	0.00100	159.610	0.660	1.027
Soap							
Amount of soap in solution	**Molar gas constant**	**Tempe-rature**	**Osmotic pressure**	**Volume of dissolved soap**	**Molar weight of soap**	**Weight of dissolved soap**	**Foam height**
0.000424	8.314	293	10333.4	1E-04	306.46	0.13	1.053
9.79E-05	8.314	293	2384.65	1E-04	306.46	0.03	0.219
4.89E-05	8.314	293	1192.32	1E-04	306.46	0.015	0.118
1.63E-05	8.314	293	397.442	1E-04	306.46	0.005	0.040

Blue water with 0.662 $CuSO_4$ g/l has an osmotic potential of about 10000 Pa, Table 1, which is enough to hold the water column of about one meter. The experimental procedure is clear in a sense that it is obvious that when frothier was added surface tension of liquid is decreased and the foam is formed. Above the surface of water, upgraded gaseous liquid two-phase system (foam) is formed which can potentially carry copper compound. It certainly creates a copper stearate scum in the form of gel that is necessary to add in a soap solution. Calculating the amount of soap is done by equalizing the osmotic pressures of blue water and soap as a collector as shown in Table 1, Column 4. Four different doses of soap in four separate experiment were used, but the best results gave the experiment in which the osmotic pressure of soap coincided with the osmotic pressure which produces a solution of blue water. Ordinary laboratory flotation cell with a height of h=30 cm would not meet the conditions of set height of foam, so this account evidence that there is at least one reason why the column is used in flotation ex traction process. A device that is used for flotation extraction of blue water has an important characteristic that highly aerate (in our case) solution, which is only possible to achieve increasing the inlet pressure in ejector. With the help of worm pump is realized the flow of materials and required excess pressure of 5 bar in order to effectively and efficiently carry out the necessary flotation extraction.

ANALYSIS THE ACHIEVED RESULTS

After treatment the blue water with major soap compound (sodium-stearate), a chemical analysis of the product was carried out and is shown in Table 1. The FTIR analysis was performed on the device - **Thermo Fisher Scientific Nicolet IS-50by ATR** (attenuated total reflectance) technique in the range of 4000 to 400 cm^{-1} at resolution 4. Upon completion of e measurement baseline correction was done - atmospheric (for elimination of signal gases CO_2 and H_2O)[7].

Table 2 *Distribution and chemical analysis of flotation extraction of blue water*

	M %	Cu %	Fe %	S %	M*Cu	M*Fe	M*S	R Cu	R Fe	R S
Concentrate	0,74	2,65	0,13	8,23	1,961	0,096	6,1	94,5	33,8	9,9
Output	99,26	0,00115	0,0019	0,56	0,114	0,188	55,6	5,5	66,2	90,1
Feed	100,00	0,0208	0,0028	0,62	2,075	0,284	61,7	100	100	100

(infra-red) spectroscopy is used primarily as a contribution to the structural analysis of organic molecules (as well as inorganic anions) in a manner that is based on the position of absorption bands by which the functional groups that are present in molecule can be identified. spectrum are vibration spectrum, i.e. absorption of radiation comes from the vibrational transitions in molecule. When the absorption of radiation occurs there is a change in oscillation frequency of chemical bond between two atoms. Based on the radiation energy that is required for a given vibration transition, (spectrum is ordered sequence of such energies), i.e. From the vibration frequency change of chemical bond, it can be concluded that between two atoms linked by chemical bond the vibration transition occurred.

In case of gel which during ionic flotation of blue water comes to the surface and for which it is assumed that it is the insoluble salt of copper and organic acid soap (mostly stearic, although they are always present to some extent, palmitic, oleic etc., since the commercial soap was used), in addition to the standard AAS analysis to determine the percentage of copper in sample ("solid" phase which floated up), analysis is done to unequivocally shows that the gel is actually insoluble salt containing Cu(II) cations, and organic nature anions (originating from the water-soluble sodium and potassium salts of higher fatty acids in soap). Therefore, if one looks at the spectrum of the dried gel, where one should have in mind that the in drying air all the trapped water cannot evaporate completely, the following can be concluded:

The intensive band at (~ 1100) probably originates from the bond (valent vibration of bond) of sulphate anions that are co-precipitated with the formation of "solid phase".

Band at (~ 1450) comes from the bonds (- deformation vibrations, i.e. change in the angle of chemical bonds; the band is in nature of medium intensity, but since the number of groups in the molecule is highin this case it is clearly visible).

Poor visible band at (~ 1650) originates from -group–it is a valent symmetric vibration of resonance structures of carboxyl anion).

The band, which should be the highest intensity at (~ 1720), i.e. valent vibration, lacks because separated gel does not contain the fatty acids but the fatty acids salts.

Band at (3000 - 3500) originates from the bond (valent vibration, extended due to hydrogen bonds between water molecules- at 3600 there is a small peak of bond which belongs to the water molecules that are not connected by hydrogen bond). Therefore the spectrum clearly shows that the sample contains molecules with hydrocarbon chain (bond), carboxyl group ( ), and water molecules (Figure 5).

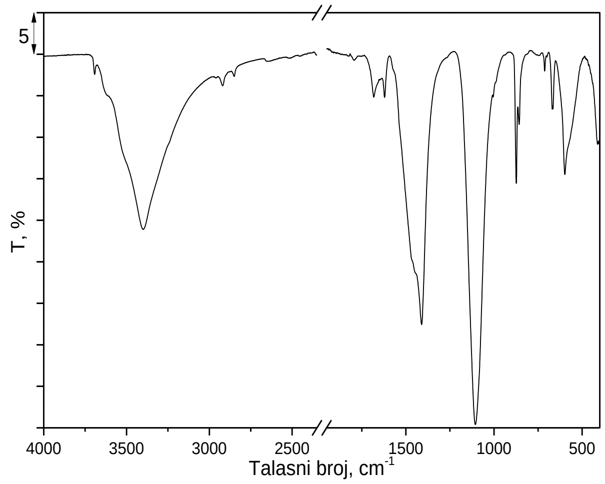

Figure 5 *IR spectrum dried gel*

The second spectrum is the spectrum of residue which was crystallized upon evaporation of the solution. Based on the appearance of deposits, it is assumed that the sediment is mostly blue stone ( ). spectrum confirms this (Figure 6). It is certain that in the solution of "blue water" there are other salts that were deposited during evaporation together with clearly present (copper(II) sulphate), but those in the spectrum are not visible, i.e. spectrum indicates the sulfate (sulfite), water, and optionally nitrate (nitrite).

Based on the spectrum of the sample obtained by evaporating the solution (figure 6), the following can be concluded:

The intense band at (~ 1100) comes from the bond (valent vibrations) of sulphate anions . Broad band at (~ 3600-2700) comes from the bond. Everything that was said regarding the presence of water in the sample is also applied to residue.

The medium intensity band at (~ 1680) probably comes from nitrate ( ) valent vibrations. Therefore the spectrum clearly shows that the sample contains molecules with hydrocarbon chain ( ), carboxyl group (band and band), and water molecules.

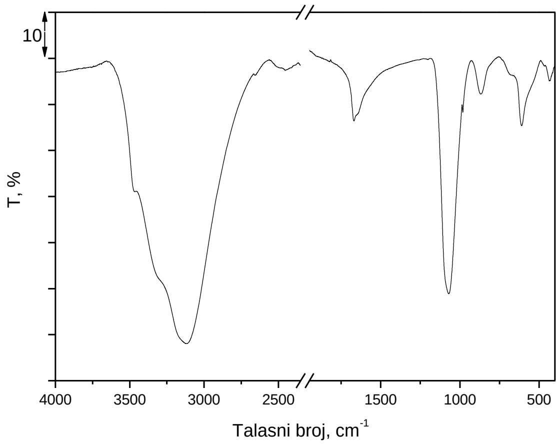

Figure 6 *IR spectrum of evapored solution*

CONCLUSION

Any physical system contains the energy of a certain amount. The amount of energy of the system is not an absolute value, but relative to the reference condition or reference level. At the beginning of the twentieth century W. Nernst performed various fields of chemistry classification based on the type of energy introduced into the system: thermochemistry, electrochemistry, photochemistry, etc. The name mechanochemistry referred to the reactions initiated by mechanical energy, eg. reactions initiated by the process of friction, breaking, during the mechanical treatment of solid components. The activation energy of mechanochemical treatment system is required to enable the external force to increase the surface of material, to affect the reagents in the flotation of various pneumatic suspensions. The processes of enrichment the mineral resources in the flotation systems are based on electrochemistry, adsorption and catalytic functioning of the individual reagents to separate the components of such systems. In order to achieve solute transport to form the gel on surface in the flotation extraction process, the activation energy must have such an impact on system and the energy barrier that resists that transport should be overcome by the external force. Adsorption extent refers to the gaseous fluid, and in a solid there is a change of intermolecular and intramolecular forces. Intramolecular forces are the forces that hold together the atoms and thus form a molecule or compound. Intramolecular forces include all types of chemical bonds. They are stronger than the intermolecular forces that occur between the atoms or molecules which are not bound. The activation energy of the reacting system in one device (reactor) plays a very important role in the physical characteristics of the system in terms of selective separation the components of the system. It is shown that one can calculate the intensity of the intramolecular force as the force of osmotic pressure, and it can be used to calculate the necessary amount of reagents for successful flotation extraction.

REFERENCES

[1] M. Manojlović Gifing, Theoretical Bases of Flotation Process, Mining Institute, Belgrade, 1969;

[2] A. M. Spasić, Multiphase Dispersed Systems, ITNMS, Belgrade, 1997;

[3] I. Bajalović, Basis of Physical Chemistry, Građevinska knjiga, Belgrade, 1978;

[4] D. Minić, A. Antić Jovanović, Physical Chemistry, Faculty pf Physical Chemistry, University of Belgrade, 2005;

[5] M. Petrov, V. Jovanović, S. Mihajlović, D. Todorović, Osmosis Flotation in Waste Water Treatment, XI Balkan Mineral Processing Congress, Mineral Processing in Sustainable Development, Durres, Albania, 22-26 May (2005), pp. 211-221;

[6] E. Beer, Manual for Sizing the Devices of Chemical Process Industry, SKTH, Zagreb, 1985;

[7] Chai T., Geng Z-X-l., Yue H., Wang H., Su C-Y, A Hybrid Intelligent Optimal Control Method for Complex Flotation Process, International Journal of Systems Science, 40 (9), 2009, 945-960;

[8] http://www1.lsbu.ac.uk/water/water_structure_science.html

[9] M. Petrov, V. Jovanović, S. Mihajlović, Ž. Sekulić, Expansional Osmosis Flotation, XXIII International Mineral Processing Congress, Volume 1, 3-8 September Istanbul (2006) pp. 638-643;

[10] P. W. Atkins, M. J. Clugston, Principles of Physical Chemistry, Školska knjiga Zagreb, 1989;

[11] A. P. Chandra, A. R. Gerson, A Review of the Fundamental Studies of the copper Activation Mechanisms for Selective Flotation of the Sulfide Minerals, Sphalerite and Pyrite, Advances in Colloid and Interface Science 145 (2009) 97–110.

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FLOTACIJA PLAVE VODE**

Izvod

Flotacija jona i molekula predstavlja perspektivan metod odvajanja komponenata iz rastvora, odnosno u našem slučaju geliranog bakar sulfata iz plave vode. Jedna od metoda flotacije jona i molekula je floto-ekstrakcija u kojoj nastaju različiti koncentracijski gradijenti višekomponentalnih kondenzovanih faza. Različiti koncentracijski gradijenti u floto-ekstrakciji nastaju usled pokretačkih sila učestvujućih molekula vođenih molekulskim interakcijama. Višekomponentna kondezovana faza ili flotacijska pulpa sastoji se iz molekula vode rastvorka i pogodnog reagensa koji ima ulogu konekcije tečne i gasovite faze u dvofaznom disperznom sistemu.U takvom sistemu dolazi do sinteze rastvorka sa reagensom i do stvaranja koagulisane komponente u vodi kao rastvaraču. Separacija nastalih koagulisanih komponenata, saglasno Van't Hoff-oj jednačini, spontano se dešava u dvofaznim sistemima tečno gasovito, kakav je sistem flotacijske pulpe. Primenom osmotskih pritisaka u kolona flotacijskoj mašini dolazi do difuzije i razdvajanja flotacijske pulpe na tešku i laku fazu. Aeriranjem se omogućava molekulima vode da formiraju svoja prirodna rastojanja koja važe samo za molekule čiste vode odnosno tešku fazu. Takođe i rastvorak formira svoju laku fazu, kserogel bakar-sulfata, kao nerastvorni proizvod. Za neke kondenzovane faze kao što su koloidni sistemi u floto-ekstrakciji je dovoljan atmosferski pritisak a za druge pak (prave rastvore) je potrebno primeniti nadpritisak u delu aeracije. U radu su prikazani rezultati istraživanja floto-ekstrakcije plave vode sa ulaznim sadržajem bakra od 0,2 g/l. Iz prikazanih rezultata istraživanja zaključuje se da postoji mogućnost prečišćavanja plave vode iz jalovišta rudnika bakra primenom floto-ekstrakcijskih tehnologija.

Ključne reči: *koncentracijski gradijent, kondenzovana faza, koagulacija, osmotski pritisak, kserogel*

UVOD

Flotacija je prvi put primenjena 1877. godine u obogaćivanju grafitne rude ali je odmah zatim bila napuštena. Od prvog patentiranog postupka (Elmore, 1898.) [1] ona se sve više primenjuje i stalno usavršava. Primena flotacije u obradi otpadnih voda se smatra revolucionarnom inovacijom jer ona protiče 6-8 puta brže od sedimentacije i završava se za 15-30 minuta. [2] Pri tome se obezbeđuje veoma visok stepen uklanjanja suspendovanog materijala, značajno se smanjuje koncentracija površinski aktivnih materijala u otpadnoj vodi i povećava sadržaj kiseonika, a sve to u znatnoj meri olakšava kasnije faze obrade. Danas se flotacija primenjuje u mnogim oblastima industrije: u obogaćivanju, u razdeljivanju ruda različitih metala i goriva, u izdvajanju visokovrednih komponenti iz rastvora, dok se u obradi otpadnih voda primenjuje za: uklanjanje suspendovanih i emulgovanih zagađivača, koncentrisanje bioloških mulјeva. Čvrste čestice, kapljice, molekuli ili joni iz tečne faze, prilepljeni uz mehurove

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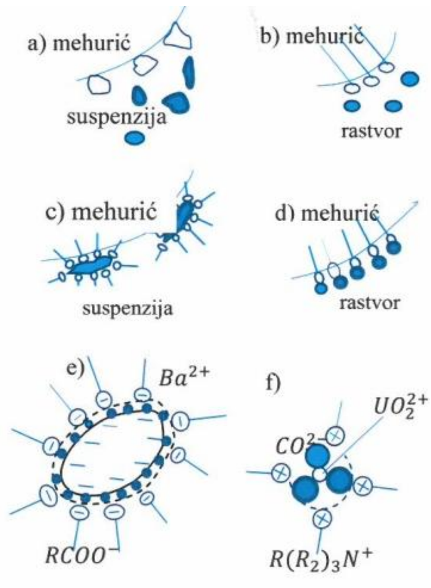
** *Prikazani rezultati predstavljaju deo istraživanja u okviru projekta TR 34006 čiju realizaciju finansira Ministarstvo prosvete, nauke i tehnološkog razvoja republike Srbije*

vazduha koji se formiraju u tečnoj fazi na različite načine, bivaju silom osmotskog pritiska iznošene na površinu tečnosti, gde se koncentrišu u obliku pene koja se odatle uklanja.

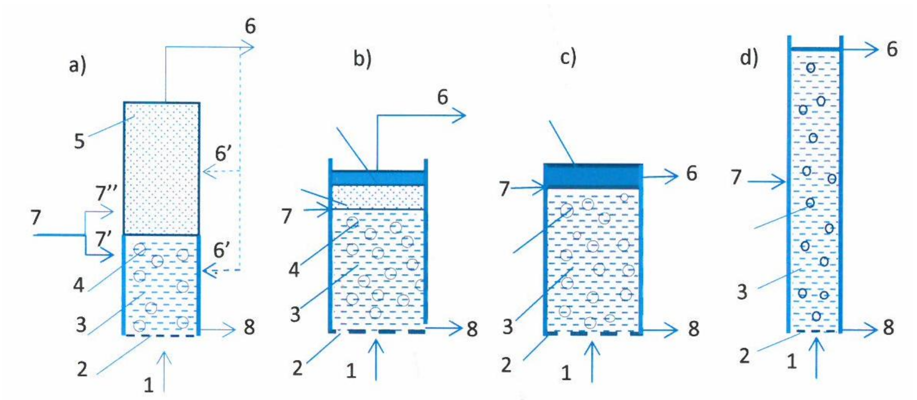
PROCESI FLOTACIJE

Proces flotacije zasnovan je na činjenici da čestice vodenih disperzija sa hidrofobnom površinom imaju sposobnost da se prilepe uz mehurić gasa. Pri uzajamnom mešanju mehurića i disperzije podobne čestice koncentrišu se na površini mehurića, a čestice koje nemaju hidrofobnu površinu ostaju u zapremini disperzije. Razdvajanje zasnovano na tim sposobnostima mehurića koristi se kao mogućnost dobjanja odvojenih čestica na osnovi njihovih različitih sposobnosti koncentrisanja na površini mehurića. Flotacija je proces molekularnog „slepljivanja“ čestica materijala koji se flotira uz graničnu površinu faza, obično gas (najčešće vazduh) - voda. Flotacija se koristi kao alternativna metoda drugim separacionim postupcima: sedimentaciji, separaciji centrifugama, filtraciji i slično, od kojih je često ili efikasnija ili ekonomski opravdanija [2]. Slika 1 ilustruje razlike između pomenutih procesa, a slika 2 pokazuje tipove flotacijskih procesa.



Sl. 1. *Ilustracija sličnosti flotacija, flotacija jona i molekula i flotacija minerala*

a) flotacijski aktivne mineralne čestice koncentrišu se na površini mehurića gasa, a flotacijki neaktivne ostaju u zapremini suspenzije;
b) Površinski aktivne komponente rastvora koncentrišu se na površini mehurića, a površinski neaktivne ostaju u zapremini rastvora;
c) Na površini mehurića koncentrišu se mineralne čestice pokrivene kolektorom;
d) Na površini mehurića koncentriše se sublat (hemijski individualno jedinjenje), koji se sastoji iz koligenda (označava jon koji se izvlači) i kolektora;
e) Joni Ba^{2+} vežu anjoni kolektora masne kiseline $RCOO^-$ sa površinom čestica kvarca;
f) Joni CO_3^{2-} bivaju vezivno sredstvo među jonima UO_2^{2+} i četiri katjona alkilamonijum kolektora $R(R_2)_3N^+$



Sl. 2. *Šema penaste separacije (a), jonske flotacije (b), flotoekstrakcije (c) i mehurastog frakcionisanja (d)*

1. vazduh, 2. raspršivač vazduha, 3. vodeni rastvor, 4. isplivavajući mehurići, 5. sloj pene, 6. gornji proizvod, 6' i 6''. gornji proizvod, odnosno gornji proizvod koji se vraća na mokru penu i gornji proizvod koji se vraća pod penu, 7. početni rastvor, 7' i 7'' dodavani početni rastvor, odnosno početni rastvor dodavan ispod i iznad nivoa pene, 8. donji proizvod, 9. pena, 10. organska tečna faza

ADSORPCIJA NA POVRŠINI MEHURA GASA

Adsorpcija na površini mehura gasa predstavlja osnovu flotacije jona i molekula. [3]

Termodinamika adsorpcije: Osnovnu termodinamičku jednačinu međufazne granice tečno-gasovito dao je Gibbs:

$$d\sigma = -\eta_s dT - \sum_{i=1}^{n} \Gamma_i^0 \, d\mu_i \qquad (1)$$

gde je:

σ - površinski napon

η_s - višak entropije u sistemu

T - apsolutna temperatura

Γ_i^0 - višak mase *i-te* komponente na jedinicu međufazne površine (adsorpcije)

μ_i - hemijski potencijal

n - broj komponenata u sistemu

Iz izraza datog u vidu jednačine 1 proističe jednačina adsorpcione izoterme.

$$d\sigma = -\sum_{i=1}^{n} \Gamma_i^0 \, d\mu_i \qquad (2)$$

ili

$$\Gamma_i^0 = \frac{\partial\sigma}{\partial\mu_i} \qquad (3)$$

Kada je

$$\mu_i = \mu_i^{\ominus} + RT \ln a_i^0 \qquad (4)$$

gde je:

$\mu_i^{\ominus}$ - standardni hemijski potencijal

a_i^0 - aktivnost *i-te* komponente u zapremini rastvora

R - univerzalna gasna konstanta

$$d\sigma = -RT \sum_{i=1}^{n} \Gamma_i^0 \, d \ln a_i^0 \quad \text{i} \qquad (5)$$

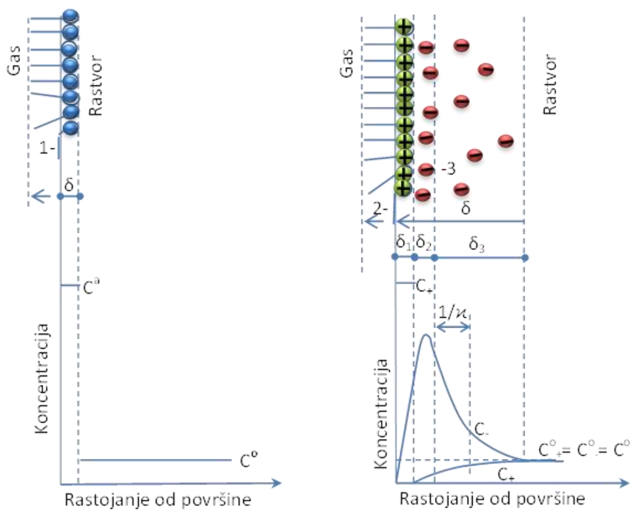
$$\Gamma_i^0 = -\frac{1}{RT}\frac{\partial\sigma}{\partial \ln a_i^0} \qquad (6)$$

U jako razblaženim rastvorima gde je $a_i^0 \approx C_i^0 C_i^0$- koncentracija *i-te* komponente u zapremini rastvora, pa umesto jednačine 6 imamo:

$$\Gamma_i^0 = -\frac{1}{RT}\frac{\partial\sigma}{\partial \ln c_i^0} \qquad (7)$$

ili

$$\Gamma_i^0 = -\frac{c_i^0}{RT}\frac{\partial\sigma}{\partial c_i^0} \qquad (8)$$



Sl. 3. *Struktura adsorpcionih slojeva na međufaznoj granici tečno – gas za sisteme voda – rastvore na površinski aktivna supstanca*

Iz jednačine 8 sledi da, ako komponente rastvora smanjuju površinski napon $(\frac{\partial\sigma}{\partial C_i^0} < 0)$ adsorpcija na međufaznoj površini je $(\Gamma_i^0 > 0)$ i obrnuto. Prvi slučaj nazivamo površinski aktivnim, a drugi površinski neaktivnim.

Ako posmatramo adsorpcioni sloj kao jedinstvenu površinsku fazu debljine δ, tada za *i-tu* komponentu rastvora možemo pisati.

$$\Gamma_i^0 = (C_i^a - C_i^0)\delta \qquad (9)$$

Ako je Γ_i^0 veličina adsorpcije, ravnotežna za koncentraciju C_i^0 u zapremini rastvora, a C_i^a odgovarajuća koncentracija Γ_i^0 u adsorpcionom sloju.

Iz jednačine 8 i 9 sledi:

$$\frac{C_i^a}{C_i^0} = 1 - \frac{1}{\delta RT}\frac{\partial\sigma}{\partial C_i^0} \qquad (10)$$

Predstavljena jednačina pokazuje za visoko površinski aktivne supstance odnos $\frac{C_i^a}{C_i^0}$ može dostići vrednost 10^4 do 10^6 i više. Sledeća ilustracija prikazuje konstrukciju adsorpcionog sloja.

a) Nejonska površinski aktivna supstanca;
b) Jonska površinski aktivna supstanca (simetrični binarni neasociran elektrolit s površinski aktivnim katjonom);

C^o - koncentracija u zapremini rastvora;
C^a - koncentracija u adsorpcionom sloju;
C_+ i C_- - koncentracija katjona i anjona;
1 - površinski aktivni molekuli
2 - površinski aktivni joni
3 - suprotno naelektrisani joni

Na osnovi razmatranja o strukturi adsorpcionog sloja očigledno je da kalkulacije zasnovane na jednačini 10 su samo ilustrativne prirode. Više veštački je pojam homogenosti debljine sloja adsorpcije u slučaju jonskih površinski aktivnih supstanci.

$$\frac{C_i^a}{C_i^0} = 1 - \frac{1}{\delta RT}\cdot\frac{\partial\sigma}{\partial C_i^0}$$

Pokretačke sile i teorijski aspekt floto-ekstrakcije jona i molekula

Osmotski pritisak Π iz Van't Hoff-e jednačine je

$$\Pi = cRT \qquad (11)$$

U toj jednačini *c* je molarna koncentracija rastvorka, *R* je gasna konstanta a *T* je apsolutna temperatura na kojoj se nalaze rastvori. Hemijske potencijal vode mora biti u ravnoteži i istina obe strane semi-permeabilne membrane.

$$\mu_P{}^{tečno} = \mu_{P+\Pi}^{rastvor} \quad (12)$$

Za rastvor se može pisati

$$\mu_{P+\Pi}{}^{rastvor} = \mu_{P+\Pi}^{tečno+RTLn(x_w)} \quad (13)$$

Promene hemijskog potencijala sa pritiskom mogu se uključiti na sledeći način

$$\mu_{P+\Pi}^{tečno} = \mu_P^{tečno} + \int_P^{P+\Pi} V_m\, dP \quad (14)$$

Kombinacijom jednačina 2, 3 i 4 uz pretpostavku da molska zapremina vode $(V_m, m^3 mol^{-1})$ =1,80356E-05 $m^3 mol^{-1}$ slabo varira u datom opsegu pritiska, važi:

$$-RTLn(x_w) = \int_P^{P+\Pi} V_m\, dP = \Pi V_m \quad (15)$$

Dakle,

$$\Pi = -k_p\, T\, Ln(1 - x_s) \quad (16)$$

gde je k_p piezoscopic konstanta $(= \frac{R}{V_m})$,

Kada je x_s nizak, važi sledeća aproksimacija

$$Ln(x_w) = Ln(1 - x_s) = -x_s \quad (17)$$

pa je

$$\Pi V_m = x_s RT \quad (18)$$

Na malim vrednostima x_s

$$x_s = \frac{n_s}{n_w} \quad (19)$$

gde je n_s broj molova rastvorka n_w broj molova vode

$$\Pi = M_s RT \quad (20)$$

Gde je $M_s = \frac{n_s}{V}$, molarna koncentracija rastvora. Na niskom osmorskom pritisku do 0,5 MPa, idealna koligativna jednačina floto-ekstrakcije ima oblik:

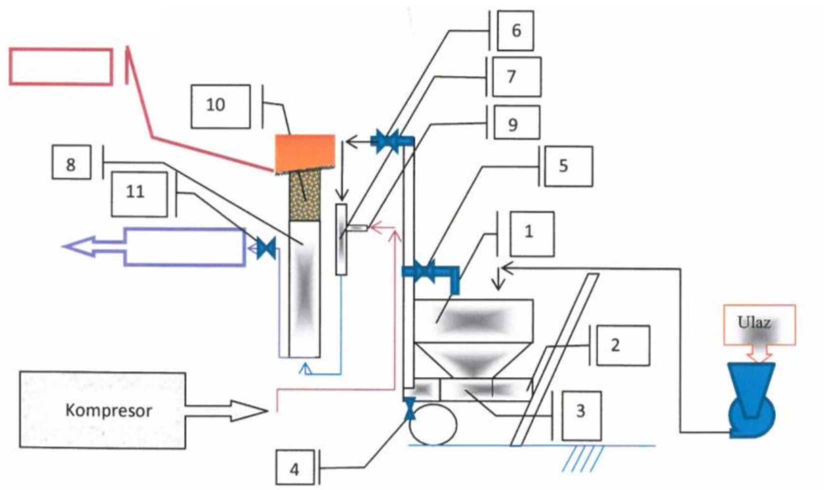
$$\Pi = M_s RT \left(\frac{x_w V^2}{1 + x_s V}\right) \quad (21)$$

V je zapremina (u litrima) rastvora koji sadrži jedan litar vode. [4]

Opis uređaja i procesa

Uređaj floto-ekstrakcije sastoji se iz tri funkcionalno ukomponovane celine [5]:

- Pužne pumpe,
- Injektora ili prskalice,
- Kolona posude.



Sl. 4. *Šematski prikaz uređaja floto-ekstrakcije*

Funkcionalna povezanost uređaja prikazana je na slici 1. Mobilna pužna pumpa (Mozly) ima koš (1) za ulaznu pulpu, motor (2), pužno kolo (3) i tri izlazna otvora sa ventilima (4) (5) i (6). U košu pumpe vrši se kondicioniranje pulpe sa reagensom (obično je to flokulant) tako što se izlaz iz pumpe vraća u koš preko povratnog voda (5). U trenutku kada se pripremljena pulpa pušta u kolonu preko injektora (7) zatvoren je ventil za ispuštanje čiste vode (11) i ventil povratnog voda (5). Šaržno punjenje kolone (8) vrši se preko injektorskog elementa koji usisava vazduh (9) ili se vazduh ubacuje preko kompresora. U višem delu kolone iznad kondezovane faze (10) nastaje dvofazni sistem karakterističan za izobarski i izotermski makroskopski tok pulpe. Dvofazni sistem uvećava svoju zapreminu tako što injektor neprekidno puni kolonu, a meniskus kondenzovane faze koji je zapravo polupropustljiva membrana pomera se naviše. Dinamička ravnoteža molekula vode kao rastvarača uspostavlja se na polupropustljivoj membrani odnosno meniskusu kondenzovane faze. Prenos mase supstance odnosno flokuliranog gela iz dela sa većim udelom kondenzovane faze u penastu ksero gel ostvaruje se na bazi osmotkog pritiska.

MATERIJAL I METODE

Jalovišta nastala u eksploataciji rude bakra imaju rastvorenu so bakra i to je takozvana plava voda. Da bi se inhibirala precipitacija soli bakra potrebno je formiranje jedinjenja sa natrijum-stearatom iz sapuna. Natrijum-stearat je so natrijuma i stearinske kiseline. Ovo je jedna od osnovnih sirovina u proizvodnji sapuna. Proces njenog dobijanja je poznat još od davnina. [5] Dobija se reakcijom biljnih ulja sa natrijum-hidroksidom. Osim za proizvodnju sredstava za čišćenje koristi se i kao emulgator u raznim kremama, šamponima i prehrambenim namirnicama. Dobija se putem saponiranja tristearina sa sodom, te se tako dobija natrijum-stearat i glicerin. U reakciji natrijum-stearata sa plavom vodom pri flotoekstrakciji jednačina 1, dolazi do stvaranja gela bakar stearata koji u dvofaznom sistemu biva sakupljen na površini i mehanički uklonjen.

$$2C_{17}H_{35}COO^- + 2Na^+ + Cu^{2+} + SO_4^{2-} = Cu(C_{17}H_{35}COO^-)_2 + 2Na^+SO_4^-$$

Osmoza je koligativno svojstvo i zavisi od broja čestica rastvorene supstance [6]. Ova osobina je upotrebljena da se izračuna potrebna masa sapuna kao reagensa za uspešnu floto ekstrakciju plave vode. Osmotski potencijal čiste vode se definiše kao nula kada je voda rastvarač. Osmotski potencijal rastvora ima negativne vrednosti u jedinicama pritiska. Na niskim koncentracijama se osmotski potencijal izražava Van't Hoff-ovom jednačinom.

$$\psi_{\Pi} = -M_S RT \tag{22}$$

Tabela 1. *Vrednosti za izračunavanje osmotskog pritiska plave vode, i sapuna kao kolektora koji je dodavan u proces floto ekstrakcije*

1	2	3	4	5	6	7	8
n, mol	R, $Jmol^{-1}K^{-1}$	T, K	P, Pa	V, m^3	M, $gmol^{-1}$	m, g	h, m
Plava voda, rastvor bakar sulfata							
Količina soli u rastvoru	**Molarna gasna konstanta**	**Tempe ratura**	**Osmotski pritisak**	**Zapremina u kojoj je rastvorena sol**	**Molarna masa soli $CuSO_4$**	**Masa rastvorene soli**	**Visina pene**
0,00414	8,314	293,0	10073,0	0,00100	159,610	0,660	1,027
Sapun							
Količina sapuna u rastvoru	**Molarna gasna konstanta**	**Tempe ratura**	**Osmotski pritisak**	**Zapremina u kojoj je rastvoren sapun**	**Molarna masa sapuna**	**Masa rastvorenog sapuna**	**Visina pene**
0,000424	8,314	293	10333,4	1E-04	306,46	0,13	1,053
9,79E-05	8,314	293	2384,65	1E-04	306,46	0,03	0,219
4,89E-05	8,314	293	1192,32	1E-04	306,46	0,015	0,118
1,63E-05	8,314	293	397,442	1E-04	306,46	0,005	0,040

Plava voda sa 0,662 $\frac{g}{l}\ CuSO_4$ ima osmotski potencijal od oko 10000 Pa, tabela 1, što je dovoljno da drži stub vode od približno jednog metra. U eksperimentalnom postupku to je bilo očigledno kada je dodat penušač koji je smanjio površinski napon tečne faze i kada je došlo do stvaranja pene. Iznad površine vode tada se nadgrađuje dvofazni sistem tečno gasovito (pena) u kojem se može potencijalno izvršiti koncentracija soli bakar-sulfata. Naravno da je za stvaranje skrame bakar-stearata u obliku gela bilo potrebno dodati rastvor sapuna. Izračunavanje količine sapuna vrši se tako što se izjednače osmotski pritisci za plavu vodu i sapun kao kolektor što je prikazano u tabeli 1, kolona 4. Upoterbljene su ukupno četiri različite doze sapuna u četiri odvojena opita, ali je najbolje rezultate dao onaj opit čiji se osmotski pritisak poklapao sa osmotskim pritiskom kojeg proizvodi rastvor plave vode. Obična laboratorijska flotacijska ćelija sa visinom od 30 cm ne bi zadovoljila postavljene uslove visine pene pa je ovaj račun dokaz da postoji najmanje jedan razlog što se koristi kolona flotacija za floto ekstrakciju. Uređaj koji je korišćen za flotoekstrakciju plave vode ima značajnu karakteristiku visoke aeriranosti (u našem slučaju) rastvora što je jedino moguće postići pomoću povećanog ulaznog pritiska u ejektor. Preko pužne pumpe ostvaruje se dotok materijala i potrebni nadpritisak od 5 bara da bi se uspešno i efikasno izvršila potrebna flotoekstrakcija.

ANALIZA POSTIGNUTIH REZULTATA

Nakon tretmana plave vode sa natrijum-stearatom iz sapuna izvršena je hemijska analiza proizvoda prikazana u tabeli 1. FTIR analiza urađena je na uređaju **Thermo Fisher Scientific Nicolet IS-50**. Snimanje je rađeno ATR (Attenuated Total Reflectance – ometana totalna refleksija) tehnikom u opsegu od 4000 do 400 cm^{-1} i 32 skana pri rezoluciji 4. Po završenom merenju urađene su korekcije bazne linije, atmosferska (za eliminaciju signala gasova CO_2 i H_2O) korekcija[7].

Tabela 2. *Raspodela i hemijska analiza proizvoda flotoekstrakcije plave vode*

	M %	Cu %	Fe %	S %	M*Cu	M*Fe	M*S	R Cu	R Fe	R S
Konc.	0,74	2,65	0,13	8,23	1,961	0,096	6,1	94,5	33,8	9,9
Otok	99,26	0,00115	0,0019	0,56	0,114	0,188	55,6	5,5	66,2	90,1
Ulaz	100,00	0,0208	0,0028	0,62	2,075	0,284	61,7	100	100	100

IR (infra-crvena) spektroskopija se koristi pretežno kao doprinos utvrđivanju strukture organskih molekula (ali i neorganskih aniona), na način da se na osnovu položaja apsorpcionih traka mogu utvrditi funkcionalne grupe koje figurišu u molekulu. IR spektri su vibracioni spektri, tj. apsorbcija IR zračenja potiče od vibracionih prelaza u molekulu, odnosno, prilikom apsorpcije zračenja dolazi do promene frekvencije oscilacije određene veze između dva atoma. Na osnovu energije zračenja koja je potrebna za određeni vibracioni prelaz, (IR spektar je uređeni niz takvih energija) tj. za promenu frekvencije vibracije hemijske veze, zaključuje se između koja dva atoma povezana hemijskom vezom se dogodio vibracioni prelaz.

U slučaju gela koji tokom jonske flotacije plavih voda ispliva na površinu i za koji se pretpostavlja da je nerastvorna so bakra i organskih kiselina sapuna (to je uglavnom stearainska, mada su uvek prisutne u nekoj meri palmitinska, oleinska i dr. budući da je reč o komercijalnom sapunu), pored standardne AAS analize za utvrđivanje procenta bakra u uzorku („čvrstoj“ fazi koja je isplivala), radi se i IR

analiza da bi se nedvosmisleno pokazalo da je gel ustvari nerastvortna so Cu(II) kationa, i anjona organske prirode (koji potiču od u vodi rastvornih natrijumovih i kalijumovih soli viših masnih kiselina koje čine sapun). Stoga, ako se pogleda IR spektar osušenog gela, pri čemu obavezno treba imati u vidu da sušenjem na vazduhu sva zarobljena voda ne može u poptpunosti da ispari, može se zaključiti sledeće:

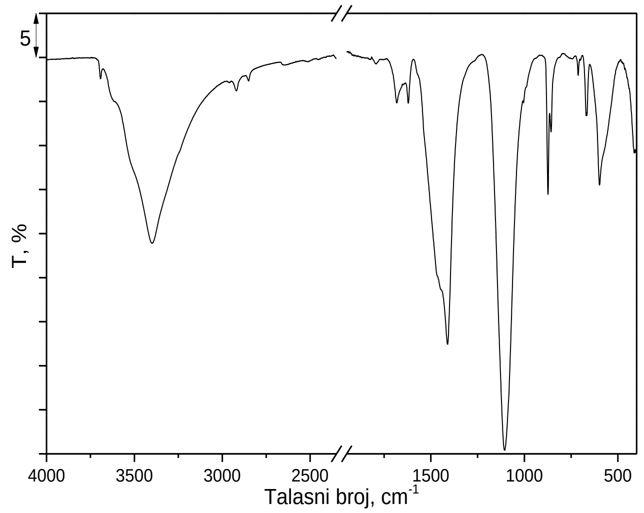
Intenzivna traka (~ 1100) potiče najverovatnije od $S = O$ veze (valetna vibracija – promena dužine S=O veze), sulfatnog aniona koji je koprecipitirao pri formiranju „čvrste faze“.

Traka (~ 1450) potiče od $C - H$ veze (CH_2 – deformaciona vibracija, tj. promena ugla hemijske veze; ova traka je po prirodi srednjeg intenziteta, ali budući da je broj CH_2 grupa u molekulu veliki ovde je jasno uočljiva).

Slabo uočljiva traka (~ 1650) je COO^--valentna simetrična vibracija rezonantne strukture karboksilnog aniona).

Traka koja bi trebala da bude najvećeg intenziteta (~ 1720), a to je valentna $C = O$ vibracija, izostaje zato što izdvojeni gel ne sadrži masne kiseline već soli masnih kiselina.

Traka (3000 – 3500) potiče od $O - H$ veze (valentna vibracija; proširena zbog vodoničnih veza između molekula vode, na 3600 vidi se mali pik $O - H$ veze koja nije vodonično spregnuta). Dakle IR spektar nedvosmisleno pokazuje da uzorak sadrži molekule sa ugljvodoničnim lancem ($C - H$ veza), karboksilnom grupom (COO^-), i molekule vode, slika 5.

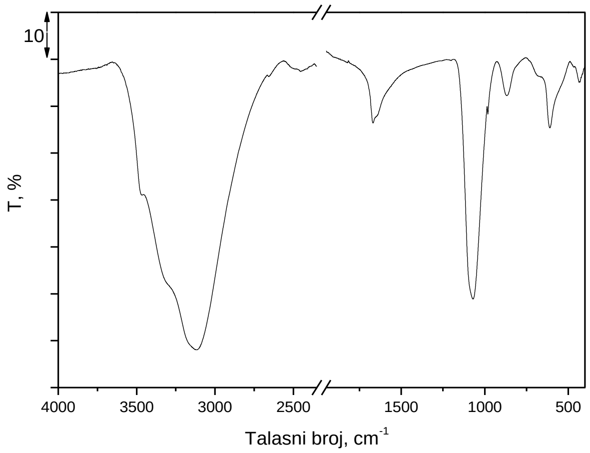


Sl. 5. *IR spektar prosušenog gela*

Drugi IR spektar je spektar taloga koji se iskristalisao nakon uparavanja rastvora. Na osnovu samog izgleda taloga predpostavlja se da je talog u najvećoj meri plavi kamen ($CuSO_4 * 5H_2O$). IR spektar to potvrđuje. Sigurno je da u rastvoru „plave vode“ postoje i druge soli koje su se tokom uparavanja zajedno taložile sa očigledno najviše zastupljenim (bakar(II)-sulfatom), ali one u *IR* spektru nisu vidljive; tj. *IR* spektar indicira sulfat (sulfit), vodu, i moguće nitrat (nitrit).

Na osnovu *IR* spektra uzorka dobijenog uparavanjem rastvora slika 6 može se zaključiti sledeće:

Intenzivna traka (~ 1100) potiče od $S = O$ veze (valentna vibracija) sulfatnog aniona SO_4^{2-}.



Sl. 6. *IR spektar uzorka uparenog rastvora*

Široka traka (~ 3600-2700) je od $O-H$ veze. Sve što je prethodno rečeno u vezi prisustva vode u uzorku isto važi i za upareni talog.

Traka srednjeg intenziteta (~ 1680) potiče najverovatnije od nitrata ($N=O$) valentna vibracija. Dakle IR spektar nedvosmisleno pokazuje da uzorak sadrži molekule sa ugljvodoničnim lancem ($C-H$), karboksilnom grupom ($C-O$ traka, i $C=O$ traka), i molekule vode

ZAKLJUČAK

Svaki fizički sistem poseduje energiju u izvesnoj količini. Količina energije sistema nije apsolutna vrednost već relativna u odnosu na referentno stanje ili referentni nivo. Početkom XX veka, *W. Nernst* je izvršio klasifikaciju različitih oblasti hemije na osnovu tipa energije unete u sistem: termohemija, elektrohemija, fotohemija itd. Naziv mehanohemija se odnosio na deo reakcija pokrenut mehaničkom energijom odnosno na reakcije koje su inicirane procesom frikcije, lomljenja, tokom mehaničkog tretiranja čvrstih komponenti. Aktivacijska energija mehanohemijskog tretmana potrebna je sistemu radi omogućavanja spoljašnjoj sili da poveća površinu materijala, da bi došlo do delovanja reagenasa u procesu pneumatske flotacije raznih suspenzija. Procesi obogaćivanja mineralnih sirovina u flotacijskim sistemima zasnovani su na elektrohemiji, adsorpciji i katalitičkom delovanju reagenasa na jedinke koje treba razdvojiti kao komponente sistema. Da bi u flotoekstrakciji došlo do transporta rastvorene supstance u vidu gela ka površini, energija aktivaciemora imatitakav uticaj na sistem da energetska barijera koja se opire tom transportu treba biti savladana spoljašnjom silom. Veličina adsorpcije odnosi se na tečno gasovito, a kod čvrste materije dolazi do promene međumolekulskih i intramolekulskih sila. Intramolekulske sile su sile koja drže zajedno atome i time formiraju molekul ili jedinjenje. Intramolekularne sile obuhvataju sve tipove hemijskih veza. One su jače od intermolekulskih sila, koje se javljaju između atoma ili molekula koji nisu vezani. Energija aktivacije reagujućeg sistema u nekom uređaju (reaktoru) ima veoma važnu ulogu na fizičke karakteristike sistema u smislu selektivnog razdvajanja komponenata sistema. U radu je pokazano da se može izračunati intenzitet intramolekularnih sila kao sila osmotskog pritiska, i to se može koristiti za izračunavanje potrebne količine reagensa za uspešnu flotoekstrakciju.

REFERENCES

[1] M. Manojlović Gifing, „Teorijske osnove flotiranja“, Rudarski institut, Beograd 1969.

[2] A. M. Spasić, „Višefazni disperzni sistemi“, ITNMS, Beograd 1997.

[3] I. Bajalović, „Osnovi fizičke hemije“ Građevinska knjiga, Beograd, 1978.

[4] D. Minić, A. Antić Jovanović, „Fizička hemija “Fakultet za fizičku hemiju, Univerzitet Beograd, 2005.

[5] M. Petrov, V. Jovanović, D. Todorović, A. Ćosović, “Ekspanziona osmoza flotacija u sistemima za pripremu i prečišćavanje otpadnih voda“, XIX Simpozijum o pripremi mineralnih sirovina sa međunarodnim učešćem, Topola 2004.

[6] E. Beer, „Priručnik za dimenzionisanje uređaja hemijske procesne industrije“, SKTH, Zagreb, 1985.

[7] Chai T., Geng Z-X-l., Yue H., Wang H., Su C-Y, A Hybrid Intelligent Optimal Control Method for Complex Flotation Process, International Journal of Systems Science, 40 (9), 2009, 945-960.

[8] http://www1.lsbu.ac.uk/water/water_ structure_science.html

[9] M. Petrov, V. Jovanović, S. Mihajlović, Ž. Sekulić: “Expansional Osmosis Flotation”, XXIII International Mineral Processing Congress, Volume 1, 3-8 September Istanbul (2006), p. 638-643.

[10] P. W. Atkins, M. J. Clugston, Principles of Physical Chemistry, Školska knjiga Zagreb, 1989

[11] A. P. Chandra, A. R. Gerson, A Review of the Fundamental Studies of the Copper Activation Mechanisms for Selective Flotation of the Sulfide Minerals, Sphalerite and Pyrite, Advances in Colloid and Interface Science 145 (2009) 97–110.

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Vitomir Milić, Igor Svrkota*, Dejan Petrović**

ANALYSIS THE EFFECTS OF TECHNO-ECONOMIC PARAMETERS ON THE ECONOMY OF UNDERGROUND MINING IN JAMA BOR**

Abstract

When a new mining method is designed, it is necessary to define the optimal parameters of method. Applicability of a method in certain conditions is tested through determination of each relevant method parameter. Their values have to be acceptable. This paper presents a case study for analyses of parameters related to the ore body Borska Reka. The analysis was focused on determination the share of costs in the final price, ore value and copper production economy.

***Keywords**: underground mining, techno-economic parameters, ore value*

1 INTRODUCTION

Borska Reka is a massive, large-scale ore body, with 600 million tonnes of ore. Low grades and great depth, 600 to 1,200 m, are serious limiting factor. That is why detailed analysis of each relevant parameter is required in order to prove the positive economic results. The main techno-economic parameters are: productivity of applied mining method; intensity of excavation; development ratio; effects of excavation; manpower norms; material and energy norms; ore recovery, ore dilution and ore loss; excavation costs and cost price of one ton of excavated ore. Cost price is a dominant parameter. It is a sum of all costs: material, energy, maintenance, amortization, wages and many other material and non-material costs. Value of ore is a variable due to directly relation to the variation of metal prices at the London Metal Exchange (LME). When metal prices at the global market are too low, they can jeopardize economies of the mines and cause great financial losses.

2 THE EFFECTS OF TECHNO-ECONOMIC PARAMETERS ON BUSINESS ECONOMY

2.1 Mining costs

Mining costs, or production costs, are the most important. They are a sum of all individual costs in production process. Production costs are a base for defining the price of excavated ore and financial planning in a certain period of time. Also, in comparison with prices of ore, concentrate or metal at the national or global market, it shows

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whether mining operations can provide profit or not.

This way the producer, in this case the mine is forced to match pre-defined frames of economic policy, and to enable basic precondition for financially justified mining operations:

$C_k \leq C_{prod.}$, din/t or US $/t (1)

i.e. cost price C_k has to be equal or lower than selling price, C_{prod}.

In cases when it is necessary to cut the costs, the structure of costs has to be analyzed in order to define possible sectors for cost cuts. For example, Fig.1 shows a structure of costs used for operational plan in Jama Bor [1].

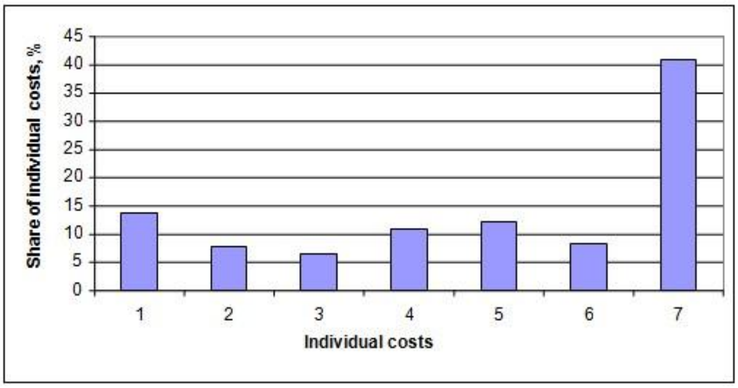

Figure 1 *Structure of costs in Jama Bor; Individual costs: 1. Material, 2. Energy, 3. Maintenance, 4. Other material costs, 5. Amortization, 6. Non-material costs, 7. Gross wages*

Such a high share of wages in total costs, as in this example, is usually a sign of poor organization, low level of mechanization and automation and similar problems, although, in case of Jama Bor, the level of mechanization is satisfying.

The most important factors in costs calculation are norms. Norms of material, energy and manpower are defined for two main purposes: calculation of material quantities, usually calculated in creation of annual operational plans, and calculation of costs, for instance costs of material, energy, wages, etc.

Norms of material are determined for each material separately, based on material consumption and achieved production. Costs of material are calculated as a product of norms and prices:

$T_{nm} = N_{nm} \cdot C_{nm}$, din/t, (US$/t) (2)

where:

T_{nm} – costs of material, din/t, (US$/t),

N_{nm} – norm of material, (unit/t),

C_{nm} - price of material, din/unit, (US$/unit).

Annual material consumption is calculated by following formula:

$Q_{nm.god.} = N_{nm} \cdot Q_{god.}$, unit/year (3)

By analogy, costs of energy are a product of energy consumption and energy price, as well as costs of wages, which are the product of norms and prices of manpower.

Development ratio, K_p, is a relation between a length of development drifts and excavated ore from developed mine section:

$$K_p = \frac{L_p}{Q_{rm}} = \frac{L_p \cdot (1 - K_o)}{Q_r \cdot K_i} =$$

$$= \frac{L_p}{Q_r \cdot K_{rm}} \text{ m/t} \quad (4)$$

Where:

L_p - total length of development drifts, m

Q_{rm} - quantity of bulk ore, t
K_o - dilution ratio
K_i - recovery ratio
Q_r - quantity of ore, t
K_{rm} - bulk ore ratio.

Quantity of excavated ore in this equation is presented by quantity of bulk ore. Sometimes, units like mm/t or m/1.000 t can be used for development ratio, but in this case it will stay in m/t.

Development ratio is a parameter that can be used for various purposes, for instance:

- For evaluation of development works, when different mining methods or different variants can be compared;
- For calculation of development costs, through following formula:

$$T_p = K_p \cdot C_{ip}, \text{ din/t (m/t x din/m = din/t)}. \quad (5)$$

When development costs are calculated, development ratio has to be defined separately for each type of drift, because costs of drifting vary. Total development costs are calculated by following formula:

$$T_p = \Sigma K_{p.i} \cdot C_{ip.i} \text{ , din/t, (US\$/t} \quad (6)$$

Development ratio is suitable for annual or long-term planning, because it provides easy calculation of lengths of development drifts. For instance, total length of drifts needed for annual production is:

$$L_p = K_p \cdot Q_{god} \text{ , m/year,}$$

and

$$L_p = \Sigma L_{pi} = \Sigma K_{pi} \cdot Q_{god.}\text{, m/year,} \quad (7)$$

where:

L_p or ΣL_{pi} – total length of development drifts per year, m/year,

K_{pi} – individual development ratio, calculated for each type of drift.

Development ratio is also suitable for calculation of drifting norms and their values per ton of ore. Norms of materials in development works are defined per meter of drift advance (unit/m), for instance kg/m, m^3/m, units/m, etc. Following formula is used to define the norms per tonnes (unit/t):

$$N_m = N'_m \cdot K_{pi}\text{, unit/t (unit/m x m/t = unit/t),} \quad (8)$$

Where N_m is norm of material per ton of excavated ore and N'_m is norm of material per meter of drift advance.

Similarly, development costs can also be defined per ton of excavated ore:

$$T_{ip} = T'_{ip} \cdot K_{pi}\text{, din/t, (US\$/t), (din/m x m/t = din/t),} \quad (9)$$

Where:

T'_{ip} - development costs in din/m, (US$/m)
T_{ip} - development costs in din/t, (US$/t).

Beside development ratio, there are some other parameters of mining methods that also have a significant influence to costs of mining. Values of these parameters have to be optimal, whether it means that they need to be maximized or minimized. For instance, mining method productivity, intensity of excavation, ore recovery and labor output should have highest possible values, while ore loss or ore dilution should be minimal.

2.2 Value of ore and economy of mining

Defining the cost price and sell price, and matching the price determined by market, is just one aspect of approach to this problem. In cases when final product is mineral raw material, or metal, whose prices are dictated by global market, economy of the mine is facing many risks. Intensive oscillations of prices, with rapid decreases, may cause a financial loss for mines. In such cases there is a dilemma, whether to abort the mining operations temporarily, or carry on the production, but with financial loss. Temporary closing or mine conservation are very complicated tasks, so some other solutions are usually found, like reducing the level of production, minimization of costs, restructuring or looking for help from the government.

The essence of business economy in this case can be simply expressed through the following relation:

$$T_u \leq V_r \text{ , din/t, (US\$/t),} \quad (10)$$

which means that total costs, T_u, per ton of excavated ore, have to be lower than total value of a ton of ore. Calculation of cost price and range of positive financial results will be considered on example copper ore mining in Bor ore deposit.

Value of ore represents total value of extractable metals in the ore, but only the ones that could be valorized. For instance, ore from the Borska Reka deposit includes copper, precious metals (gold and silver), but also magnetite and molybdenum. However, in calculation of ore value, last two components are not taken in consideration, because their economic valorization, based on existing technology, has not been confirmed yet.

Generally, value of ore can be defined by following relation:

$$V_r = \frac{m_r}{m_m} \cdot K_{im} \cdot K_f \cdot K_m \cdot C_m \text{ ,}$$
$$\text{din/t (US\$/t),} \quad (11)$$

where:

m_r - percentage of metal in the ore, %,

m_m - percentage of metal in final product, %,

K_{im} - metal recovery ratio,

$K_{im} = 1 - K_{om}$,

(K_{om} - metal dilution ratio)

K_f - metal recovery ratio in mineral processing,

K_m - metal recovery ratio in metallurgical processing,

C_m - price of metal on local or global market, din/t or US$/t.

Relation m_r/m_m is used in cases where the final product purity is less than 100%. In case of copper extraction, its final purity is 99.9%, so previous formula will be [1]:

$$V_r = 0{,}01 \cdot m_r \cdot K_{im} \cdot K_f \cdot K_m \cdot C_m\text{,}$$
$$\text{din/t, (US\$/t)} \quad (12)$$

When the value of complex ore is defined, it is calculated as a sum of values of individual components:

$$V_r = 0.01 \cdot \Sigma m_i \cdot K_{im\,i} \cdot K_{f\,i} \cdot K_{m\,i} \cdot C_{m\,i}\text{,}$$
$$\text{din/t (US\$/t)} \quad (13)$$

Parameters in this equation are same as in previous, the only difference is that they refer to individual components in the ore.

In calculation of value of ore in the ore body Borska Reka, total valorization of each component in the ore: copper, precious metals, sulfur, magnetite and molybdenum has been used, through following relation:

$$V_r = 0{,}01 \,.\, m_r \,.\, (1-K_{om}) \,.\, K_f \,.\, K_m \,.\, C_m +$$
$$+ V_{pm} + V_{FeS_2} + V_{Fe_3O_4} + V_{Mo}\text{ ,}$$
$$\text{din/t, (US\$/t),} \quad (14)$$

Where:

V_{pm} – value of precious metals in a ton of ore, din/t, (US$/t),

V_{FeS_2} - value of sulfur, expressed through pyrite, din/t, (US$/t),

$V_{Fe_3O_4}$ - value of magnetite concentrate in a ton of ore, din/t, (US$/t),

V_{Mo} - value of molybdenum concentrate in a ton of ore, din/t, (US$/t)

Values of individual components are defined based on their percentage in the ore, metal recovery ratio in mining, mineral processing and smelting and price of metal at global market. Value of precious metals is:

$$V_{pm} = V_{Au} + V_{Ag}\text{, din/t, (US\$/t)} \quad (15)$$

$$V_{Au} = 0{,}001 \,.\, m_{Au} \,.\, K_{im} \,.\, K_{f.Au} \,.$$
$$.\, K_{m.Au} \,.\, C_{Au}\text{ , din/t, (US\$/t)} \quad (16)$$

$$V_{Ag} = 0{,}001 \,.\, m_{Ag} \,.\, K_{im} \,.\, K_{f.Ag} \,.\, K_{m.Ag} \,.$$
$$.\, C_{Ag}\text{ , din/t, (US\$/t)} \quad (17)$$

Where:

m_{Au} , m_{Ag} – content of gold and silver in the ore , g/t,

$K_{f.Au}$, $K_{f.Ag}$ – gold and silver recovery ratio in mineral processing,

K_{mAu}, $K_{m.Ag}$ – gold and silver recovery ratio in smelting,

C_{Au}, C_{Ag} – prices of gold and silver at global market, din/kg, (US$/kg).

In calculations, a special attention should be paid on units. Content of precious metals is usually given in g/t, so factor 0.001 is used to convert it in kilos, since price of precious metals is usually given in US$/kg.

Values of concentrates of magnetite and molybdenum are calculated without taking into consideration the recovery in smelting, because concentrates are considered as the final product which can be sold on the market:

$$V_{Fe3O4} = \frac{m_{Fe3O4} \cdot K_{im} \cdot K_{f.Fe3O4}}{m_{k.Fe3O4}} \cdot C_{k.Fe3O4},$$

din/t, (US$/t) (18)

$$V_{Mo} = \frac{m_{Mo} \cdot K_{im} \cdot K_{f.Mo}}{m_{k.Mo}} \cdot C_{kMo},$$

din/t, (US$/t) (18a)

Where:

m_{Fe3O4},....m_{Mo} - content of magnetite and molybdenum in the ore, %

$m_{k.Fe3O4}$,....$m_{k.Mo}$ - content of magnetite and molybdenum concentrate in the ore, %

$K_{f.Fe3O4}$,....$K_{f.Mo}$ - magnetite and molybdenum recovery ratios in mineral processing,

$C_{k.Fe3O4}$,....$C_{k.Mo}$ - cost price of a ton of magnetite and molybdenum concentrate, din/t, (US$/t).

This is how previous formulas were derived:

- Value of metal in the ore is:

$V_r = 0{,}01 . m_r . K_{im} . K_f . K_m . C_m$, din/t, (US$/t),

- In order to calculate the value of metal per ton of concentrate, the value of concentrate is calculated as:

$V_k = 0{,}01 . m_k . K_m . C_m = C_k$, din/t, (US$/t) (19)

- Price of metal calculated through price of concentrate is:

$$C_m = \frac{C_k}{0{,}01 \cdot m_k \cdot K_m}, \text{ din/t, (US\$/t)} \quad (20)$$

When relation (20) is included in formula for calculation of value of ore:

$$V_r = 0{,}01 \cdot m_r \cdot K_{im} \cdot K_f \cdot K_m \cdot \frac{C_k}{0{,}01 \cdot m_k \cdot K_m} = \frac{m_r \cdot K_{im} \cdot K_f}{m_k} \cdot C_k$$

din/t, (US$/t) (21)

In some previous analyses [3], [4], [5], only values of copper and precious metals were taken into consideration in defining the ore value since only their valorization was certain. Generally, there are three ways to define the ore value.

The first one was already explained in this paper, it is based on partial calculation of values of individual components:

$V_r = V_{Cu} + V_{Au} + V_{Ag}$, din/t, (US$/t) (22)

$V_{Cu} = 0{,}01 . m_{Cu} . K_{im} . K_{f.Cu} . K_{m.Cu} . C_{Cu}$, din/t, (US$/t)

$V_{Au} = 0{,}001 . m_{Au} . K_{im} . K_{f.Au} . K_{m.Au} . C_{Au}$, din/t, (US$/t)

$V_{Ag} = 0{,}001 . m_{Ag} . K_{im} . K_{f.Ag} . K_{m.Ag} . C_{Ag}$, din/t, (US$/t)

The second way is to define the equivalent ore grade, which means that grade of copper is increased according to the value of precious metals. Calculation of equivalent ore grade is given in the example of the ore body Borska Reka, while the ore value is given in US$ per ton. Ore grades are as follows: 0.763% of copper, 0.315 g/t of gold, 1.67 g/t of silver [6]. Prices of metals are: copper - 4,500 US$/t, gold - 34,350 US$/kg, silver - 450 US$/kg [7]. The ore va-lue, as the sum of values of individual metals, is calculated by the following parameters:

Table 1 *Values of recovery ratios*

Parameter	Copper	Gold	Silver
Metal recovery ratio, K_{im}	0.90	0.90	0.90
Mineral processing recovery ratio, K_f	0.86	0.40	0.50
Smelting recovery, K_m	0.97	0.92	0.89

Value of copper:

V_{Cu} = 0.01 x 0.763 x 0.9 x 0.86 x x 0.97 x 4,500.00 = 25,778 US$/t

Value of gold:

V_{Au} = 0.001 x 0.315 x 0.9 x 0.4 x x 0.92 x 34,350.00 = 3,584 US$/t

Value of silver:

V_{Ag} = 0.001 x 1.67 x 0.9 x 0.5 x x 0.89 x 450 = 0.301 US$/t

Total value of metal in a ton of ore: 29,663 US$/t

Equivalent ore grade, which refers to total value of metal, is than calculated by the following formula:

$$m_{ekv.} = \frac{\sum V_m}{0{,}01 \cdot K_{im} \cdot K_f \cdot K_m \cdot C_{Cu}} =$$

$$= \frac{29{,}663}{0{,}01x0{,}9x0{,}86x0{,}97x4.500{,}00} =$$

= 0,878 % Cu.

This means that, due to presence of precious metals in the ore, the copper grade in the ore increased from 0.763% to 0.878%, or by 0.115%. Although the increase of ore grade in % does not seem too significant, this means that value of ore is increased by 3.882 US$/t, or by 15.06%, which is very significant for the final financial result.

The third way is based on precious metals ratio [5]. In this case, total value of ore is calculated by following relation:

$$V_r = 0.01 \cdot m_r \cdot K_{im} \cdot K_f \cdot K_m \cdot K_{pm} \cdot C_m, \text{ din/t, (US\$/t)} \quad (23)$$

A part of formula without precious metals ratio (K_{pm}) is a value of copper in the ore (V_{Cu}), while the entire formula provides total value of ore. So, it can be expressed like this:

$V_r = V_{Cu} \cdot K_{pm}$,

and

$$K_{pm} = \frac{V_r}{V_{Cu}} \quad (24)$$

In this example, value of precious metals ratio is: $K_{pm} = \frac{29{,}663}{25{,}778} = 1{,}151$

2.3 Determining the ore value for mining

Mining ore value is an economic category, introduced in order to separate the value of ore which should cover costs of mining. Total ore value needs to cover costs of mining, mineral processing and smelting, so, for a positive financial result, the ore value has to be higher than the sum of costs:

$$V_r \geq T_d + T_f + T_m, \text{ din/t, (US\$/t)}, \quad (25)$$

where:

T_d – costs of mining, din/t, (US$/t),

T_f – costs of mineral processing, din/t, (US$/t),

T_m – costs of smelting, din/t, (US$/t).

To define these costs, it is necessary to determine a quantity of excavated ore needed for a ton of concentrate and a ton of metal. Quantity of ore needed for production of one tone of concentrate is:

$$Q_r^k = \frac{m_k}{m_r \cdot K_{im} \cdot K_f}, \ t_r/t_k, \text{ (tons of ore per ton of concentrate)} \quad (26)$$

Quantity of ore needed for production of one ton of metal is:

$$Q_r^m = \frac{m_m}{m_r \cdot K_{im} \cdot K_f \cdot K_m}, \ t_r/t_m, \text{ (tons of ore per ton of metal)} \quad (27)$$

Quantity of concentrate needed for production of one ton of metal is:

$$Q_k = \frac{m_m}{m_k \cdot K_m}, \text{ t}_k/\text{t}_m \text{ (tons of concentrate per ton of metal)} \quad (28)$$

For copper ore in the ore body Borska Reka, and designed copper grade in the concentrate m_k = 20 % Cu, the calculation is provided bellow:

$$Q_r^k = \frac{20.0}{0.763x0.9x0.86} = 33.87, \text{ t}_r/\text{t}_k,$$

$$Q_r^m = \frac{99.9}{0.763x0.9x0.86x0.97} = 174.39, \text{ t}_r/\text{t}_m,$$

$$Q_k = \frac{99.9}{20x0.97} = 5.15, \text{ t}_k/\text{t}_m.$$

It is now possible to determine the costs of mineral processing per ton of ore, if the costs of mineral processing per ton of concentrate (T_k) are known. Similarly, it is possible to determine metallurgical costs per ton of ore, if the metallurgical costs per ton of copper (T_t) are known.

- Mineral processing costs per ton of ore:

$$T_f = \frac{T_k}{Q_r^k} = \frac{120}{33.87} = 3.54, \text{ US\$/t},$$

- Metallurgical costs per ton of ore:

$$T_m = \frac{T_t}{Q_r^m} = \frac{600}{174.39} = 3.44, \text{ US\$/t}$$

Now the mining ore value can be calculated:

$$V_{rr} = V_r - (T_f + T_m), \text{ din/t, (US\$/t)}. \quad (29)$$

Value of ore V_r according to equation (25) is $V_r = T_d + T_f + T_m$, and if it is put in the upper equation, than $V_{rr} = T_d$ and the relation for proving the financially justified mining is:

$$V_{rr} > T_d \quad (30)$$

In the ore body Borska Reka, the mining ore value is:

$$V_{rr} = 29.663 - (3.54 + 3.44) = 29.663 - 6.98 = 22.683 \text{ US \$/t}$$

3 ANALYSIS OF RESULTS

The results show that, for prices at the London Metal Exchange on a day of analysis (copper – 4,500 US$/t, gold – 34,350 US$/kg, silver – 450 US$/kg), there is a possibility for the financially justified mining. In order to provide it, the mining costs have to be minimized and limited to 10 US$/t, mineral processing costs to 4 US$/t and metallurgical costs up to 4 US$/t. Since the value of ore is 25,778 US$/t for the ore grade of 0.763% Cu, and 29,663 US$/t for the equivalent ore grade of 0.878% Cu, it is obvious that the ore value is higher than costs and the positive financial results are possible.

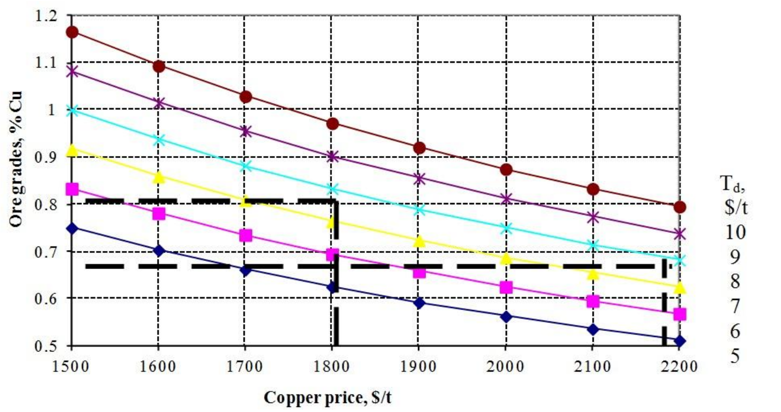

Figure 2 *Relationship between the variation of ore grades and copper price for different values of mining costs (5 – 10 US$/t)*

Dominant factor in business economy of mining is the price of metals, primarily copper, gold and silver, at LME. In last 15 years, the prices of metals varied significantly. The range of copper price was from 1,800 US$/t to almost 10,000 US$/t. Several years ago, the analyses were based on the copper price at 2,400 US$/t, as it was at the beginning of this century [5]. A detailed analysis requires defining the relations between the mining ore value and variation of prices at LME and variation of ore grades. The result of analysis shows that the costs of underground mining could not be lower than 7 - 8 US$/t, while the mineral processing and metallurgical costs in RTB Bor are much higher than it was planned. In order to provide the positive results, the mining operations have to be deployed inside the 0.5% Cu contour, with the average ore grade of 0.8% Cu (Figure 2).

4 CONCLUSION

In analyses of economy of mining, the most important influential factors are the ore value, which depends on the ore grades and prices of metals at LME, and costs of mining, mineral processing and smelting. Analysis in this paper was focused on the ore body Borska Reka, above the Level XIX, and remaining ore reserves in the ore bodies Tilva Ros, P_2A, T_3 and D in Jama Bor. According to data gained from RTB Bor technical documentation, the average ore grades are as follows: 0.763% Cu, 0.315 g/t Au and 1.67 g/t Ag. The current prices at LME are: 4,500 US$/t for copper, 34,350 US$/t for gold and 450 US$/t for silver. The ore value, calculated from these data, is 25,778 US$/t. The quivalent ore grade, i.e. copper grade increased by grades of precious metals, is 0.878% Cu. In this case, the ore value is 29,663 US$/t.

Based on this ore value, the financially justified underground mining is achievable if the mining costs are limited to 10 US$/t, mineral processing costs up to 4 US$/t and metallurgical costs bellow 4 US$/t.

However, the actual costs are much higher. The main reasons for increased mining costs are unfavorable distribution of the ore bodies in the Bor ore deposit and low level of output, reaching only 700,000 t/year. Mineral processing costs are also excessive, mainly due to the obsolete equipment. Significant increase of annual output in underground mining is necessary, because it enables reducing of fixed costs and therefore total costs, which is the main task for future of underground mining in Jama Bor.

REFERENCES

[1] Z. Milicevic, R. Nikolic, Fundamentals of Mine Design, Technical Faculty in Bor, 2003 (in Serbian);

[2] V. Milic, Z. Milicevic, Fundaments of Mining, Technical Faculty in Bor, 2005 (in Serbian);

[3] Z. Milicevic, Valorization of Low Graded Copper Ore and defining of Real Ore Value, 23th October Conference on Mining and Metallurgy, D. Milanovac, 1991, p.457;

[4] Z. Milicevic et al., Optimization of sublevel caving, II International Symposium: Application of Numerical Methods and Computers in Geology, Mining and Metallurgy, Belgrade, 1991, p.457 (in Serbian);

[5] Z. Milicevic, Possibilities of Mining in RTB Bor Mines, 33th October Conference on Mining and Metallurgy, Bor, 2001, p.1;

[6] Technical Documentation of RTB Bor, Jama Bor, Annual Operating Plan, Bor, 2014;

[7] http://www.infomine.com/investment/metal-prices/

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ANALIZA UTICAJA TEHNO-EKONOMSKIH POKAZATELJA NA EKONOMIČNOST EKSPLOATACIJE U JAMI BOR**

Izvod

Pri istraživanju mogućnosti primene nove konstrukcije metoda otkopavanja neophodno je definisati optimalne parametre metode. Primenljivost za konkretne uslove podrazumeva proračun svih pokazatelja koji moraju da imaju povoljne vrednosti. Analiza pokazatelja uradjena je na primeru rudnog tela Borska reka. Posebna pažnja posvećena je odredjivanju troškova u strukturi cene koštanja, odredjivanju vrednosti rude, vrednosti rude za rudarenje i ekonomičnosti proizvodnje rude bakra.

Ključne reči: *podzemna eksploatacija, tehno-ekonomski pokazatelji, vrednost rude*

1. UVOD

U rudnom telu Borska reka u konturi sa srednjim sadržajem bakra od 0,3% nalazi se oko 600.000.000 t rude. Nisak sadržaj korisne komponente i velika dubina od 600 do 1200 m dubine na kojoj rudno telo zaleže zahtevaju detaljnu analizu svih pokazatelja zbog potvrde ekonomičnosti otkopavanja. Osnovni tehno-ekonomski pokazatelji na ekonomičnost eksploatacije su: proizvodnost primenjene metode otkopavanja, intenzitet otkopavanja, koeficijent pripreme, učinci na otkopavanju, normativi radne snage, materijala i električne energije, iskorišćenje, gubici i osiromašenje rude, troškovi otkopavanja i cena koštanja 1 t rude. Dominantni uticaj ima cena koštanja proizvodnje mineralne sirovine. Cena koštanja predstavlja sumu svih troškova na dobijanju mineralnih sirovina: troškovi materijala, energije, održavanja, amortizacije, troškovi bruto ličnih dohodaka i ostali materijalni i nematerijalni troškovi. Vrednost rude je promenljiva i direktno je uslovljena cenama metala na svetskom tržištu. Veće variranje ovih cena, naročito kada se radi o većem padu cena, može dovesti rudnik u situaciju da ne može ekonomično poslovati.

2. UTICAJ TEHNO-EKONOMSKIH POKAZATELJA NA EKONOMIČNOST POSLOVANJA

2.1. Troškovi otkopavanja

Troškovi otkopavanja ili cena koštanja proizvodnje mineralne sirovine su jedan od najznačajnih pokazatelja i predstavljaju sumu svih troškova na dobijanju mineralne sirovine. Oni se koriste za definisanje prodajne cene mineralne sirovine, odnosno da se planiraju ekonomski parametri poslovanja rudnika u toku obračunskog perioda. Takodje, na osnovu uporedjenja poznatih cena osnovnog proizvoda (koncentrata, metala i

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sl.) na domaćem ili svetskom tržištu može se odrediti mogućnost ekonomičnog rada rudnika.

Na taj način, proizvodjači, u ovom slučaju rudnici, primorani su da se uklapaju u unapred definisane okvire ekonomske politike, pa je potrebno zadovoljiti osnovni preduslov ekonomičnosti eksploatacije mineralnih sirovina da je:

$$C_k \leq C_{prod.}, \text{ din/t ili US \$/t} \quad (1)$$

tj. da je cena koštanja, C_k, manja ili granično jednaka sa prodajnom cenom, C_{prod}.

Medjutim, u slučaju kada se razmatra potreba racionalizacije proizvodnje, potrebno je pažljivo analizirati strukturu cene koštanja, jer se iz nje može uočiti u kom pravcu se najpre može intervenisati u cilju njenog smanjenja. Kao primer, navodi se struktura cene koštanja uzeta iz jednog plana za jamu Bor [1].

Sl. 1. *Primer učešća pojedinih troškova u strukturi cene koštanja za Jamu Bor (1. Troškovi materijala, 2. Troškovi energije, 3. Troškovi održavanja 4. Ostali materijalni troškovi, 5. Amortizacija, 6. Nematerijalni troškovi, 7. Troškovi bruto LD)*

Visoko učešće troškova radne snage obično govori o neracionalnom poslovanju, niskom stepenu organizacije rada, mehanizacije i automatizacije pojedinih procesa, mada se, u konkretnom slučaju ne može govoriti i o niskom stepenu mehanizovanosti procesa, obzirom da je on u suštini zadovoljavajući.

Za određivanje troškova materijala, energije i radne snage najznačajniji su njihovi normativi [2].

Normativi materijala, energije i radne snage proračunavaju se iz dva osnovna razloga: radi utvrdjivanja potrebnih količina materijala za nabavku, što se radi pri izradi godišnjih operativnih planova proizvodnje, i za odredjivanje troškova materijala, energije i radne snage.

Normativi materijala se izračunavaju za svaku vrstu materijala posebno, na osnovu potrebne količine materijala na radilištima, i dobijene količine mineralne sirovine.

Troškovi materijala izračunavaju se iz proizvoda normativa i cena materijla, tj.:

$$T_{nm} = N_{nm} \,.\, C_{nm}, \text{ din/t, (US\$/t)} \quad (2)$$

gde su:

T_{nm} – troškovi normativnog materijala, din/t, (US$/t),

N_{nm} – normativi materijala, (jed.mere/t),

C_{nm} - cena normativnog materijala, din/jed. mere, (US$/jed. mere).

Za planiranje godišnje potrošnje normativnih materijala, izračunavanje se vrši po formuli:

$$Q_{nm.god.} = N_{nm} \,.\, Q_{god.}, \text{ (jed. mere/god.)} \quad (3)$$

Po istoj analogiji, odredjuju se troškovi energije na osnovu normativa potrošnje energije i cene energije, kao i troškovi radne snage na osnovu normativa i cene radne snage.

Koeficijent pripreme, K_p, se odredjuje iz dužina izradjenih prostorija i količina pripremljene rude njihovom izradom, po poznatom izrazu:

$$K_p = \frac{L_p}{Q_{rm}} = \frac{L_p \cdot (1 - K_o)}{Q_r \cdot K_i} =$$

$$= \frac{L_p}{Q_r \cdot K_{rm}} \quad \text{m/t.} \qquad (4)$$

I u ovom slučaju treba računati sa količinama rudne mase, jer je ona relevantna za obračun. U praksi projektovanja i stručnom žargonu koeficijenti pripreme se nekad izražavaju u mm/t ili m/1.000 t, medjutim za praktično korišćenje pogodnije je izražavanje usvojenim jedinicama mere, u m/t.

Koeficijent pripreme se koristi za različite namene:

- kao pokazatelj pripreme radi uporedjenja različitih metoda ili varijanti odredjene metode,
- za izračunavanje troškova pripreme po formuli:

$T_p = K_p \,.\, C_{ip}$, din/t (m/t x din/m=din/t) (5)

Za ove potrebe, obzirom na različite cene izrade 1 m prostorija, potrebno je izračunavati koeficijente pripreme za svaku vrstu prostorija posebno. Ukupni troškovi pripreme odredjuju se izrazom:

$T_p = \Sigma K_{p.i} \,.\, C_{ip.i}$, din/t, (US$/t) (6)

Pri izradi godišnjih operativnih ili dugoročnih planova, a i za druge potrebe, koeficijentom pripreme se na najjednostavniji način odredjuju potrebne dužine pripremnih prostorija ili dužine svake vrste prostorija pojedinačno. Dužina pripremnih prostorija, koja se mora izraditi u toku jedne godine, na primer, iznosi:

$L_p = K_p \,.\, Q_{god}$, m/god.,

odnosno

$L_p = \Sigma L_{pi} = \Sigma K_{pi} \,.\, Q_{god.}$, m/god., (7)

gde su:

L_p ili ΣL_{pi} - ukupna dužina pripremnih prostorija koja bi trebalo da se izradi u toku jedne godine, m/god,

K_{pi} - pojedinačni (parcijalni) koeficijenti pripreme za svaku vrstu prostorija posebno.

Takodje, koeficijent pripreme se može pogodno koristiti i za preračunavanje normativa izrade pripremnih prostorija i njihovo prevodjenje na 1 t proizvedene mineralne sirovine. Normativi potrošnje materijala i drugi, na izradi pripremnih prostorija daju se u jedinici mere po metru dužnom prostorije (jed.mere/m), na primer kg/m, kom/m, m^3/m itd. Za prevodjenje ovih normativa u jed.mere/t, koristi se izraz:

$N_m = N'_m \,.\, K_{pi}$, jed.mere/t

(jed.mere/m x m/t = jed.mere/t), (8)

U formuli su:

N_m – normativ materijala po toni dobijene mineralne sirovine,

N'_m - normativ materijala po metru izradjene prostorije.

Na isti način se i troškovi izrade pripremnih prostorija mogu prevesti na jednu tonu dobijene mineralne sirovine po formuli:

$T_{ip} = T'_{ip} \,.\, K_{pi}$, din/t, (US$/t),

(din/m x m/t = din/t), (9)

T'_{ip} – troškovi izrade prostorije u din/m, (US$/m)

T_{ip} – troškovi izrade prostorije u din/t, (US$/t).

I ostali pokazatelji značajno utiču na odredjivanje troškova podzemne eksploatacije primenom odgovarajućih metoda otkopavanja. Osnovni zahtev je da, pri izboru optimalnih parametara metoda otkopavanja, pokazatelji imaju najpovoljnije vrednosti. Proizvodnost metode, intezitet otkopavanja, iskorišćenje rude, učinci na otkopavanju treba da imaju što veće vrednosti, a gubici rude i osiromašenje minimalne vrednosti.

2.2. Odredjivanje vrednosti rude i ekonomičnosti proizvodnje mineralne sirovine

Utvrdjivanje cene koštanja i prodajne cene, odnosno uklapanje cene u limitirane prodajne cene na domaćem tržištu, predstavlja samo jedan vid pristupa ovoj problematici. Za slučaj kada se radi o proizvodnji mineralne sirovine ili konačnog proizvoda (metala na primer), čije su cene uslovljene cenama na svetskom tržištu, ekonomika poslovanja rudnika suočava se sa znatno više rizika. Veće variranje ovih cena, naročito kada se radi o većem padu cena na svetskom tržištu, može lako dovesti rudnik u situaciju da ne može ekonomično poslovati, kada se javlja dilema da li privremeno obustaviti proizvodnju ili je nastaviti sa negativnim ekonomskim efektima poslovanja. Konzerviranje ili zatvaranje rudnika nije nimalo jednostavan postupak, pa se moraju tražiti druga rešenja (značajno redukovanje proizvodnje, poslovanje sa minimalnim troškovima rada, izvesno prestrukturiranje ili obezbedjenje sredstava od države, koja treba da omogući rudniku da prebrodi teškoće u periodu niskih cena na tržištu).

Suština ekonomičnog poslovanja u ovakvim prilikama može se jednostavno izraziti na sledeći način:

$$T_u \leq V_r, \text{ din/t, (US\$/t)}, \qquad (10)$$

što znači da ukupni troškovi, T_u, svedeni na 1 t rude, treba da budu manji od ukupne vrednosti 1 t rude. Problematika odredjivanja cene koštanja i utvrdjivanje oblasti ekonomičnog poslovanja razmotriće se na primeru eksploatacije rude bakra u Boru.

Vrednost rude definiše se ukupnom vrednošću korisnih komponenti u njoj, pri čemu se uzimaju samo one komponente koje se mogu valorizovati. Tako na primer, ruda u rudnom telu „Borska reka“, osim minerala bakra i plemenitih metala (zlata i srebra), sadrži još i manje količine magnetita i molibdena, ali se one obično ne uzimaju u obzir jer prema sadašnjem nivou tehnologije nije utvrdjena mogućnost njihove valorizacije na ekonomičan način.

U opštem slučaju vrednost rude se može definisati sledećim izrazom:

$$V_r = \frac{m_r}{m_m} \cdot K_{im} \cdot K_f \cdot K_m . C_m, \quad \text{din/t (US\$/t)}, \qquad (11)$$

gde su:

- m_r - sadržaj metala u rudi, %,
- m_m - sadržaj metala u konačnom produktu, %,
- K_{im} - koeficijent iskorišćenja metala u procesu otkopavanja, koji je jednak $K_{im} = 1 - K_{om}$
- K_{om} – koeficijent osiromašenja metala,
- K_f - koeficijent iskoršćenja metala u procesu flotacijske prerade,
- K_m - koeficijent iskorišćenja metala pri metalurškoj preradi,
- C_m - cena metala na domaćem ili svetskom tržištu, din/t ili US$/t.

Izraz m_r/m_m koristi se u slučajevima kada je finalni proizvod (metal ili dr.) manje čistoće od 100 %, U slučaju prerade bakra, njegova čistoća je 99,9 % pa se uzima kao 100 %, te prethodna formula ima sledeći oblik [1]:

$$V_r = 0{,}01 \,.\, m_r \,.\, K_{im} \,.\, K_f \,.\, K_m \,.\, C_m, \quad \text{din/t, (US\$/t)} \qquad (12)$$

Kada se radi o eksploataciji kompleksnih ruda, njihova vrednost se izračunava iz sume vrednosti pojedinih komponenti, tj.:

$$V_r = 0{,}01 \,.\, \Sigma\, m_i \,.\, K_{im.i} \,.\, K_{f.i} \,.\, K_{m.i} \,.\, C_{m.i}, \quad \text{din/t, (US\$/t)} \qquad (13)$$

U formuli su pojedine oznake adekvatne prethodnim, samo se odnose na pojedine korisne komponente u rudi.

Za rudu rudnog tela „Borska reka“ u Borskom ležištu računata je vrednost rude s obzirom na ukupnu valorizaciju svih korisnih komponenti: bakra, plemenitih metala, sumpora, magnetita i molibdena. Za to se može koristiti sledeća formula:

$$V_r = 0{,}01 \,.\, m_r \,.\, (1-K_{om}) \,.\, K_f \,.\, K_m \,.\, C_m + V_{pm} + V_{FeS_2} + V_{Fe_3O_4} + V_{Mo}, \quad \text{din/t, (US\$/t)}, \qquad (14)$$

gde su:

- V_{pm} - vrednost plemenitih metala u 1 t rude, din/t, (US$/t),
- V_{FeS_2} - vrednost sumpora izražena preko sadržaja pirita, din/t, (US$/t),
- $V_{Fe_3O_4}$ - vrednost koncentrata magnetita, koja se odnosi na 1 t rude, din/t, (US$/t),
- V_{Mo} – vrednost koncentrata molibdena, koja se odnosi na 1 t rude, din/t, (US$/t)

Vrednosti pojedinih komponenti izračunavaju se na osnovu njihovog sadržaja u rudi, koeficijenata eksploatacionog, flotacijskog i metalurškog iskorišćenja metala i cena metala na svetskom tržištu. Vrednost plemenitih metala iznosi.

$V_{pm} = V_{Au} + V_{Ag}$, din/t, (US$/t) (15)

$V_{Au} = 0{,}001 \cdot m_{Au} \cdot K_{im} \cdot K_{f.Au} \cdot K_{m.Au} \cdot C_{Au}$, din/t, (US$/t) (16)

$V_{Ag} = 0{,}001 \cdot m_{Ag} \cdot K_{im} \cdot K_{f.Ag} \cdot K_{m.Ag} \cdot C_{Ag}$, din/t, (US$/t) (17)

U formulama su:

m_{Au}, m_{Ag} - sadržaji zlata i srebra u rudi, g/t,

$K_{f.Au}$, $K_{f.Ag}$ - koeficijenti flotacijskog iskorišćenja zlata i srebra

K_{mAu}, $K_{m.Ag}$ - koeficijenti metalurškog iskorišćenja zlata i srebra,

C_{Au}, C_{Ag} - cene zlata i srebra na svetskom tržištu, din/kg , (US$/kg).

Pri proračunima vrednosti treba obratiti posebnu pažnju na korišćene jedinice. Pošto se sadržaj plemenitih metala daje u g/t, faktorom 0,001 se ovaj sadršaj prevodi u kilograme, u kojima se obično izražava cena plemenitih metala, (US$/kg).

Vrednosti koncentrata magnetita i molibdena se izračunavaju bez metalurških iskorišćenja, jer se računa sa plasmanom koncentrata, tj. njegovom prodajom drugim preradjivačima.

$$V_{Fe3O4} = \frac{m_{Fe3O4} \cdot K_{im} \cdot K_{f.Fe3O4}}{m_{k.Fe3O4}} \cdot C_{k.Fe3O4},$$

din/t , (US$/t) (18)

$$V_{Mo} = \frac{m_{Mo} \cdot K_{im} \cdot K_{f.Mo}}{m_{k.Mo}} \cdot C_{kMo},$$

din/t, (US$/t) (18a)

U formulama su:

$m_{Fe3O4}, \ldots m_{Mo}$ - sadržaji magnetita i molibdena u rudi, %

$m_{k.Fe3O4}, \ldots m_{k.Mo}$ - sadržaji koncentrata magnetita i molibdena, %

$K_{f.Fe3O4}, \ldots K_{f.Mo}$ - koeficijenti flotacijskog iskorišćenja magnetita i molibdena,

$C_{k.Fe3O4}, \ldots C_{k.Mo}$ - cena koštanja 1t koncentrata magnetita i molibdena, din/t, (US$/t).

Prethodne formule izvedene su na sledeći način:

- vrednost metala u rudi je:

$V_r = 0{,}01 \cdot m_r \cdot K_{im} \cdot K_f \cdot K_m \cdot C_m$, din/t, (US$/t),

- da bi se izračunala vrednost prema ceni 1 t koncentrata, odredjuje se njegova vrednost, koja iznosi:

$V_k = 0{,}01 \cdot m_k \cdot K_m \cdot C_m = C_k$, din/t, (US$/t)(19)

- iz ovog izraza dobija se vrednost (cena) metala u odnosu na cenu koncentrata:

$$C_m = \frac{C_k}{0{,}01 \cdot m_k \cdot K_m}$$, din/t, (US$/t) (20)

Zamenom u izraz za vrednost rude (prema konkretnoj vrsti metala) dobija se:

$$V_r = 0{,}01 \cdot m_r \cdot K_{im} \cdot K_f \cdot K_m \cdot \frac{C_k}{0{,}01 \cdot m_k \cdot K_m} = \frac{m_r \cdot K_{im} \cdot K_f}{m_k} \cdot C_k$$

din/t, (US$/t) (21)

U većem broju radova [3], [4], [5] i drugim, vrednost rude bakra računata je uzimanjem u obzir samo vrednosti bakra i plemenitih metala, čija je valorizacija izvesna. Ona se u principu može računati na tri načina.

Prvi način je već prikazan napred, a sastoji se u posebnom (parcijalnom) proračunu vrednosti pojedinih komponenti, tj.:

$V_r = V_{Cu} + V_{Au} + V_{Ag}$, din/t, (US$/t) (22)

$V_{Cu} = 0{,}01 \cdot m_{Cu} \cdot K_{im} \cdot K_{f.Cu} \cdot K_{m.Cu} \cdot C_{Cu}$, din/t, (US$/t)

$V_{Au} = 0{,}001 \cdot m_{Au} \cdot K_{im} \cdot K_{f.Au} \cdot K_{m.Au} \cdot C_{Au}$, din/t, (US$/t)

$V_{Ag} = 0{,}001 \cdot m_{Ag} \cdot K_{im} \cdot K_{f.Ag} \cdot K_{m.Ag} \cdot C_{Ag}$, din/t, (US$/t)

Drugi način je preko izračunavanja ekvivalentnog sadržaja bakra, a to je onaj uvećani sadržaj bakra u rudi, koji svojom vrednošću obuhvata i vrednost plemenitih metala. Proračun ekvivalentnog sadržaja daje se na primeru rudnog tela "Borska reka", a usvaja se izražavanje vrednosti u US$/t. Sadržaj bakra u rudi je prosečno 0,763 %, zlata 0,315 g/t, a srebra 1,67 g/t [6] Cene metala su: bakra 4.500,00 US$/t, zlata 34.350 US$/kg, srebra 450 US$/kg [7]. Vrednost rude kao suma vrednosti pojedinih metala izračunava se na bazi usvojenih sledećih pokazatelja:

Tabela 1. *Vrednosti pokazatelja koeficijenata iskorišćenja*

Pokazatelj	Bakar	Zlato	Srebro
Koef. iskorišćenja metala, K_{im}	0,90	0,90	0,90
Koef. flotacijskog iskoriš., K_f	0,86	0,40	0,50
Koef. metalurškog iskor. , K_m	0,97	0,92	0,89

Vrednost bakra:

V_{Cu} = 0,01 x 0,763 x 0,9 x 0,86 x x 0,97 x 4.500,00 = 25,778 US$/t

Vrednost zlata:

V_{Au} = 0,001 x 0,315 x 0,9 x 0,4 x x 0,92 x 34.350,00 = 3,584 US$/t

Vrednost srebra:

V_{Ag} = 0,001 x 1,67 x 0,9 x 0,5 x 0,89 x x 450 = 0,301 US$/t

Ukupna vrednost metala u 1 t rude je 29,663 US$/t

Ekvivalentni sadržaj bakra u rudi, koji odgovara ukupnoj vrednosti metala, odredjuje se iz sledećeg izraza:

$$m_{ekv.} = \frac{\sum V_m}{0{,}01 \cdot K_{im} \cdot K_f \cdot K_m \cdot C_{Cu}} =$$

$$= \frac{29{,}663}{0{,}01x0{,}9x0{,}86x0{,}97x4.500{,}00} =$$

= 0,878 % Cu.

Kao što se vidi, sadržaj plemenitih metala utiče na povećanje ekvivalentnog sadržaja bakra od vrednosti 0,763 % Cu na vrednost 0,878 % Cu, odnosno za 0,115 % Cu. Međutim, bez obzira na relativno malu veličinu, povećanje vrednosti rude je za 3,882 US$/t ili za 15,06 %, čime se može pokriti izvodjenje većeg broja procesa pri eksploataciji rude.

Treća mogućnost, koja je korišćena u više radova [5], bazira se na koeficijentu učešća plemenitih metala, koji se izračunava po sličnom postupku. U tom slučaju, se ukupna vrednost rude može izraziti formulom:

$$V_r = 0{,}01 \,.\, m_r \,.\, K_{im} \,.\, K_f \,.\, K_m \,.\, K_{pm} \,.\, C_m, \text{ din/t , (US\$/t)} \qquad (23)$$

U uzetom primeru, deo izraza bez koeficijenta plemenitih metala, daje vrednost bakra u rudi (V_{Cu}), a ukupni izraz (sa koeficijentom K_{pm}) daje ukupnu vredost rude. Prema tome, može se napisati da je:

$V_r = V_{Cu} \,.\, K_{pm}$, odakle je

$$K_{pm} = \frac{V_r}{V_{Cu}} \qquad (24)$$

Za uzeti primer, vrednost ovog koeficijenta iznosi:

$$K_{pm} = \frac{29{,}663}{25{,}778} = 1{,}151$$

2.3. Odredjivanje vrednosti rude za rudarenje

Vrednost rude za rudarenje je ekonomska kategorija uvedena sa ciljem da označi onu vrednost rude, koja pripada rudarima, odnosno koja treba da opravda učinjene troškove na dobijanju rude. S obzirom da ukupna vrednost rude treba da pokrije troškove eksploatacije (dobijanja), flotacijske i metalurške prerade, to se može napisati da je potreban uslov za ekonomičnu eksploataciju:

$$V_r \geq T_d + T_f + T_m, \text{ din/t, (US\$/t)} \qquad (25)$$

gde su:

T_d - ukupni troškovi dobijanja (rudarske eksploatacije) rude, din/t , (US$/t),

T_f - troškovi flotacijske prerade, svedeni na 1 t rude, din/t, (US$/t),

T_m - troškovi metalurške prerade, svedeni na 1 t rude, din/t, (US$/t).

Da bi se odredili ovi troškovi, potrebno je znati koja je količina rude potrebna za dobijanje 1 t koncentrata ili 1 t metala. Količina rude potrebna za dobijanje 1 t koncentrata, iznosi:

$$Q_r^k = \frac{m_k}{m_r \cdot K_{im} \cdot K_f}, \ t_r / t_k , \qquad (26)$$

a za dobijanje 1 t metala potrebno je dobiti sledeću količinu rude:

$$Q_r^m = \frac{m_m}{m_r \cdot K_{im} \cdot K_f \cdot K_m}, \; t_r/t_m, \quad (27)$$

Za dobijanje 1 t metala potrebna je sledeća količina koncentrata:

$$Q_k = \frac{m_m}{m_k \cdot K_m}, \; t_k / t_m \quad (28)$$

Za slučaj eksploatacije rude bakra, a za usvojeni sadržaj koncentrata m_k = 20 % Cu, izračunavanjem se dobijaju sledeće količine:

- količina rude za 1 t koncentrata:

$$Q_r^k = \frac{20{,}0}{0{,}763x0{,}9x0{,}86} = 33{,}87, \; t_r/t_k,$$

- količina rude za 1 t metala

$$Q_r^m = \frac{99{,}9}{0{,}763x0{,}9x0{,}86x0{,}97} = 174{,}39, \; t_r/t_m,$$

- količina koncentrata za 1 t metala:

$$Q_k = \frac{99{,}9}{20x0{,}97} = 5{,}15, \; t_k/t_m.$$

Primenom ovih formula, i izračunatih vrednosti, mogu se dobiti troškovi flotiranja, ako su poznati troškovi dobijanja 1 t koncentrata, kao i troškovi metalurške prerade, ako se znaju troškovi topljenja i rafinacije 1 t bakra. U usvojenom primeru ovi troškovi iznose:

- troškovi flotacijske prerade:

$$T_f = \frac{T_k}{Q_r^k} = \frac{120}{33{,}87} = 3{,}54 \text{ , US\$/t rude,}$$

- troškovi metalurške prerade:

$$T_m = \frac{T_t}{Q_r^m} = \frac{600}{174{,}39} = 3{,}44 \text{ , US\$/t rude.}$$

Ako se znaju troškovi flotacijske i metalurške prerade svedeni na 1 t rude, tada se može odrediti i vrednost rude za rudarenje, koja iznosi:

$$V_{rr} = V_r - (T_f + T_m), \text{ din/t, (US\$/t)} \quad (29)$$

Prema napred datom izrazu, odnosno pri njegovoj graničnoj vrednosti $V_r = T_d + T_f + T_m$, proizilazi da je $V_{rr} = T_d$, mada bi trebalo da bude zadovoljen uslov da je:

$$V_{rr} > T_d \quad (30)$$

jer samo taj uslov obezbedjuje ekonomično otkopavanje ležišta meneralne sirovine.

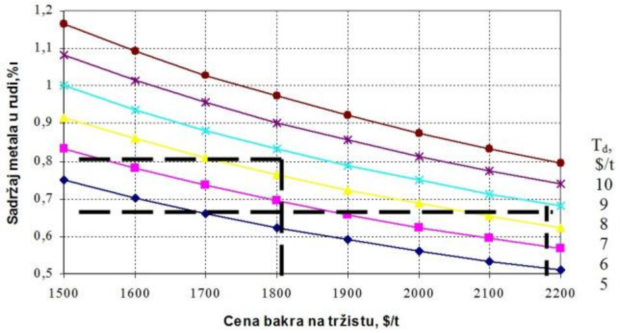
Za uzeti primer proračuna, vrednost rude za rudarenje iznosi:

$$V_{rr} = 29{,}663 - (3{,}54 + 3{,}44) = 29{,}663 - 6{,}98 = 22{,}683 \text{ US \$/t}$$

3. ANALIZA DOBIJENIH REZULTATA

Dobijeni rezulti proračuna ukazuju da u uslovima cena bakra i plemenitih metala na svetskom tržištu, na dan ocene i to: bakra 4.500,00 US$/t, zlata 34.350 US$/kg, srebra 450 US$/kg [7], postoji realna mogućnost da se ostvari ekonomski opravdana podzemna eksploatacija rude bakra. To podrazumeva da troškovi podzemne eksploatacije - dobijanja imaju minimalnu vrednost koja treba da se kreće oko 10 US $/t, troškovi flotacijske pripreme do 4 US $/t i troškovi metalurške prerade manje od 4 US $/t. Pošto je pri sadržaju rude bakra od 0,763 % Cu vrednost bakra u rudi 25,778 US $/t, a pri ekvivaletnom sadržaju bakra od 0,878 US $/t ukupna vrednost metala u rudi 29,663 US $/t bila bi značajno veća od ukupnih troškova eksploatacije i mogla bi da omogući i pozitivne efekte eksploatacije.

Očigledno je da dominantu ulogu na ekonomske efekte poslovanja ima cena bakra, zlata i srebra. Analizirajući period od poslednjih 15 godina beleže se značajne promene cena obojenih i plemenitih metala. Bakar je imao cenu i ispod 1.800 US$/t pa do blizu 10.000 US$/t. U ranijem periodu [5] vršene su ekonomske analize koje su bile bazirane na cenama metala od 2.400 US$/t, kakve su i bile na početku poslednje decenije prošlog veka. Detaljna analiza ukazuje da je neophodno sagledati kakve su promene vrednosti rude i vrednosti rude za rudarenje, pri promenljivim cenama bakra i sadržajima metala u rudi. Zaključak je da troškovi podzemne eksploatacije ne mogu biti ispod 7 – 8 US$/t, a da su troškovi troškove flotacijske i metalurške prerade mnogo veći od prosečno planiranih. To zahteva da se eksploatacija obavlja unutar konture rudnog tela sa višim sadržajem metala (0,5 %), u kojoj je prosečni sadržaj metala u rudi 0,8 % (sl. 2.)



Sl. 2. *Grafik funkcionalne zavisnosti promene sadržaja metala u rudi od cena bakra na svetskom tržištu, a za različite troškove dobijanja (5 – 10 US$/t)*

4. ZAKLJUČAK

Pri analizi objektivne mogućnosti ekonomične eksploatacije rude bakra najveći uticaj imaju vrednost rude i plementih metala koji zavise od sadržaja korisnih komponenti i od njihovih cena na svetskom tržištu i troškovi podzemne eksploatacije, flotacijske pripreme i metalurške prerade. U ovom radu proračuni su uradjeni za rudno telo „Borska reka“ iznad XIX horizonta, preostale rude u rudnim telima „Tilva Roš“ i „P_2A“, „T3“ i „D“. Prema podacima koji su preuzeti iz tehničke dokumentacije RBB-a i to: srednji sadržaji bakra Cu = 0,763 %, zlata Au = 0,315 g/t, i srebra Ag = 1,67 g/t, i cena (na dan ocene) bakra 4.500 US $/t, zlata 34 350 US $/kg i srebra 450 US $/kg, dobija se vrednost bakra u rudi 25,778 US $/t. Ekvivalentni sadržaj bakra u rudi koji odgovara ukupnoj vrednosti metala $m_{ekv.}$ = 0,878 % povećava vrednost bakra tako da je ukupna vrednost metala u 1 t rude 29,663 US $/t.

Ovako dobijena vrednost rude može omogućiti ekonomsku opravdanost podzemne eksploatacije pod uslovom da su troškovi dobijanja 10 US $/t, troškovi flotacijske pripreme do 4 US $/t i troškovi metalurške prerade manje od 4 US $/t.

Međutim, ostvareni troškovi u praksi su mnogo veći zbog razuđenosti rudnih tela koja se sada otkopavaju i pre svega male godišnje proizvodnje u Jami od samo 700.000 t. Troškovi flotacijske pripreme, takođe, nadmašuju vrednosti troškova zbog zastarelosti opreme. Višestrukim povećanjem godišnjeg kapaciteta, značajno se smanjuju jedinični troškovi, svedeni na tonu dobijene rudne mase, a samim tim i ukupni troškovi. To je i osnovni zahtev za buduću podzemnu eksploataciju u Jami Bor.

LITERATURA

[1] Ž. Milićević, R. Nikolić, Osnove projektovanja rudnika. Univerzitetski udžbenik. Bor, 2003. godine

[2] V. Milić, Ž. Milićević, Osnovi eksploatacije ležišta mineralnih sirovina. Osnovi univerzitetski udžbenik. Bor, 2005.

[3] Ž. Milićević, Valorizacija siromašnih ruda bakra zavisi i od odredjivanja realne vrednosti rude. 23. Oktobarsko savetovanje rudara i metalurga, D. Milanovac 1991. s. 457.

[4] Ž. Milićević, D. Stanujkić, V. Milić, Optimizacija parametara metode podetažnog zarušavanja. II Medjunarodni simpozijum Primena matematičkih metoda i računara u geologiji, rudarstvu i metalurgiji“. Beograd 1991. s.457.

[5] Ž. Milićević, Objektivne mogućnosti rudarenja u rudnicima bakra RTB – Bor. 33. Oktobarsko savetovanje rudara i metalurga, Bor 2001. s. 1.

[6] Tehnička dokumentacija RBB, pogon Jama Bor. Godišnji operativni plan. Bor, 2014.

[7] http://www.infomine.com/investment/metal-prices/ ….. 2015. godine

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CHANGES IN Pt-Rh CATALYSTS IN THE WORKING ENVIRONMENT***

Abstract

The surface reconstruction on rhodium-platinum catalyst gauzes has been examined using the scanning electron microscope techniques. The nucleation and growth of large cage-like features, developed on the gauze surfaces during operation in the ammonia oxidation process, were studied in detail. It is concluded that a vapor phase mechanism involving transport of platinum oxide is responsible for the observed reaction, and the reason why this process operates only over a limited range of temperature and pressure is explained. Some comments are also made on the related reconstruction observed on gauzes, used during the production of hydrogen cyanide by the Andrussow process.
***Keywords**: platinum, platinum catalyst gauze*

INTRODUCTION

Rhodium-platinum gauzes serve as catalysts for the oxidation of ammonia during production of nitric acid and for manufacture of hydrogen cyanide. The former, which is based upon the reaction

$$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$$

has given rise to several papers previously published here [1-4], and manufacture of hydrocyanic acid from methane, ammonia and air by the Andrussow process

$$2CH_4 + 2NH_3 + 3O_2 \rightarrow 2HCN + 6H_2O$$

has also been reported [5].

There have been many studies of the surface reconstruction processes which take place when platinum and rhodium-platinum gauzes are used in such catalytic reactions [6, 7]. Flytzani-Stephanopoulos and Schmidt have reviewed the available literature on thermal etching and morphological changes [8-10]. Most studies have been carried out on pure platinum, with more limited work on rhodium-platinum. Features observed include facets, pits and more extensive cage-like growths. The latter are particularly common under commercial plant operating conditions and therefore merit special attention.

A number of questions remain unanswered from the previous investigations. The mechanism for the nucleation and growth of the cage-like structures is not clear, and the reasons why they are observed only over a limited range of temperature and gas mixtures are not explained. Also their relation to the faceting and pitting observed

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at high temperatures is not understood. Furthermore, the effect of the presence of rhodium on the reconstruction process has not been studied in detail. Identical gauzes are used in hydrogen cyanide production. These run at higher temperatures and they also face and heavily reconstruct. It has never been fully explained why their reconstructions differ, nor why there is a much lower rate of metal loss in this process-whereas metal loss from ammonia oxidation gauzes is 13 per cent ammonia (corresponding to operating temperatures of 650 to 1200^{0}C) for times from 0.5 to 15 hours. Gauze temperatures where measured by pyrometry and conversion efficiencies by wet chemical analysis. A scanning electron microscope was used to study the surface microstructural changes occurring on 10 per cent rhodium-platinum gauzes, with some work being carried out on pure platinum gauzes for comparison.

OBSERVATION THE SURFACES

The results exposing rhodium-platinum gauzes to 6, 8 10 and 12 per cent ammonia-air mixtures in the miniature reactor for fifteen hours show in Figure 1. The reconstruction process occurs only over a limited range of gas mixtures. It is particularly interesting to note that at 6 per cent ammonia, the catalytic reaction virtually stopped after only four hours, leaving a herringbone-type of structure on the surface. After operation in 12 per cent ammonia, the gauze surface was smooth with angular holes and cavities. Only at intermediate ammonia concentrations did extensive surface reconstruction occur. All the effects occurred at slightly lower ammonia levels than in a commercial plant, apparently due largely to differences in heat dissipation conditions in the miniature reactor.

The nucleation of reconstruction was studied using a shorter exposure time of two hours. Figure 3 shows the role of re-crystallization and grain boundaries. The asreceived gauze shows surface markings due to wire drawing. However, during pretreatment with a hydrogen torch the gauze re-crystallizes from its drawn texture, and grain boundary grooves become clearly visible. The following exposure for two hours in the reactor in 10 per cent ammonia, deep cavities develop along grain boundaries, while similar exposure in 13.5 per cent ammonia results in a smooth more rounded surface.

The progressive development with time of the cage-like growths, including the encroachment into grain interiors, can be seen in Figure 4, which shows the effects of exposure for 0.5, 1,2 and 4 hours in an air 8 per cent ammonia mixture. After only half an hour the previously smooth re-crystallized surface shown in Figure 2 (b) has started to reconstruct, Figure 3 (a), this seeming to occur most extensively on some preferred-orientation grains. Figure 3 (b) shows the build up of the growths on these crystals. It is interesting to note the part played in propagating the reconstruction into grain interiors by the intersection of thermal facets and grain boundary grooves. Figures 3 (c) and 3 (d) show clearly that the reconstruction spreads out from these intersection points. The surface is finally completely covered by the cage-like growths as in Figure 1 (b).

The larger pilot plant was used to compare pure platinum and rhodium-platinum alloy catalyst gauzes. This allowed accurate observation of the two types of catalyst materials under identical operating conditions. The pilot plant gave same type of reconstruction for a given gas mix as a commercial plant, with a rate of reconstructions somewhat faster than that of a commercial plant but slower than for the miniature laboratory reactor. The reconstruction in the case of pure platinum gauzes was significantly faster than that for identically treated alloy gauzes. For example, Figures 4 (a) and 4 (b) show the microstructures observed on the two types of gauze after a two hour exposure to a 10 per cent ammonia mixture. It is possible that the presence of rhodium on surface layer of catalyst restricts the rate of platinum evaporation, so reducing the vapor transport processes. This is considered below.

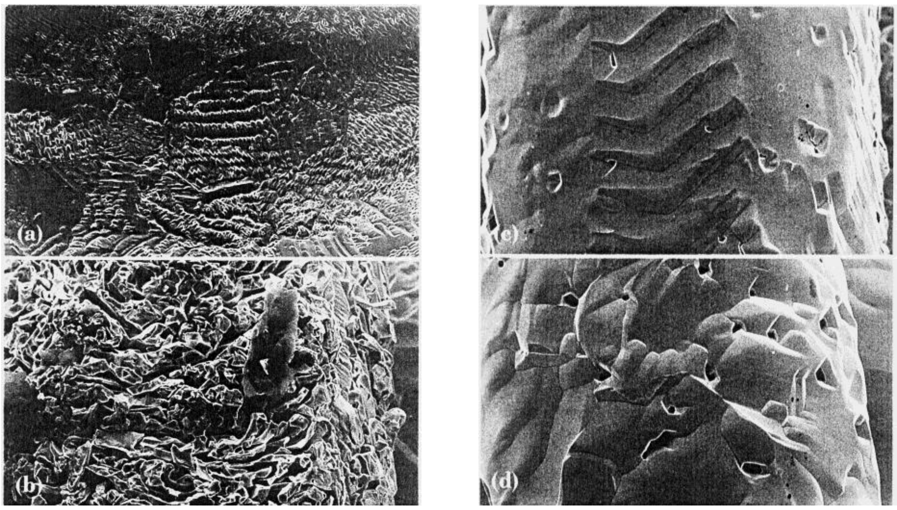

Fig. 1 *These gauzes, which were exposed to a range of gas mixtures during operation for 15 hours in a miniature reactor, demonstrate that the changes in surface structure are influenced by the gas mixture: a) air-6 per cent ammonia, this catalyst became inactive during operation, b) air-8 per cent ammonia, c) air-10 per cent ammonia, d) air-12 per cent ammonia, x1000*

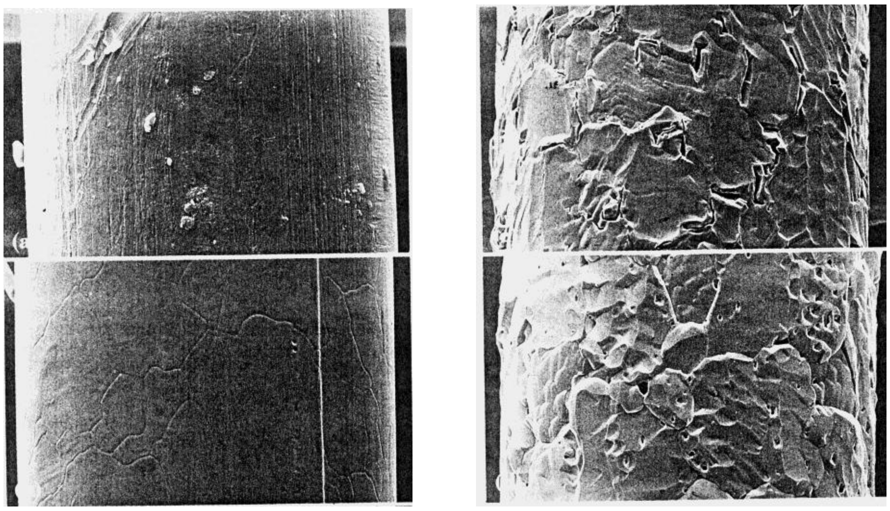

Fig. 2 *The nucleation of the reconstruction process was observed on gauzes after two hours in a miniatures reactor. a) Drawing striations are visible on the as-received gauze, but pretreatment in a hydrogen flame causes re-crystallization b) when the grain boundaries become visible. Exposure to air-10 per cent ammonia c) results in development of deep cavities along grain boundaries, while in air-13 per cent ammonia d) more rounded holes develop and the surface is smoother, x1000*

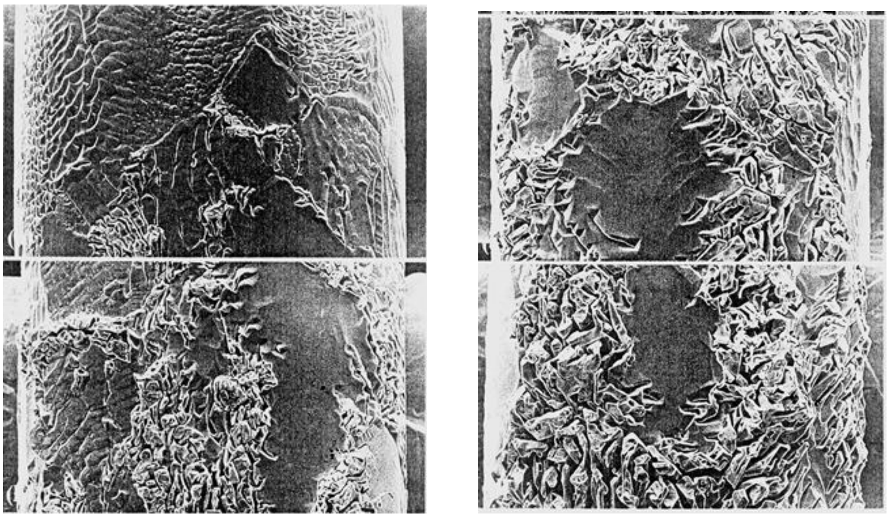

Fig. 3 *On rhodium-platinum gauzes exposed to air-8 per cent ammonia the progressive build up of the reconstructing surface can be seen with increasing time, until the surface becomes completely covered by the cage-like, growths, a) ½ hour, b)1 hour, c) 2 hours and d) 4 hours, x1000*

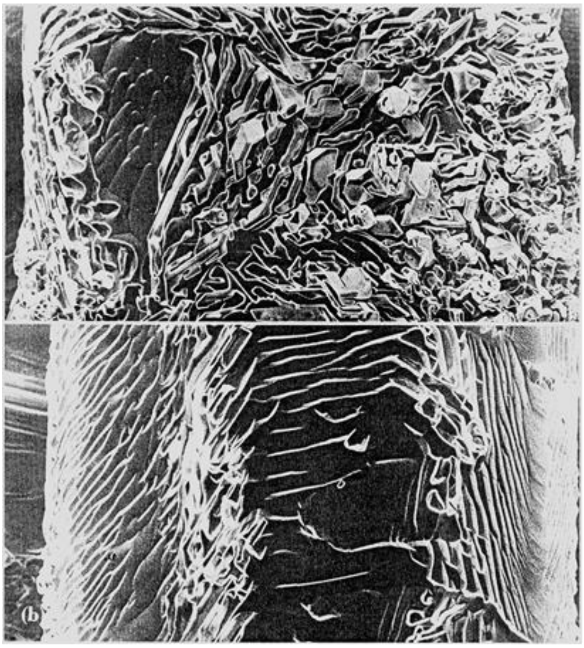

Fig. 4 *After reaction in the pilot plant for two hours in an air-10 per cent ammonia mixture, it is apparent that the rate of reconstruction the surfaces of pure platinum and 10 per cent rhodium-platinum are markedly different. In each case the leading face of the third gauze in a pack is shown a) pure platinum, b) rhodium-platinum, x1600*

RESULTS AND DISCUSSION

The high vapor pressure of PtO_2 compared to that of platinum [11-14], along with the observations of weight losses from operational gauzes – and hence the need for catchment gauzes (II) – indicate that there is substantial PtO_2 volatilization in the ammonia oxidation process. A vapor phase mechanism for reconstruction is therefore likely, as first proposed by Schmidt and colleagues [15-18]. This model has been developed further, to explain the microstructural features of reconstruction and their dependence on conditions such as gas composition and temperature [19,20]. Consider the boundary between two grains, where a groove will develop on heating simply due surface tension effects. The feed gas contains excess oxygen and the catalytic reaction is very efficient so most of ammonia will be oxidised on initial contract with the outer surface of gauze. The gas reaching the bottom of the grain boundary groove will therefore be more strongly oxidizing than the gas on surface. Platinum oxide will form here preferentially, and will diffuse outwards, to where it meets a more reducing atmosphere, and so platinum will be deposited on the outer surface. Thus the grooves will deepen, and the surface will build up, resulting in the hollow cage-like growths seen on reconstructed gauzes, the process being driven by gradients in oxygen potential. The intersections between thermal facets on the grain surfaces and grain boundary grooves form particularly potent sites for the nucleation and development of the surface growths, since these are the most deeply recessed points on the gauze surfaces.

To understand why the reconstruction occurs only over a limited range of temperature and gas mixtures, the main physical processes taking place on the gauzes have to be considered:

- Platinum oxide vapor formation, migration and decomposition
- The selective oxidation of the rhodium species
- Thermal faceting
- The formation of grain boundary grooves
- Surface diffusion
- Bulk diffusion in both the metal and the oxide.

CONCLUSION

The extent of each process is dependent on the reaction conditions, the vapour transport process dominating over only a limited range of these conditions. If the temperature is too low (low ammonia content in the gas stream), there is insufficient PtO_2 vapor pressure, so the dominant process is the selective oxidation of rhodium to form Rh_2O_3. Under these conditions, the catalyst is rapidly deactivated. If the temperature is too high (high ammonia content), then the surface and bulk diffusion are greatly enhanced, leading to a smoothing out of the surface features and a consequent large reduction the surface area. The lower rate of reconstruction observed in the case of rhodium-platinum gauzes suggests that the partial vapor pressure of PtO_2 over the alloy is lower than over pure platinum. This would help to explain the reduced weight losses observed commercially when the alloy gauzes are used.

REFERENCES

[1] Pielaszek, Platinum Metals Rev., 28(3) (1984) 109-114.

[2] A. R McCabe, G. D. W. Smith, Platinum Metals Rev. 27(1) (1983) 19-25.

[3] A. E. Heywood, Platinum Metals Rev., 26(1) (1982) 28-32.

[4] F. Sperner, W. Hohmann, Platinum Metals Rev., 20(1)(1976) 12-20.
[5] J. M. Pirie, Platinum Metals Rev., 2 (1) (1958) 7-11.
[6] J. A. Busby, A. G. Knapton, A.E.R. Budd, Proc. Fertiliser Society, 1978, pp.169.
[7] L. D. Schmidt, D. Luss, F. Catal., 22(2) (1971) 269-279.
[8] M. Flytzani-Stephanopoulos, L. D. Schmidt, Prog. Surf, Sci., 9 (3) (1979) 83-111.
[9] A. R. McCabe, G. D. W. Smith, Platinum Metals Rev., 32(1) (1988) 11-18
[10] A. S. Darling, Int. Metall. Rev., 18 (3) (1973), 91-122.
[11] H. Holzmann, Platinum Metals Rev., 13 (1) (1969) 2-8.
[12] R. W. McCabe, T Pignet, L. D. Schmidt, F. Catal., 32 (1) (1974) 114-126.
[13] M. Flytzani-Stephanopoulos, S. Wong and L.D. Schmidt, F. Catal, 49 (1) (1977) 51-82
[14] A. R. McCabe and G.D.W. Smith, 8th International Congress on Catalysis, Berlin (West), Germany, Publ Verlag-Chemie, Berlin 1984, Vol. 4, pp. 73-84.
[15] L. Hannevold, O. Nilsek, A. Kjshus, H. Fjellray, Applied Catalysis A: General, 284 (1-2) (2005)163-176.
[16] L. Hannewold, Applied Catalysis A: General, 284 (1-2) (2005)185-192.
[17] R. Kraehnert, M. Baerns, Applied Catalysis A: General, 327(1)(2007)73-81
[18] V. Meille., Applied Catalysis A: General, 315(2006)1-17
[19] I. B. Chatterj, J. B. Joshi, Chemical Engineering Journal, 125(3)(2007) 149-163.
[20] A. Kolodziej, S. Lojewska, Chemical Engineering and Processing, 48(3)(2009) 816-822.
[21] J. Cher, B. Lim, EW. P. Lee, Y. Xia, Chemical Engineering and Processing 4(2009)81-95.
[22] B. Trumić, D. Stanković, S. Dimitrijević, A. Ivanović, L. Gomidželović, S. Marjanović, Copper 39(2)(2014) 89-94.
[23] B. Trumic, L. Gomidželović, A. Ivanovic, S. Dimitrijevic, S. Marjanovic, V. Krstić, D. S. Stankovic, Copper 40(1)(2015) 17-24.

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SELECTION OF THE IMPACT ROLLERS OF BELT CONVEYOR

Abstract

This work gives the methodology of impact rollers calculation on the example of a shuttle belt conveyor for ore T 3506 designed for the needs of the Majdanpek open pit with capacity of 1600 t/h. The analysis was made by calculation according to the manufacturer instructions of the "Rulmeca" company and it includes checking the static and dynamic load on the impact rollers. The technical characteristics of the impact rollers are also given as well as their graphical representation.

***Keywords**: belt conveyor for ore, impact rollers calculation, technical characteristics*

1 INTRODUCTION

At the loading part of a belt conveyor carrying rollers, besides being subjected to the weight of material and the weight of conveyor belt, are also subjected to the impact load of material falling on a conveyor belt. This impact load has to be taken into account in selecting the carrying rollers on points where the loading of material takes place.

The shuttle belt conveyor for ore T 3506 is placed above the open storage for ore and it is designed in such a way that the loading of material is done via stationary belt conveyor T 3507 and material discharge is done through a drive pulley or take up pulley depending on a conveyor belt direction. During the operation of belt conveyor, it moves translationally in order to fill the open storage for ore in the full length. As a result of translation motion of belt conveyor, the material loading also takes place in the full length of belt conveyor dictating the selection of carrying rollers as impact rollers.

The shuttle belt conveyor for ore T 3506 is made as horizontal one, and carrying rollers are made as the impact rollers placed in troughing sets containing three rollers in each set [1].

2 TECHNICAL DESCRIPTION OF IMPACT ROLLERS

Impact rollers consist of a steel roller with diameter lesser than nominal diameter of the roller itself on which rubber rings are fitted which serve for amortization when material falls on the belt.

Impact roller (label PSV4,30F,159NA, 473; manufacturer Rulmeca) belongs to the PSV series of rollers and consists of roller shell, bearing housings, spindle, bearings, sealing and rubber rings. The roller shell is a machined steel pipe for which the bearing housings are welded. The bearing housings are made of steel by deep drawn with subsequent machining so that, along with the roller shell, they make a compact assembly

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providing good balance and concentricity of the assembly parts. The spindle is made of steel, it is machined and deep groove ball bearings with single raw 6206 are fitted on it. Sealing includes the external stone guard, external section and internal section. The sealing prevents the ingress of impurities from outside (dust, sand, water etc.), impurities from inside (rust, condensate) and it also insures the lubrication of the bearings by grease. The rubber rings are fitted on the outer side of roller shell. Total mass of the roller is 12.6 kg. The impact roller sectional view is given in Figure 1.

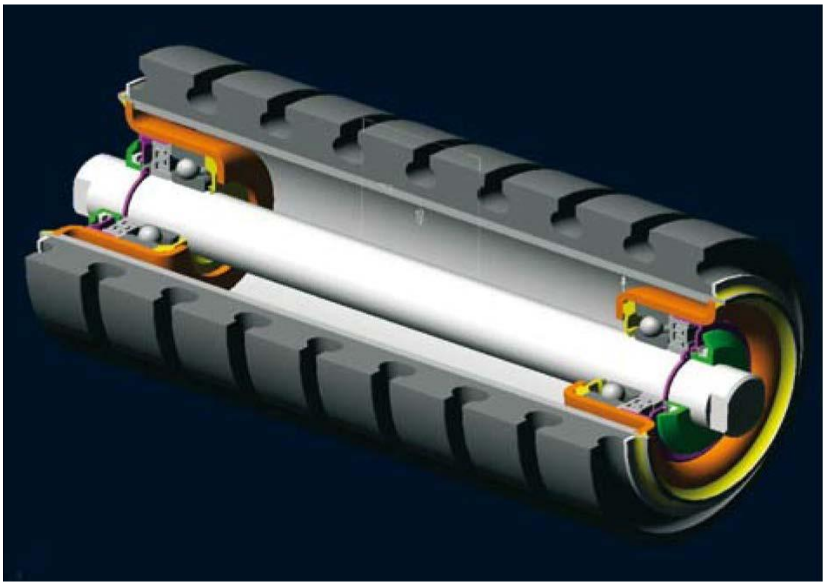


Figure 1 *Impact roller sectional view*

The impact roller PSV4,30F,159NA, 473 dimensions are given in Figure 2.

Øe=159 mm
D=89 mm
d=30 mm
d_1=30 mm
ch=22 mm
A=497 mm
B=465 mm
C=473 mm
E=50 mm

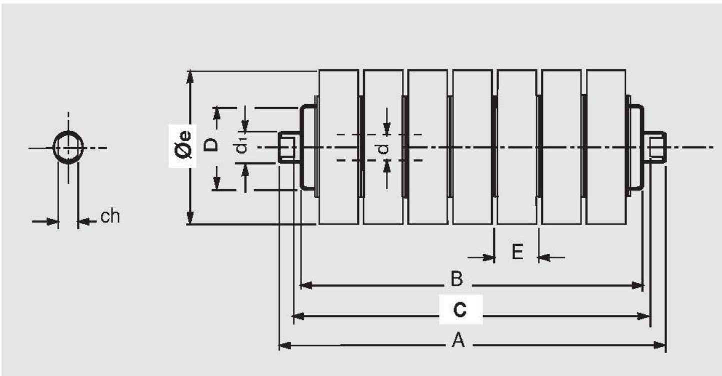
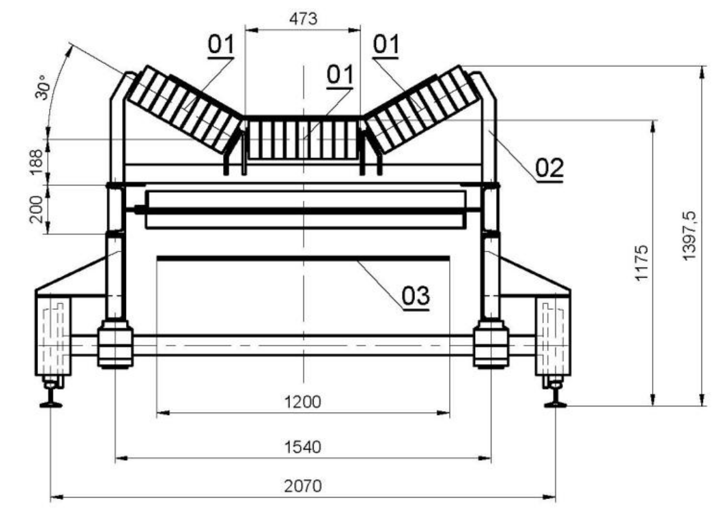


Figure 2 *Impact roller PSV4,30F,159NA,473 dimensions*

Three impact rollers are placed in the troughing set (label A3P/55,1200,F22,H188, YA,R; manufacturer Rulmeca) made of steel profiles. The side rollers are inclined at an angle of , as it can be seen from the conveyor cross section, while the central roller is horizontal so it is located in the most unfavourable position in terms of load.

Cross sectional view of the shuttle belt conveyor T 3506 is given in Figure 3.



Legend:
Pos. 01 Impact roller PSV4,30F,159NA,473
Pos. 02 Troughing set A3 P/55,1200,F22,H188,YA,R
Pos. 03 Belt 1200/4 EP250 10/3

Figure 3 *Cross section of shuttle belt conveyor T 3506*

3 CALCULATION OF IMPACT ROLLERS

3.1 Constant loading with uniform fine material

1. Calculation of impact rollers according to this criterion is aimed for selection the impact roller of suitable capacity regarding the total load consisting of the impact force of material on one side, and on the other side consisting of the load of material and belt weight, and it is given according to [2].

2. Impact force

3. Impact force on the central roller

where:

– - belt load capacity

- load fall height

- participation factor of roller under the highest stress for side rollers inclination angle of

4. Static load on the carrying troughing set

5. Dynamic load on the carrying troughing set

6. Load on the roller carrying the highest force

Where are:

- spacing of carrying troughing sets

— - mass of belt per linear meter

– - belt load capacity

– - belt speed

[-] - impact factor for lump size of and belt speed of the belt conveyor of –

[-] - service factor of belt conveyor operation of over 16 h/day

[-] - environment factor for present abrasive or corrosive material

[-] - participation factor of roller under the highest stress for side rollers inclination angle of

7. Total load on the troughing set central roller

where:

- roller load capacity for belt speed of – and working life of .

3.2 Loading of material consisting of large lumps

1. Calculation of impact rollers according to this criterion is aimed to check the bearings static load of selected roller compared with dynamic falling force during material fall, and it is given according to [2].

2. Dynamic falling force during material fall

where:

- mass of material lump for ; prismatic shape of lumps and material density of —

- load fall height

— - constant of elasticcity for impact rollers with rubber rings

- bearing static load for bearing 6206 in kg

4 DISCUSSION OF CALCULATION

The results obtained by calculation indicate that the selection of an impact roller primarily depends on the impact load value of the material falling on the belt of conveyor.

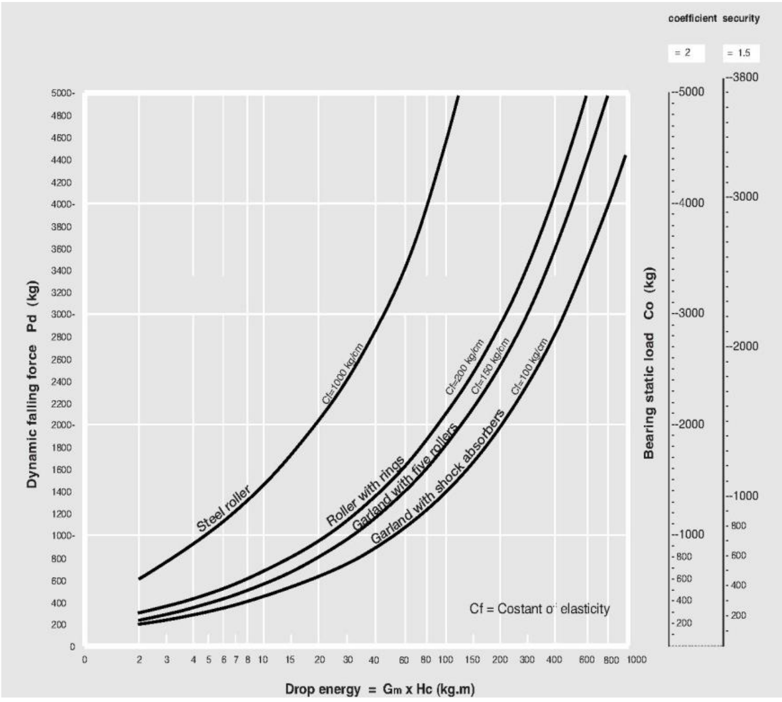


Figure 4 *Diagram of relation between dynamic falling force of material fall and drop energy*

In calculation by the first criterion the total load on the troughing set central roller is compared with the load capacity of the flat steel roller with diameter of 89 mm on which rubber rings are fitted. In the calculation by the second criterion, the required bearing static load is determined with coefficient of security 2 assuming that only one of two roller bearings can with-stand the total dynamic falling force of material fall. For simpler determination the dynamic falling force of material fall, there is a diagram in literature [2] given in Figure 4 that shows the relation between it and the drop energy expressed as a product for different cases of amorti-zation considering the required bearing static load with corresponding security coefficient.

5. CONCLUSION

As it can be seen from the calculation, the selected roller PSV4,30F,159NA,473 meets both criteria, i.e. at constant loading with uniform fine material and at loading of material consisting of large lumps.

Impact rollers selection is often done from the manufacturer catalogue data. On this occasion, it is necessary to analyze how the impact roller works in the given operating conditions, so this work may be a useful contribution in that sense.

REFERENCES

[1] Technical Design of Relocation the Crushing Plant from the North Mining District and Construction a New Transport System No. 3 for Ore of the

South Mining District Deposit in the Copper Mine Majdanpek - Technical Mechanical Design of Installation the Primary Sieve with Stacker for Large Fraction Screening Product and Reversible Conveyor"; Mining and Metallurgy Institute Bor; Section MEGA; 2013 (in Serbian);

[2] Rollers and Components for Bulk Handling; Rulmeca Company Catalogue, Rulli Rulmeca S.p.A.; 4th edition; July 2003.

[3] R. Rajković, R. Lekovski, B. Rajković, "Transportation Costs of Stacionary Conveyor for Overburden Transportation System of Veliki Krivelj copper Pit in Relation to Inclination of Bearing Rollers", 39th International October Conference on Mining and Metallurgy, 07-10. October 2007, Soko Banja - Serbia.

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IZBOR AMORTIZACIONIH ROLNI TRAKASTOG TRANSPORTERA ZA RUDU

Izvod

U ovom radu je, na primeru pokretnog reverzibilnog trakastog transportera za rudu T 3506 projektovanog za potrebe površinskog kopa u Majdanpeku sa kapacitetom 1600 t/h, data metodologija proračuna amortizacionih rolni.

Analiza je urađena računskim putem prema uputstvima proizvođača firme "Rulmeca" i obuhvata proveru statičkog i dinamičkog opterećenja amortizacionih rolni.

Takođe su date tehničke karakteristike amortizacionih rolni kao i njihov grafički prikaz.

***Ključne reči**: trakasti transporter za rudu, proračun amortizacionih rolni, tehničke karakteristike*

1. UVOD

Na utovarnom delu trakastog transportera noseće rolne su pored opterećenja od težine materijala i od težine transportne trake opterećene i na udarno opterećenje od materijala koji pada na transportnu traku. Ovo udarno opterećenje neophodno je uzeti u obzir pri izboru nosećih rolni na mestima gde se obavlja utovar materijala na traku.

Pokretni reverzibilni trakasti transporter za rudu T 3506 je pozicioniran iznad otvorenog sklada za rudu i projektovan je tako da se utovar materijala obavlja preko stacionarnog trakastog transportera T 3507, a istovar materijala se obavlja preko pogonskog ili zateznog bubnja u zavisnosti od smera kretanja trake transportera. Pri radu transportera on vrši translatorno kretanje kako bi se obavilo punjenje otvorenog sklada za rudu po celoj dužini. Kao posledica translatornog kretanja transportera i utovar materijala se obavlja po celoj njegovoj dužini što uslovljava izbor nosećih rolni kao amortizacionih.

Pokretni reverzibilni trakasti transporter za rudu T 3506 je izveden kao horizontalni, a noseće rolne su izvedene kao amortizacione i nalaze se u slogovima od po tri rolni u svakom slogu [1].

2. TEHNIČKI OPIS AMORTIZACIONIH ROLNI

Amortizacione rolne se sastoje od čelične rolne manjeg prečnika od nazivnog prečnika same rolne na koju su montirani gumeni prstenovi koji služe za amortizaciju pri padu materijala na traku.

Amortizaciona rolna (oznake PSV4,30F, 159NA,473; proizvođača Rulmeca) pripada seriji PSV rolni i sastoji se od omotača rolne, kućišta ležajeva, osovine, ležajeva, zaptivača i gumenih prstenova. Omotač rolne predstavlja obrađenu čeličnu cev za koju se zavaruju kućišta ležajeva. Kućišta ležajeva se izrađuju dubokim izvlačenjem od čelika sa nahnadnom mašinskom obradom tako da

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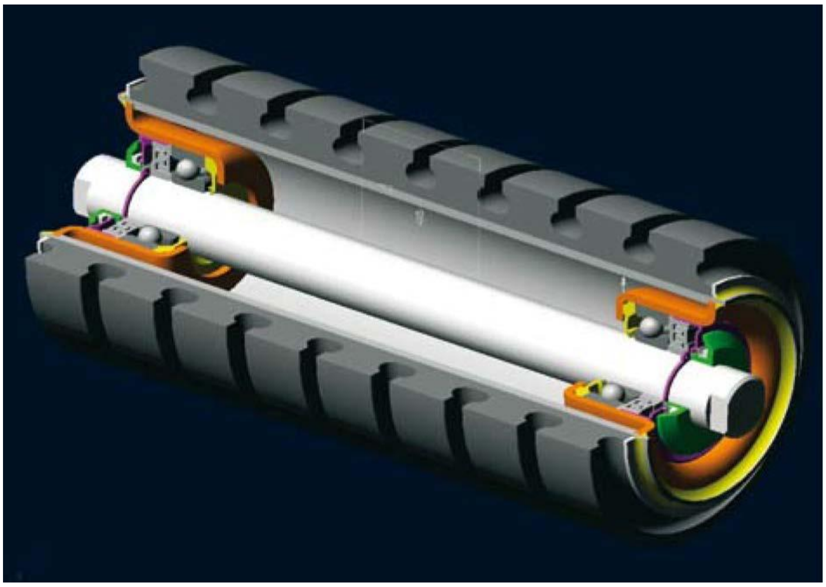
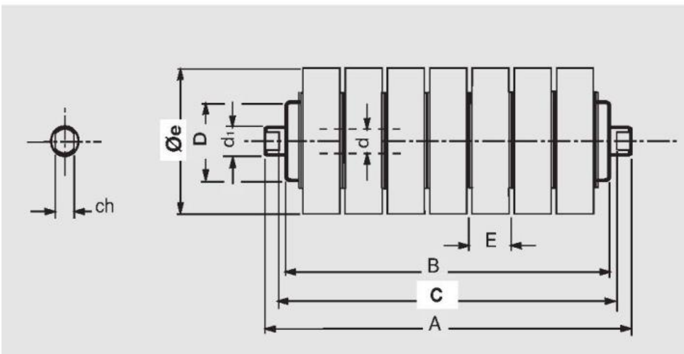
sa omotačem rolne čine jedan kompaktan sklop koji obezbeđuje dobro balansiranje rolne i koncentričnost elemenata sklopa. Osovina je od čelika, mašinski obrađena i na nju se montiraju prsteni kuglični jednoredi ležajevi 6206. Zaptivanje obuhvata spoljašnji štitnik, spoljašnju i unutrašnju sekciju. Zaptivanjem se onemogućava prodor nečistoća sa spoljašnje strane (prašina, pesak, voda itd.), nečistoća sa unutrašnje strane (rđa, kondenzat) i takođe se osigurava podmazivanje ležajeva mašću. Sa spoljne strane omotača rolne montiraju se amortizacioni gumeni prstenovi. Ukupna masa rolne je 12,6 kg. Amortizaciona rolna u preseku data je na slici 1.



Sl. 1. *Amortizaciona rolna u preseku*

Dimenzije amortizacione rolne PSV 4,30F,159NA,473 su date na slici 2.

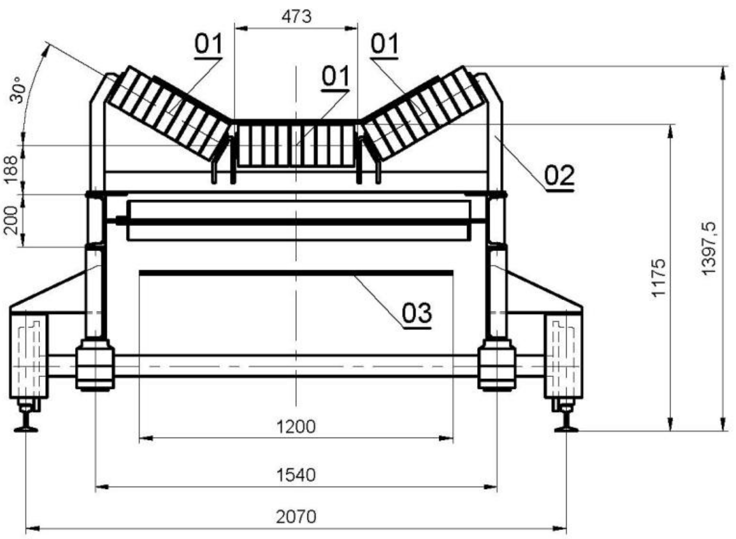
Øe=159 mm
D=89 mm
d=30 mm
d_1=30 mm
ch=22 mm
A=497 mm
B=465 mm
C=473 mm
E=50 mm



Sl. 2. *Dimenzije amortizacione rolne PSV4,30F,159NA,473*

U nosećem slogu (oznake A3P/55,1200, F22, H188,YA,R; proizvođača Rulmeca) izrađenom od čeličnih profila nalaze se tri amortizacione rolne. Bočne rolne su nagnute pod uglom , kao što se vidi u poprečnom preseku transportera, dok je centralna rolna horizontalna tako da se ona nalazi u najnepovoljnijem položaju u smislu opterećenja.

Prikaz poprečnog preseka pokretnog reverzibilnog trakastog transportera T 3506 dat je na slici 3.



Legenda:
Poz. 01 Amortizaciona rolna PSV4,30F,159NA,473
Poz. 02 Noseći slog A3 P/55,1200,F22,H188,YA,R
Poz. 03 Traka 1200/4 EP250 10/3

Sl. 3. *Poprečni presek pokretnog reverzibilnog trakastog transportera T 3506*

3. PRORAČUN AMORTIZACIONIH ROLNI

3.1. Konstantan utovar sa ravnomernim sitnim materijalom

1. Proračun amortizacionih rolni prema ovom kriterijumu ima za cilj izbor amortizacione rolne odgovarajuće nosivosti prema ukupnom opterećenju od udarne sile materijala sa jedne strane i opterećenju od težine materijala i trake sa druge strane i dat je prema [2].

2. Udarna sila

3. Udarna sila na centralnu rolnu

gde su:

– - kapacitet transportera

- visina pada tereta

- uticajni faktor rolne pod najvećim opterećenjem za ugao nagiba bočnih rolni

4. Statičko opterećenje na noseći slog

5. Dinamičko opterećenje na noseći slog

6. Opterećenje na rolnu koja nosi najveću silu

gde su:

- rastojanje nosećih slogova

— - masa trake po dužnom metru

– - kapacitet transportera

— - brzina trake

- faktor udara za veličinu komada i brzinu trake trakastog transportera —

- radni faktor za rad trakastog transportera preko 16 h dnevno

- faktor radne sredine za prisutan abrazivni ili korozivni materijal

- uticajni faktor rolne pod najvećim opterećenjem za ugao nagiba bočnih rolni

7. Ukupno opterećenje na centralnu rolnu nosećeg sloga

gde je:

- nosivost rolne za brzinu trake — i za radni vek od .

3.2. Utovar sa materijalom koji se sastoji od krupnih komada

1. Proračun amortizacionih rolni prema ovom kriterijumu ima za cilj proveru statičke nosivosti ležajeva izabrane rolne u odnosu na dinamičku silu pri padu materijala i dat je prema [2].

2. Dinamička sila pri padu materijala

gde su:

- masa komada materijala za ; prizmatični oblik komada i stvarnu gustinu materijala —

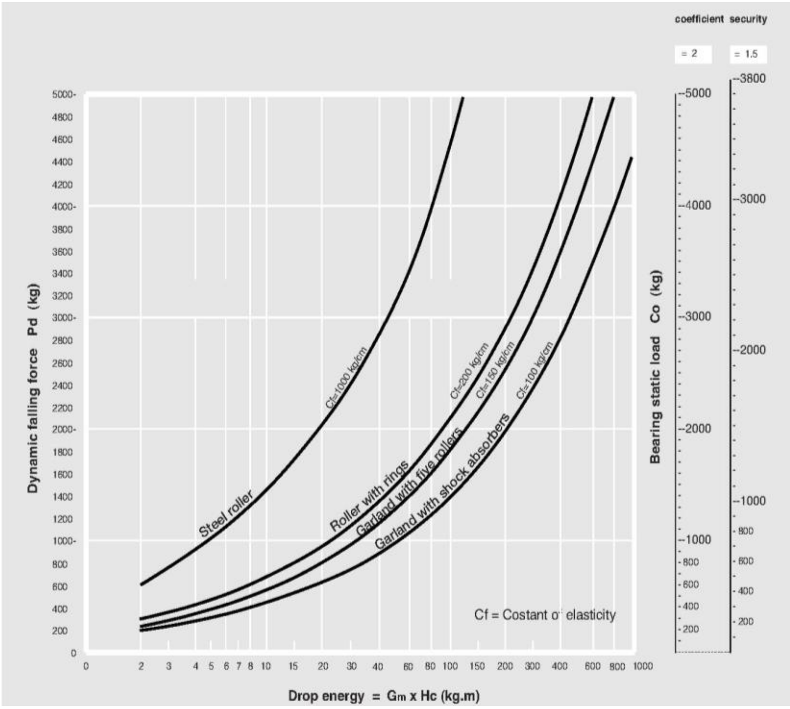
–visina pada tereta

— - koeficijent elastičnosti amortizacionih rolni za rolne sa gumenim prstenovima

- statička nosivost ležaja 6206 u kg

4. DISKUSIJA PRORAČUNA

Proračunom dobijeni rezultati pokazuju da izbor amortizacione rolne zavisi pre svega od veličine udarnog opterećenja od materijala koji pada na transportnu traku.



Sl. 4. *Dijagram zavisnosti dinamičke sile od pada materijala od energije pada*

Pri proračunu po prvom kriterijumu se ukupno opterećenje na centralnu rolnu nosećeg sloga upoređuje se nosivošću glatke čelične rolne prečnika 89 mm na koju se montiraju gumeni prstenovi. Pri proračunu po drugom kriterijumu se potrebna statička nosivost ležajeva usvaja sa stepenom sigurnosti 2 odnosno pretpostavlja se da celokupnu dinamičku silu od pada materijala može da primi samo jedan od dva ležaja rolne. Za jednostavnije određivanje dinamičke sila od pada materijala u literaturi [2] se daje dijagram dat na crtežu 4. u kome se ona daje u zavisnosti od energije pada kao proizvoda za različite slučajeve amortizacije uzimajući u obzir potrebnu statičku nosivost ležajeva sa odgovarajućim stepenom sigurnosti.

5. ZAKLJUČAK

Kao što se iz proračuna vidi izabrana rolna PSV4,30F,159NA,473 zadovoljava po oba kriterijuma tj. pri konstantnom utovaru sa ravnomernim sitnim materijalom i pri utovaru sa materijalom koji se sastoji od krupnih komada.

Izbor amortizacionih rolni često se vrši iz kataloških podataka proizvođača. Tom prilikom je potrebno analizirati kako se amortizaciona rolna ponaša u datim radnim uslovima, te ovaj rad može biti koristan doprinos u tom smislu.

LITERATURA

[1] „Tehnički projekat preseljenja drobiličnog postrojenja sa Severnog revira i izgradnje novog transportnog sistema br. 3 za rudu ležišta Južni Revir

u Rudniku bakra Majdanpek-Tehni-čki mašinski projekat ugradnje primarnog sita sa odlagališnim transporterom za nadrešetni proizvod i reverzibilnim transporterom"; Institut za rudarstvo i metalurgiju Bor; odeljenje MEGA; 2013.

[2] Katalog firme Rulmeca: „Rollers and components for bulk handling"; Rulli Rulmeca S.p.A.; 4. izdanje; jul 2003.

[3] R. Rajković, R. Lekovski, B. Rajković, "Troškovi transporta stacionarnim transporterom transportnog sistema jalovine površinskog kopa bakra "Veliki Krivelj" u funkciji nagiba nosećih valjaka", 39. Međunarodno oktobarsko savetovanje o rudarstvu i metalurgiji, 07-10 oktobar 2007, Soko Banja - Srbija.

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Milena Jovašević-Stojanović[**]

MEASURING THE CONCENTRATION OF SUSPENDED PARTICLES (PM_{10}) IN THE INDOOR ENVIRONMENT USING THE AUTOMATIC MONITORS[***]

Abstract

The aim of this paper was to determine the applicability of the automatic monitors for measuring the indoor air pollution with suspended particles, PM_{10} fraction. The measurement results of the automatic monitor were compared with the results obtained by the reference gravimetric method. Comparative measurements over a period of 50 days were carried out during the winter of 2012 in the Laboratory of Applied Electronics in the Mining and Metallurgy Institute Bor. The analysis showed that there is a strong correlation ($R^2 = 0.61$) between the mean hourly PM_{10} concentrations, measured by the automatic monitors. The OSIRIS monitor underestimates the 24-h mean PM_{10} concentrations (the average of 30%) compared to the reference gravimetric method. Contrary to that, the EPAM-5000 monitor overestimates the 24-h mean PM_{10} concentrations (the average of 40%) compared to the reference gravimetric method. Calibration of the automatic monitors was made on the basis of the results obtained by the gravimetric method. It was determined that both examined automatic monitors are applicable for indicative measurements of PM_{10} concentrations in the indoor environment. In order to use these automatic monitors in the air pollution health impact studies, it is necessary to calibrate them, on daily basis, with the reference gravimetric method.

Keywords: *suspended particles, gravimetry, measurement, automatic monitor*

1 INTRODUCTION

It is believed that the air quality in urban areas has a greater impact on population health than the other environmental factors, and that the ambient air pollutants are one of the most significant causes of health problems in general [1-6]. According to WHO (World Health Organization), every year over 2.7 million people dies due to the air pollution [2]. PM_{10} fraction of suspended particles (coarse particles) is primarily composed of atmospheric dust, which is caused by the mechanical crowning of granular material, for example, from paved and unpaved roads, agricultural activities, construction works and natural processes. Industrial operations like milling, grinding and other, to some extent, contribute to the fraction of coarse particles present in the ambient air [2].

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[***] *This work is supported by a Grant from the Ministry of Education and Science of the Republic of Serbia, as a part of the Project III42008: "Evaluation of Energy Performances and Indoor Environment Quality of Educational Buildings in Serbia with Impact to Health" within the framework of the Technological Development Program*

Particulate matter (PM) in the indoor air originates from the outdoor infiltration and additional indoor sources such as heating devices, cooking, tobacco smoking, etc. Automatic air particle monitors measures and records aerosol concentrations in real-time, and, therefore, it can provide insights into particulate levels and temporal variability of PM concentrations over short time intervals (a few seconds), which is not possible using gravimetric sampling methods. Numerous real-time particle monitoring and gravimetric sampling campaigns have been carried out to characterize PM mass concentrations in the indoor environment. This was done with the aim to increase the reliability and quality of information necessary for preparation the studies on the impact of particulate air pollution on human health.

In this work, the PM_{10} concentrations, obtained using the automatic monitors OSIRIS (Turnkey) and EPAM-5000 (SKC Inc.), were analyzed. Also, the average daily PM_{10} concentrations were compared with those obtained using the gravimetric method. The aim of this study was to determine whether these monitors are suitable for measuring the concentration of PM_{10} particles in the indoor environment, to study their reliability in operation and determines the deviation of their results in comparison with the reference gravimetric method.

2 MATERIALS AND METHODS

Comparative measurements of PM_{10} concentration were carried out in the period from 20.12.2011 to 15.02.2012 in the Laboratory of Applied Electronics in the Mining and Metallurgy Institute Bor. The laboratory has an approximate volume of 125 m^3, and double glass windows, with the surface of about 3 m^2. The door and windows were usually closed during the measurement campaign. The real-time aerosol monitors were placed in the center of the laboratory, at height of 1 m from the ground. A gravimetric sampler, Sven/Leckel LVS3 [7] was also placed in the laboratory next to the automatic monitors. Gravimetric samples were collected once a day (at 8 AM). Whatman QMA grade filters with the diameter of 47 mm were used for collecting the gravimetric samples. Before and after sampling, the filter mass was measured in accordance with a procedure prescribed by SRPS EN12341:2008 [8]. Based on the difference in mass of exposed and unexposed filters and known volume of air that flow through the sampler, the daily mean mass concentrations of PM_{10} were calculated.

Figure 1 *Front panel of the OSIRIS PM_{10} monitor*

The automatic monitors, used in the study, applied the light scattering technique to calculate the PM_{10} concentrations. OSIRIS (Turnkey) monitor, shown in Figure 1, is designed for the indicative measurement of PM concentration in the range of 0.5 - 20 µm [9]. EPAM-5000 (SKC Inc.) monitor, shown in Figure 2, uses the reflection of light from the particles to calculate the PM concentration per unit volume, in contrast to the OSIRIS monitor which uses the diffraction of light from the particles. EPAM-5000 is suitable for measuring the PM concentration in the range of 0.1 - 100 µm [10]. Both automatic monitors used in the study, in fact, calculate the mass concentration based on the intensity of light scattered from particles so that they have to be calibrated for each environment using the reference gravimetric method. Daily calibration is necessary because the size distribution of particles per unit of volume is time dependent. The flow rate of measuring instruments was calibrated using the certified flow meter several times during the measurement campaign, at the beginning and after every two weeks of measurements. Automatically monitors were set up to record 1-hour average concentration of PM_{10} particles. For calculation the daily averages, minimum 90% of 1-hour averages were required, otherwise, the value was considered as the missing. Visual inspection of raw data was also carried out.

Figure 2 *Front panel of the EPAM-5000 monitor*

3 RESULTS AND DISCUSSION

The regression analysis was carried out on the mean hourly PM_{10} concentrations which were measured by automatic monitors. Dispersion diagram is shown in Figure 3. It can be seen that there is a significant coincidence between the measurement results obtained by the automatic monitors. Applying the ordinary least squares linear regression, the following regression equation is obtained:

$$y = 0.468 * x - 0.71 \qquad (1)$$

In the equation (1) $\boldsymbol{y}$ expresses PM_{10} concentration obtained by the OSIRIS monitor and $\boldsymbol{x}$ expresses PM_{10} concentration obtained by the EPAM-5000 monitor. Regression slope significantly different from one was considered to indicate the multiplicative bias of PM_{10} concentrations between instruments. It is obvious that the PM_{10} concentrations measured by the EPAM-5000 monitor are, on average, more than twice higher than the PM_{10} concentrations measured by the OSIRIS monitor. Regression intercept significantly different from zero was considered to indicate the additive bias of PM_{10} concentrations between instruments. The coefficient of determination (R^2) is used to describe the correlation of PM_{10} concentrations between instruments while the standard deviation is used to describe how widely values are dispersed from the average value. The coefficient of determination calculated using the correlation analysis is R^2 = 0.61. This value indicates the strong correlation between the measurement results of automatic monitors (61% of the results was explained by linear dependence).

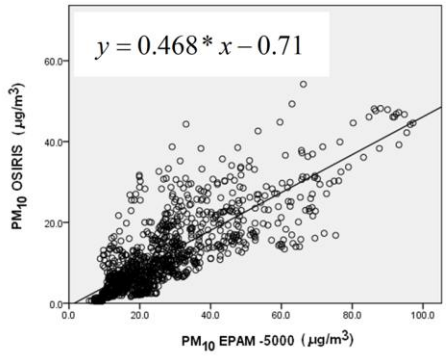

Figure 3 *Scatter plot of 1–h average PM_{10} mass concentrations, EPAM-5000 vs. OSIRIS*

The average daily PM_{10} concentrations were calculated from the 1-hour average PM_{10} concentrations. So, the obtained average daily PM_{10} concentrations were compared with the average daily PM_{10} concentrations obtained using the gravimetric method. Basic statistics for the average daily PM_{10} concentrations is shown in Table 1. Data from this table clearly indicates that the average of daily PM_{10} concentrations provided by the OSIRIS monitor is 30% lower compared to that obtained by the reference gravimetric method. In contrast, the average daily PM_{10} concentration that gives EPAM-5000 monitor is 40% higher compared to that obtained by the reference gravimetric method. It is shown in reference [11] that the average daily PM_{10} concentrations, measured by the OSIRIS monitor, were 12% lower compared to that determined by the gravimetric method. The measurements described in this reference were carried out in a room with the larger volume (175 m^3) and the room was empty of people during the campaign of measurement. In the same work, as well as in the reference [12], it was shown that the automatic monitors, using the same principle of light reflection, as EPAM-5000 use, commonly overestimate the PM_{10} and $PM_{2.5}$ concentrations in relation to those obtained by the gravimetric method (usually more than twice).

Table 1 *Statistics of 24-h average PM_{10} concentrations (μg/m^3), (SD - standard deviation)*

	PM_{10} OSIRIS	**PM_{10} EPAM-5000**	**PM_{10} LVS3**
Min	8.7	12.2	7.8
Max	25.8	53.3	48.2
Mean	14.0	27.8	19.8
SD	6.9	12.0	12.5

In order to obtain more accurate results, automatic monitors are calibrated on the basis of the PM_{10} concentrations obtained by the reference gravimetric method, using the method that is shown in the paper [12]. For each day with measurements, the calibration factor was calculated according to the following formula:

$$F = \frac{G}{S} \quad (2)$$

In the equation (2) F is the calibration factor, G is the average daily PM_{10} concentration obtained by the gravimetric method, whilst S is the corresponding average daily PM_{10} concentration measured by the OSIRIS or EPAM-5000 monitor. The OSIRIS and EPAM-5000 measurements were normalized so that each 1-hour average PM_{10} concentration were multiplied by calibration factor F. Appearance of line charts of PM_{10} concentrations after applying the described calibration procedure is shown in Figure 4.

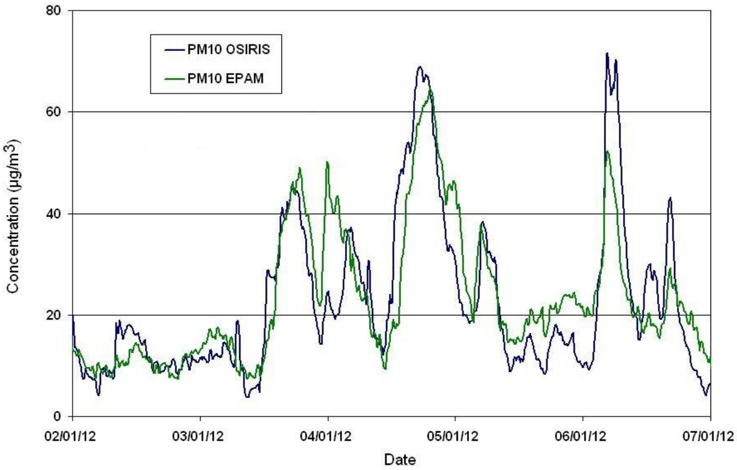

Figure 4 *Line chart of 1–h average PM_{10} mass concentrations*

4 CONCLUSION

In this work, the results of measurement of the PM_{10} concentration, using automatic monitor OSIRIS and EPAM-5000, in the indoor environment, were analyzed. The analysis showed that there is a strong correlation between the results of measurements of these automatic monitor. The linear dependence can describe/explain more than 61% of the measurement results. The average daily PM_{10} concentrations measured by the automatic monitors were compared with the average daily PM_{10} concentrations obtained by the gravimetric method. The average of daily PM_{10} concentrations provided by the OSIRIS monitor is 30% lower compared to that obtained by the reference gravimetric method. Contrary to that, the average daily PM_{10} concentration that gives EPAM-5000 monitor is 40% higher compared to that obtained by the reference gravimetric method. In order to improve the accuracy of the PM_{10} concentration readings of the automatic monitors, comparing with the results obtained by the gravimetric method, it is necessary to perform the calibration procedure on daily basis. One procedure of calibration is described in the paper. Based on the above-mentioned facts, it can be concluded that the observed automatic monitors can be used for the indicative measurement of PM_{10} concentrations in the indoor environments. Both of the air particle monitors used in this study proved to be practical for PM_{10} measurements in the indoor environments, as it is small, portable, and quiet enough not to disturb the occupants of rooms where monitoring is performed. Their use allows an insight into the changes in the PM_{10} concentrations during the day, which can be helpful in identifying the sources of particles, as well as in the preparation of studies on the impact of air pollution with PM_{10} on human health.

REFERENCES

[1] Jovašević-Stojanović M., Matić-Besarabić S., Cvetković A.,Tošović S., Zeković I., The Importance of Monitoring the Respirable Particles in the Urban Areas in Order to Assess the Health Effects, Hygiene and Human Ecology, Belgrade, 2010, pp. 95-118;

[2] Tasić V., Kovačević R., Jovašević-Stojanović M., Apostolovski–Trujić T., Šteharnik M., Stanković S., Analysis of Suspended Particles PM10 in the Grammar School 'Bora Stanković' in Bor, Copper, Vol. 40, No. 1, pp. 63−74, 2015;

[3] Anderson H. R., Bremner S. A., Atkinson R. W., Harrison R. M., Walters S., Particulate Matter and Daily Mortality and Hospital Admissions in the West Midlands Conurbation of the United Kingdom: Associations with Fine and Coarse Particles, Black Smoke and Sulphate, Occup. Environ Med, Vol. 58, No. 8, pp. 504–510, 2001;

[4] Atkinson R. W., Fuller G. W., Anderson H. R., Harrison R. M., Armstrong B., Urban Ambient Particle Metrics and Health: a Time Series Analysis, Epidemiology Vol. 21, No. 4, pp 501-511, 2010;

[5] Pope III C.A., Dockery D.W., Health effects of fine particulate air pollution: Lines that connect, Journal of the Air and Waste Management Association, Vol. 56, pp. 709-742, 2006;

[6] Pope III CA, Burnett RT, Thun MJ, Calle EE, Krewski D, Kazuhiko I, et al. Lung Cancer, Cardiopulmonary Mortality, and Long-Term Exposure to Fine Particulate Air Pollution. J Am Med Assoc, Vol. 287, pp. 1132–41, 2002;

[7] http://www.envitech-bohemia.cz/ domain/envitech-bohemia/files/1/ odberova/lvs3_mvs6_e.pdf (accessed 28.09.2015);

[8] SRPS EN 12341:2008 Air Quality – Determining the Fraction PM10 of Suspended Particles – Referece Method and Field Test Procedure to Demonstrate the Equivalence of Measuring Methods ("Official Gazette RS" No.104/08);

[9] Turnkey Instruments, Airborne Particle Monitors, Turnkey Instruments Ltd., 2006. http://www.turnkey-instruments com/images/documents/Turnkey-Dust-Monitors.pdf (accessed 28.09.2015);

[10] http://www.skcinc.com/catalog/pdf/ instructions/1516.pdf (accessed 28.09.2015);

[11] Tasić V., Jovašević-Stojanović M., Vardoulakis S., Milošević N., Kovačević R., Petrović J., Comparative Assessment of a Real-Time Particle Monitor Against the Reference Gravimetric Method for PM10 and PM2.5 in Indoor Air, Atmos Environ, Vol. 54, pp. 358-364, 2012;

[12] Ramachandran G., Adgate J. L., Pratt G. C., Sexton K., Characterizing Indoor and Outdoor 15-minute Average PM2.5 Concentrations in Urban Neighborhoods. Aerosol Sci Technol, Vol. 37, pp 33-45, 2003.

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MERENJE KONCENTRACIJA SUSPENDOVANIH ČESTICA (PM_{10}) U UNUTRAŠNJEM PROSTORU PRIMENOM AUTOMATSKIH MONITORA***

Izvod

Cilj rada je da se ispita primenljivost automatskih monitora za određivanje koncentracija suspendovanih čestica frakcije PM_{10} u unutrašnjem prostoru. Rezultati merenja automatskih monitora upoređivani su sa rezultatima dobijenim referentnom gravimetrijskom metodom. Uporedna merenja, u trajanju od 50 dana, vršena su 2012 godine, tokom zime, u laboratoriji za primenjenu elektroniku Instututa za rudarstvo i metalurgiju u Boru. Analiza je pokazala da postoji jaka korelacija (R^2=0.61) između srednjih satnih koncentracija PM_{10} koje su izmerene automatskim monitorima. Srednje dnevne koncentracije PM_{10} izmerene OSIRIS monitorom u proseku su za 30% niže u odnosu na koncentracije dobijene primenom referentne gravimetrijske metode. Nasuprot tome, srednje dnevne koncentracije PM_{10} izmrene EPAM-5000 monitorom u proseku za 40% više u odnosu na koncentracije dobijene gravimetrijskom metodom. Kalibracija automatskih monitora vršena je na osnovu rezultata dobijenih gravimetrijskom metodom. Utvrđeno je da su ispitivani monitori primenljivi za indikativna merenja aerozagađenja PM_{10} česticama u unutrašnjem prostoru. Da bi se rezultati ovih automatskih monitora koristili za izradu studija o uticaju aerozagađenja na zdravlje ljudi neophodno je da se oni svakoga dana kalibrišu pomoću rezultata dobijenih referentnom gravimetrijskom metodom.

Ključne reči: *suspendovane čestice, gravimetrija, merenje, automatski monitor*

1. UVOD

Smatra se da kvalitet vazduha u urbanim sredinama ima veći uticaj na zdravlje stanovništva nego ostali faktori životne sredine, a da zagađivači ambijentalnog vazduha predstavljaju jedan od najznačajnijih uzroka zdravstvenih problema uopšte [1-6]. Prema podacima WHO (World Health Organization - Svetska Zdravstvena Organizacija) u Svetu se godišnje usled aerozagađenja dogodi preko 2.7 miliona smrtnih slučajeva [2]. Frakcija suspendovanih čestica PM_{10} (grube čestice) je prvenstveno sastavljena od atmosferske prašine koja je nastala usled mehaničkog krunjenja granularnog materijala, na primer, od asfaltiranih i neasfaltiranih puteva, poljoprivrednih aktivnosti, građevinskih radova i prirodnih procesa. Industrijske operacije kao mlevenje, brušenje i druge aktivnosti takođe u izvesnoj meri povećavaju prisustvo grubih čestica u ambijentalnom vazduhu [2].

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*** *Ovaj rad je proistekao iz projekta br. III42008:"Unapređenje energetskih karakteristika i kvaliteta unutrašnjeg prostora u zgradama obrazovnih ustanova u Srbiji" koji je finansiran od strane Ministarstva prosvete, nauke i tehnološkog razvoja Republike Srbije*

Suspendovane čestice u unutrašnjem prostoru (stambeni i poslovni objekti) potiču od infiltracije čestica iz spoljašnje sredine i nekog unutrašnjeg izvora, kao što su peći za grejanje prostorija, kuvanje ili dim od cigareta. Automatski monitori suspendovanih čestica mere i beleže koncentracije frakcija ovih čestica u realnom vremenu (npr. svakih nekoliko sekundi). Na taj način, primena ovih uređaja pruža uvid u intenzitet čestičnog zagađenja i njegovu dinamiku i u toku kratkih vremenskih intervala. Ovo nije moguće ostvariti primenom referentne gravimetrijske metode merenja. Širom Sveta sprovedene su brojne kampanje uporednih merenja koncentracija suspendovanih čestica automatskim monitorima i analizatorima u odnosu na gravimetrijsku metodu. Cilj ovih istraživanja bio je povećanje tačnosti i pouzdanosti informacija potrebnih za izradu studija o uticaju aerozagađenja suspendvanim česticama na zdravlje ljudi.

U ovom radu analizirani su rezultati merenja koncentracija suspendovanih čestica frakcije PM_{10} u unutrašnjem prostoru primenom automatskih monitora. Takođe, srednje dnevne koncentracije PM_{10} čestica, izmerene pomoću automatskih monitora, upoređivane su sa koncentracijama dobijenim gravimetrijskom metodom merenja. Korišćeni su automatski monitori tipa OSIRIS (Turnkey) i EPAM-5000 (SKC Inc.). Cilj istraživanja bio je da se ustanovi primenljivost ovih monitori za merenje koncentracija PM_{10} čestica u unutrašnjem prostoru, da se ispita njihova pouzdanost u radu, i utvrdi odstupanje njihovih rezultata u odnosu na referentnu gravimetrijsku metodu merenja.

2. MATERIJAL I METOD RADA

Uporedna merenja koncentracija PM_{10} čestica vršena su u periodu od 20.12.2011. do 15.2.2012. u laboratoriji za primenjenu elektroniku u Institutu za rudarstvo i metalurgiju u Boru. Laboratorija ima približnu zapreminu od 125 m^3. Pod laboratorije je od laminata, a prozori od duplog stakla, površine oko 3 m^2. Vrata, kao i prozori, obično su bila zatvorena tokom kampanje merenja. Automatski monitori postavljeni su u sredini laboratorije na visinu od 1 m u odnosu na pod. U njihovoj blizini postavljen je i jedan gravimetrijski sempler proizvodnje Sven / Leckel LVS3 sa glavom za uzorkovanje čestica frakcije PM_{10} [7]. Gravimetrijski uzorci uzimani su jednom dnevno (u 8 h ujutru). Za uzorkovanje su korišćeni Whatman QMA filtri prečnika 47 mm. Pre i posle uzorkovanja merena je masa filtera, saglasno proceduri propisanoj standardom SRPS EN12341:2008 [8]. Na osnovu razlike masa eksponiranih i neeksponiranih filtera i poznatog protoka vazduha kroz uzorkivač sračunate su srednje dnevne masene koncentracije suspendovanih čestica.

Sl. 1. *Izgled prednje strane OSIRIS monitora*

U eksperimentu su korišćeni automatski monitori suspendovanih čestica koji za detekciju koriste princip skretanja svetlosti (light scattering technique). OSIRIS (Turnkey) monitor, prikazan na slici 1, namenjen je za indikativna merenja koncentracija suspendovanih čestica iz opsega od 0.5 - 20 μm [9]. EPAM-5000 (SKC Inc.) monitor, prikazan na slici 2, koristi refleksiju svetlosti od čestica za izračunavanje koncentracije suspendovanih čestica u jedinici zapremine, za razliku od OSIRIS monitora koji koristi difrakciju svetlosti od čestica. EPAM-5000 je pogodan je za merenje koncentracije čestica veličine od 0.1 - 100 μm [10].

Oba monitora računaju masene koncentracije na bazi intenziteta skretanja svetlosti laserskog zraka od čestica, tako da ih treba kalibrisati za svaku sredinu u kojoj se merenja vrše, primenom referentne gravimetrijske metode. Kalibraciju je neophodno raditi svakog dana zato što je distrubucija veličine čestica u jedinici zapremine promenljiva u vremenu i veoma zavisna od lokacije na kojoj se merenje vrši. Provera protoka svih mernih instrumenata vršena je sertifikovanim meračem protoka na početku kampanje merenja, kao i svake druge nedelje tokom kampanje. Automatski monitori bili su podešeni tako da beleže srednje satne vrednosti koncentracija PM_{10} čestica.

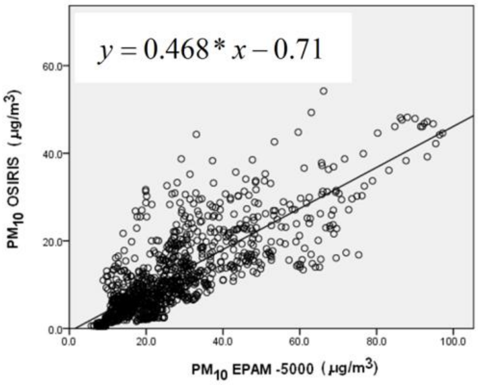
Sl. 2. *Izgled prednje strane EPAM-5000 monitora*

3. REZULTATI ISTRAŽIVANJA I DISKUSIJA

Izvršena je regresiona analiza srednjih vrednosti satnih masenih koncentracija suspendovanih čestica frakcije PM_{10} koje su izmerne pomoću automatskih monitora. Dijagram rasturanja prikazan je na slici 3. Sa ove slike može se uočiti da postoji značajna podudarnost rezultata merenja automatskih monitora. Primenom metode najmanjeg srednjeg kvadrata dobijena je sledeća regresiona jednačina:

$$y = 0.468 * x - 0.71 \quad (1)$$

U jednačini (1) ***y*** predstavlja koncentraciju PM_{10} čestica izmerenu OSIRIS monitorom, dok je ***x*** koncentracija PM_{10} čestica izmerena EPAM-5000 monitorom. Na osnovu ove jednačine može se konstantovati da su koncentracije PM_{10} čestica izmerene EPAM-5000 monitorom u proseku dva puta više od koncentracija koje su izmerene OSIRIS monitorom. Primenom korelacione analize određen je koeficijent determinacije $R^2 = 0.61$. Ova vrednost ukazuje da na to da postoji jaka korelacija rezultata merenja automatskih monitora (61% rezultata objašnjeno je pomoću linearne zavisnosti).



Sl. 3. *Dijagram rasturanja srednjih satnih koncentracija suspendovanih čestica frakcije PM_{10}, EPAM-5000 vs. OSIRIS*

Na osnovu srednje satnih vrednosti koncentracije PM_{10} čestica, koje su izmerili automatski monitori, sračunate su srednje dnevne koncentracije. Tako dobijene srednje dnevne koncentracije PM_{10} čestica upoređene su sa srednje dnevnim koncentracijama PM_{10} čestica dobijenim primenom gravimetrijske metode. Osnovna statistika srednje dnevnih vrednosti koncentracija suspendovanih čestica PM_{10} prikazana je u Tabeli 1. Iz ove tabele uočava se da su prosečne srednje dnevne koncentracije koje daje OSIRIS monitor za 30% niže u odnosu na koncentracije dobijene referentnom gravimetrijskom metodom. Suprotno tome, prosečne srednje dnevne koncentracije koje daje EPAM-5000 monitor su za 40% više u odnosu na koncentracije dobijene referentnom gravimetrijskom metodom. U referenci [11] je prikazano da su srednje dnevne vrednosti koncentracija PM_{10} čestica, merene OSIRIS monitorom, za 12% niže u odnosu na vrednosti dobijene gravimetrijskom metodom. Merenja opisana u tom radu vršena su u prostoriji veće zapremine (175 m^3) u kojoj nije bilo ljudi tokom kampanje merenja. U istom radu, kao i u radu [12], pokazano je da automatski anali-zatori, koji koriste princip refleksije svetlosti za detekciju čestica, kakav je EPAM-5000, najčešće precenjuju koncentracije suspendovanih čestica, frakcija PM_{10} i $PM_{2.5}$, u odnosu na koncentracije dobijene gravimetrijskom metodom (i više od 2 puta).

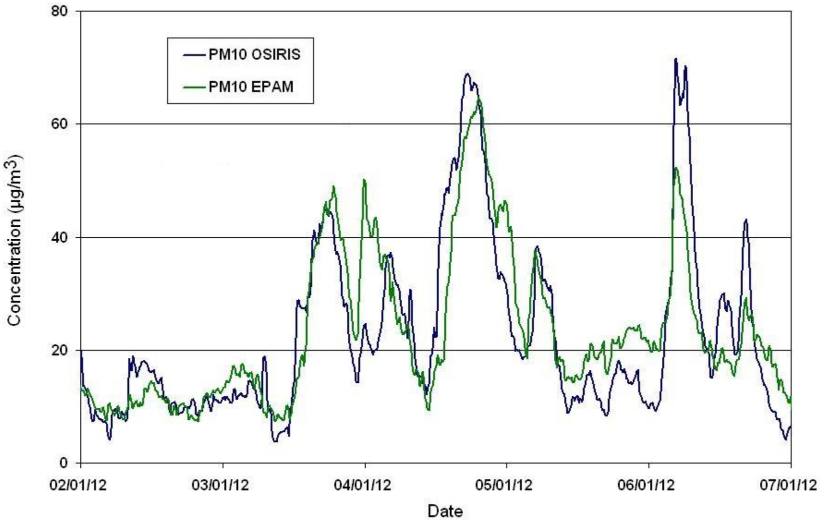
Tabela 1. *Statistika srednje dnevnih koncentracija suspendovanih čestica PM_{10} ($\mu g/m^3$), (Mean - aritmetička sredina, SD - standardna devijacija)*

	PM_{10} OSIRIS	**PM_{10} EPAM-5000**	**PM_{10} LVS3**
Min	8.7	12.2	7.8
Max	25.8	53.3	48.2
Mean	14.0	27.8	19.8
SD	6.9	12.0	12.5

Da bi se dobili tačnije vrednosti PM_{10} koncentracija u toku dana, rezultati automatskih monitora normalizovani su na bazi rezultata dobijenih referentnom gravimetrijskom metodom, primenom postupka prikazanog u radu [12]. Za svaki dan izračunat je kalibracioni faktor prema sledećoj formuli:

$$F = \frac{G}{S} \qquad (2)$$

U jednačini (2) ***F*** predstavlja kalibracioni faktor, ***G*** je srednja dnevna vrednost koncentracije PM_{10} čestica dobijena gravimetrijskom metodom, a *S* je odgovarajuća srednja dnevna vrednost koncentracije PM_{10} čestica izmerena OSIRIS ili EPAM-5000 monitorom. Merenja OSIRIS i EPAM-5000 monitora su normalizovana tako što je za svaki dan sračunat kalibracioni faktor ***F***, a zatim je svaka srednje satna vrednost koncentracije PM_{10} pomnožena ovim faktorom. Izgled linijskog dijagrama koncentracija PM_{10} čestica nakon primene opisanog postupka prikazan je na slici 4.



Sl. 4. *Linijski dijagram srednje satnih vrednosti koncentracija PM_{10} čestica*

4. ZAKLJUČAK

U ovom radu analizirani su rezultati merenja koncentracija suspendovanih čestica, frakcija PM_{10}, u unutrašnjem prostoru, primenom automatskih monitora OSIRIS i EPAM-5000. Analiza je pokazala da postoji jaka korelacija između rezultata merenja ovih automatskih monitora. Linearna zavisnost može da opiše/objasni više od 61% rezultata merenja. Izvršeno je upoređivanje srednje dnevnih koncentracija PM_{10} čestica izmerenih automatskim monitorima sa srednje dnevnim koncentracijama PM_{10} čestica koje su dobijene primenom gravimetrijske metode. Srednje dnevne koncentracije PM_{10} čestica izmerene OSIRIS monitorom su za 30% niže u odnosu na koncentracije dobijene gravimetrijskom metodom. Suprotno tome, srednje dnevne koncentracije koje daje EPAM-5000 monitor za 40% su više u odnosu na koncentracije dobijene gravimetrijskom metodom. Da bi rezultati automatskih monitora PM_{10} čestica bili u saglasnosti sa rezultatima dobijenim gravimetrijskom metodom potrebno je svakodnevno vršiti njihovu kalibraciju. U radu je opisan jedan od primenjivanih postupaka za kalibraciju. Na osnovu rezultata ispitivanja automatskih monitora ustanovljeno je da su oni pogodni za indikativna merenja suspendovanih čestica frakcije PM_{10} u unutrašnjem prostoru. Njihovom primenom omogućuje se uvid u promene koncentracija suspendovanih čestica tokom dana, što može biti od velike koristi pri identifikaciji izvora ovih čestica, kao i pri izradi studija o uticaju aerozagađenja suspendovanim česticama na zdravlje ljudi.

LITERATURA

[1] Jovašević-Stojanović M., Matić-Besarabić S., Cvetković A.,Tošović S., Zeković I., Značaj monitoringa respirabilnih čestica u urbanim sredinama u cilju procene zdravstvenih efekata, Higijena i humana ekologija, Beograd, 2010, str. 95-118

[2] Tasić V., Kovačević R., Jovašević-Stojanović M., Apostolovski-Trujić T., Šteharnik M., Stanković S., Analiza suspendovanih čestica PM10 u gimnaziji 'Bora Stanković' u Boru, Bakar, Vol. 40, No. 1, str. 63−74, 2015.

[3] Anderson H.R., Bremner S.A., Atkinson R.W., Harrison R.M., Walters S., Particulate matter and daily mortality and hospital admissions in the West Midlands conurbation of the United Kingdom: associations with fine and coarse particles, black smoke and sulphate, Occup Environ Med, Vol. 58, No. 8, pp 504–510, 2001.

[4] Atkinson R. W., Fuller G. W., Anderson H. R., Harrison R. M., Armstrong B., Urban ambient particle metrics and health: a time series analysis, Epidemiology Vol. 21, No. 4, pp 501–511, 2010.

[5] Pope III C. A., Dockery D. W., Health effects of fine particulate air pollution: Lines that connect, Journal of the Air and Waste Management Association, Vol. 56, pp 709-742, 2006.

[6] Pope III CA, Burnett R T, Thun MJ, Calle EE, Krewski D, Kazuhiko I, et al. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. J Am Med Assoc, Vol. 287, pp 1132–41, 2002.

[7] http://www.envitech-bohemia.cz/ domain/envitech-bohemia/files/1/ odberova/lvs3_mvs6_e.pdf (pristupljeno 28.09.2015)

[8] SRPS EN 12341:2008 Kvalitet vazduha - Određivanje frakcije PM10 suspendovanih čestica - Referentna metoda i postupak ispitivanja na terenu radi demonstriranja ekvivalentnosti mernih metoda ("Službeni glasnik RS" broj 104/08)

[9] Turnkey Instruments, Airborne Particle Monitors, Turnkey Instruments Ltd., 2006. http://www.turnkey-instruments com/images/documents/Turnkey-Dust-Monitors.pdf (pristupljeno 28.09.2015)

[10] http://www.skcinc.com/catalog/pdf/ instructions/1516.pdf (pristupljeno 28.09.2015)

[11] Tasić V., Jovašević-Stojanović M., Vardoulakis S., Milošević N., Kovačević R., Petrović J., Comparative assessment of a real-time particle monitor against the reference gravimetric method for PM10 and PM2.5 in indoor air, Atmos Environ, Vol. 54, pp. 358-364, 2012.

[12] Ramachandran G., Adgate J.L., Pratt G.C., Sexton K., Characterizing indoor and outdoor 15-minute average PM2.5 concentrations in urban neighborhoods. Aerosol Sci Technol, Vol. 37, pp. 33-45, 2003.

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