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TECHNOGENIC DEPOSIT IN THE AREA OF THE OLD FLOTATION TAILING DUMP IN BOR (FIELD 1 AND FIELD 2)[**]

Abstract

The copper ore mining in Bor was started at the beginning of the twentieth century. Parallel to this, the ore smelting was carried out in the first period. After construction of the Flotation Plant (1934), the ore dressing was performed and obtaining the concentrate of copper and precious metals. Until the 60's of the last century, the ore processing, obtained from exploitation from the copper deposits Bor (the Old Open Pit and underground mine Jama Bor), was carried out. After this period of ore obtained from the Bor mine, the ore from the deposit Lipa, Cerovo (Mali Krivelj) was also processed. Technogenic waste of flotation was obtained as by-product of this process by flotation that was disposed from 1934 to 1980 in the area of the Old Flotation Tailing Dump in Bor (Field 1 and Field 2).

Based on the previous geological explorations in the mentioned zone, the increased copper contents were indicated in the subject area. The implementation of detailed geological explorations would evaluate the potentiality of the area, in order to review the possibilities of raw material leaching, as well as solving a serious environmental problem in the center of the town of Bor.

Keywords: *tailing dump, technogenic formations, copper ore mining, open pit*

INTRODUCTION

Technogenic copper deposit the "Old Bor Flotation Tailing Dump" is located in the industrial circle of the Mining and Metallurgy basin (RTB), or in the town of Bor. Bor is usually a typical mining town, founded by the mine (Figures 1 and 2).

The largest amount of technogenic formations separated in the immediate vicinity of the Bor and Krivelj mines in an area of over 4 km^2. They are presented by creations that occurred by exploitation of mineral deposits of copper (overburden) and mineral processing (flotation tailings) Figure 2 shows the old flotation tailing dump in Bor.

For the relief of the terrain, in wider area of Bor, a significant impact had intensive volcanic activity (during the late Mesozoic and Cenozoic), which is accompanied by strong tectonic movements.

However, the formation of current look of relief was influenced by the economic activity in the mineral-raw material complex.

The processes of exploitation, preparation, and processing of ore in Bor and its surroundings, caused the changes of relief and formation of some inverse morphological forms, such as the open pits and landfills (rock overburden, mining waste, flotation tailings, smelter slags, calcined pyrite).

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Figure 1 *The spatial position of the old flotation tailing dump in relation to the town center*

Figure 2 *The Old flotation tailing dump in Bor (May 2011)*

It should be emphasized that the human activity has significantly influenced the formation of the current look of relief. The exploitation of copper deposits (the old open pit in Bor and open pit "Veliki Krivelj") caused the changes to the natural environment, for now, primarily in terms of the degradation of the natural terrain, creating inverted form, in the form of depression (open pit mining), on one hand, and on the other side of the rise of the accumulated material of rock overburden (waste rock) as well as flotation tailings especially dangerous to the natural environment.

The starting point for a preliminary evaluation of the potentials was the results of previous explorations that were collected, analyzed and synthesized. Preliminary evaluation of the potentials was performed based on the results of completed geological explorations, which were conducted by the Mine Geological Department of the Copper Mine Bor and Bureau of Geology and Mining and Metallurgy Institute Bor (old name: Copper Institute Bor) in the period 1947-2010, and based on data from the old documentation of the mine dating from 1909 until 1941. Based on the applied methodology of previous explorations, it can be concluded that the deposition of tailings from the flotation used the former bed of the Bor stream, so that today the river bed is filled and the ground is leveled. According to the previous studies, tailings disposal in the research area started by the French, and during the Second World War, the Germans continued. After the Second World War deposition of tailings in the area in question was carried out by 1980'. Starting from the results of previous exploration works, it can be concluded that the degree of exploration of the research area is low. Detailed geological explorations were carried out by the system of exploration drilling in the Field 1. Problems that should be dealt with the implementation of exploration works is reflected in the following:

- Define the geological characteristics, structural complex, contour and shape the physical and mechanical properties of paleorelief (the riverbed of the Bor stream) and tailings, then determine the quality, and make technological preparations and testing capabilities of application the technogenic raw materials.
- Analyze the factors and indicators of geological and economic evaluation characteristic of detailed geological studies (metallogenic geological, mining, technology, market, regional and socio-economic factors and corresponding indicators) on the basis of which the evaluation of potentials of exploration area, the classification and categorization of mineral materials.
- After the potentiality evaluation based on the results obtained from the detailed implementation of applied exploration, and possible mining activities, the reclamation and remediation will be carried out in the subject area.

GEOLOGICAL STRUCTURE OF THE OLD FLOTATION TAILING DUMP IN BOR (field 1 and field 2)

Previous geological explorations, especially on geological maps, clearly indicate that the wider environment Bora, and therefore the wider environment of the old flotation tailings in Bor, are mostly built from volcanic - pyroclastic and sedimentary rocks of the Cretaceous age. On smaller scale, they are represented by granites and the Palaeozoic rocks of Jurassic, Tertiary and Quaternary age. Greater distribution of Cretaceous formations, including the deposition of the copper mineralization, the most significant are hydrothermally altered volcanic rocks of the Cretaceous age.

The space of the old Flotation Tailing Dump (Field 1 and Field 2) is a specific in maby ways. Geological characteristics of technogenic raw materials of the old flotation tailing dump (Field 1 and Field 2), conditioned by the immediate background on which they are deposited, and the way formation the landfill. The immediate surface of the landfill is mostly of the geogenic creations (the Bor conglomerates, volcanoclastic rocks and alluvial deposits. For tailings disposal from the flotation, the former bed of the Bor stream is used, so that today the entire riverbed is filled and the ground is leveled. Tailing dump is located close to the existing facilities of RTB, primarily the Bor Flotation Plant. Based on the available documentation on previous explorations, it can be concluded that the former bed of the Bor stream is much carved and that the stream was steep.

Disposal of tailings was carried out in this way that the initial dam was formed on a downstream part of the stream of larger particles of sand and surface overburden, and then the entire length of the stream was used for tailings disposal. Disposal of tailings began by French, in the northern part of the Bor stream, near the train station, since 1934 until 1941, when the Germans continued to deposit tailings. The Germans continued to deposit tailings in the lower southern parts of the Bor stream. After the war, disposal of tailings was continued so that the entire riverbed was filled with tailings, with the trained field first pitch has been leveled at an approximate elevation of 360 its first field in the field. Field 1 has an oval shape. Dimension of long axis (NW - SE) was about 400 m and shorter (SW - NE), about 300 meters. South of Field 1, downstream at about 600 m, the dam was formed by flotation of sand. Width of Dam 1 is approximately 30 m. At about 800 m from the dam, downstream one dam is formed, the second dam. Between Dams 1 and 2 dams the flotation tailings was deposited so that the coarsest particles are separated and deposited on the banks of the Bor streams and dams, and the central part of the area between the dams filled with finer flotation tailing. In the area between the Dam and the Dam , the Field 2 was formed in terrain on the field 2 that is flattened at an approximate elevation of 368 m. Field 2 has an elliptical shape. Dimension long axis (NW - SE) was about 800 m and shorter (SW - NE), about 600 m. The entire area (Field 1 and Field 2) has an elliptical shape, which includes surfaces of about 1 km^2. Technogenic copper deposit the Old Flotation Tailing Dump in Bor, was the result of ore enrich-ment obtained by exploitation the old open pit and underground mining. For many years the flotation tailings disposal was done in the form of sludge, dust and sand. Flotation concentration of minerals due to mine-ralogical and petrologic characteristics of ores and useful minerals, as well as due to the imperfections of technological process, 85 % separates copper in concentrate, with the remainder allocated in the flotation tailings. Similarly with the other useful components, the percentage share of beneficial components separated in the concentrate or the tailings depending on their utilization of applied technological process of enrichment.

For the space the old flotation tailings in Bor, tectonics is important because it actually works on contemporary creations that were exposed by tectonic forces acting in geological time. However, it should provide a brief overview of the fissure tectonics in geogenic surface of deposits. The most striking structure in the immediate vicinity of the exploration area is the Bor fault. The Bor fault is actually a fissure (rupture) zone, the width of which reaches 30-40 m, with milonitic zone from 4 to 8 m thick. The main structural directions are from the Bor deposit to the north, the present system of smaller sub-parallel faults along the eastern rim of the Bor metallogenic zone. By the morphostructural analysis of the area (Petkovic, 1984), it was found that the large Bor fault can be traced to the fault Veliki Pek. It presents a complex zone of breaking, formed in the post mineral period. A steep decline (75-80°) to the southwest and has left transcurrent to the left reverse movement. These structures indicate some premineralization movement and they are spatially found only in the eastern edge of TMC.

REVIEW OF PREVIOUS EXPLORATIONS

Evidence of mining activities in the area of the Bor metallogenic zone dated back to the 6th millennium ago (Rudna Glava), followed by the ancient antic and Roman periods. Modern geological explorations in Eastern Serbia begun in the late 19th century and in 1903' an adit cut off the ore body Coka Dulkan in Bor. Since then, mining and geological explorations in the Bor copper mineralization have been intensified.

The wider area of exploration field of the Old Bor tailing dump is the surrounding of Bor, or an area that was previously largely treated as the wider environment of Bor. Geological data on this field are found in the works by Žujović (1889, 1893, 1900), Antula (1904), Lazarevic (1909, 1910), Cvijic (1904), V. Petkovic (1935), Ilic and Simic (1949), Antonijevic (1957, 1959), and M. and F. Drovenik (1956), M. Drovenik

(1953, 1959, 1961, 1966, 1968, 1983), M. Drovenik, Antonijević I. et al. (1962, 1967). The explorations related to study of tailing dumps and slag landfills and their use as technogenic raw materials started at the beginning of the sixties and the interruption lasts until today. It was only at the beginning of this century, in terms of less mining, paying greater attention to tailing dump as potential areas for finding the economically interesting concentrations of copper and other useful components. It contributes to steady increase in the price of copper and precious metals lately.

In wider area of exploration area the Old Flotation Tailing Dump (Field 1 and Field 2), in the area of mine field Bor, extensive explorations were conducted. Explorations in the postwar period were carried out from June in 1961 to the end of January 1962, with the applied geological works, and mining exploration works (exploration drilling). Drilling was carried out in the period from 1961 to 1962. Exploration drilling is included in the part of the research area, the so-called Field 1, wherein drilled 87 shallow drill holes per square network of 40x40 m. The drill hole length was 10 m, and only a small number have length of 30 m. The percentage of removed core was about 100 % [VII]. The drill holes were analyzed for copper, and total oxide, and sulfur. Analyses of the associated beneficial and detrimental components were also carried out.

Exploitation of the Bor deposit, since the beginning of the last century, caught on 26 ore bodies - hole and surface mine (largely at the same time. Thereby was obtained the total of 146 270 000 tons of ore from which copper was extracted 2,437 million tons of metal copper, 139 140 kg, 415 000 kg of gold and silver. It was also excavated and 436,2 million tons of barren mass of overburden and associated rocks [I].

The exploitation of copper deposits, the old open pit in Bor (Figure 3), and later by the underground mining and enrichment of ore and concentrate obtained in the Bor Flotation Plant, have caused the changes of paleorelief in terms of degradation the natural terrain, creating elevations of accumulated material of tailings. Metallur-gical treatment of concentrates resulted in formation of slag. The largest amount of slag is disposed at the site between the open pit ore body "H" and former Pralište where the workshops of the old open pit are located, and it is the location known as the "Slag Depot – 1".

Figure 3 *The old open pit Bor, Bor (August 2005)*

Depending on the technology that was used in the exploitation phase of metallurgical melting process, it was produced in the slag, as well as to the characteristics of the ore, copper concentrate and flux, the technogenic waste was created, very different - both physically and mineralogically, and chemical characteristics. All slag formed in different time periods were delayed at several sites, and in some locations were carried out and move due to mining activities at the opening and expansion of open pit mines (the old open pit mine and open pit ore body "H").

DESIGN SOLUTIONS FOR DETAILED GEOLOGICAL SURVEY OF APPLIED GEOLOGICAL EXPLORATIONS

Based on the analysis and synthesis of current research and literature data, are defined by the concept and methodology of research in the future. Detailed applied geological explorations will be carried out with the aim of finding the additional amount of copper from technogenic deposits to increase the mineral - raw materials of “RBB”, and therefore increase the amount of ore that will be processed. Detailed geological explorations in the area of the old flotation tailings are focused on gradual, systematic and comprehensive research and testing in this area and finding economically interesting amounts of secondary raw material. The overall geological explorations are subordinated and adapted geology – metal - terrain conditions, the degree of its exploration, current issues and goals of exploration.

The main objective is to carry out detailed geological studies to determine the data needed for the study on ore reserves , which is necessary for future mine design , and obtaining the relevant data for the reclamation and remediation of the area which is located in the town of Bor. Geological investigations in the coming period applied to complex research methods, which includes the following activities: surveying works, geological work, drilling, field testing, laboratory and technological research in the laboratory and pilot plant scale. Geological survey will be followed by geological mapping and sampling, core drilling to investigate the quality and quantity of mineral resources: samples will be taken for mineralogical and petrological studies; soil testing will be performed in order to assess the possibilities for exploitation of mineral resources. The quality testing involves taking a sample of mineral raw materials for chemical and technological studies. Exploration carried out to define the geological structure and geological characteristics of the research area, and confirm the results of investigations of mineral resources obtained earlier research works.

CONCLUSION

The subject property is located in the town of Bor, near the Bor Flotation Plant. Based on previous geological studies, the copper mineralization is indicated in the said zone which would be explored by realization of geological works to the level B and C1 category reserves, and determine the quality of mineral resources, and the content of copper, gold, silver and other useful but also harmful components.

The main objective of geological research area the Old Bor tailing dump is to be in accordance with the data collected on the results of previous research to make the selection of optimal design solutions (type and scope of work) for the upcoming research for the purpose of finding copper and associated useful components in technogenic dumps raw materials. Density of exploration works depends on the achieved results of which depends on further explorations. Based on exploration study, the potentiality of study area was carried out. The implementation of detailed applied exploration in the form of research papers, it is expected to be reliably determine the characteristics of technogenic deposits (type and volume of works), the quality of mineral resources, determine reserves to levels B and C1 categories. Based on the exploration results rated to the geological, technical - exploitation, technological, market, regional and social-economic factors and the corresponding data research. The economic importance of exploration the technogenic raw materials, in the old flotation tailings in Bor, the market value of useful components that can be drawn from them, favorable regional factors, environmental protection through subsequent reclamation and remediation research area, are of course direct reasons that justify the projected performance of geological exploration. Geological exploration of the research area and finding economically interesting concentrations of copper and associated minerals (gold, silver and molybdenum) will be definitely found as very significant reflection in terms of geological and economic efficiency of the presented geological exploration.

Certainly it can be said that the projected geological survey research area the Old flotation tailing dump as the general socio - economic trends and needs, as well as long-term planning and development orientation of RTB, the town of Bor and the Republic of Serbia. Therefore, it is with this aspect can be concluded that the importance and economic feasibility of the projected research task beyond doubt, which is the direct reason for the current study consistently implemented.

The obtained results of detailed geological explorations would be synthesized through development an elaborate on completed geological explorations and Elaborate on mineral reserves. Explorations would be accompanied with development of appropriate graphic documentation, periodic reports, and Elaborate on completed geological explorations.

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TEHNOGENO LEŽIŠTE NA PROSTORU STAROG FLOTACIJSKOG JALOVIŠTA BOR (POLJE 1 I POLJE 2)[**]

Izvod

Početkom dvadesetog veka započeta je eksploatacija rude bakra u Boru. Paralelno sa tim vršeno je, u prvom periodu, topljenje rude. Nakon izgradnje flotacijskih pogona (1934. godine) vršeno je obogaćivanje rude, i dobijanje koncetrata bakra i plemenitih metala. Do 60-tih godina prošlog veka u Flotaciji Bor vršena je priprema rude dobijena eksploatacijom iz ležišta bakra Bor (stari površinski kop i Jama Bor). Nakon tog perioda pripreme rude dobijene iz borskog rudnika, priprema se, i ruda iz ležišta: Lipa, Cerovo (M. Krivelj). Kao nus-produkt ovog procesa dobijen je tehnogeni otpad flotiranja koji je deponovan od 1934. godine do 1980. godine, na prostoru Starog flotacijskog Jalovišta u Boru (Polje 1 i polje 2).

Na bazi dosadašnjih geoloških istraživanja u pomenutoj zoni, indicirani su povišeni sadržaji bakra na predmetnom prostoru. Realizacijom detaljnih geoloških istraživanja ocenila bi se potencijalnost prostora, cilju sagledavanje mogućnosti luženja sirovine, kao i rešavanje velikog ekološkog problema u samom centru grada Bora.

Ključne reči: *jalovište, tehnogene tvorevine, eksploatacije rude bakra, površinski kop*

UVOD

Tehnogeno ležište bakra “Staro borsko flotacijsko jalovište“ nalazi se u industrijskom krugu «Rudarsko-topioničarskog basena» (RTB), odnosno u samom gradu Boru. Bor je inače tipični rudarski grad, nastao uz rudnik. (slike 1 i 2).

Najveća količina tehnogenih tvorevina izdvojena je u neposrednoj okolini borskog i kriveljskog rudnika, na površini od preko 4 km^2. Predstavljene su tvorevinama koje su nastale eksploatacijom rudnih ležišta bakra (raskrivka) i pripremom mineralnih sirovina (flotacijska jalovišta). Na slici 2 prikazano je staro flotacijsko jalovište u gradu Boru.

Na reljef terena, u širem području Bora, znatan uticaj imala je intenzivna vulkanska aktivnost (krajem mezozoika i tokom kenozoika), koja je praćena snažnim tektonskim pokretima.

Međutim, na formiranje sadašnjeg izgleda reljefa uticala je i privredna aktivnost u mineralno-sirovinskom privrednom kompleksu. Procesi eksploatacije, pripreme, i prerade rude u Boru i okolini, uslovili su promene reljefa i nastajanje pojedinih inverznih morfoloških oblika, kao što su površinski kopovi i deponije (stenske otkrivke, rudničke jalovine, flotacijske jalovine, topioničke šljake, piritnih ogoretina).

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Sl. 1. *Prostorni položaj starog flotacijskog jalovišta u odnosu na gradsko jezgro*

Sl. 2. *Staro flotacijsko jalovište u Boru (maj 2011.)*

Posebno treba naglasiti da je i ljudska aktivnost znatno uticala na formiranje sadašnjeg izgleda reljefa. Eksploatacija ležišta bakra (stari površinski kop u Boru i površinski kop „Veliki Krivelj“) uslovila je izmene prirodnog ambijenta, za sada prvenstveno u smislu degradacije prirodnog reljefa, uz stvaranje inverznih oblika, u vidu depresije (površinski kopovi), s jedne strane, i sa druge strane uzvišenja od nagomilanih materijala stenske jalovine (otkrivke), kao i flotacijske jalovine posebno opasne po prirodni ambijent.

Polazna osnova za preliminarnu ocenu potencijalnosti, bili su rezultati ranijh istraživanja, koji su prikupljeni, analizirani i sintetizovani. Preliminarna ocena potencijalnosti je urađena na osnovu rezultata izvršenih geoloških istraživanja, koja su izvršili: rudnička geološka služba Rudnika bakra Bor i Biroa za geologiju, i Institut za rudarstvo i metalurgiju Bor (stari naziv: Institut za bakar Bor), u periodu 1947-2010. god., kao i na osnovu podataka stare dokumentacije rudnika iz perioda od 1909. godine do 1941. godine. Polazeći od primenjene metodologije dosadašnjih istraživanja, može se zaključiti da je za deponovanje jalovine iz flotacije korišćeno nekadašnje korito Borskog potoka, tako da je danas čitavo korito ispunjeno, a teren iznivelisan. Prema podacima dosadašnjih istraživanja, deponovanje jalovine na istražnom prostoru započeli su Francuzi, a za vreme Drugog svetskog rata nastavili Nemci. Posle Drugog Svetskog rata deponovanje jalovine na predmetnom prostoru vršeno je do 1980. godine. Polazeći od rezultata dosadašnjih istraživanja, može se zaključiti da je stepen istraženosti na istražnom prostoru nizak. Detaljna geološka istraživanja, sistemom istražnog bušenja, vršena su u na polju 1. Problematika koju treba rešavati realizacijom istražnih radova ogleda se u sledećem:

- Definisati geološke karakteristike, strukturni sklop, konturu i oblik, fizičko-mehaničke karakteristike paleo reljefa (korito Borskog potoka), i samog jalovišta, zatim odrediti kvalitet, i izvršiti tehnološka ispitivanja mogućnosti pripreme i primene, tehnogene sirovine.
- Analizirati faktore i pokazatelje geološko-ekonomske ocene karakteristične za detaljna geološka istraživanja (metalogenetske, geološke, rudarske, tehnološke, tržišne, regionalne i socijalno-ekonomske faktore i odgovarajuće pokazatelje) na osnovu kojih se vrši ocena potencijalnosti istražnog prostora, klasifikacija i kategorizacija ležišta mineralnih sirovina.
- Nakon izvršene ocene potencijalnosti na osnovu rezultata dobijenih realizacijom primenjenih detaljnih istraživanja, i moguće rudarske aktivnosti, izvršila bi se sanacija i rekultivacija na predmetnom prostoru.

GEOLOŠKA GRAĐA STAROG FLOTACIJSKOG JALOVIŠTA U BORU (Polje 1 i Polje 2)

Dosadašnja geološka istraživanja, posebno rad na geološkim kartama, nedvosmisleno ukazuju da je šira okolina Bora, a samim tim i šire okoli starog flotacijskog jalovišta u Boru, pretežno izgrađena od vulkansko-piroklastičnih i sedimentnih stena kredne starosti. U manjem obimu zastupljeni su paleozojski graniti i stene jurske, tercijerne i kvartarne starosti. Veće rasprostranjenje imaju kredne tvorevine, među kojima za depoziciju bakrove mineralizacije najveći značaj imaju hidrotermalno izmenjene vulkanske stene kredne starosti.

Prostor starog flotacijskog jalovišta (Polje 1 i Polje 2), je po mnogo čemu specifičan. Geološke karakteristike tehnogenog sirovine starog flotacijskog jalovišta (Polje 1 i Polje 2), uslovljene su pre svega neposrednom podlogom na kojoj su deponovane, kao i načinom obrazovanja deponije. Neposredna podloga deponije su najvećim delom geogene tvorevine (borski konglomerati, vulkanoklastične stene i aluvijalni nanos. Za deponovanje jalovine iz flotacije, je poslužilo nekadašnje korito Borskog potoka, tako da je danas čitavo korito ispunjeno, a teren iznivelisan. Jalovište se nalazi neposredno uz postojeće objekte RTB-a, u prvom redu Borske flotacije. Na osnovu dostupne dokumentacije o dosadašnjim istraživanjima može se zaključiti da je nekadašnje korito Borskog potoka znatno usečeno, i da su obale potoka bile strme.

Deponovanje flotacijske jalovine vršeno je na taj način, što se na nizvodnom delu potoka formirala inicijalna brana od krupnijih čestica peska i površinske raskrivke, a onda je celom dužinom potoka vršeno odlaganje flotacijske jalovine. Deponovanje flotacijske jalovine započeli su Francuzi, u severnom delu Borskog potoka, u neposrednoj blizini železničke stanice, od 1934. godine pa sve do 1941. godine, kada su

Nemci nastavili sa deponovanjem flotacijske jalovine. Nemci su sa deponovanjem jalovine nastavili u nižim južnim delovima Borskog potoka. Posle rata nastavljeno je deponovanje jalovine, tako da je čitavo korito ispunjeno flotacijskom jalovinom, pri čemu je obrazovano Polje 1. Teren je poravnjan na približnoj koti 360 m u Polju 1. U planu, Polje 1 ima ovalan oblik. Dimenzija duže ose (SZ – JI) je (bila) oko 400 m, a kraće (JZ – SI) oko 300 metara. Južno od polja 1, nizvodno na oko 600 m, formirana je brana od flotacijskog peska. Širina brane 1 iznosi oko 30 m. Na oko 800 m od brane 1 formirana je nizvodno, druga brana. Između brane 1 i brane 2 deponovana je flotacijska jalovina tako da su najgrublje čestice odvajane i taložene na obalama Borskog potoka i brana, dok je središni deo prostora između brana ispunjen finijom flotacijskom jalovinom. Na prostoru između brane 1 i brane 2 formirano je Polje 2. Teren na Polju 2 izravnan je na približnoj koti 368 m. U planu, Polje 2 ima elipsast oblik. Dimenzija duže ose (SZ – JI) je (bila) oko 800 m, a kraće (JZ – SI) oko 600 metara. Celokupni prostor (Polje 1 i Polje 2) ima elipsast oblik, koji obuhvata povrišinu od oko 1 km^2. Tehnogeno ležište bakra Staro flotacijsko jalovište u Boru, nastalo je kao rezultat obogaćivanja rude dobijene eksploatacijom na Starom površinskom kopu i podzemnom eksploatacijom. Dugi niz godina vršeno je odlaganje flotacijske jalovine u vidu mulja, prašine i peska. Flotacijskom koncentracijom rude, usled mineraloško-petroloških karakteristika rude i korisnih minerala, kao i usled nesavršenosti tehnološkog postupka, 85% bakra izdvaja se u koncentrat, dok se ostatak izdvaja u flotacijsku jalovinu. Slično je i sa drugim korisnim komponentama. Procentualno učešće korisnih komponenti izdvojenih, u koncentrat ili u flotacijsku jalovinu, zavisi od njihovog iskorišćenja primenjenim tehnološkim postupkom obogaćivanja.

Za sam prostor Starog flotacijskog jalovišta u Boru, tektonika nije značajna, jer se praktično radi o savremenim tvorevinama koje nisu bile izložene tektonskim silama koje deluju u geološkom vremenu. Ipak treba dati kratak osvrt na rasednu tektoniku u geogenoj podlozi ležišta. Najmarkantnija struktura, neposrednoj okolini istražnog prostora, je „Borski rased". Borski rased je u stvari rasedna (razlomna) zona, čija širina dostiže i 30-40 m, sa milonitskom zonom od 4 do 8 m debljine. Glavni strukturni pravci su, od borskog ležišta prema severu, predstavljeni sistemom manjih subparalelnih raseda duž istočnog oboda borske metalogenetske zone. Morfostrukturnom analizom područja (Petković, 1984), utvrđeno je da se veliki "Borski rased" može pratiti sve do raseda "Veliki Pek". Predstavlja složenu zonu razlamanja formiranu u postrudnom periodu. Strmog je pada (75–80°), prema jugozapadu i ima levo transkurentno do levo reversno kretanje. Ovakve strukture ukazuju na izvesna prerudna kretanja i prostorno su konstatovane samo u istočnom obodu TMK.

PREGLED RANIJE IZVRŠENIH ISTRAŽIVANJA

Dokazi o rudarskoj aktivnosti na području borske metalogenetske zone potiču iz vremena od pre 6 milenijuma (Rudna Glava), zatim iz staroantičkog i rimskog perioda. Savremenija geološka istraživanja na terenima Istočne Srbije započinju krajem 19. veka, a 1903. godine je u Boru potkopom presečeno rudno telo Čoka Dulkan. Od tada se rudarsko-geološka istraživanja u Borskom rudištu bakra inteziviraju.

Šire područje istražnog prostora Staro Borsko jalovište, je okolina Bora, odnosno područje koje je ranije mahom tretirano kao šira okolina Bora. Geološke podatke o ovom terenu nalazimo u radovima Žujovića (1889, 1893, 1900), Antule (1904), Lazarevića (1909, 1910), Cvijića (1904), V. Petkovića (1935), Ilića, i Simića (1949), Antonijevića (1957, 1959), F. Drovenika i M. Drovenika (1956), M. Drovenika (1953, 1959, 1961, 1966, 1968, 1983), M. Drovenika, I. Antonijevića i dr. (1962, 1967). Istraživanja vezana za istraživanja jalovišta i šljačišta, odnosno za njihovo korišćenje kao tehnogenih sirovina, počinju početkom šezdesetih godina prošlog veka i sa prekidima traju do danas. Tek početkom ovoga veka, u uslovima sve manje rudničke, obraća se veća pažnja na jalovišta kao potencijalne prostore za pronalaženje ekonomski interesantnih koncentracija bakra i drugih korisnih komponenti. Tome doprinosi i stalni porast cena bakra i plemenitih metala u poslednje vreme.

U široj okolini istražnog prostora "Staro flotacijsko jalovište" (Polje 1 i Polje 2), na području Rudnog polja Bor, vršena su obimna istraživanja. Istraživanja u posleratnom periodu vršena su od juna 1961. do kraja januara 1962. godine, pri čemu su primenjeni geološki radovi, i rudarski istražni radovi (istražno bušenje). Istražno bušenje vršeno je u periodu od 1961. do 1962 godine. Istražnim bušenjem obuhvaćen je deo istražnog prostora, takozvano Polje 1, pri čemu je izbušeno 87 plitkih bušotina po kvadratnoj mreži 40x40 m. Dužina bušotina bila je 10 m, a samo manji broj je imao dužinu od 30 m. Procenat izvađenog jezgra bio je oko 100% (Stevanović, 1963). Bušotine su analizirane na bakar, ukupni i oksidni, i sumpor. Analize na prateće korisne i štetne komponente nisu rađene.

Eksploatacija borskog ležišta**,** od početka prošlog veka, zahvatila je 26 rudnih tela – jamski i površinskim kopom (dobrim delom u isto vreme). Pri tome je dobijeno ukupno 146.270.000 t rude bakra iz koje je estrakovano 2.437.000 tona metala bakra, 139.140 kg zlata i 415.000 kg srebra. Takođe je otkopano i 436.200.000 tona jalovih masa, otkrivke i pratećih stena (Maksimović M., Nikolić K., 2005)

Eksploatacija ležišta bakra, starim površinskim kopom u Boru (slika 3.), a kasnije i podzemnom eksploatacijom, kao i obogaćivanje rude i dobijanje koncentrata u borskoj flotaciji, uslovile su izmene paleoreljefa, smislu degradacije prirodnog reljefa, uz stvaranje uzvišenja od nagomilanih materijala flotacijske jalovine. Metalurška prerada koncentrata uslovila je stvaranje deponija šljake. Najveća količina šljake odložena je na lokalitetu između površinskog kopa rudnog tela „H“ i bivšeg prališta radionice starog površinskog kopa, pa je ova lokacija poznata kao „Depo šljake – 1.

Sl. 3. *Stari borski površinski kop, Bor (avgust 2005.)*

U zavisnosti od tehnologija koja su bila korišćena u eksploataciji, faze metalurškog procesa topljenja u kojima je nastajala šljaka, kao i samih karakteristika rude, koncentrata bakra i topitelja, stvaran je tehnogeni otpad, veoma različitih – kako fizičkih i mineraloških, tako i hemijskih karakteristika. Sve šljake nastale u različitim vremenskim periodima odlagane su na više lokaliteta, a sa pojedinih lokacija vršena su i premeštanja usled izvođenja rudarskih radova pri otvaranju i proširenju površinskih kopova (stari površinski kop i površinski kop rudnog tela „H“).

PROJEKTNA REŠENJA DETALJNIH PRIMENJENIH GEOLOŠKIH ISTRAŽIVANJA

Na osnovu analize i sinteze dosadašnjih istraživanja i literaturnih podataka, definisani su koncepcija i metodologija istraživanja u narednom periodu. Detaljna primenjena geološka istraživanja vršiće se sa ciljem pronalaženja dodatnih količina bakra iz tehnogenog ležišta, radi povećanja mineralno – sirovinske baze RBB–a, a samim tim i povećanje količina rude koja će se preraditi. Detaljna geološka istraživanja na prostoru Starog flotacijskog jalovišta usmerena su na postupno, sistematično i sveobuhvatno istraživanje i ispitivanje ovog prostora i pronalaženja ekonomski interesantnih količina tehnogene sirovine. Celokupna geološka istraživanja su podređena i prilagođena geološko – metalogenetskim prilikama terena, stepenu njegove istraženosti, aktuelne problematike i cilju istraživanja.

Osnovni cilj je da se izvrše detaljna geološka istraživanja radi utvrđivanja podataka potrebnih za izradu Elaborata o rudnim rezervama, koji je neophodan za buduća rudarska projektovanja, ali i dobijanju relevantnih podataka za rekultivaciju i remedijaciju ovog prostora koji se nalazi u samom gradu Boru. Geološkim istraživanjem u narednom periodu primenile bi se kompleksne metode istraživanja, koje obuhvataju sledeće radove: geodetske radove, geološke radove, istražno bušenje, studijska ispitivanja, laboratorijska i tehnološka ispitivanja u laboratorijskom i poluindustrijskom obimu. Geološko istraživanje biće praćeno geološkim kartiranjem i oprobavanjem jezgra bušotina radi ispitivanja kvaliteta i kvantiteta mineralne sirovine: uzimaće se uzorci za mineraloško–petrološka ispitivanja; vršiće se geomehanička ispitivanja radi sagledavanje mogućnosti eksploatacije mineralne sirovine. Ispitivanje kvaliteta obuhvata uzimanje proba mineralne sirovine za hemijska i tehnološka ispitivanja. Istražnim radovima definisaće se geološka građa i geološke karakteristike istražnog prostora, i potvrditi rezultati ispitivanja kvaliteta mineralne sirovine dobijenih ranijim istražnim radovima.

ZAKLJUČAK

Predmetni prostor se nalazi se u gradu Boru, u neposrednoj blizini flotacijskih postrojenja „Borske flotacije“. Na bazi dosadašnjih geoloških istraživanja u pomenutoj zoni, indicirana je mineralizacija bakra, koja bi se realizacijom geoloških radova, istražila do nivoa B i C_1 kategorije rezervi, i utvrdio kvalitet mineralne sirovine, odnosno sadržaj bakra, zlata, srebra i drugih korisnih, ali i štetnih komponenti.

Osnovni cilj geoloških istraživanja, prostora "Staro borsko jalovište", je da se u skladu sa prikupljenim podacima o rezultatima dosadašnjih istraživanja izvrši izbor optimalnih projektnih rešenja (vrsta i obim radova) za predstojeća istraživanja, u cilju pronalaženja rude bakra i pratećih korisnih komponenti, u deponijama tehnogene sirovine. Gustina istražnih radova zavisi od postignutih rezultata, od čega zavisi i nastavak istraživanja. Na osnovu, studijskih istraživanja, izvršila bi se ocena potencijalnosti istraživanog područja. Realizacijom detaljnih primenjenih istraživanja u vidu istražnih radova, očekuje se da se pouzdanije utvrde karakteristike tehnogenog ležišta (obim, razmera, uslovi zaleganja), kvalitet mineralne sirovine, utvrde rezerve do nivoa B i C1 kategorije. Na osnovu rezultata istraživanja ocenili bi se geološki, tehničko – eksploatacioni, tehnološki, tržišni, regionalni i socijalno – ekonomski faktori i odgovarajući pokazatelji istraživanja.

Ekonomski značaj istraživanja tehnogenih sirovina, na području starog flotacijskog jalovišta u Boru, tržišna vrednost korisnih komponenti koje se mogu dobiti iz njih, povoljni regionalni faktori, zaštita životne sredine kroz kasniju rekultivaciju i remedijaciju istražnog prostora, su svakako direktni razlozi koji opravdavaju izvođenje projektovanih geoloških istraživanja. Geološka istraživanja ovog istražnog prostora i pronalaženje ekonomski interesantnih koncentracija bakra i pratećih minerala (zlata, srebra i molibdena), svakako će naći vrlo značajan odraz u smislu geološke i ekonomske efektivnosti izvedenih geoloških istraživanja.

Zasigurno se može reći da su projektovana geološka istraživanja istražnog prostora "Staro flotacijsko jalovište", u funkciji opštih društveno – ekonomskih kretanja i potreba, kao i dugoročnih planova i razvojnih orjentacija RTB-a, grada Bora i Republike Srbije. S toga se i sa ovog aspekta može zaključiti da je značaj i ekonomska opravdanost projektovanog istraživačkog zadatka nesumnjiva, što je i direktni razlog da se predmetna istraživanja dosledno realizuju.

Dobijeni rezultati detaljnih geoloških istraživanja, sintetizovali bi se kroz izradu Elaborata o izvršenim geološkim istraživanjima i Elaborata o rudnim rezervama. Istraživanja bi pratila izrada odgovarajuće grafičke dokumentacije, periodičnih izveštaja, kao i izrada Elaborata o izvršenim geološkim istraživanjima.

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MODELING OF ROCK MASSIF IN THE JAMA BOR WITH SPECIAL FOCUS ON THE PREVIOUS EXPLORATIONS OF THE ORE BODY »BORSKA REKA«***

Abstract

Research the stability of underground structures that are almost done, can be divided into the frameworks of theoretical processing, basic laboratory analyses and information on previous experiences in the exploitation of deep deposits and, as such, they can serve as a reference for more detailed research. In this paper, the example of the ore body "Borska Reka" in the underground mine Jama Bor, shows one of the ways to get the reliable data on the working environment that can be used to model the rock mass. Therefore, the results will provide a realistic assessment the stability of the analyzed structures.

Keywords: *rock mass modeling, stability of underground structures, triaxial tests*

INTRODUCTION

Modeling of the rock mass is done for the needs of research the stability of underground structures. It starts from defining the geometry of underground structure that may lead to an increase or decrease of its stability. It is recommended that any change in the geometry follows the correct sequence. This sequence is defined by: the location of structure, its orientation, the characteristics of surrounding rocks, size and other factors.

Selection of an adequate cross-section depends on several factors, such as: the characteristics of work environment, stress state, and dimensions or purpose of underground structure.

Underground structures (mining activities) often have significantly expressed one dimension compared to the other two, so the problem in most cases can be considered as two-dimensional. From this point of view, the order of required analyses is determined and may be as follows:

- Determining the technical requirements: shape and size of the room, depth;
- Determining the characteristics of the work environment - Modeling of the rock mass:
  - Depending on the level of exploration the work environment, the volume of tests also depends;
  - Determine the engineering-technical and other parameters using the appropriate test;

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- Determine the massif quality using the geomechanical classifications.

- Defining the stress of rock mass;
- Determining the stress on the contour of underground structure and/or in the massif;
- Determining the stress concentration coefficient and assessment the stability degree.

If further stability analysis is required, the size of unstable zone around underground structure is determined. Analysis is continued both by changing the structure geometry or entering the appropriate parameters of support system.

For the appropriate cross and longitudinal sections of underground structure with defining a discontinuity and boundary conditions, a view of stress-strain state in the area of observed structure is obtained.

For consideration and prediction the behavior of the system rock mass - support system at all stages of construction, it is necessary to conduct the appropriate stress-deformation analyses for the proposed types of support systems.

The objective is to determine the way in which the shape and size of disrupted (unstable) zone around the structure changes (zone exposed to tensile and/or shear). At the same time, the stability of constructed structures is estimated as well as the mining operations that are planned by the mining projects for development.

MODELING OF ROCK MASS

Properties of the work environment

In order to determine the characteristics of the work environment, the current technical documentation of geological, petrological-mineralogical, structural and physical-mechanical tests was reviewed, which were conducted for the ore body "Borska reka" in the Jama Bor. Based on this, it can be generally concluded that much was done and a lot of work and effort were invested.

Here, it will only be mentioned the year when the subject research was carried out starting from 1997 [1], 1999 [2] and 2007 [3], and in the phase of preparation, also the most recent Elaborate on engineering-geological (geotechnical), geomechanical explorations and laboratory testing of the ore and rock mass at the copper deposit "Borska reka", carried out by the Mining and Metallurgy Institute Bor.

However, since the research was carried out over a period of nearly 20 years, there are discrepancies in the interpretation of results due to the application of different measuring methods. As the laboratory tests were mainly carried out on samples taken from drill holes, the research was used that was conducted on the samples of rock masses from underground works in the same reporting period of time. [4]

Thus, for further analysis in this paper, a part of the results of geotechnical testing is shown that will be able to be compared with the aspects of modeling the rock mass. This research, carried out in 1999, will be compared with the results of recent research, carried out during 2014.

Research conducted on samples taken from the core of the exploration drill holes

Data are drawn from the Elaborate from 1999 on parameters that are needed to define the work environment in terms of strength calculation and stability analysis. [2]

Since data are presented per each drill hole separately, in order to have an idea of the mean value of data at the level closest to the XVII horizon, i.e., K-155, it was necessary to systematize data and they are shown in Table 1. Table 1 shows the values for the first sampling interval from each drill hole, and statistical indicators are given at the end of column for corresponding parameter, while below row shows statistical indicators for complete results from each interval in the corresponding drill hole.

In addition to these physical and mechanical tests, it should be noted that based on the structural characteristics of rock mass, obtained by mapping the core of exploratory drill holes as well as mapping the drifts at the XVII horizon, the quality of the rock mass could be assessed.

Table 1 *Data from Elaborate from 1999*

Drill hole	X_b **[m]**	Y_b **[m]**	Z_b **[m]**	γ **[KN/m³]**	σ_c **[MPa]**	σ_i **[MPa]**	φ **[°]**	**C [MPa]**	**E [MPa]**	**G [MPa]**	ν	**RQD**
Mean values of the first interval				**27.66**	**79.4**	**6.5**	**58**	**11.3**	**32363**	**13108**	**0.24**	**78**
Standard deviation				0.85	19.76	1.78	2.43	2.92	8552.10	3619.87	0.06	12.02
Coefficient of variation				3.07%	24.88%	27.44%	4.19%	25.87%	26.43%	27.62%	25.33%	15.45%
P a r a m e t r e s				γ	σ_c	σ_i	φ	**C**	**E**	**G**	ν	**RQD**
Mean values of complete results				**27.96**	**73.6**	**7.3**	**56**	**11.0**	**32626**	**13021**	**0.26**	**72**
Standard deviation				0.95	18.96	1.74	2.65	2.83	6482.10	2730.48	0.07	16.48
Coefficient of variation				3.40%	25.75%	23.95%	4.71%	25.81%	19.87%	20.97%	26.43%	22.84%

In addition to data in the table below, it is only noted that testewd specific gravity (γs) ranges from 27.62÷30.30 KN/m³, humidity (W) of 0.34÷1.51%, and porosity (n) of 1.31÷7.80%.

Since the data of triaxial tests are not systematized in the aforementioned Elaborate, the values obtained for the angle of internal friction (φ) are in the range of 39°÷46° and cohesion (C) of 16÷23 MPa. These values are certainly different from those shown in the Table above, due to the primary reason that there are those parameters obtained by transfer through the laboratory values of compressive strength and tensile.

Research conducted on samples taken from constructed rooms

The required research was carried out on samples taken from the ore body "Borska reka" from the XVII horizon. [4]

In testing the physical properties, the bulk density of taken samples was determined, while the uniaxial compressive strength, tensile strength and triaxial strength were tested in mechanical strength testing. In addition to these values, the deformation parameters were determined.

Selection of sampling place was carried out in the pit with the help of drift plan at the XVII horizon. In this way, the selected samples are the starting material for production and preparation of test bodies, which were tested in the laboratory by appropriate methods. For those reasons, the rock mass samples had smaller dimensions. They were appropriately selected and taken from the main mass and they are a part of this mass from the given place from which the adequate sample was taken.

Sampling was done at five places from which the test bodies were obtained (marked as S-1, U-2, U-3, U-4 and U-5).

In this way, all parameters, obtained from the corresponding tests, relate to the physic-mechanical parameters of mineralized massif [4].

Here, only detailed tests of triaxial strength and deformability will be displayed.

Test of triaxial strength and the obtained values of main stresses in triaxial tests are shown in Table 2 [6].

Table 2 *Values of the principal stresses in triaxial tests*

Designation of series (samples) with values of the principal stresses at fracture									
U – 1		U – 2		U – 3		U – 4		U – 5	
σ_3 [MPa]	σ_1 [MPa]	σ_3 [MPa]	σ_1 [MPa]	σ_3 [MPa]	σ_1 [MPa]	σ_3 [MPa]	σ_1 [MPa]	σ_3 [MPa]	σ_1 [MPa]
0	76	0	71	0	83.2	0	86	0	88
10	107	8	98.6	5	111.8	10	145.6	5	118.1
15	143	16	150	10	132	15	185	10	145
20	168	24	195	15	176	20	230.2	15	205
25	190	32	204	20	195	30	242	25	227.4
30	203								
40	230								

The Hoek-Brown constant (m_i) is determined by triaxial testing and data processing for intact (undisturbed) rock, which takes that the second constant is s = 1.

In the case of methods of determining the elastic deformability of rock materials, it should be noted that the tests are mostly confined to determining the elasticity modulus, deformation modulus and the Poisson ratio, noting that deformation modulus is always smaller than elasticity modulus.

In testing the elasticity modulus, the unit deformation in direction of forces can be registered, the unit deformation can be determined perpendicular to the effect of force, which is defined by the Poisson ratio.

A number of different methods and procedures are applied which differ among themselves only through the use of a large number of meters for registration of deformations and forces, or stresses. In this case, testing the deformation characteristics was carried out with a triaxial cell under the influence of pressure [7].

The Phillips measuring bridge with direct reading in μmm/mm. was used for deformation registration on strain gauges, induced by load. To prevent measurement due to high sensitivity of this measuring system and minimum temperature changes, a test body was made which is connected with the measuring bridge, and on which the identical strain gauges are affixed, which are used as the temperature compensation. The strain gauge with the following characteristics was selected for strain gauges that can register the deformations of test body:

Manufacturer: Tokyo Sokki Kenkyujo Co., Ltd

- Type PL-20-11
- Gauge length 20 mm
- Gauge resistance 120±0.3 Ω
- Gauge Factor 2.10

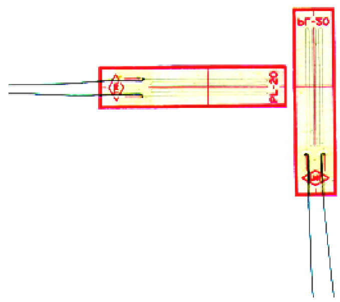


Figure 1 *Appearance and position of strain gauges on test body*

Tests were performed with lateral pressure of 16 MPa. Each table is followed by σ - ε diagram, from which the backward deformations of test body can be read in order to determine the elasticity modulus and hysteresis curve shape.

To simulate the stress state of the rock mass at greater depths, it is necessary to test for the appropriate depth of works (γH). Thus, for example, the lateral pressure of 16 MPa for depth of 550÷580 m, 24 MPa for 880 ÷ 900 m, etc.

In deformation testing, the elastic-plastic behavior of the rock mass was determined, which is reflected in the residual plastic deformations. Due to this reason, the parameters of plasticity need to be included in the model parameters [8].

Table 3 *An example of measuring results on one of the test bodies with constant lateral pressure of 16 MPa*

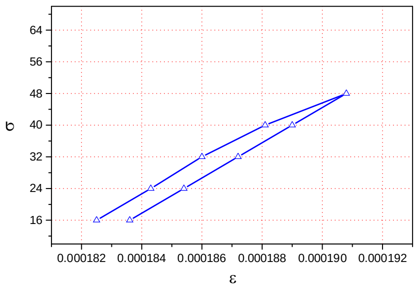
σ_1	Reading [μ mm/mm]						Deformations		Koef. Poissona	Note:
	Horizontal			Vertical			ε_h	ε_v	ν	
[MPa]	1	2	sredina	1	2	sredina	[mm]	[mm]		
16	15400	15750	15575	13900	13910	13905	0.0000414	0.0001825	0.227	Dimensions of test body are
24	15330	15700	15515	14005	14080	14043	0.0000413	0.0001843	0.224	
32	15300	15665	15483	14095	14256	14176	0.0000412	0.0001860	0.221	h = 76.20 mm
40	15270	15635	15453	14220	14440	14330	0.0000411	0.0001881	0.219	d = 38.10 mm
48	15160	15570	15365	14490	14590	14540	0.0000409	0.0001908	0.214	
40	15230	15615	15423	14280	14520	14400	0.0000410	0.0001890	0.217	Volume
32	15260	15640	15450	14200	14330	14265	0.0000411	0.0001872	0.219	O=dπ
24	15310	15690	15500	14040	14220	14130	0.0000412	0.0001854	0.222	O = 119.647
16	15400	15755	15578	13930	14055	13993	0.0000414	0.0001836	0.226	mm

Based on investigations of deformability for the initial lateral pressure of 16 Mpa, the parameters of elasticity were obtained, as follows:

ν = 0.221

E = 44120 MPa

E_d = 34076 MPa



Based on selected lateral pressure for this test, the mean value of data for E and ν, Table 4, will be used in modeling the rock mass and development the numerical model.

Table 4 *Table of test results the deformation characteristics*

Ordinal number of the test body	**E [MPa]**	**E_d [MPa]**	**ν -**
Mean value	40490	33255	0.216
Standard deviation	2629	1066	0.004
Coefficient of variation	6.49%	3.20%	1.72%

Assessment the quality of rock massif

Assessment the quality of rock massif is carried out using the geological strength index - GSI. In this case, for the XVII horizon of the ore body "Borska reka", based on the physical appearance of taken undisturbed samples, recorded structure and condition of the surfaces "in situ", the GSI assessment for this area is in the range of 65÷75.

However, RMR classification can be used for GSI determination.

In previous research for the ore body "Borska reka, the RQD value was stated of 72%÷92% for all exploratory drill holes that were drilled to test the deeper parts of the ore body. For the mean RQD value in the first interval of sampling from the core of exploratory drill holes, which are the closest to the horizon XVII, the value of 78% was statistically determined.

In considering and determining the RMR classification, the value of RQD = 78% and σ_{ci} = 72 MPa is taken, which was obtained by triaxial tests in exploration the rock massif at the XVII horizon. Considering the information on structural characteristics from previous research, and using the classification of Bieniawski from 1989, the value for description of rock mass at the XVII horizon of the ore body "Borska reka" is obtained and it is 73 points. For getting GSI over RMR the classification of Bieniawski, $GSI=RMR_{89}-5$, i.e. GSI = 68, is taken.

Comparing the values obtained from the RMR classification and physical appearance of the cores from taken samples, it can be concluded that it would be acceptable if the value GSI is 70. Here, it must be carefully because the factor of damage the structure must be included in development from which the samples were taken (the impact of blasting) as well as the time after development (movement along the contour).

The research results of rock massif

Based on laboratory tests of mechanical strength, deformation characteristics and assessment the massif quality, the laboratory values of rock massif parameters at the XVII horizon of the ore body, "Borska reka", Table 5 [5], are obtained.

Thus defined parameters were used in modeling the rock massif and analysis the stability of structures at the XVII horizon of the ore body "Borska reka" to the aim of proving the possibility of using the methodology that uses the Hoek-Brown failure criterion.

Table 5 *Physico-mechanical parameters obtained by laboratory tests on samples of rock mass from the XVII horizon of the ore body "Borska reka"*

Working environment (XVII horizon)	γ [kN/m^3]	σ_c [MPa]	σ_i [MPa]	E_t [MPa]	E_d [MPa]	ν -	φ [°]	m_i -	C [MPa]	RMR_{89}	GSI
K-155 silicified andesite	28,2	63,39	6,71	40490	33255	0,216	41.6	15,09	18.9	73	70

Determining the relevant physic-mechanical parameters of rock massif

To determine the physic-mechanical parameters of rock massif to be used for further numerical analysis and calculations, it is necessary to compare the results of laboratory tests, the existing correlations between the physic-mechanical, structural properties and the results of categorizing the rock masses, as well as defining the strength of rock massif by the Hoek-Brown failure criterion, based on previous research. On that basis, carefully evaluate and determine the parameters that will be relevant or authoritative to characterize the state of rock mass, and thus enter into the modeling of rock massif.

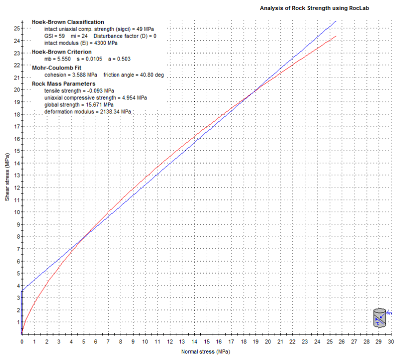
Until now, according to the preliminary analyses, carried out within the framework of the latest research, there are data that show a partial lower values that describe the physic-mechanical properties of the rock material, Table 6 and Figure 2.

Table 6 *Physico-mechanical parameters obtained by laboratory tests on samples taken from drill holes within the recent geomechanical explorations the rock mass of the ore body "Borska reka"*

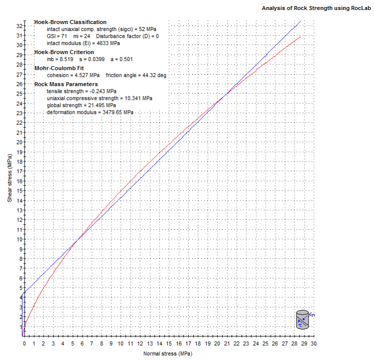
Geotechnical environment	γ [kN/m^3]	σ_c [MPa]	σ_i [MPa]	E_t [MPa]	E_s [MPa]	ν -	φ [°]	m_i -	C [MPa]	RMR_{89}	GSI
Bor·s pelytes	25.4	49	4.95	5600	3730	0.34	36.0	24	12.13	54	
Andesites	25.9	52	5.37	6927	4633	0.31	36.8	26	12.90	66	
Kaolinizated andesites	27.0	25	3.04	5490	3672	0.37	30.4	20	7.53	34	
Silicified andesites	27.7	67	7.57	10790	7127	0.32	37.4	28	16.70	51	

It is therefore necessary, when the results are final and the Elaborate is complete, to perform a comparative analysis of data for modeling the rock massif and make appropriate conclusions regarding the relevant data to continue going in the calculation the stability and defining the ways and methods of exploitation the copper ore from the ore body Borska reka in the Jama Bor.

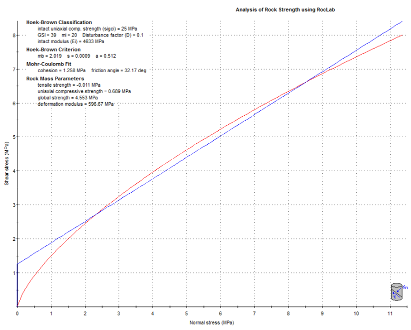
Since these are great depths, where safety is a priority, the geomechanical research has a great importance, and also the responsibility in precise defining of parameters. Sometimes the exaggeration in providing the satisfactory safety factor, in the case of the ore body Borska reka, may deter from further investment due to the economic reasons. Therefore, the responsibility for defining these parameters becomes even greater.



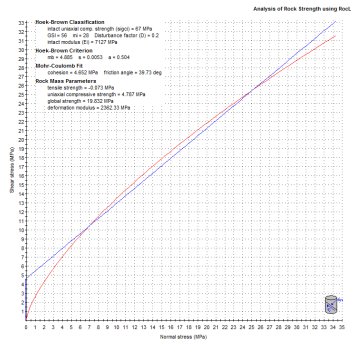
Bor's pelytes



Andesites



Kaolinized andesites



Silicified andesites

Figure 2 *Strength parameters of the rock mass for all isolated environment*

CONCLUSION

Based on the previous results of conducted laboratory tests on samples of rock massif and core from exploration drill holes, with taking into account the state of rock massif, degree of representativeness of samples, effect of size and others, a selection of parameters of physico-mechanical properties of rock masses was done that are applicable to the modeling of rock massif.

By development of software packages that deal with the preparation and analysis of numerical models, the application the Hoek-Brown failure criterion has also experienced a particular progress. This fracture criterion is one of the most widely used and generally accepted criteria for modeling of rock massif.

Therefore, this work contains, in addition to a part on the results of physico-mechanical research the ore body "Borska reka", a precisely determining the triaxial strength and deformability of rock massif. Such contribution to modeling of rock massif, with knowledge on direction and intensity of stresses in the massif and applying the appropriate mathematical model, leads to optimal solutions in sizing the underground structures as a function of depth and required safety factor.

Generally speaking, development of modern underground mining is followed by more complex mining-geological conditions. Therefore, the problems in the underground construction are related to the solutions that must be based on a good knowledge the rules of development the mechanical processes in the rock mass. Physical-structural and mechanical properties of rock massif, technological specifities of exploitation system and preparation method of block caving also predetermine the mechanical state of these complex systems.

All of this requires a different approach, type and scope of geotechnical research, especially if the use of numerical models is planned. They require a selection of forms of underground structures, modeling of rock massif and failure criterion parameters based on a detailed study of rock massif through the appropriate laboratory and field tests. That makes it even greater justification for a more detailed introduction to the new techniques, already applied, in the world, so there is no reason that such a program is not applied to our deposits.

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MODELIRANJE STENSKOG MASIVA U JAMI BOR SA POSEBNIM OSVRTOM NA DOSADAŠNJA ISTRAŽIVANJA RUDNOG TELA »BORSKA REKA«***

Izvod

Istraživanje stabilnosti podzemnih objekata koja su do skoro kod nas rađena, mogu se svrstati u okvire teoretske obrade, osnovnih laboratorijskih analiza i informacija o dosadašnjim iskustvima na eksploataciji dubokih ležišta i kao takva mogu da služe kao orijentacija za detaljnija istraživanja. U ovom radu se, na primeru rudnog tela »Borska Reka« u Jami Bor, prikazuje jedan od načina kako doći do pouzdanih podataka o radnoj sredini koje možemo koristiti za modeliranje stenskog masiva. Samim tim i rezultati će omogućiti realnu procenu stabilnosti analiziranih objekata.

Ključne reči: *modeliranje stenskog masiva, stabilnost podzemnih objekata, triaksijalna ispitivanja*

UVOD

Modeliranje stenskog masiva radi se za potrebe istraživanja stabilnosti podzemnih objekata. Započinje od definisanja same geometrije podzemnog objekata koja može da dovede do povećanja ili smanjenja njegove stabilnosti. Preporučuje se da svaka promena geometrije prati odgovarajući redosled. Taj redosled je definisan: lokacijom objekta, njegovom orijentacijom, osobinama okolnih stena, veličinom i drugim činiocima.

Na izbor adekvatnog poprečnog preseka utiče nekoliko činilaca, kao što su: svojstva radne sredine, naponsko stanje i dimenzije odnosno namena podzemnog objekta.

Podzemni objekti (rudarski radovi) najčešće imaju znatno izraženu jednu dimenziju u odnosu na druge dve, pa se problem u većini slučaja može smatrati dvodimenzionalnim. Sa tog aspekta se i utvrđuje redosled potrebnih analiza i on može biti sledeći:

- Utvrđivanje tehničkih uslova: oblik i veličina prostorije, dubina;
- Utvrđivanje osobina radne sredine - Modeliranje stenskog masiva:
  - U zavisnosti od stepena istraženosti radne sredine zavisi i obim ispitivanja;
  - Odgovarajućim ispitivanjima utvrditi inženjersko - tehničke i druge parametre;
  - Primenom geomehaničkih klasifikacija odrediti kvalitet masiva.
- Definisanje napona stenskog masiva;

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*** *Ovaj rad je proistekao kao rezultat projekta TR 33021 "Istraživanje i praćenje promena naponsko deformacijskog stanja u stenskom masivu "in-situ" oko podzemnih prostorija sa izradom modela sa posebnim osvrtom na tunel Kriveljske reke i Jame Bor", koga finansira Ministarstvo prosvete, nauke i tehnološkog razvoja Republike Srbije*

- Određivanje napona na konturi podzemnog objektai/ili u masivu;
- Određivanje koeficijenta koncentracije napona i ocena stepena stabilnosti.

Ukoliko je potrebna dalja analiza stabilnosti, određuje se veličina nestabilne zone oko podzemnog objekta. Analiza se nastavlja ili promenom geometrije objekta ili unošenjem parametara odgovarajućeg podgradnog sistema.

Za odgovarajuće poprečne i uzdužne preseke podzemnog objekta uz definisanje diskontinuiteta i graničnih uslova dobija se slika naponsko-deformacijskog stanja u zoni posmatranog objekta.

Radi sagledavanja i predviđanja ponašanja sistema stenski masiv - podgradni sistem, u svim fazama izgradnje objekta, neophodno je sprovoditi odgovarajuće naponsko-deformacijske analize za predložene tipove podgradnih sistema.

Cilj je da se utvrdi način na koji se oblik i veličina poremećene (nestabilne) zone oko objekta menja (zone izložene dejstvu zatezanja i/ili smicanja). Ujedno, procenjuje se stabilnost izrađenih objekata kao i rudarskih radova koji su rudarskim projektom predviđeni za izradu.

MODELIRANJE STENSKOG MASIVA

Osobine radne sredine

U cilju utvrđivanja osobina radne sredine, pregledana je dosadašnja tehnička dokumentacija o geološkim, petrološko-mineraloškim, strukturnim kao i fizičko-mehaničkim ispitivanjima, koja su rađena za rudno telo "Borska reka" u Jami Bor. Na osnovu toga se može generalno izvući zaključak da je dosta toga urađeno i da je uložen veliki rad i trud.

Ovde će se samo navesti godine kada su vršena predmetna istraživanja i to počev od 1997 [1], 1999 [2] i 2007 [3], a u fazi izrade je i najnoviji Elaborat o inženjersko-geološkim (geotehničkim), geomehaničkim istraživanjima i laboratorijskim ispitivanjima rude i stenskog masiva na ležištu bakra „Borska Reka", koga radi Institut za rudarstvo i metalurgiju Bor.

Međutim, obzirom da su istraživanja rađena u periodu od skoro 20 godina, postoje odstupanja kod interpretacije rezultata iz razloga primene različitih metoda merenja. Kako su laboratorijska ispitivanja rađena uglavnom na uzorcima uzetih iz bušotina, korišćena su i istraživanja koja su rađena na uzorcima stenske mase iz samih podzemnih radova u istom posmatranom periodu vremena. [4]

Stoga se za dalju analizu, u ovom radu, prikazuje deo rezultata geomehaničkih ispitivanja koji će moći da se komparativno uporede sa aspekta modeliranja stenskog masiva. To su istraživanja urađena tokom 1999. godine koja će biti uporediva sa rezultatima najnovijih istraživanja koja su rađena tokom 2014. godine.

Istraživanja urađena na uzorcima uzetim iz jezgra istražnih bušotina

Iz Elaborata iz 1999 godine su izvučeni podaci o parametrima koji su potrebni za definisanje radne sredine sa aspekta proračuna čvrstoće i analize stabilnosti [2].

Obzirom da su podaci prikazani po svakoj bušotini pojedinačno, da bi imali predstavu o srednjoj vrednosti podataka na nivou najbližem XVII horizontu tj. K-155, bilo je potrebno da se sistematizuju podaci i oni su prikazani u tabeli 1. U tabeli su prikazane vrednosti za prvi interval uzorkovanja iz svake bušotine, na kraju kolone dati su statistički pokazatelji za odgovarajući parametar, dok su u redu ispod prikazani statistički pokazatelji za kompletne rezultate sa svakog intervala iz odgovarajuće bušotine.

Pored ovih fizičko-mehaničkih ispitivanja, potrebno je pomenuti da se na osnovu strukturnih karakteristika stenskog masiva koji su dobijeni kartiranjem jezgra istražnih bušotina kao i kartiranjem hodnika na nivou XVII horizonta, mogao proceniti kvalitet stenske mase.

Tabela1. *Podaci iz Elaborata iz 1999. godine*

Bušotina	X_b [m]	Y_b [m]	Z_b [m]	γ [KN/m^3]	σ_c [MPa]	σ_i [MPa]	φ [°]	C [MPa]	E [MPa]	G [MPa]	ν	RQD
Srednje vrednosti prvog intervala				**27.66**	**79.4**	**6.5**	**58**	**11.3**	**32363**	**13108**	**0.24**	**78**
Standardno odstupanje				0.85	19.76	1.78	2.43	2.92	8552.10	3619.87	0.06	12.02
Koeficijent varijacije				3.07%	24.88%	27.44%	4.19%	25.87%	26.43%	27.62%	25.33%	15.45%
P a r a m e t r i				γ	σ_c	σ_i	φ	**C**	**E**	**G**	ν	**RQD**
Srednje vrenosti kompletnih rezultata				**27.96**	**73.6**	**7.3**	**56**	**11.0**	**32626**	**13021**	**0.26**	**72**
Standardno odstupanje				0.95	18.96	1.74	2.65	2.83	6482.10	2730.48	0.07	16.48
Koeficijent varijacije				3.40%	25.75%	23.95%	4.71%	25.81%	19.87%	20.97%	26.43%	22.84%

Pored podataka koji su u tabeli prikazani, samo se napominje da se ispitivana specifična težina (γs) kreće u granicama od 27,62÷30,30 KN/m^3, vlažnost (W) od 0,34÷1,51 % i poroznost (n) od 1,31÷7,80 %.

Obzirom da podaci triaksijalnih ispitivanja nisu sistematizovani u pomenutom Elaboratu, dobijene vrednosti za ugao unutrašnjeg trenja (φ) su u granicama od 39°÷46° i kohezije (C) od 16÷23 MPa. Ove vrednosti se naravno razlikuju od onih koje su prikazane u gornjoj tabeli, iz osnovnog razloga jer su tamo ti parametri dobijeni prevođenjem preko laboratorijskih vrednosti čvrstoće na pritisak i zatezanje.

ISTRAŽIVANJA URAĐENA NA UZORCIMA UZETIM IZ IZGRAĐENIH PROSTORIJA

Urađena su potrebna istraživanja na uzorcima uzetim iz rudnog tela "Borska reka" sa XVII horizonta. [4]

Kod ispitivanja fizičkih osobina utvrđivana je zapreminska težina uzetih uzoraka, dok je kod ispitivanja mehaničkih čvrstoća, ispitivana jednoaksijalna čvrstoća na pritisak, čvrstoća na zatezanje i triaksijalna čvrstoća. Pored ovih veličina utvrđivani su i parametri deformabilnosti.

Izbor mesta uzimanja uzoraka vršen je u jami uz pomoć plana hodnika na XVII horizontu. Na ovaj način izabrani uzorci su početni materijal za izradu i pripremu probnih tela, koja su ispitivana u laboratoriji odgovarajućim metodama. Iz tih razloga su uzorci iz stenske mase bili manjih dimenzija. Oni su na odgovarajući način odabrani i uzimani iz osnovne mase i predstavljaju deo te mase sa datog mesta sa koga je uzet odgovarajući uzorak.

Uzimanje uzorka je urađeno na pet mesta iz kojih su dobijena probna tela (označeni su sa U–1, U–2, U–3, U–4 i U-5).

Na taj način se i svi parametri, koji su se dobili iz odgovarajućih ispitivanja, odnose na fizičko-mehaničke parametre orudnjenog masiva. [4]

Ovde će se samo detaljnije prikazati ispitivanje triaksijalne čvrstoće i ispitivanje deformabilnosti.

Ispitivanje triaksijalne čvrstoća i dobijene vrednosti glavnih napona kod triaksijalnog ispitivanja prikazani su u tabeli 2.[6]

Tabela 2. *Vrednosti glavnih napona kod triaksijalnog ispitivanja*

Oznaka serije (uzorka) sa vrednostima glavnih napona pri lomu									
U – 1		U – 2		U – 3		U – 4		U – 5	
σ_3 [MPa]	σ_1 [MPa]	σ_3 [MPa]	σ_1 [MPa]	σ_3 [MPa]	σ_1 [MPa]	σ_3 [MPa]	σ_1 [MPa]	σ_3 [MPa]	σ_1 [MPa]
0	76	0	71	0	83.2	0	86	0	88
10	107	8	98.6	5	111.8	10	145.6	5	118.1
15	143	16	150	10	132	15	185	10	145
20	168	24	195	15	176	20	230.2	15	205
25	190	32	204	20	195	30	242	25	227.4
30	203								
40	230								

Triaksijalnim ispitivanjem i obradom podataka određuje se i Hoek-Brown konstanta (m_i) za intaktnu (neporemećenu) stenu, pri čemu se uzima da je druga konstanta s=1.

Kada se radi o metodama određivanja deformabilnosti elastičnih stenskih materijala, treba ukazati da se ispitivanja uglavnom svode na određivanje modula elastičnosti, modula deformacije i Poissonovog koeficijenta, uz napomenu da je modul deformacije uvek manji od modula elastičnosti.

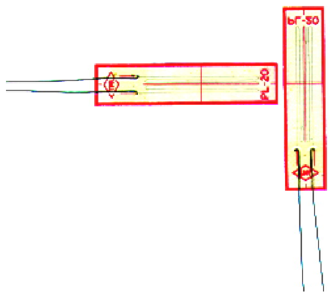
Prilikom ispitivanja modula elastičnosti moguće je pored registrovanja jedinične deformacije, u pravcu dejstva sile, utvrditi i jediničnu deformaciju upravno na dejstvo sile, čiji je odnos definisan Poissonovim koeficijentom.

U primeni je veliki broj različitih metoda i postupaka koji se između sebe razlikuju jedino kroz primenu velikog broja merača za registrovanje deformacija i sila, odnosno napona. U ovom slučaju, ispitivanje deformacionih karakteristika je vršeno sa triaksijalnom ćelijom pod uticajem svestranog pritiska. [7]

Za registrovanje deformacija na mernim trakama, izazvanim opterećenjem, korišćen je Philips-ov merni most sa očitavanjem direktno u µmm/mm. Da bi se zbog velike osetljivosti ovog mernog sistema i na minimalne promene temperature, predupredile greške pri merenju, izrađeno je probno telo koje je povezano sa mernim mostom, a na kome su zalepljene identične merne trake koje služe kao temperaturna kompenzacija. Za merne trake koje mogu da registruje deformaciju na probnom telu, izabrana je merna traka, sledećih karakteristika:

Proizvođač: Tokyo Sokki Kenkyujo Co., Ltd

- Tip (Type) PL-20-11
- Dužina trake (Gauge length) 20 mm
- Otpor trake (Gauge Resist) 120±0.3 Ω
- Faktor trake (Gauge Factor) 2.10



Sl. 1. *Izgled i položaj mernih traka na probnom telu*

Ispitivanja su rađena sa bočnim pritiskom od 16 MPa. Svaku tabelu prati i σ - ε dijagram, sa koga se očitava zaostala deformacija probnog tela u cilju utvrđivanja modula elastičnosti i oblika histerezisne krive.

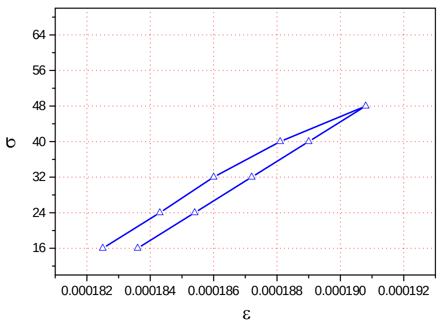
- Za simulaciju naponskog stanja stenskog masiva na većim dubinama potrebno je izvršiti ispitivanja za odgovarajuću dubinu izvođenja radova (γH). Tako je npr. bočni pritisak 16 MPa za dubinu 550÷580 m, 24 MPa za 880÷900 m itd.
- Prilikom ispitivanja deformabilnosti utvrđeno je elasto-plastično ponašanje stenske mase, koje se ogleda u zaostalim plastičnim deformacijama. Iz tog razloga u parametre modela je potrebno uključiti i parametre plastičnosti. [8]

Tabela 3. *Primer rezultata merenja deformacija na jednom od probnih tela sa konstantnim bočnim pritiskom od 16 MPa*

σ_1	Očitavanje[μ mm/mm]						Deformacije		Koef. Poissona	Napomena:
	horizontalno			vertikalno			ε_h	ε_v		
[MPa]	1	2	sredina	1	2	sredina	[mm]	[mm]	ν	
16	15400	15750	15575	13900	13910	13905	0.0000414	0.0001825	0.227	Dimenzije probnog tela su:
24	15330	15700	15515	14005	14080	14043	0.0000413	0.0001843	0.224	
32	15300	15665	15483	14095	14256	14176	0.0000412	0.0001860	0.221	
40	15270	15635	15453	14220	14440	14330	0.0000411	0.0001881	0.219	h = 76.20 mm
48	15160	15570	15365	14490	14590	14540	0.0000409	0.0001908	0.214	d = 38.10 mm
40	15230	15615	15423	14280	14520	14400	0.0000410	0.0001890	0.217	
32	15260	15640	15450	14200	14330	14265	0.0000411	0.0001872	0.219	Obim
24	15310	15690	15500	14040	14220	14130	0.0000412	0.0001854	0.222	O=dπ
16	15400	15755	15578	13930	14055	13993	0.0000414	0.0001836	0.226	O = 119.647 mm

Na osnovu ispitivanja deformabilnosti za početni bočni pritisak od 16 MPa dobijeni su parametri elastičnosti, i to:

ν = 0.221
E = 44120 MPa
E_d = 34076 MPa



Na osnovu izabranog bočnog pritiska za ovo ispitivanje, kod modeliranja stenskog masiva i izrade numeričkog modela koristiće se srednja vrednost podataka za E i ν, tabela 4.

Tabela 4. *Tabela rezultata ispitivanja deformacionih karakteristika*

Redni broj probnog tela	E [MPa]	E_d [MPa]	ν -
Srednja vrednost	40490	33255	0.216
Standardno odstupanje	2629	1066	0.004
Koeficijent varijacije	6.49%	3.20%	1.72%

Procena kvaliteta stenskog masiva

Procena kvaliteta stenskog masiva se vrši geološkim indeksom čvrstoće – GSI. U konkretnom slučaju, za XVII horizont u rudnom telu “Borska reka”, na osnovu fizičkog izgleda uzetih neporemećenih uzoraka, snimljene strukture i stanje površina “in situ”, procena GSI za ovakvu sredinu kreće se u granicama od 65÷75.

Međutim, za određivanje GSI moguće je koristiti i RMR klasifikaciju.

U dosadašnjim istraživanjima za rudno telo “Borska reka” konstatovana je vrednost RQD od 72% ÷ 92%, za sve istražne bušotine koje su bušene u cilju ispitivanja dubljih delova rudnog tela. Za srednju vrednost RQD na prvom intervalu uzorkovanja iz jezgra istražnih bušotina, koji su najbliži XVII horizontu, statistički je određena vrednost od 78%.

Kod razmatranja i utvrđivanja RMR klasifikacije, uzima se vrednost RQD = 78%

i σ_{ci} = 72 MPa koja je dobijena triaksijalnim ispitivanjima u istraživanju stenskog masiva na XVII horizontu. Uzimajući podatke o strukturnim karakteristikama, iz dosadašnjih istraživanja, a koristeći klasifikacija Bieniawskog iz 1989, dolazimo do vrednosti za opis stenske mase na XVII horizontu rudnog tela "Borska reka" i ona iznosi 73 poena. Za dobijanje GSI preko RMR klasifikacije Bieniawskog, uzima se GSI=RMR_{89} –5, tj. GSI = 68.

Upoređivanjem vrednosti dobijenih na osnovu RMR klasifikacije i fizičkog izgleda jezgra iz uzetih uzoraka, možemo konstatovati da bi bilo prihvatljivo da vrednost GSI iznosi 70. Ovde se mora biti oprezan, jer se mora uključiti i faktor oštećenja prostorije prilikom izrade iz kojih su uzeti uzorci (uticaj miniranja) kao i u vremenu posle izrade (pomeranja po konturi).

Rezultati istraživanja stenskog masiva

Na osnovu laboratorijskih ispitivanja mehaničkih čvrstoća, deformacionih karakteristika i procene kvaliteta masiva dolazimo do laboratorijskih vrednosti parametara stenskog masiva na XVII horizontu u rudnom telu "Borska Reka", tabela 5.[5]

Ovako definisani parametri su korišćeni kod modeliranja stenskog masiva i analizu stabilnosti objekata na nivou XVII horizonta u rudnom telu "Borska reka" u cilju dokazivanja mogućnosti korišćenja metodologije koja koristi Hoek-Brown-ovom kriterijumu loma.

Tabela 5. *Fizičko-mehanički parametri dobijeni laboratorijskim ispitivanjima na uzorcima stenskog masiva sa XVII horizonta rudnog tela "Borska reka"*

Radna sredina (XVII horizont)	γ [kN/m^3]	σ_c [MPa]	σ_i [MPa]	E [MPa]	E_d [MPa]	ν -	φ [°]	m_i -	C [MPa]	RMR_{89}	GSI
K-155 Silifikovan andezit	28,2	63,39	6,71	40490	33255	0,216	41.6	15,09	18.9	73	70

Određivanje relevantnih fizičko-mehaničkih parametara stenskog masiva

Da bi se odredili fizičko-mehanički parametri stenskog masiva koji bi se koristili za dalju numeričku analizu i proračune, potrebno je uporediti rezultate laboratorijskih ispitivanja, postojećih korelacionih veza između fizičko-mehaničkih, strukturnih svojstava i rezultata kategorizacije stenskih masa, kao i definisanje čvrstoće stenskog masiva po Hoek-Brown-ovom kriterijumu loma, na osnovu dosadašnjih istraživanja. Na osnovu toga pažljivo proceniti i odrediti parametre koji će biti relevantni tj. merodavni da karakterišu stanje stenske mase, a samim tim i ući u modeliranje stenskog masiva.

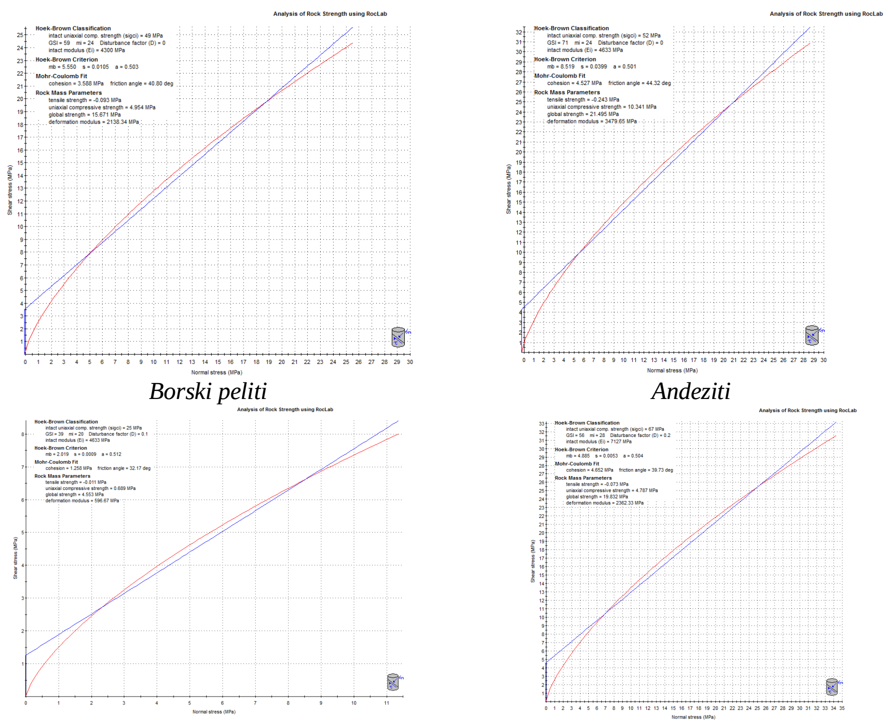
Do sada, prema prvim analizama koja su urađena u okviru najnovijih istraživanja, došlo se do podataka koji pokazuju delimično niže vrednosti koji opisuju fizičko-mehanička svojstva stenskog materijala, tabela 6 i slika 2.

Tabela 6. *Fizičko-mehanički parametri dobijeni laboratorijskim ispitivanjima na uzorcima uzetih iz bušotina u okiru najnovijih geomehaničkih istraživanja stenskog masiva iz rudnog tela "Borska reka"*

Geotehnička sredina	γ [kN/m^3]	σ_c [MPa]	σ_i [MPa]	E_t [MPa]	E_s [MPa]	ν -	φ [°]	m_i -	C [MPa]	RMR_{89}	GSI
Borski peliti	25,4	49	4,95	5600	3730	0,34	36,0	24	12,13	54	
Andeziti	25,9	52	5,37	6927	4633	0,31	36,8	26	12,90	66	
Andeziti kaolinisani	27,0	25	3,04	5490	3672	0,37	30,4	20	7,53	34	
Andeziti silifikovani	27,7	67	7,57	10790	7127	0,32	37,4	28	16,70	51	

Upravo zbog toga je potrebno, kada rezultati budu konačni i Elaborat završen, izvršiti komparativnu analizu podataka za modeliranje stenskog masiva i doneti odgovarajuće zaključke u vezi relevantnih podataka sa kojima će se dalje ići u proračune stabilnosti i definisanja načina i metode eksploatacije rude bakra iz rudnog tela Borska reka u Jami Bor.

Kako se radi o velikim dubinama, gde je bezbednost na prvom mestu, geomehanička istraživanja dobijaju veliki značaj, ali i odgovornost kod preciznog definisanja parametara. Nekad i preterivanje u obezbeđivanju zadovoljavajućeg faktora sigurnosti, u slučaju rudnog tela Borska reka, može da odvrati od daljeg investiranja iz ekonomskih razloga. Samim tim, odgovornost kod definisanja ovih parametara postaje još veća.



Borski peliti — *Andeziti* — *Andeziti kaolinisani* — *Andeziti silifikovani*

Sl. 2. *Parametri čvrstoće stenske mase za sve izdvojene sredine*

ZAKLJUČAK

Na osnovu rezultata do sada obavljenih laboratorijskih ispitivanja na uzorcima stenskog masiva i jezgra istražnih bušotina uz uvažavanje stanja stenskog masiva, stepena reprezentativnosti uzoraka, efekta razmere i dr., izvršen je izbor parametara fizičko-mehaničkih svojstava stenske mase koji su merodavni za modeliranje stenskog masiva.

Razvojem programskih paketa koji se bave pripremom i analizom numeričkih modela i primena Hoek-Brown kriterijuma loma doživela je poseban napredak. Ovaj kriterijum loma je jedan od opšte prihvaćenih i najkorišćenijih kriterijuma za modeliranje stenskog masiva.

Samim tim, ovaj rad sadrži, pored dela o rezultatima fizičko-mehaničkih ispitivanja rudnog tela ”Borska reka” upravo i određivanje triaksijalne čvrstoće i deformabilnosti stenskog masiva. Takav doprinos modeliranju stenskog masiva, uz poznavanje pravca i inteziteta napona u masivu i primenom adekvatnog matematičkog modela, dolazi do optimalnih rešenja kod dimenzionisanja podzemnih objekata u funkciji dubine i potrebnog faktora sigurnosti.

Uopšteno govoreći, razvoj savremene podzemne eksploatacije prate sve složeniji rudarsko - geološki uslovi. Zato su i problemi u podzemnoj gradnji vezani za rešenja koja se moraju bazirati na dobrom poznavanju zakonitosti razvoja mehaničkih procesa u stenskom masivu. Fizičko - strukturne i mehaničke osobine stenskog masiva, tehnološke specifičnosti sistema eksploatacije i način pripreme otkopnih blokova predodređuju i mehaničko stanje tih složenih sistema.

Sve ovo traži drugačiji pristup, vrstu i obim geomehaničkih istraživanja, naročito ako se planira upotreba numeričkih modela. Oni zahtevaju izbor oblika podzemnih objekata, modeliranje stenskog masiva i parametara kriterijuma loma na osnovu detaljnog izučavanja stenskog masiva kroz odgovarajuća laboratorijska i terenska ispitivanja. To čini još većom opravdanost za detaljnijim upoznavanjem sa novim tehnikama koje se u svetu već uveliko primenjuju, pa nema razloga da se takav program ne primeni i na naša ležišta.

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Vladan Marinković, Ljubiša Obradović*, Mile Bugarin*, Goran Stojanović*

THE IMPACT OF POLLUTED WASTEWATER ON WATER QUALITY OF THE BOR RIVER AND SURROUNDING GROUNDWATER**

Abstract

Due to the immediate vicinity of the mining and industrial facilities, the water pollution in the Bor River is extremely high. Sources of the Bor River pollution are active and inactive mining operations (surface and underground), flotation tailing dumps, waste rock dumps from the open pit, waste water generated in the process of copper ore processing and municipal wastewater.

The Bor River basin has an area of approximately 61.0 km². Maximum length of the river flow is about 10.0 km with an altitude difference of 160 m. The Bor River belongs to the basin of the Bela River, the basin of the River Timok or the Danube basin. In its course, it runs through the village of Slatina, connecting downstream of the village with the Krivelj River and Ravna River forming the Bela River. The Bela River, downstream from the village of Vražogrnac flows into the River Veliki Timok, which empties into the Danube [1] [2].

Wastewater from the mining and industrial facilities are still discharged directly into the river, so the water pollution in the river has also a large impact on the ground water pollution, especially in the area of the village of Slatina, located downstream from the town of Bor.

In addition to the waste water, discharged into the Bor River, the major threat to the environment is also a large amount of flotation tailings, located on the coast of this river, which, due to the frequent accidents, occurred in the Bor Flotation Plant during the last century, was directly discharged into the Bor River [3].

This paper work gives a detailed overview of the quality of surface and groundwater both of the Bor River and water polluting of this river.

Keywords: *Bor River, waste water, underground water, pollution*

INTRODUCTION

Due to the immediate vicinity of the mining and industrial facilities, the water pollution in the Bor River is extremely high. Sources of the Bor River pollution are active and inactive mining operations (surface and underground), flotation tailing dumps, waste rock dumps from the open pit, waste water generated in the process of copper ore processing and municipal wastewater (Figure 1) [4] [5].

* *Mining and Metallurgy Institute Bor*

** *This work is the result of the Project TR37001 "The Impact of Mining Waste from RTB Bor on the Pollution of Surrounding Water Systems with the Proposal of Measures and Procedures for Reduction Harmful Effects on the Environment", funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia*

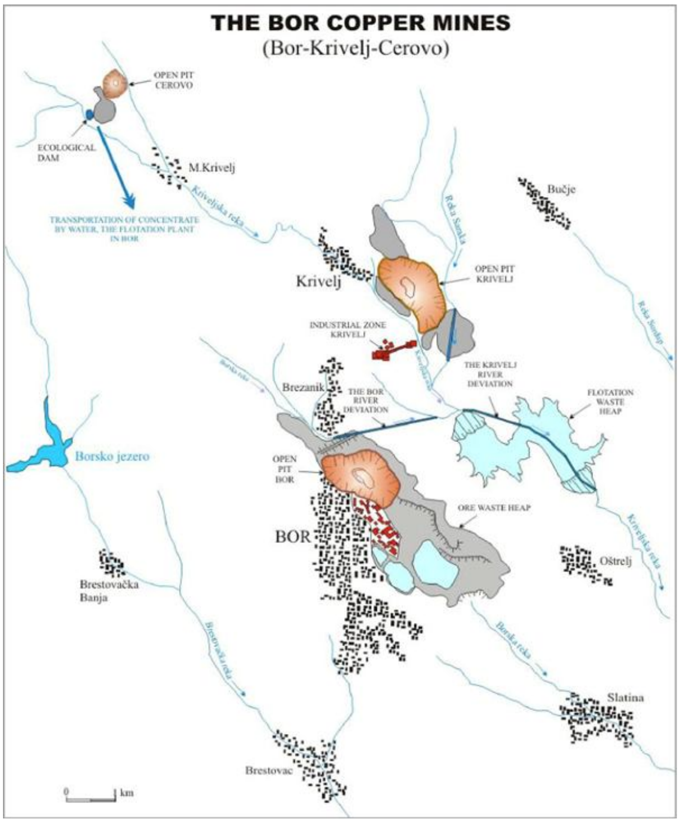

Figure 1 *Waste water generated in RBB Bor and TIR complex*

In addition to the waste water, discharged into the Bor River, the major threat to the environment is also a large amount of flotation tailings, located on the coast of this river, which, due to the frequent accidents, occurred in the Bor Flotation Plant during the last century, was directly discharged into the Bor River [3].

THE IMPACT OF POLLUTED WASTEWATER

The Bor River basin has an area of approximately 61.0 km². Maximum length of the river flow is about 10.0 km with an altitude difference of 160 m. The Bor River belongs to the basin of the Bela River, the basin of the River Timok or the Danube basin. In its course, it runs through the village of Slatina, connecting downstream of the village with the Krivelj River and Ravna River forming the Bela River. The Bela River, downstream from the village of Vražogrnac flows into the River Veliki Timok, which empties into the Danube [1].

Waste water from mining and industrial facilities is still discharged directly into the river, so the water pollution in the river has also a large impact on the ground water pollution, especially in the area of the village of Slatina, located downstream from the town of Bor [4] [5], (Figure 1).

Such pollution has a very large negative impact on the health of residents of the village of Slatina since the coastal of the Bor River is used for different purposes [4] [5], (Figure 2).

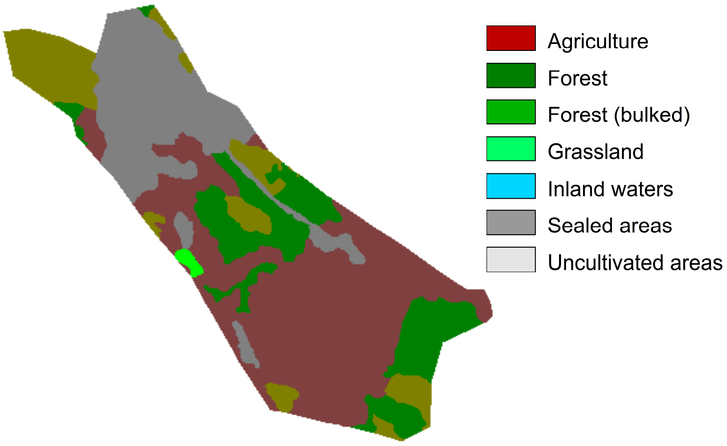

Figure 2 *The use of land in the catchment area of the Bor River*

Proportions of the land use are listed in Table 1.

Table 1 *Proportions of the catchment area of the Bor River*

Land use [%]	
Cereals, fodder plants	Cereals, fodder plants
Grassland	Grassland
Forest (very bulked)	Forest (very bulked)
Forest (medium)	Forest (medium)
Sealed areas	Sealed areas

In the period from February to June 2011, a continuous sampling of water samples from the Bor River was carried out twice a month. Tables 2 and 2a present some of the results of water analyses from the Bor River.

Tables 2 and 2a *Results of physical-chemical testing the samples from the location of the Bor River*

Sampling spot	T (^{0}C) air	T (^{0}C) water	Color/ smell	Electrical conductivity µS/cm	pH	Cu mg/dm^3	Pb mg/dm^3	Zn mg/dm^3
Bor River	*17.2*	17.6	muddy/ without	1472	5.00	16.9	0.23	2.9

Sampling spot	Cd (mg/dm^3)	Ni (mg/dm^3)	Cr (mg/dm^3)	Se (mg/dm^3)	As (mg/dm^3)	Fe-total (mg/dm^3)	Susp.matters (mg/dm^3)	SO_4^{-2} (mg/dm^3)
Bor River	<0.1	0.37	<0.1	<0.2	<0.1	36.9	899.0	1204.3

Testing Also, in the same period, water samples were taken twice a month from piezometers in the coastal of the Bor River. Tables 3 and 3a present some of the results of water analyses from this piezometer.

Tables 3 and 3a *Results of physical-chemical testing the samples of ground water*

Sampling Spot	T (^{0}C) air	T (^{0}C) water	Color/smell	Electrical conductivity µS/cm	pH	Cu mg/dm^3	Pb mg/dm^3	Zn mg/dm^3
P4	20	16.0	muddy/ without	1777	5.21	5.1	<0.1	2.9

Sampling spot	Cd (mg/dm^3)	Ni (mg/dm^3)	Cr (mg/dm^3)	Se (mg/dm^3)	As (mg/dm^3)	Fe-total (mg/dm^3)	Susp.matters (mg/dm^3)	SO_4^{-2} (mg/dm^3)
P4	<0.1	0.37	<0.1	<0.2	<0.1	36.9	899.0	1204.3

CONCLUSION

In the Republic of Serbia, the protection of surface water is according to the legislation which made the water classification into four classes according to the level of pollution and use. The limit values of elements are given in the Official Gazette of the Republic of Serbia No. 31/82 (Chemical Quality Parameters).

Surface water within the Bor River cannot be classified (according to their composition) neither in the class IV and they fall into the water with high levels of potentially toxic elements (heavy metals) according to the level of maximum allowable concentration.

Such pollution has a very large negative impact on the health of residents of the village of Slatina, located downstream from the town of Bor and industrial complexes which pollute the Bor River, and which flows through the village itself.

The favorable copper prices on the world market have also affected the copper production in Bor that grows from year to year. Also, the pollution level in the Bor River increases with increased production. In order to reduce the level of pollution in the Bor River, it is necessary as soon as possible to access the modern methods of remediation both of polluted industrial water and coastal contaminated land.

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UTICAJ ZAGAĐENIH OTPADNIH VODA NA KVALITET VODE BORSKE REKE I OKOLNIH PODZEMNIH VODA**

Izvod

Usled neposredne blizine rudničkih i industrijskih objekata zagađenost vode u Borskoj reci je izuzetno visoka. Izvore zagađenja Borske reke predstavljaju aktivni i neaktivni rudarski radovi (površinski i podzemni), flotacijska jalovišta, odlagališta kopovske jalovine, otpadne vode nastale u procesu prerade rude bakra i komunalne otpadne vode.

Sliv Borske reke je površine oko 61,0 km². Maksimalna dužina toka je oko 10.0 km sa visinskom razlikom od 160 m. Borska reka pripada slivu Bele Reka, slivu reke Timok, odnosno slivu Dunava. U svom toku protiče kroz selo Slatinu, spajajući se nizvodno od sela sa Kriveljskom rekom i Ravnom rekon formirajući Belu reku. Bela reka se nizvodno od sela Vražogrnac uliva u reku Veliki Timok, koji se uliva u reku Dunav [1] [2].

Otpadne vode iz rudničkih i industrijskih objekata se još uvek ispuštaju direktno u reku, tako da zagađenje vode u reci ima velikog uticaja i na zagađenje podzemnih voda, pogotovo u oblasti sela Slatina koje se nalazi nizvodno od grada Bora.

Pored otpadnih voda koje se ispuštaju u Borsku reku veliku opasnost po životnu sredinu predstavlja i velika količina flotacijske jalovine koja se nalazi u priobalju ove reke, koja je usled čestih akcidentnih situacija koja su se dešavala u Borskoj flotaciji tokom prošlog veka ispuštana direktno u Borsku reku [3].

Ovaj rad daje detaljan prikaz kvaliteta površinskih i podzemnih voda Borske reke i voda koje ovu reku zagađuju.

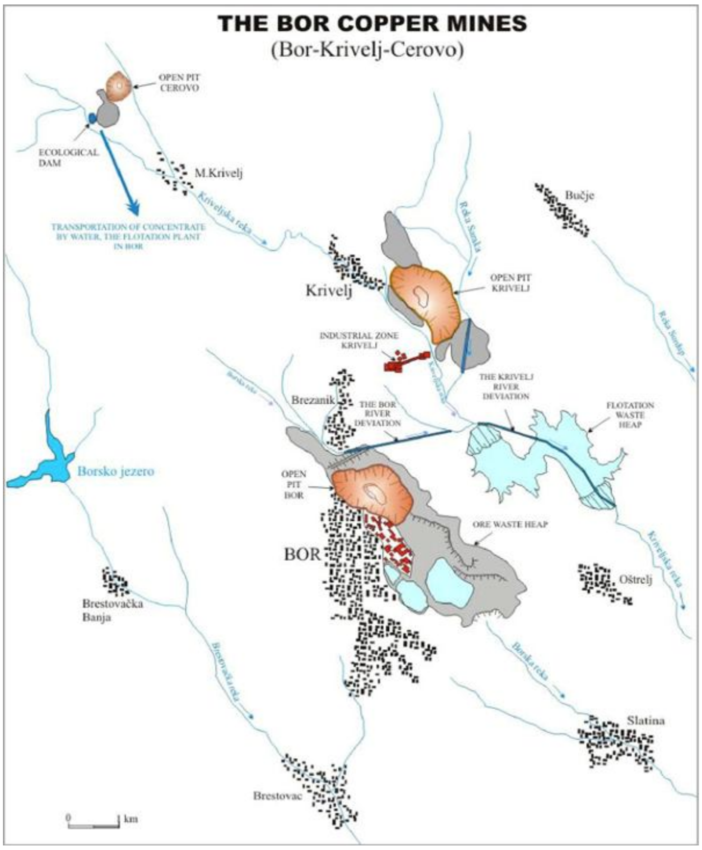
Ključne reči: *Borska reka, otpadne vode, podzemne vode, zagađenje*

UVOD

Usled neposredne blizine rudničkih i industrijskih objekata zagađenost vode u Borskoj reci je izuzetno visoka. Izvore zagađenja Borske reke predstavljaju aktivni i neaktivni rudarski radovi (površinski i podzemni), flotacijska jališta, odlagališta kopovske jalovine, otpadne vode nastale u procesu prerade rude bakra i komunalne otpadne vode (slika 1) [4] [5].

* *Institut za rudarstvo i metalurgiju Bor*

** *Ovaj rad je proistekao iz projekta TR37001 „Uticaj rudarskog otpada iz RTB Bor na zagađenje 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*



Sl. 1. *Otpadne vode nastale u RBB Bor i TIR kompleksu*

Pored otpadnih voda koje se ispuštaju u Borsku reku veliku opasnost po životnu sredinu predstavlja i velika količina flotacijske jalovine koja se nalazi u priobalju ove reke, koja je usled čestih akcidentnih situacija koja su se dešavala u Borskoj flotaciji tokom prošlog veka ispuštana direktno u Borsku reku [3].

UTICAJ ZAGAĐENIH OTPADNIH VODA

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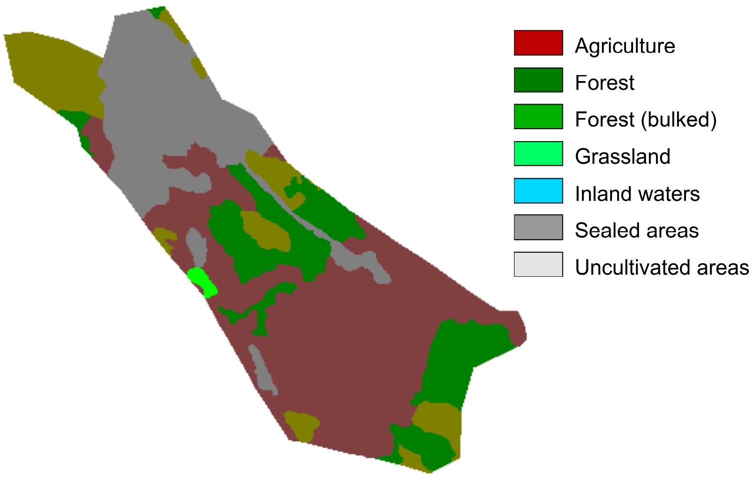
Otpadne vode iz rudničkih i industrijskih objekata se još uvek ispuštaju direktno u reku, tako da zagađenje vode u reci ima velikog uticaja i na zagađenje podzemnih voda, pogotovo u oblasti sela Slatina koje se nalazi nizvodno od grada Bora [4] [5], (slika 1).

Ovakvo zagađenje ima izuzetno veliki negativan uticaj na zdravlje stanovnika sela Slatina obzirom da se priobalje Borske reke koristi u različite namene [4] [5], (slika 2).



Sl. 2. *Upotreba zemljišta u slivu Borske reke*

Procentualni udeo pojedinih vrsta upotrebe zemljišta u slivu Borske reke navedeni su u tabeli 1.

Tabela 1. *Proporcija u slivu Borske reke*

Upotreba zemljišta [%]	
Žitarice, krmno bilje	43,83
Livade	1,70
Šume (vrlo prostrane)	12,77
Šume (srednje)	19,15
Zatvorene oblasti	22,55

U periodu od februara do juna meseca 2011. godine je vršeno kontininualno uzimannje uzoraka vode iz Borske reke, uzorkovanje je vršeno dva puta mesečno. U tabelama 2 i 2a su prikazani neki od rezultata analiza vode iz Borske reke.

Tabela 2 i 2a. *Rezultati fizičko hemijskih ispitivanja uzoraka vode iz Borske reke*

Mesto uzorkovanja	T (^{o}C) vazduha	T (^{o}C) vode	Boja/miris	El.provod. μS/cm	pH	Cu (mg/dm^3)	Pb (mg/dm^3)	Zn (mg/dm^3)
Borska reka	17.2	17.6	Mutna/bez	1472	5.00	16.9	0.23	2.9

Mesto uzorkovanja	Cd (mg/dm^3)	Ni (mg/dm^3)	Cr (mg/dm^3)	Se (mg/dm^3)	As (mg/dm^3)	Fe-total (mg/dm^3)	Sus.mater. (mg/dm^3)	SO_4^{-2} (mg/dm^3)
Borska reka	<0.1	0.37	<0.1	<0.2	<0.1	36.9	899.0	1204.3

Takođe u istom periodu, dva puta mesečno je vršeno i uzimanje uzoraka vode iz piozometra izrađenog u priobalju Borske reke. U tabelama 3 i 3a su prikazani neki od rezultata analiza vode iz ovog piezometra.

Tabela 3 i 3a. *Rezultati fizičko hemijskih ispitivanja uzoraka podzemne vode*

Mesto uzorkovanja	T (°C) vazduha	T (°C) vode	Boja/miris	El.provod. µS/cm	pH	Cu (mg/dm^3)	Pb (mg/dm^3)	Zn (mg/dm^3)
Borska reka	20	16.0	Mutna/bez	1777	5.21	5.1	<0.1	2.9

Mesto uzorkovanja	Cd (mg/dm^3)	Ni (mg/dm^3)	Cr (mg/dm^3)	Se (mg/dm^3)	As (mg/dm^3)	Fe-total (mg/dm^3)	Sus.mater. (mg/dm^3)	SO_4^{-2} (mg/dm^3)
Borska reka	<0.1	0.37	<0.1	<0.2	<0.1	36.9	899.0	1204.3

ZAKLJUČAK

U republici Srbiji, zaštita površinskih voda vrši se zakonskom regulativom, koja se zasniva na klasifikaciji voda na četiri klase prema nivou zagađenosti i upotrebi. Granične vrednosti elemenata date su u Službenom listu Republike Srbije br. 31/82 (parametrihemijskog kvaliteta).

Na osnovu ovog pravilnika površinske vode Borske reke po svom sastavu ne mogu da se svrstaju ni u IV klasu i spadaju u vode sa visokim sadržajem y potencijalno toksičnih elemenata (teški metali) prema nivou maksimalno dozvoljene koncentracije.

Ovakvo zagađenje ima izuzetno veliki negativan uticaj po zdravlje stanovnika sela Slatina koje se nalazi nizvodno od grada Bora i industrijskih kompleksa koj zagađuju Borsku reku, a koja protiče kroz samo selo.

Povoljno kretanje cene bakra na svetskom tržištu je uticalo i na proizvodnju bakra u Boru koja raste iz godine u godinu. Takođe sa povećanjem proizvodnje raste i nivo zagađenja u Borskoj reci.

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Suzana Lutovac, Zoran Gligorić*, Čedomir Beljić*, Marina Ravilić**

DERIVATION THE SOIL OSCILLATION LAW AND DETERMINATION OF ITS PARAMETERS**

Abstract

This paper gives an analysis the method for determining the parameters of soil oscillation law, suggested by Professor M. A. Sadovski as well as the level of its applicability for blasting with commercial explosives for the needs of mining and other economic activities. The applicability of this law was analyzed on examples of mass blasting at the Open Pit "Drenovac" that are carried out for deposit mining.

As the relation between the soil oscillation velocity and basic parameters affecting its magnitude, are the following: the amount of explosive, distance from the blasting site, characteristics of the rock material and type of blasting, the equation of M. A. Sadovski, where the oscillation velocity v is given in the form of of the function, is most frequently used:

$$v = K \cdot R^{-n},$$

where R is reduced distance, and K and n parameters conditioned by soil characteristics and blasting conditions, thereby v is decreasing and convex function of variable R.

To determine parameters in the equation of Sadovski, in addition to the common method of least squares, another model was applied. There by, it has been stated that both models can be used to calculate the oscillation velocity of the rock mass.

Keywords: *working environment, blasting, rock destruction, seismic effect, oscillation velocity, soil oscillation law*

1 INTRODUCTION

For evaluation and control the seismic effect of blasting, as well as to plan it, the determination of soil oscillation law is required, with the strike: blasting field - facilities to be protected [12]. One of the most commonly used equations is that of M.A. Sadovski defining the law of alteration in oscillation velocity of soil depending on distance, explosive amount and conditions of blasting and geological characteristics of the soil, being determined on the basis of test blasting for the specific work environment.

By application the law of rock mass oscillation in blasting, determination of soil oscillation velocity is enabled for each blast operation in advance, thus blasting is, as regards seismic effect, under control, which gives an opportunity to plan the magnitude of shock waves for each future blast operation [2]. In this way, the adverse blasting effects are reduced. Adverse effects of blasting imply, in addition to the seismic ones, those of air blast waves, fly rock mass, etc. [14]. Thus the production efficiency is in

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creased and, at the same time, construction and mining facilities, as well as the environment in the vicinity of the blast site, are protected.

2 SOIL OSCILLATION LAW

To establish the correlation between the oscillation velocity and three basic parameters affecting its size: the explosive quantity, properties of rock material and distance, several mathematical models are developed in the world. One of most frequently used models, i.e. equations, is the equation of Sadovski defining the law on velocity alteration of soil oscillation depending on distance, explosive amount and blasting method [9]. The law, defined in this way, offers the possibility to determine the seismic effect of blasting towards a structure or settlement, whereby the connection, between the velocity of soil oscillation and consequences that can affect facilities, is used. The equation of M.A Sadovski is given in the form:

$$v = K \cdot \left(\frac{r}{\sqrt[3]{Q}} \right)^{-n} \tag{1}$$

where there are:

- v - velocity of soil oscillation [cm/s]
- K - coefficient conditioned by soil characteristics and blasting conditions, determined by terrain surveying,
- n - exponent conditioned by characteristics of soil and blasting conditions, determined by field measurements,
- r - distance from the blasting site to the monitoring point [m],
- Q - amount of explosive [kg].

2.1 Derivation the equation of rock mass oscillation law

2.1.1 Derivation the equation of rock mass oscillation – the I way

The equation of Sadovski was derived from the condition: if the radius of charge and distance from the blasting site to the monitoring point increase in the same or approximately the same ratio, the soil oscillation velocity remains the same [1 pp. 42 and 43], that is :

$$v = K_v \cdot \left(\frac{r_o}{r} \right)^n , \tag{2}$$

where there is

- r_o –radius of explosive charge [m],
- r- distance from the blasting site to the monitoring point [m].

Radius of explosive charge (r_0) and amount of explosive (Q) are related by equation:

$$Q = \frac{4}{3} \cdot \pi \cdot r_o^3 , \tag{3}$$

from where there is:

$$r_o = \sqrt[3]{\frac{3 \cdot Q}{4 \cdot \pi}} . \tag{4}$$

By replacing the value (r_o) from equation (4), in t equation, the following is obtained (2):

$$v = K_v \cdot \left(\frac{\sqrt[3]{\frac{3 \cdot Q}{4 \cdot \pi}}}{r} \right)^n = K_v \cdot \left(\sqrt[3]{\frac{3}{4 \cdot \pi}} \right)^n \cdot \left(\frac{\sqrt[3]{Q}}{r} \right)^n =$$

$$= K_v \cdot K_1 \cdot \left(\frac{r}{\sqrt[3]{Q}} \right)^{-n} = K \cdot \left(\frac{r}{\sqrt[3]{Q}} \right)^{-n} = K \cdot R^{-n}$$

where :

$$\left(\sqrt[3]{\frac{3}{4 \cdot \pi}} \right)^n = K_1 ;$$

$$K_v \cdot K_1 = K ;$$

$$\frac{r}{\sqrt[3]{Q}} = R .$$

R – reduced distance or derived distance is the one from the blasting site to the monitoring point reduced to the amount of explosive, being given in the form $R = \frac{r}{r_0}$.

Thus, the oscillation law of rock mass is obtained, i.e. the Sadovski equation in the form :

$$v = K \cdot R^{-n} \tag{5}$$

2.1.2 Derivation the equation of rock mass oscillation – the II way

If, in blasting in the specific environment, the relative increase in oscillation velocity of the rock mass and relative increase of reduced distance are monitored, then it can be seen that their relations at various levels have approximately the same value [8(A)] which will be marked (-n), meaning that:

$$\frac{\frac{\Delta v}{v}}{\frac{\Delta R}{R}} \approx -n \tag{6}$$

Thereby, it can be considered that:

$$\lim_{\Delta R \to 0} \frac{\frac{\Delta v}{v}}{\frac{\Delta R}{R}} = -n \ ,$$

which means that is :

$$\frac{\frac{dv}{v}}{\frac{dR}{R}} = -n \ . \tag{7}$$

Equation (7) can be written in the form:

$$\frac{dv}{v} = -n \cdot \frac{dR}{R} \ ,$$

where by integration, it is obtained:

$$\int \frac{dv}{v} = -n \cdot \int \frac{dR}{R} \ ,$$

namely:

$$\log v = \log R^{-n} + \log K \tag{8}$$

where:

K – constant of integration.

Equation (8) can be written in the form:

$$\log v = \log k \cdot R^{-n} \ ,$$

from where, it is obtained:

$$v = K \cdot R^{-n} \ , \tag{8a}$$

being the equation of rock mass oscillation of M. A. Sadovski.

The equation of Sadovski is commonly shown in the form:

$$v = K \cdot Q_{red}^{n} \tag{9}$$

where:

Q_{red} – reduced amount of explosive

$$Q_{red} = \frac{\sqrt[3]{Q}}{r} \ , \tag{10}$$

where:

R - distance from the blasting site to the monitoring point [m],

Q - overall amount of explosive in a mine series [kg].

2.2 Models of determination the soil oscillation law parameters

There are two parameters K and n in equation (5) which should be determined for the specific work environment and IN particular blasting conditions. Regarding to the characteristics of the rock mass oscillation law, it is possible to determine the parameters K and n in a number of ways, i.e. models, thereby using the values obtained by experimental measurements.

2.2.1 Determination of parameters by model 1

The smallest square method is mainly used to obtain the parameters (K) and (n), which represent the common model [3]. Equation (5) uses logarithms and thus is reduced to the following form:

$$\log v = \log K - n \log R \tag{11}$$

By introduction the replacement: v = y; K = a; R = x; n = b; the equation gets the following form:

$$\log a - b \log x = \log y \tag{12}$$

Normal equation system for finding parameters (a) and (b) in this case is:

$$N\log a - b\sum_{i=1}^{N}\log x_i = \sum_{i=1}^{N}\log y_i$$

$$(\log a)\sum_{i=1}^{N}\log x_i - b\sum_{i=1}^{N}(\log x_i)^2 = \sum_{i=1}^{N}\log x_i \cdot \log y_i \qquad (13)$$

where:

N - is the number of carried out surveys·

2.2.2 Determination of parameters by model 2

Starting from the rock mass oscillation law from the equation (5):

$$v = K \cdot R^{-n},$$

which is derived by different way (Chapter 2.1.2), whereby the parameter K, occurring as constant of integration [8(B)], can be determined from conditions (initial condition) that for $R = R_1$ is $v = v_1$.

Parameters K and n will be determined using the experimental data of pairs (R_i, v_i), i = 1, 2,..., N, provided that the curve of oscillation velocity of rock mass passes through the point $M_1(R_1, v_1)$. In that case, out of (5) for $R = R_1$ and $v = v_1$, the following is obtained:

$$v_1 = K \cdot R_1^{-n},$$

where:

$$K = v_1 \cdot R_1^{n}. \qquad (14)$$

By replacement thevalues for K from (14) in equation (5), the equation is obtained:

$$v = v_1 \cdot \left(\frac{R_1}{R}\right)^n. \qquad (15)$$

From equation (15), for $R = R_1$ there is obtained $v = v_1$ for any n, in the case n>0. For $R = R_i$, i = 2, 3,.., N, from the equation (15), it can be taken that:

$$v_i = v_1 \cdot \left(\frac{R_1}{R_i}\right)^n, \text{ i = 2,3,...,N},$$

from where the relation is obtained:

$$v_1 \cdot v_2 \cdot \ldots \cdot v_N = v_1^N \cdot \left(\frac{R_1^N}{R \cdot_1 R_2 \cdot \ldots \cdot R_N}\right)^n. \qquad (16)$$

From relation (16), parameter n can be determined. By logarithm operation of relation (16), the following is obtained:

$$n\log\left(\frac{R_1^N}{R_1 \cdot R_2 \cdot \ldots \cdot R_N}\right) = \log\left(\frac{v_1 \cdot v_2 \cdot \ldots \cdot v_N}{v_1^N}\right),$$

where the following is found:

$$n = \frac{\log\left(\frac{v_1 \cdot v_2 \cdot \ldots \cdot v_N}{v_1^N}\right)}{\log\left(\frac{R_1^N}{R_1 \cdot R_2 \cdot \ldots \cdot R_N}\right)}. \qquad (17)$$

By replacement the value for parameter n in equation (17), found in this way, the relation for oscillation velocity of rock mass in monitored environment is obtained:

$$v = v_1 \cdot \left(\frac{R_1}{R}\right)^n. \qquad (18)$$

Thus, to determine the parameter n, all experimental data were taken into account.

3 DEFINING THE STATISTICAL CRITERIA

To evaluate the degree of correlation between recorded (measured) and calculated data in this work, the *coefficient of linear correlation r* [5] between logarithm of reduced distance R and logarithm of the oscillation velocity v was used. Additionally, the *curve line dependency index ρ* [6(A)] between the reduced distance R and oscillation velocity v was also taken into account.

Evaluation the relationship degree of two variables [13] to values of the curve line dependency index ρ is given in the follo-wing survey:

- $0.0 < \rho < 0.2$ - none or highly poor correlation,
- $0.2 < \rho < 0.4$ - poor correlation,
- $0.4 < \rho < 0.7$ - significant correlation,
- $0.7 < \rho < 1.0$ - strong or highly strong correlation.

The same is valid for absolute value of linear correlation coefficient r.

As a convenience measure of the obtained functional relationship for the given experimental data, the criterion „3S" was also used [6(B)]. This criterion uses squares of differences between the obtained experimenal data and the calculated ones for oscillation velocities of v. If those differences are one after another ε_1, ε_2 ... ε_N, then it is :

$$S = \sqrt{\frac{\varepsilon_1^2 + \varepsilon_2^2 + ... + \varepsilon_N^2}{N}} \qquad (19)$$

According to this criterion, for evaluation the convenience of obtained functional correlation, the following relations are valid:

- If it is $|\varepsilon_{max}| > 3S$, the obtained functional correlation is rejected as unfavorable,
- If it is $|\varepsilon_{max}| < 3S$, the functional correlation is accepted as a good one.

4 SURVEY OF MASS BLASTING AT THE OPEN PIT "DRENOVAC"

4.1 General characteristics of the open pit "Drenovac"

This work includes research, carried out during mass blasting at the open pit "Drenovac" in Mionica [7(A)]. The open pit "Drenovac" is of elevated type and it is situated almost at the very top of the hill of the same name.

The limestone deposit covers the surface of 7.7 ha. The altitude difference of the deposit is about 70 m from the elevation 440-520. There is a diabase - chert formation in the floor of limestone, approximately at the elevation of 438 m.

The limestone is of fissure porosity as stated by mapping of both the terrain and test bore holes. The length of cores is from 30 to 40 cm. Cracks and fissures are mostly filled with calcite, and to a lesser extent they are filled with limonite debris, namely limonite dross. During drilling, circulation loss-water was insignificant, which points to low effective porosity of limestone.

Limestone is a firm petrified environment. It is tectonically undamaged thus it represents a unique monolithic mass. The impact of present cracks and fissured is insignificant on physico-mechanical characteristics.

The following values were obtained by testing the physico-mechanical properties of the working environment:

- volume mass 2.68 [kN/m³]
- porosity 0.7-1.5 [%]
- cohesion 0.25 [MPa]
- uniaxial strength
  - in dry state 120-134 [MPa]
  - in water saturated state 83-129 [MPa]
- angle of internal friction 41 [°].

4.2 Blasting method

Measurements of seismic shock waves at the open pit "Drenovac", carried out during blasting, were conducted in order to exploit the deposit [7(B)]. Eight blasting operations were carried out.

The amonex-1 28/200, amonex-1 60/1000, ANFO-J in bags of 25 kg and ANFEX-PP 70/1500 were used as explosives. The explosive was activated in boreholes by nonel detonators, marked N-25/500 and K-42 connectors. Basic data, related to the number of boreholes (N_b), overall explosive amount (Q_{total}), maximum explosive amount by deceleration interval (Q_i), overall borehole depth (L_{total}), and average stemming length (L_{sl}), are present in Table 1.

Table 1 *Survey of blasting parameters*

Blasting	N_b	Q_{total}[kg]	Q_i[kg]	L_{total}[m]	L_{sl}[m]
I	27	661.4	36.2	211.0	2.8 – 3.0
II	28	1,980.6	71.2	488.0	2.8 – 3.0
III	15	915.3	66.2	213.0	2.8 – 3.0
IV	16	745.0	47.0	175.0	3.0 – 3.2
V	40	1,895.0	60.5	453.0	3.0 – 3.2
VI	22	1,774.4	85.2	402.0	3.0 – 3.2
VII	43	1,988.6	54.2	518.0	3.0 – 3.2
VIII	20	600	32.0	273.0	3.0 – 3.5

The record of soil oscillation velocity for blasting number 1 - measuring point 3 is shown in Figure 1.

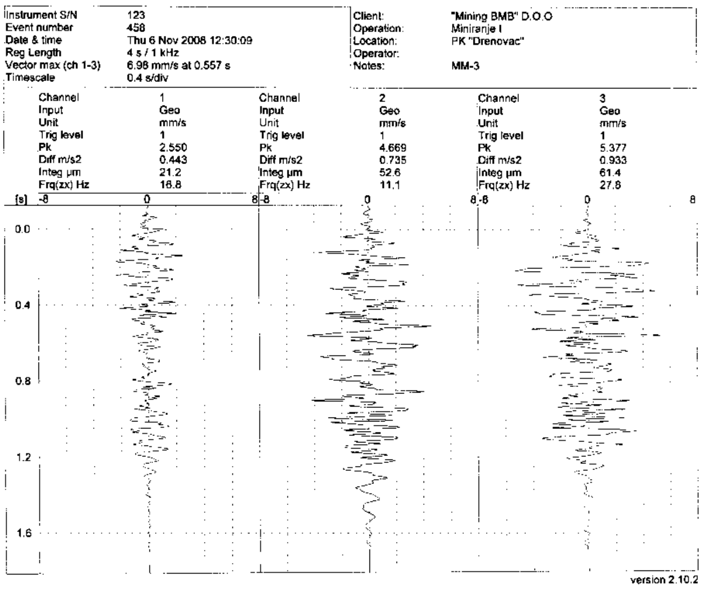

Figure 1 *Image of soil oscillation velocity for blasting I-MM3*

4.3 Calculation the soil oscillation law parameters

Table 2 gives the values of distances from blast sites to monitoring points r, the amount of explosive Q , calculated values of reduced distances R, recorded values of soil oscillation velocities by components v_t, v_v, v_l and resulting oscillation velocities v_{rez} for blasting from I to VIII of totally seven measuring points MM.

Table 2 *Survey of blasting parameters and measurement results*

No.	Blasting	MM	r [m]	Q [kg]	R	v_t [cm/s]	v_v [cm/s]	v_l [cm/s]	V_{rez} [cm/s]
1	I	MM – 2	383.87	661.4	44.0585	0.070	0.100	0.110	0.1643
2	I	MM – 3	250.49	661.4	28.7499	0.255	0.466	0.537	0.7616
3	I	MM – 5	647.42	661.4	74.3073	0.080	0.090	0.080	0.1446
4	II	MM – 1	605.54	1980.6	48.2182	0.060	0.060	0.070	0.1100
5	II	MM – 2	334.15	1980.6	26.6078	0.080	0.120	0.150	0.2081
6	II	MM – 3	256.71	1980.6	28.4042	0.510	0.500	1.090	1.3031
7	II	MM – 6	527.05	1980.6	41.9681	0.090	0.230	0.160	0.2943
8	III	MM – 1	616.35	915.3	63.4804	0.091	0.083	0.082	0.1482
9	III	MM – 2	250.14	915.3	25.7629	0.192	0.573	0.719	0.9392
10	III	MM – 3	412.66	915.3	42.5015	0.380	0.605	0.412	0.8247
11	III	MM – 5	714.10	915.3	73.5481	0.138	0.096	0.116	0.2045
12	III	MM – 6	541.13	915.3	55.7332	0.170	0.241	0.177	0.3454
13	III	MM – 7	530.89	915.3	54.6785	0.133	0.236	0.193	0.3326
14	IV	MM – 1	723.77	745.0	79.8390	0.060	0.080	0.070	0.1221
15	IV	MM – 2	410.33	745.0	45.2635	0.140	0.170	0.180	0.2844
16	IV	MM – 3	223.89	745.0	24.6973	0.310	0.420	0.540	0.7511
17	IV	MM – 5	644.64	745.0	71.1102	0.110	0.200	0.200	0.3035
18	IV	MM – 7	426.38	745.0	47.0339	0.200	0.230	0.210	0.3701
19	V	MM – 1	737.38	1895.0	60.0667	0.050	0.070	0.040	0.0948
20	V	MM – 3	210.96	1895.0	17.1847	0.550	0.790	1.150	1.4996
21	V	MM – 7	422.53	1895.0	34.4192	0.210	0.360	0.320	0.5254
22	VI	MM – 3	231.44	1774.4	19.1171	0.577	1.160	0.709	1.4768
23	VI	MM – 5	650.53	1774.4	53.7341	0.055	0.071	0.077	0.1165
24	VI	MM – 6	640.06	1774.4	52.8693	0.081	0.150	0.168	0.2393
25	VI	MM – 7	425.36	1774.4	35.1350	0.340	0.465	0.259	0.6316
26	VII	MM – 3	333.13	1988.6	26.4910	0.534	0.460	0.602	0.9268
27	VII	MM – 6	530.48	1988.6	42.1845	0.101	0.190	0.150	0.2623
28	VII	MM – 7	415.31	1988.6	33.0260	0.284	0.525	0.286	0.6618
29	VIII	MM – 1	609.20	600.0	72.2286	0.030	0.070	0.070	0.1034
30	VIII	MM – 3	387.35	600.0	45.9254	0.339	0.527	0.629	0.8878
31	VIII	MM – 6	532.35	600.0	63.1171	0.067	0.112	0.079	0.1607
32	VIII	MM – 7	493.85	600.0	58.5524	0.072	0.157	0.156	0.2327

Based on data, given in Table 2, the soil oscillation law is calculated by formula (5) - by the models 1 and 2. The calculation of curve was carried out for values of reduced distances from R = 17.1847 to R = 79.8390.Thus, the curve parameters were calculated enabling to determine the equation of soil oscillation in the form of:

♦ Model 1

$$v_1 = 166.3916 \cdot R^{-1.6433} \qquad (20)$$

where by the linear dependence between log v and log R is obtained, expressed by equation (20), with *the linear correlation coefficient* (r) amounting:

r = -0.8

Graphic survey of soil oscillation law is shown in Figure 2.

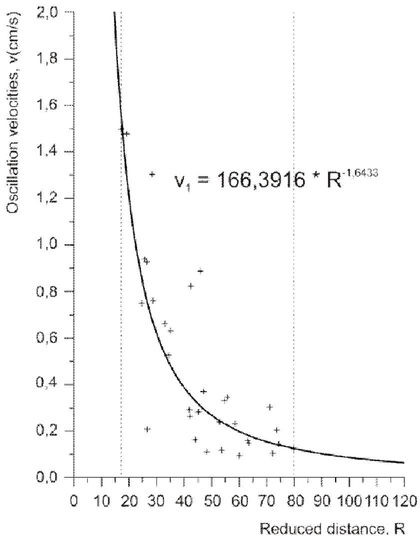

Figure 2 *Graphic survey of soil oscillation law curve at the open pit Drenovac*

♦ Model 2

$$v_2 = 143.2699 \cdot R^{-1.6032} \tag{21}$$

Based on the obtained equations of soil oscillation (20) and (21), it is possible to calculate values of soil oscillation velocities for corresponding reduced distances for models 1 and 2.

Table 3 presents the survey of reduced distances R, recorded oscillation velocities v_r, calculated oscillation velocities v_{i1}, v_{i2} as well as the difference between recorded and calculated soil oscillation velocities for models 1 and 2.

Table 3 *Survey of recorded and calculated soil oscillation velocities for models 1 and 2*

No.	R	v_r [cm/s]	v_{i1} [cm/s]	v_{i2} [cm/s]	$v_r - v_{i1}$	$v_r - v_{i2}$
1	44.0585	0.1643	0.3307	1.4996	-0.1664	0.0000
2	28.7499	0.7616	0.6670	1.2641	0.0946	0.2127
3	74.3073	0.1446	0.1401	0.8384	0.0045	-0.0873
4	48.2182	0.1100	0.2852	0.7835	-0.1752	0.1557
5	26.6078	0.2081	0.7576	0.7493	-0.5495	0.1775
6	28.4042	1.3031	0.6804	0.7440	0.6227	-0.5359
7	41.9681	0.2943	0.3583	0.6700	-0.0640	0.6331
8	63.4804	0.1482	0.1815	0.6572	-0.0333	0.1044
9	25.7629	0.9392	0.7988	0.5262	0.1404	0.1356
10	42.5015	0.8247	0.3509	0.4924	0.4738	0.0330
11	73.5481	0.2045	0.1425	0.4765	0.0620	0.1551
12	55.7332	0.3454	0.2248	0.3583	0.1206	-0.0640
13	54.6785	0.3326	0.2319	0.3554	0.1007	-0.0931
14	79.8390	0.1221	0.1245	0.3512	-0.0024	0.4735
15	45.2635	0.2844	0.3164	0.3315	-0.0320	-0.1672
16	24.6973	0.7511	0.8562	0.3174	-0.1051	-0.0330
17	71.1102	0.3035	0.1506	0.3101	0.1529	0.5777

18	47.0339	0.3701	0.2971	0.2985	0.0730	0.0716
19	60.0667	0.0948	0.1987	0.2868	-0.1039	-0.1768
20	17.1847	1.4996	1.5539	0.2475	-0.0543	-0.0082
21	34.4192	0.5254	0.4963	0.2411	0.0291	-0.1246
22	19.1171	1.4768	1.3043	0.2345	0.1725	0.0981
23	53.7341	0.1165	0.2387	0.2274	-0.1222	0.1180
24	52.8693	0.2393	0.2451	0.2101	-0.0058	0.0226
25	35.1350	0.6316	0.4798	0.2017	0.1518	-0.1069
26	26.4910	0.9268	0.7631	0.1863	0.1637	-0.0256
27	42.1845	0.2623	0.3552	0.1846	-0.0929	-0.0364
28	33.0260	0.6618	0.5311	0.1539	0.1307	0.1496
29	72.2286	0.1034	0.1468	0.1501	-0.0434	-0.0467
30	45.9254	0.8878	0.3089	0.1458	0.5789	0.0587
31	63.1171	0.1607	0.1832	0.1434	-0.0225	0.0012
32	58.5524	0.2327	0.2073	0.1278	0.0254	-0.0057

Based on the data in Table 3, a statistical analysis was carried out and the following values were obtained:

for Model 1:

The curve line dependency index ρ_1 between the reduced distance R and soil oscillation velocity is:

$\rho_1 = 0.8380$ (there is a *strong correlation* between R an v, given in formula (20)).

Maximum difference between the recorded and calculated oscillation velocities of the soil $(\varepsilon_{max}) = \max|\varepsilon_i|$, amounts:

$\varepsilon_{max1} = 0.6227$, $S_1 = 0.2200$,

$3S_1 = 0.6600$

As there is $\varepsilon_{max1} < 3S_1$, the supposed *functional relationship is accepted as a good one.*

for Model 2:

$\rho_2 = 0.8357$ (there is a *strong correlation* between R an v, given in formula (21)).

$\varepsilon_{max2} = 0.6331$, $S_2 = 0.2214$,

$3S_2 = 0.6642$.

$\varepsilon_{max2} < 3S_2$ (supposed *functional relationship is accepted as a good one*).

5 CONCLUSION

To establish the relationship between the oscillation velocity of the rock mass and basic parameters affecting its magnitude, the followings are: the amount of explosive, distance from the blasting site, characteristics of the rock mass and type of blasting, it is the equation of M. A. Sadovski that is used most commonly. It defines the law on alteration in the oscillation velocity of the rock mass and is given in the form of function:

$$v = K \cdot R^{-n},$$

where R is reduced, i.e. derived distance, and parameters K and n the coefficient and exponent conditioned by characteristics of the soil and conditions of blasting and can have only the positive values. Thereby, v is a decreasing and convex function.

In this work, the law of Sadovski is also derived in another way using the quotient of relationship between the relative increase in oscillation velocities of the rock mass and relative increase of reduced distances. Thereby, in a marginal case, a differential equation, whose general integral overlaps with the law of Sadovski, is obtained.

In this paper, the oscillation velocity is calculated, i.e. the parameters K and n are determined in two ways - models. Based on the analysis and data processing, it can be concluded:

The parameters n and K in Sadovski law are determined in two ways - models in the specific work environment. Thereby, the obtained corresponding functions present the oscillation velocities of the rock mass depending on reduced distance. The calculated corresponding indexes of the curve line correlation point out that there is a highly strong curve line relationship between the reduced distance and oscillation velocity of the rock mass, expressed in the obtained functions.

Comparing the values of recorded oscillation velocities of the rock mass with the corresponding calculated ones, it can be seen that they are approximately the same. On the basis of obtained values of curve line dependency coefficients and the values of linear correlation coefficients between the reduced distance logarithm and oscillation velocity logarithm, it can be concluded that both models can be used for calculating the oscillation velocity of the rock mass.

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O IZVOĐENJU ZAKONA OSCILOVANJA TLA I ODREĐIVANJU NJEGOVIH PARAMETARA[**]

Izvod

U ovom radu izvršena je analiza metode za određivanje parametara zakona oscilovanja tla, koji je predložio ruski profesor M. A. Sadovski, kao i stepen njegove primenljivosti za miniranja sa privrednim eksplozivima za potrebe rudarstva i drugih privrednih delatnosti. Primenljivost ovog zakona, analizirana je na primerima masovnih miniranja na PK „Drenovac“, koja se izvode radi eksploatacije ležišta.

Kao vezu između brzine oscilovanja tla i osnovnih parametara koji utiču na njenu veličinu, a to su: količina eksploziva, rastojanje od mesta miniranja, osobina stenskog materijala i način izvođenja miniranja, najčešće se koristi jednačina M. A. Sadovskog, gde je brzina oscilovanja v data u obliku:

$$v = K \cdot R^{-n},$$

gde R predstavlja redukovano tj. svedeno rastojanje, a parametri K i n uslovljeni su karakteristikama tla i uslovima miniranja. Pri tome je v opadajuća i konveksna funkcija promenljive R.

Za određivanje parametara u jednačini Sadovskog, pored uobičajene metode najmanjih kvadrata primenjen je još jedan model. Pri tom je konstatovano da se oba modela mogu koristiti za izračunavanje brzine oscilovanja stenske mase.

Ključne reči: *radna sredina, miniranje, razaranje stena, seizmičko dejstvo, brzina oscilovanja, zakon oscilovanja tla*

1. UVOD

Za ocenu i kontrolu seizmičkog dejstva miniranja, kao i njegovo planiranje, neophodno je utvrditi zakon oscilovanja tla u pravcu minsko polje - objekti koji se štite. [12]. Jedna od najčešće korišćenih je jednačina M. A. Sadovskog, koja definiše zakon promene brzine oscilovanja tla u zavisnosti od rasto-janja, količine eksploziva, uslova izvođenja miniranja i geoloških karakteristika tla, a određuje se na osnovu probnih miniranja za konkretnu radnu sredinu.

Primenom zakona oscilovanja stenske mase pri miniranju omogućava se da se za svako miniranje unapred odredi brzina oscilovanja tla, a miniranja se u pogledu seizmičkog dejstva stavljaju pod kontrolu, što pruža mogućnost da se veličina potresa za svako sledeće miniranje unapred planira [2]. Na taj način smanjuju se negativni efekti miniranja. Pod negativnim efektima miniranja osim seizmičkog dejstva miniranja podrazumevamo i dejstvo vazdušnog talasa,

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zvučni efekat, razbacivanje odminirane stenske mase itd. [14]. Na taj način povećava se efikasnost proizvodnje i ujedno štite građe-vinski i rudarski objekti u okolini mesta miniranja, kao i životna sredina.

2. ZAKON OSCILOVANJA TLA

Za uspostavljanje korelacione veze između brzine oscilovanja i tri osnovna parametra koji utiču na njenu veličinu: količine eksploziva, osobine stenskog materijala i rastojanja, u svetu je razvijeno više modela. Jedan od najčešće korišćenih modela je jednačina Sadovskog, koja definiše zakon promene brzine oscilovanja tla u zavisnosti od rastojanja, količine eksploziva i načina izvođenja miniranja [9]. Tako definisan zakon pruža mogućnost da odredimo seizmičko dejstvo miniranja u pravcu nekog objekta ili naselja, pri čemu se koristi veza između brzine oscilovanja tla i posledica koje se mogu odraziti na objekte.

Jednačina M. A. Sadovskog data je u obliku:

$$v = K \cdot \left(\frac{r}{\sqrt[3]{Q}} \right)^{-n} \qquad (1)$$

gde je:

v - brzina oscilovanja tla [cm/s],

K - koeficijent koji je uslovljen karakteristikama tla i uslovima miniranja, a određuje se terenskim merenjima,

n - eksponent koji je uslovljen karakteristikama tla i uslovima miniranja, a određuje se terenskim merenjima,

r - rastojanje od mesta miniranja do mesta opažanja [m],

Q - količina eksploziva [kg].

2.1. Izvođenje jednačine zakona oscilovanja stenske mase

2.1.1 Izvođenje jednačine zakona oscilovanja stenske mase - I način

Jednačina Sadovskog izvedena je iz uslova: ako se radijus punjenja i rastojanje od mesta izvođenja miniranja do mesta opažanja povećavaju u istoj ili približno istoj razmeri brzina oscilovanja tla ostaje ista [1], tj. da je:

$$v = K_v \cdot \left(\frac{r_o}{r} \right)^{n}, \qquad (2)$$

gde je:

r_o - radijus eksplozivnog punjenja [m],

r - rastojanje od mesta miniranja do mesta opažanja [m].

Radijus eksplozivnog punjenja (r_0) i količina eksploziva (Q) vezani su jednačinom:

$$Q = \frac{4}{3} \cdot \pi \cdot r_o^3, \qquad (3)$$

odakle je:

$$r_o = \sqrt[3]{\frac{3 \cdot Q}{4 \cdot \pi}}. \qquad (4)$$

Zamenom vrednosti (r_o) iz jednačine (4) u jednačini (2) dobijamo:

$$v = K_v \cdot \left(\frac{\sqrt[3]{\frac{3 \cdot Q}{4 \cdot \pi}}}{r} \right)^{n} = K_v \cdot \left(\sqrt[3]{\frac{3}{4 \cdot \pi}} \right)^{n} \cdot \left(\frac{\sqrt[3]{Q}}{r} \right)^{n} =$$

$$= K_v \cdot K_1 \cdot \left(\frac{r}{\sqrt[3]{Q}} \right)^{-n} = K \cdot \left(\frac{r}{\sqrt[3]{Q}} \right)^{-n} = K \cdot R^{-n}$$

gde je:

$$\left(\sqrt[3]{\frac{3}{4 \cdot \pi}} \right)^{n} = K_1;$$

$$K_v \cdot K_1 = K;$$

$$\frac{r}{\sqrt[3]{Q}} = R.$$

R - redukovano rastojanje ili svedeno rastojanje predstavlja rastojanje od mesta miniranja do mesta opažanja svedeno na količinu eksploziva, a dato u obliku $R = \frac{r}{r_0}$

Na taj način dobili smo zakon oscilovanja stenske mase tj. jednačinu Sadovskog u obliku:

$$v = K \cdot R^{-n} \quad (5)$$

2.1.2. Izvođenje jednačine zakona oscilovanja stenske mase - II način

Ako se pri miniranju u datoj sredini posmatraju relativni priraštaji brzine oscilovanja stenske mase i relativni priraštaji redukovanog rastojanja [8(A)], onda se može videti da njihovi odnosi pri raznim nivoima imaju približno istu vrednost koju ćemo označiti sa (-n), što znači da je:

$$\frac{\frac{\Delta v}{v}}{\frac{\Delta R}{R}} \approx -n \quad (6)$$

Pri tome se može uzeti da je:

$$\lim_{\Delta R \to 0} \frac{\frac{\Delta v}{v}}{\frac{\Delta R}{R}} = -n ,$$

što znači da je:

$$\frac{\frac{dv}{v}}{\frac{dR}{R}} = -n . \quad (7)$$

Jednačinu (7) možemo napisati u obliku:

$$\frac{dv}{v} = -n \cdot \frac{dR}{R} ,$$

odakle se integracijom dobija:

$$\int \frac{dv}{v} = -n \cdot \int \frac{dR}{R} ,$$

odnosno:

$$\log v = \log R^{-n} + \log K \quad (8)$$

gde je:

K – konstanta integracije.

Jednačina (8) može se napisati u obliku:

$$\log v = \log k \cdot R^{-n} ,$$

odakle se dobija:

$$v = K \cdot R^{-n} , \quad (8a)$$

a to je jednačina oscilovanja stenske mase M.A. Sadovskog.

Jednačina Sadovskog često se iskazuje u obliku:

$$v = K \cdot Q_{red}^{n} \quad (9)$$

gde je:

Q_{red} – redukovana količina eksploziva

$$Q_{red} = \frac{\sqrt[3]{Q}}{r} , \quad (10)$$

gde je:

r - rastojanje od mesta miniranja do mesta opažanja [m],

Q - ukupna količina eksploziva u minskoj seriji [kg].

2.2. Modeli određivanja parametara zakona oscilovanja tla

U jednačini (5) javljaju se dva parametra K i n, koje treba odrediti za konkretnu radnu sredinu i pri određenim uslovima miniranja. S obzirom na svojstvo zakona oscilovanja stenske mase, moguće je parametre K i n odrediti na više načina tj. modela, koristeći pri tome vrednosti dobijene eksperimentalnim merenjima.

2.2.1 Određivanje parametara po modelu 1

Za dobijanje parameatra (K) i (n) uglavnom se koristi metoda najmanjih kvadrata, koja predstavlja uobičajeni model [3]. Jednačina (5) se logaritmuje i tako svodi na sledeći oblik:

$$\log v = \log K - n \log R \quad (11)$$

Uvođenjem zamene: v = y; K = a; R = x; n = b; jednačina dobija sledeći oblik:

$$\log a - b \log x = \log y \quad (12)$$

Normalan sistem jednačina za nalaženje parametara (a) i (b) u ovom slučaju glasi:

$$N\log a - b\sum_{i=1}^{N}\log x_i = \sum_{i=1}^{N}\log y_i$$

$$(\log a)\sum_{i=1}^{N}\log x_i - b\sum_{i=1}^{N}(\log x_i)^2 = \sum_{i=1}^{N}\log x_i \cdot \log y_i \qquad (13)$$

gde je:

N – broj izvršenih merenja.

2.2.2. Određivanje parametara po modelu 2

Polazeći od zakona za brzinu oscilovanja stenske mase iz jednačine (5):

$$v = K \cdot R^{-n},$$

koji je izveden na drugi način (poglavlje 2.1.2), pri čemu parametar K, koji se pojavio kao konstanta integracije [8(B)], možemo da odredimo iz uslova (početnog uslova) da za $R = R_1$ bude $v = v_1$.

Parametre K i n odredićemo koristeći eksperimentalne podatke parova (R_i, v_i), i = 1, 2,..., N, uz uslov da kriva brzine oscilovanja stenske mase prolazi kroz tačku $M_1(R_1, v_1)$. U tom slučaju iz (2.5) za $R = R_1$ i $v = v_1$ dobijamo:

$$v_1 = K \cdot R_1^{-n},$$

odakle je:

$$K = v_1 \cdot R_1^{n}. \qquad (14)$$

Zamenom vrednosti za K iz (14) u jednačini (5) dobijamo jednačinu:

$$v = v_1 \cdot \left(\frac{R_1}{R}\right)^n. \qquad (15)$$

Iz jednačine (15) se za $R = R_1$ dobija $v = v_1$ za bilo koje n, u našem slučaju n>0. Za $R = R_i$, i = 2, 3,..., N, iz jednačine (15) možemo uzeti da je:

$$v_i = v_1 \cdot \left(\frac{R_1}{R_i}\right)^n, \text{ i = 2, 3,..., N,}$$

odakle se dobija relacija:

$$v_1 \cdot v_2 \cdot ... \cdot v_N = v_1^N \cdot \left(\frac{R_1^N}{R_1 \cdot R_2 \cdot ... \cdot R_N}\right)^n. \qquad (16)$$

Iz relacije (16) možemo odrediti parametar n. Logaritmovanjem relacije (16) dobijamo:

$$n\log\left(\frac{R_1^N}{R_1 \cdot R_2 \cdot ... \cdot R_N}\right) = \log\left(\frac{v_1 \cdot v_2 \cdot ... \cdot v_N}{v_1^N}\right),$$

odakle nalazimo:

$$n = \frac{\log\left(\frac{v_1 \cdot v_2 \cdot ... \cdot v_N}{v_1^N}\right)}{\log\left(\frac{R_1^N}{R_1 \cdot R_2 \cdot ... \cdot R_N}\right)}. \qquad (17)$$

Zamenom ovako nađene vrednosti za parametar n u jednačini (17), dobijamo za brzinu oscilovanja stenske mase u posmatranoj sredini relaciju:

$$v = v_1 \cdot \left(\frac{R_1}{R}\right)^n. \qquad (18)$$

Na ovaj način za određivanje parametra n uzeti su u obzir svi eksperimentalni podaci.

3. DEFINISANJE STATISTIČKIH KRITERIJUMA

Za ocenu stepena povezanosti između registrovanih (izmerenih) i izračunatih podataka u ovom radu koristili smo *koeficijent linearne korelacije r* [5] između logaritama redukovanog rastojanja R i logaritama brzine oscilovanja v. Pored toga, uzimali smo u obzir i *indeks krivolinijske zavisnosti ρ* [6(A)] između redukovanog rastojanja R i brzine oscilovanja v.

Ocena stepena povezanosti dve promenljive [13] prema vrednostima indeksa krivolinijske zavisnosti ρ data je u narednom pregledu:

0,0 < ρ < 0,2 nikakva ili veoma slaba veza,

0,2 < ρ < 0,4 slaba povezanost,

0,4 < ρ < 0,7 značajna povezanost,

0,7 < ρ < 1,0 jaka ili vrlo jaka povezanost.

Isto važi i za apsolutnu vrednost koeficijenta linearne korelacije r.

Kao mera pogodnosti dobijene funkcionalne veze za date eksperimentalne podatke koristili smo i kriterijum „3S“ [6(B)]. Ovaj kriterijum koristi kvadrate razlika između dobijenih eksperimentalnih podataka i izračunatih podataka za brzine oscilovanja v. Ako su te razlike redom ε_1, ε_2 ... ε_N, tada je:

$$S = \sqrt{\frac{\varepsilon_1^2 + \varepsilon_2^2 + ... + \varepsilon_N^2}{N}} \qquad (19)$$

Prema ovom kriterijumu, za ocenu pogodnosti dobijene funkcionalne veze važe sledeći odnosi:

- ako je $|\varepsilon_{max}| > 3S$, odbacuje se dobijena funkcionalna veza kao nepovoljna,
- ako je $|\varepsilon_{max}| < 3S$, prihvata se funkcionalna veza kao dobra.

4. PRIKAZ MASOVNIH MINIRANJA NA PK „DRENOVAC“

4.1. Opšte karakteristike površinskog kopa „Drenovac"

Ovaj rad obuhvata ispitivanja koja su izvršena pri masovnim miniranjima na površinskom kopu „Drenovac“ – Mionica [7(A)]. Površinski kop ’’Drenovac’’ je visinskog tipa i nalazi se gotovo na samom vrhu istoimenog brda. Merenja su izvršena na masivnim ili slojevitim krečnjacima.

Ležište krečnjaka zahvata površinu od 7,7 ha. Visinska razlika ležišta je oko 70 m, od kote 440-520 m. U podini krečnjaka je dijabaz – rožna formacija i ona se približno nalazi na koti oko 438 m.

Kartiranjem terena i istražnih bušotina konstatovano je da je krečnjak prslinsko pukotinske poroznosti. Dužina kernova je od 30-40 cm. Prsline i pukotine su najvećim delom zapunjene kalcitom, u manjem obimu pukotine su zapunjene limonitisanom drobinom, odnosno skramama limonita. Prilikom bušenja vrlo malo se gubila isplaka - voda, što ukazuje da je efektivna porozonost krečnjaka mala.

Krečnjak je čvrsta dobro okamenjena sredina. Tektonski je neoštećena tako da predstavlja jedinstvenu monolitnu masu. Prisutne prsline i pukotine malo utiču na opšte fizičko-mehaničke karakteristike. Ispitivanjem fizičko-mehaničkih osobina radne sredine dobijene su sledeće vrednosti:

- zapreminska masa 2,68 [kN/m³]
- poroznost 0,7-1,5 [%]
- kohezija 0,25 [MPa]
- jednoaksijalna čvrstoća
  - u suvom stanju 120-134 [MPa]
  - u vodozasićenom stanju 83-129 [MPa]
- ugao unutrašnjeg trenja 41 [°].

4.2. Način izvođenja miniranja

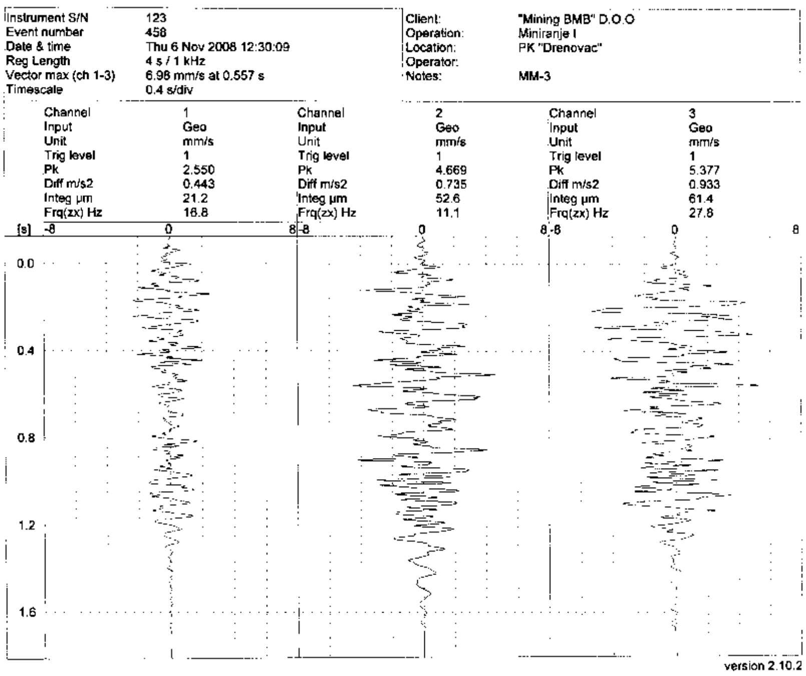
Merenja seizmičkih potresa na PK „Drenovac“ obavljena su pri miniranjima koja se izvode radi eksploatacije ležišta [7(B)]. Izvedeno je osam miniranja.

Kao eksploziv korišćen je amonex-1 28/200, amonex-1 60/1000, ANFO-J u vrećama od 25 kg i ANFEX-PP 70/1500. Aktiviranje eksploziva u bušotinama vršeno je nonel detonatorima, oznake N-25/500 i konektorima K-42. Osnovni podaci vezani za broj bušotina (N_b), ukupnu količinu eksploziva Q_{uk}, maksimalnu količinu eksploziva po intervalu usporenja Q_i, ukupnu dubinu bušotina L_{uk}, i prosečnu dužinu čepa $L_{pč}$, dati su u tabeli 1.

Tabela 1. *Prikaz parametara miniranja*

Miniranje	N_b	Q_{uk}[kg]	Q_i[kg]	L_{uk}[m]	$L_{pč}$[m]
I	27	661,4	36,2	211,0	2,8 – 3,0
II	28	1.980,6	71,2	488,0	2,8 – 3,0
III	15	915,3	66,2	213,0	2,8 – 3,0
IV	16	745,0	47,0	175,0	3,0 – 3,2
V	40	1.895,0	60,5	453,0	3,0 – 3,2
VI	22	1.774,4	85,2	402,0	3,0 – 3,2
VII	43	1.988,6	54,2	518,0	3,0 – 3,2
VIII	20	600	32,0	273,0	3,0 – 3,5

Na slici 1. prikazan je snimak brzine oscilovanja tla za miniranje broj I - merno mesto broj 3.



Sl. 1. *Snimak brzine oscilovanja tla za miniranje I – MM3*

4.3. Proračun parametara zakona oscilovanja tla

Vrednosti rastojanja od mesta miniranja do mesta opažanja r, količina eksploziva Q, izračunate vrednosti redukovanih rastojanja R, registrovane vrednosti brzina oscilovanja tla po komponentama v_t, v_v, v_l i rezultujuće brzine oscilovanja v_{rez} za miniranja od I - VIII na ukupno sedam mernih mesta MM date su u tabeli 2.

Tabela 2. *Prikaz parametara miniranja i rezultata merenja*

R. b.	Min b.	MM	r [m]	Q [kg]	R	v_t [cm/s]	v_v [cm/s]	v_l [cm/s]	V_{rez} [cm/s]
1	I	MM – 2	383,87	661,4	44,0585	0,070	0,100	0,110	0,1643
2	I	MM – 3	250,49	661,4	28,7499	0,255	0,466	0,537	0,7616
3	I	MM – 5	647,42	661,4	74,3073	0,080	0,090	0,080	0,1446
4	II	MM – 1	605,54	1980,6	48,2182	0,060	0,060	0,070	0,1100
5	II	MM – 2	334,15	1980,6	26,6078	0,080	0,120	0,150	0,2081
6	II	MM – 3	256,71	1980,6	28,4042	0,510	0,500	1,090	1,3031
7	II	MM – 6	527,05	1980,6	41,9681	0,090	0,230	0,160	0,2943
8	III	MM – 1	616,35	915,3	63,4804	0,091	0,083	0,082	0,1482
9	III	MM – 2	250,14	915,3	25,7629	0,192	0,573	0,719	0,9392
10	III	MM – 3	412,66	915,3	42,5015	0,380	0,605	0,412	0,8247
11	III	MM – 5	714,10	915,3	73,5481	0,138	0,096	0,116	0,2045
12	III	MM – 6	541,13	915,3	55,7332	0,170	0,241	0,177	0,3454
13	III	MM – 7	530,89	915,3	54,6785	0,133	0,236	0,193	0,3326
14	IV	MM – 1	723,77	745,0	79,8390	0,060	0.080	0,070	0,1221
15	IV	MM – 2	410,33	745,0	45,2635	0,140	0,170	0,180	0,2844
16	IV	MM – 3	223,89	745,0	24,6973	0,310	0,420	0,540	0,7511
17	IV	MM – 5	644,64	745,0	71,1102	0,110	0,200	0,200	0,3035
18	IV	MM – 7	426,38	745,0	47,0339	0,200	0,230	0,210	0,3701
19	V	MM – 1	737,38	1895,0	60,0667	0,050	0,070	0,040	0,0948
20	V	MM – 3	210,96	1895,0	17,1847	0,550	0,790	1,150	1,4996
21	V	MM – 7	422,53	1895,0	34,4192	0,210	0,360	0,320	0,5254
22	VI	MM – 3	231,44	1774,4	19,1171	0,577	1,160	0,709	1,4768
23	VI	MM – 5	650,53	1774,4	53,7341	0,055	0,071	0,077	0,1165
24	VI	MM – 6	640,06	1774,4	52,8693	0,081	0,150	0,168	0,2393
25	VI	MM – 7	425,36	1774,4	35,1350	0,340	0,465	0,259	0,6316
26	VII	MM – 3	333,13	1988,6	26,4910	0,534	0,460	0,602	0,9268
27	VII	MM – 6	530,48	1988,6	42,1845	0,101	0,190	0,150	0,2623
28	VII	MM – 7	415,31	1988,6	33,0260	0,284	0,525	0,286	0,6618
29	VIII	MM – 1	609,20	600,0	72,2286	0,030	0,070	0,070	0,1034
30	VIII	MM – 3	387,35	600,0	45,9254	0,339	0,527	0,629	0,8878
31	VIII	MM – 6	532,35	600,0	63,1171	0,067	0,112	0,079	0,1607
32	VIII	MM – 7	493,85	600,0	58,5524	0,072	0,157	0,156	0,2327

Na osnovu podataka datih u tabeli 2 izračunava se zakon oscilovanja tla po formuli (5) - po modelima 1 i 2. Proračun krive izvršen je za vrednosti redukovanih rastojanja od R = 17,1847 do R = 79,8390. Na taj način izračunati su parametri krive, koji omogućuju da se odredi jednačina oscilovanja tla u obliku:

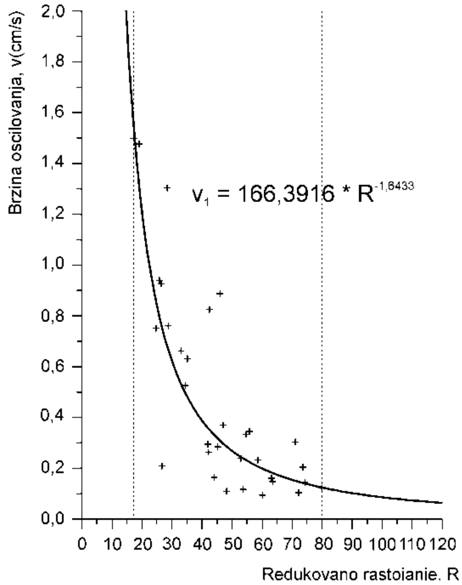
♦ Model 1

$$v_1 = 166{,}3916 \cdot R^{-1{,}6433} \qquad (20)$$

pri čemu je između log v i log R dobijena linearna zavisnost, izražena jednačinom (20) sa *koeficijentom linearne zavisnosti r* koji iznosi:

r = -0,8

Grafički prikaz zakona oscilovanja tla dat je na slici 2.



Sl. 2. *Grafički prikaz krive brzine oscilovanja tla na PK „Drenovac“*

♦ **Model 2**

$$v_2 = 143{,}2699 \cdot R^{-1{,}6032} \qquad (21)$$

Na osnovu dobijenih jednačina oscilovanja tla (20) i (21), moguće je izračunati vrednosti brzina oscilovanja tla za odgovarajuća redukovana rastojanja za model 1 i 2.

U tabeli 3. dat je pregled redukovanih rastojanja R, registrovanih brzina oscilovanja tla v_r, izračunatih brzina oscilovanja tla v_{i1}, v_{i2}, kao i razlika između registrovanih i izračunatih brzina oscilovanja tla za model 1 i 2.

Tabela 3. *Prikaz registrovanih i izračunatih brzina oscilovanja tla za model 1 i 2*

Redni br.	R	v_r [cm/s]	v_{i1} [cm/s]	v_{i2} [cm/s]	$v_r - v_{i1}$	$v_r - v_{i2}$
1	44,0585	0,1643	0,3307	1,4996	-0,1664	0,0000
2	28,7499	0,7616	0,6670	1,2641	0,0946	0,2127
3	74,3073	0,1446	0,1401	0,8384	0,0045	-0,0873
4	48,2182	0,1100	0,2852	0,7835	-0,1752	0,1557
5	26,6078	0,2081	0,7576	0,7493	-0,5495	0,1775
6	28,4042	1,3031	0,6804	0,7440	0,6227	-0,5359
7	41,9681	0,2943	0,3583	0,6700	-0,0640	0,6331
8	63,4804	0,1482	0,1815	0,6572	-0,0333	0,1044
9	25,7629	0,9392	0,7988	0,5262	0,1404	0,1356
10	42,5015	0,8247	0,3509	0,4924	0,4738	0,0330
11	73,5481	0,2045	0,1425	0,4765	0,0620	0,1551
12	55,7332	0,3454	0,2248	0,3583	0,1206	-0,0640
13	54,6785	0,3326	0,2319	0,3554	0,1007	-0,0931

14	79,8390	0,1221	0,1245	0,3512	-0,0024	0,4735
15	45,2635	0,2844	0,3164	0,3315	-0,0320	-0,1672
16	24,6973	0,7511	0,8562	0,3174	-0,1051	-0,0330
17	71,1102	0,3035	0,1506	0,3101	0,1529	0,5777
18	47,0339	0,3701	0,2971	0,2985	0,0730	0,0716
19	60,0667	0,0948	0,1987	0,2868	-0,1039	-0,1768
20	17,1847	1,4996	1,5539	0,2475	-0,0543	-0,0082
21	34,4192	0,5254	0,4963	0,2411	0,0291	-0,1246
22	19,1171	1,4768	1,3043	0,2345	0,1725	0,0981
23	53,7341	0,1165	0,2387	0,2274	-0,1222	0,1180
24	52,8693	0,2393	0,2451	0,2101	-0,0058	0,0226
25	35,1350	0,6316	0,4798	0,2017	0,1518	-0,1069
26	26,4910	0,9268	0,7631	0,1863	0,1637	-0,0256
27	42,1845	0,2623	0,3552	0,1846	-0,0929	-0,0364
28	33,0260	0,6618	0,5311	0,1539	0,1307	0,1496
29	72,2286	0,1034	0,1468	0,1501	-0,0434	-0,0467
30	45,9254	0,8878	0,3089	0,1458	0,5789	0,0587
31	63,1171	0,1607	0,1832	0,1434	-0,0225	0,0012
32	58,5524	0,2327	0,2073	0,1278	0,0254	-0,0057

Na osnovu podataka iz tabele 3. izvršena je statistička analiza i dobijene su sledeće vrednosti.

Model 1:

Indeks krivolinijske zavisnosti ρ_1 između redukovanog rastojanja R i brzine oscilovanja tla v, iznosi:

$\rho_1 = 0{,}8380$ (postoji *vrlo jaka povezanost* između R i v, data u formuli (20)).

Maksimalna razlika između registrovanih i izračunatih brzina oscilovanja tla $(\varepsilon_{\max}) = \max|\varepsilon_i|$, iznosi:

$\varepsilon_{max1} = 0{,}6227$, $S_1 = 0{,}2200$,

$3S_1 = 0{,}6600$.

Pošto je $\varepsilon_{max1} < 3S_1$, pretpostavljena *funkcionalna veza se prihvata kao dobra*.

Model 2:

$\rho_2 = 0{,}8357$ (postoji *vrlo jaka povezanost* između R i v, data u formuli (21)).

$\varepsilon_{max2} = 0{,}6331$, $S_2 = 0{,}2214$,

$3S_2 = 0{,}6642$.

$\varepsilon_{max2} < 3S_2$ (pretpostavljena *funkcionalna veza prihvata se kao dobra*).

5. ZAKLJUČAK

Za uspostavljanje veze između brzine oscilovanja stenske mase i osnovnih parametara koji utiču na njenu veličinu, a to su: količina eksploziva, rastojenje od mesta miniranja, osobina stenskog materijala i način izvođenja miniranja, najčešće se koristi jednačina profesora M. A. Sadovskog, koja definiše zakon promene brzine oscilovanja stenske mase i data je u obliku funkcije:

$$v = K \cdot R^{-n},$$

gde R predstavlja redukovano tj. svedeno rastojanje, a parametri K i n koeficijent i eksponent koji su uslovljeni karakteristikama tla i uslovima miniranja i mogu imati samo pozitivne vrednosti. Pri tome je v opadajuća i konveksna funkcija.

U radu je zakon Sadovskog izveden i na drugi način, korišćenjem količnika odnosa između relativnih priraštaja brzina oscilovanja stenske mase i relativnih priraštaja redukovanih rastojanja. Pri tome je u graničnom slučaju dobijena jedna diferencijalna jednačina čiji se opšti integral poklapa sa zakonom Sadovskog.

U ovom radu, izračunata je brzina oscilovanja, tj. određeni su parametri K i n na dva načina - modela. Analizom i obradom dobijenih podataka može se zaključiti:

Parametri n i K u zakonu Sadovskog određivani su na dva načina – modela u datoj radnoj sredini. Pri tome su dobijene odgovarajuće funkcije kojima su predstavljene brzine oscilovanja stenske mase u zavisnosti od redukovanog rastojanja. Izračunati odgovarajući indeksi krivolinijske korelacije pokazuju da između redukovanog rastojanja i brzine oscilovanja stenske mase postoji vrlo jaka krivolinijska veza izražena dobijenim funkcijama.

Upoređujući vrednosti registrovanih brzina oscilovanja stenske mase sa odgovarajućim izračunatim vrednostima, vidimo da one imaju približno iste vrednosti. Na osnovu dobijenih vrednosti koeficijenata krivolinijske zavisnosti i vrednosti koeficijenata linearne korelacije između logaritama redukovanog rastojanja i logaritama brzine oscilovanja zaključujemo da se oba modela mogu koristiti za izračunavanje brzine oscilovanja stenske mase.

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SOOT PARTICIPATION IN TOTAL AIR POLLUTION IN THE MUNICIPALITY OF BOR WITH STATISTICAL DATA PROCESSING[**]

Abstract

For effective air quality management, one of the main conditions is the identification of pollution sources, determining their share in the overall pollution as well as implementation the measures for control and reducing the pollution. The aim of this paper is that, based on collected data, to make a conclusion on how soot affects the level of pollution in the municipality of Bor. The results presented in this paper were obtained on the basis of processed daily and average annual values of soot concentrations for these years. Analysis of samples was carried our on refractometer at 24 hour continuously, seven days a month at a particular measurement point. For statistical data processing, the statistical software SPSS (Statistical Package for the Social Sciences) version 17.0 was used. Based on the results obtained using the software, there is the conclusion that there is little correlation between the metrological parameters and soot concentration in the municipality of Bor, and that there is no increased concentration at the measuring points despite pyrometallurgical treatment of copper concentrate in RTB Bor. The great importance to the increased soot concentration has the use of fossil fuels for heating households, as it is not the case in Bor, because more than 90% of households are heated by district heating system.

Keywords: *soot, pollution, Bor municipality, statistical software SPSS*

INTRODUCTION

The Municipality of Bor is located in East Serbia; it covers an area of 856 km^2 and there around 50,000 citizens in it, according to the census of 2011 [1, 2]. Bor is located at altitude of 378 m, and belongs to the continental climate area. The average annual precipitation is 688 mm, the snow cover remains for 60 days, and the average annual temperature is 10.2°C. The area of Bor is located in the area of high-frequency winds, but the winds are of moderate intensity. The dominant winds in the study area are NE (9.9%), W (8.2%) and NW (7.7%), and the direction of E (7.6%), the wind from the south direction of lower frequency (4.4%). The basic meteorological parameters are given in Table 1 [3 - 9]. The standard deviation is shown to see how natural samples on average deviate from arithmetic mean of the sample.

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[**] *This work is the result of the Project TR 33038 “Improving Technology of Exploitation and Processing of Copper Ore with Monitoring the Living and Working Environment in the RTB Bor Group”, funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia*

Table 1 *Meteorological observations for the period 2005-2010 from the meteorological station at the Mining and Metallurgy Institute in Bor*

Meteorological parameters		**Year**					
		2005	**2006**	**2007**	**2008**	**2009**	**2010**
Temperature (°C)							
	Minimum	-2.7	-3.6	-0.9	-1.9	0.9	-3.0
	Maximum	22.0	21.6	24.7	23.2	21.9	22.9
	Average value	9.9	10.1	11.7	11.4	11.3	10.5
	SD	8.5	8.3	8.3	8.1	7.9	8.45
Air humidity (%)							
	Minimum	64	60	43	54	52	65
	Maximum	84	81	86	84	86	83
	Average value	75.3	70.5	68	69	67	76
	SD	6.27	7.06	12.93	9.76	10.95	7.41
Atmospheric pressure (mbar)							
	Minimum	965.7	965.8	967.4	949.5	966.6	964.1
	Maximum	978.5	981.5	976.7	980.4	975.1	972.5
	Average value	971.9	972.7	971.6	971.1	971.0	969.4
	SD	3.3	4.6	2.7	7.6	3.8	3.46
Wind speed (m/s)							
	Minimum	0.1	0.3	0.4	0.3	0.2	0.3
	Maximum	0.8	0.7	0.8	1.0	1.0	2.2
	Average value	0.45	0.45	0.55	0.6	0.5	0.8
	SD	0.25	0.13	0.17	0.19	0.28	0.80
Maximum wind gust (m/s)							
	Minimum	4.4	8.2	11.3	10.3	7.8	5.3
	Maximum	17	17.0	18.4	19.6	19.4	16.8
	Average value	12.6	13.6	14.0	16.5	13.9	12.2
	SD	3.8	3.1	2.4	2.8	3.5	4.73

SD – standard deviation

SOURCES OF POLLUTION

The primary sources of pollution in Bor are mining and metallurgy. Pollution comes from the process of mining and processing of copper ore, and a source of pollution is also the overburden from the open pit and flotation tailing dumps.

The secondary source of pollution is the soot that is produced by combustion of fossil fuels. A quantity of soot in the air originates from traffic and the emission is present throughout the year, while the second quantity of soot is typical for the winter (heating) season and it originates from the central town heating plant, which use coal as fuel.

MEASURING POINTS

The layout of measuring points depends on the type of settlement, meteorological and topographical factors of the area, the position of industrial facilities, layout of main roads, as well as the nature and amount of gas emissions. Monitoring of air quality in the area of the municipality of Bor is performed at the following measuring points:

1. Town Park: measuring point is 800 m far in the direction WSW of the Mining and Smelter Basin Bor as the dominant source of pollution. It is located in the urban area of the town (Local Community Old Center). Measuring point is situated in the old part of the town where there are the major business, trading and administrative town facilities.

2. Mining and Metallurgy Institute Bor: measuring point is 1,900 m far in the direction SSW in the urban area of the town. Measuring point is located in the most densely inhabited part of the town. In the vicinity of the measuring point, there are several schools, major roads and the sports and recreation center.

3. Jugopetrol: measuring point is 2,500 m far in the direction SSE from the source of pollution. In the area around this measuring point, the smallest numbers of inhabitants live. It is located in the area of suburb, which is the industrial zone. The area is significant for being the gust of winds with the highest frequency.

4. Brezonik: measuring point is 2.000 m far in the direction NNW in the area of suburb. [10]

AIR POLLUTION

The concept of air pollution is the specific content of harmful substances in the air. The amount and types of these substances depends on the damage that can cause the human and animal health, as well as plants and materials. Pollutants can be in solid, liquid or gaseous state. Solid particle is the term used to describe particles that are suspended in the air.

Suspended particles are pollutants that differ in size, mass, surface, chemical composition, mechanism of formation and origin. Their concentration in the air is a function of the emission source, reactions in the atmosphere and meteorological conditions. Suspended particles are mixture of very fine solid particles and liquid drops, which consist of a number of components, including acids (nitrates and sulfates), organic matter, metals, non-metals, soot, dust and soil particles. [11]

According to the size, the solid particles can be divided into: **coarse particles** (2.5-10 μm) arising from mechanical resuspension of dust, erosion and soil treatment or for-ming from the industrial processes such as production of cement, concrete, ceramics and mining. Characteristic elements which are concentrated in this fraction are Al, Si, Ca, Fe and Na; **fine particles** (<2.5 μm) originating from anthropogenic activities such as: combustion, various industrial processes and traffic. Particles of diameter <1 μm are formed by condensation of metals or organic matters from the combustion process and **ultrafine particles** (from 0.01 to 0.1 μm) in the atmosphere are in the form of an aerosol. Ultrafine particles are usually derived from the combustion of diesel fuel, gasoline and other organic fuels; they are composed of particles of carbonaceous soot and they are mixed with organic compounds.

Particles having diameter larger than 50 μm will remain in the air for several minutes and precipitate close to the pollution source. Smaller particles PM_{10} can remain in the air for several days and under the influence of wind they may scatter over a large area around the main source of pollution. Fine particles, size of 0.1 to 2.5 μm, remain in the atmosphere infinitely, whereby prevent the passage of sunlight and reduce visibility. They are usually removed from the air by rain or collision with other particles [12]

According to the origin, the suspended particles can be divided into: **primary** particles, emitted directly from the source of pollution (eg. construction sites, unpaved roads, chimneys, fires, etc.) and **secondary** particles, formed by complex mechanisms in the atmosphere after emission from pollution sources (for example, particles emitted from the power plants, industries or exhaust gases from traffic).

SOOT

Soot is produced by burning the fossil fuels. These are fine, small particles about 5 µm, that float in the air and act as a gas. They contain toxic and carcinogenic substances, easily penetrate the respiratory tract and damage them.

Soot in the suspended particles is the major threat to human health. Exposure to certain harmful substances may lead to the genetic mutations, reducing the immune capacity of the body, but most often deteriorates the existing diseases, such as asthma and chronic obstructive pulmonary disease. Some bacteria and toxic gases have the ability to get in touch with particles of soot, which further enhances their harmful impact on human health [13].

ANNUAL LEVEL OF SOOT CONCENTRATION IN THE BOR MUNICIPALTY

Table 2 shows the average annual concentrations of soot at the measuring points in the urban area of Bor in the period from 2005 to 2011. Measurements were made at the measuring points Town Park and Jugopetrol in 2005 and 2006, as well as at the measuring point Brezonik in 2008. Measurement of soot concentration is not carried out in the suburb. In the urban area, measurements are carried out at four measuring points. The largest number of measurements, during the five-year period, was carried out at the measuring point Institute, and then at the measuring points Jugopetrol, Brezonik and Town Park.

Table 2 *Soot concentration at the measuring points in the municipality of Bor in the period from 2005 to 2011*

Measuring point	Soot concentration							Total number of samples (N)	Average value
	2005	2006	2007	2008	2009	2010	2011		
Brezonik	7	5	6	/	19.41	9	13.8	949	10.03
Town Park	/	/	4	7	10.93	7	10.2	883	7.83
Institute	7	8	7	15	12	8.4	9.4	988	9.54
Jugopetrol	/	/	6	11	11.05	5	6.7	957	7.95

* *all concentrations expressed in µg/m^3*

In the urban areas, Brezonik (measuring point Brezonik) is the most polluted area, while in other areas the level of pollution is around the same and below the limit of 15 µg/m^3. Total number of samples that were used in the statistical analysis is shown in Table 2.

EXPERIMENTAL PART

ANALYSIS OF SAMPLES

Measurements within the air quality control are carried out in a 24 hour continuity, seven days a month at specific measuring point, after which the mobile measuring station is moved to the other measuring point.

DESCRIPTIVE STATISTICAL ANALYSIS

Descriptive statistical analysis is a set of methods that are used for calculation, presentation and description the basic characteristics of statistical series. It includes the following actions:

1. Clustering and sorting of statistical data,
2. Presentation of statistical data and calculation, and

3. Determining the basic measures of statistical series.

Clustering of data is done according to the values or modes of observed characteristics. As the final result of clustering, the statistical series occurs, which presents the arranged set of variations of the observed characteristics of statistical mass.

In order to find the areas with similar levels of pollution in the Bor municipality, collected data in the paper were processed using the multivariational statistical methods: regression and correlation analysis, one-factor analysis of variance (ANOVA). The data represent the soot concentrations and meteorological, processed in the statisticalcal program SPSS statistics version 17.0 [14, 15, 16].

MULTIVARIATIONAL ANALYSIS

Regression, correlation and analysis of variance

Regression analysis is a form of multivariate analysis that describes the shape of connection between two or more variables. The simple regression model includes only two variables: one independent and one dependent. Dependent variable is the variable whose variations should be explained on the basis of movements explaining the variables. Regression model that describes the linear interdependence between two variables is called a linear regression model [17].

Correlation analysis is another form of multivariate analysis and it is used to describe the intensity, i.e. degree of agreement of variations and direction of relationships between two variables. Correlation between variables describes the significance value and the correlation coefficient that can be obtained by one-way ANOVA. Analysis of variance compares the variability of results (variance) between various groups with variability within each group.

- Indicator (quotient) F represents the variance between groups divided by the variance within the groups, the greater the value of F quotients, the greater the variability between groups.
- Quotient t (or t-test) is the ratio of difference between two mean values of group divided with the group variability, the higher t-value, the results are more significant.
- p-value does not show the bond strength, but with how much confidence should be seen the obtained results. Significance of the analysis results is affected by the sample size. For small sample data (N = 30), moderate correlations can be calculated. The usual level of significance is $p < 0.05$.
- Correlation coefficient (R) is a degree indicator of quantitative agreement between variables and ranges from $-1 \le R \le 1$. For R = 0 there is no correlation between the variables.
- Determination coefficient (R^2) is statistical criterion for obtaining an answer to the question of whether the chosen variable explains well the dependent variable variations in the spatial linear model. [17] The parameter R^2 shows which part of variation of dependent variable is explained by regression model. It is in the range of $0 \le R^2 \le 1$.

EFFECT OF METEOROLOGICAL PARAMETERS ON SOOT CONCENTRATION

Dispersion diagram is a graphical presentation the pairs of variables, which describes the nature, intensity and direction of agreement between two variables [17].

Table 3 and Figures 1, 2, 3 and 4 show the results of regression analysis at monthly level for data from automatic measuring station, installed by the Environmental Protection Agency (SEPA) at the measuring point Mining and Metallurgy Institute. Measurements were carried out in the period from early 2005 to the end of 2010.

Table 3 shows the results of variance analysis for soot concentrations (μg/m^3) of temperature (°C), humidity (%), atmospheric pressure (mbar) and wind speed (m/s) in the period from 2005 to 2010 at the measuring point Mining and Metallurgy Institute. Data from the measuring point Institute were selected for analysis because the meteorological station in the municipality of Bor is only situated at this measuring point.

Table 3 *Correlation between the soot concentration and meteorological parameters in the period from 2005 to 2010 at the measuring point MMI Bor (ANOVA)*

Correlation	R	R^2	F	*p*-value	*t*
Soot – air temperature	0.205	0.042	2.491	0.120	-1.578
Soot - air humidity	0.313	0.098	6.178	0.016	2.486
Soot – atmospheric pressure	0.148	0.022	1.283	0.262	1.132
Soot – wind speed	0.142	0.020	1.181	0.282	-1.087

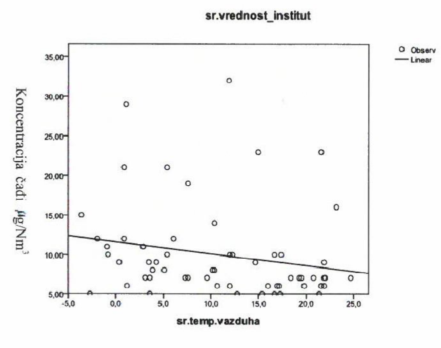

Figure 1 *Correlation between the soot concentration and average air temperature from 2005 to 2010 at the measuring point MMI Bor*

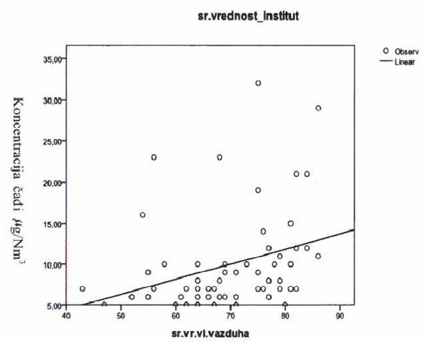

Figure 2 *Correlation between the soot concentration and average air humidity from 2005 to 2010 at the measuring point MMI Bor*

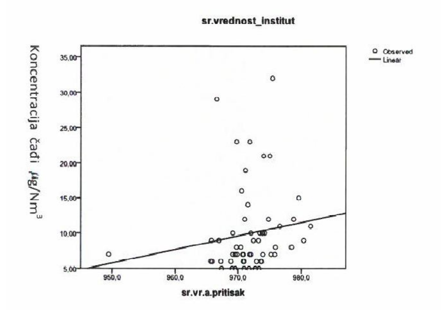

Figure 3 *Correlation between the soot concentration and average value of atmospheric pressure from 2005 to 2010 at the measuring point MMI Bor*

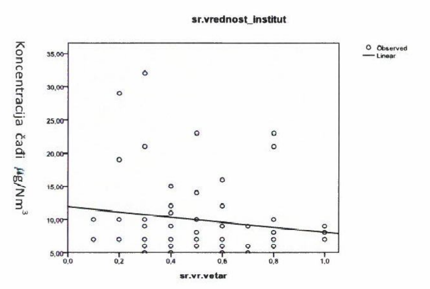

Figure 4 *Correlation between the soot concentration and average value of wind speed from 2005 to 2010 at the measuring point MMI Bor*

The following can be concluded based on the results of regression analysis:

- There is a positive linear correlation of moderate strength (R = 0.205) between the concentration of soot and air temperature. However, only 4.2% of variations is explained by regression analysis, which shows that in addition to temperature, there are many factors that affect the amount of soot concentration, although the level of significance is p = 0.120. The usual level of significance is p <0.05.

- There is a positive linear correlation of moderate strength (R = 0.313) between the concentration of soot and air humidity. However, only 9.8% of variations is explained by regression analysis, which shows that in addition to the air humidity, there are many factors that affect the amount of soot concentration, although the level of significance is p = 0.016. The usual level of significance is p <0.05.
- There is a positive linear correlation of small strength (R = 0.148) between the concentration of soot and atmospheric pressure. Only 2.2% of variations is explained by regression analysis, which shows that in addition to the atmospheric pressure there are many factors that affect the amount of soot concentration, although the level of significance is p = 0.262. The usual level of significance is p <0.05.
- There is a positive linear correlation of small strength (R = 0.141) between the concentration of soot and wind speed. Only 2.0% of variations is explained by regression analysis, which shows that in addition to the wind speed there are many factors that affect the amount of soot concentration, although the level of significance is p = 0.222. The usual level of significance is p <0.05.

The effect of meteorological parameters: temperature (°C), air humidity (%), atmospheric pressure (mbar) and wind speed (m/ s) on the concentration of soot, showed poor correlation and poor level of significance for the results of the analysis.

EFFECT OF HEATING SEASON ON SOOT CONCENTRATION

Table 4 and Figures 5 and 6 show the results of variance analysis for soot concentrations (μg/m^3) in the periods from October 2009 to March 2010 and in the period from April to September 2010 at the measuring point Mining and Metallurgy Institute Bor . These periods are used for analysis, because there are the most data on soot concentration for 2009 and 2010.

Table 4 *Correlation between the soot concentration and heating season*

Correlation	R	R^2	F	*p*-value	*t*
Soot – heating season	0.038	0.001	0.258	0.001	3.48
Soot– season without heating	0.117	0.014	2.505	0.115	1.583

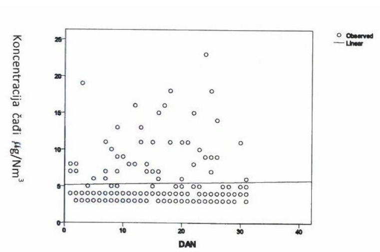

Figure 5 *Simple linear correlation between the soot concentration and winter heating period from October 2009 to March 2010 at the measuring point MMI Bor*

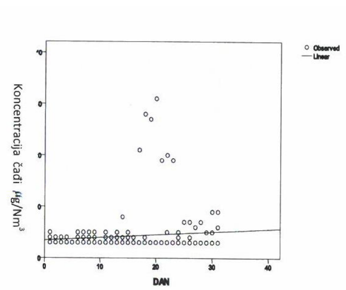

Figure 6 *Simple linear correlation between the soot concentration and summer period without theating from April 2009 to September 2010 at the measuring point MMI Bor*

The following can be concluded based on the results of regression analysis:

- There is a positive linear correlation of very small strength ($R = 0.038$) between the concentration of soot and heating season, i.e. the use of fossil fuels for the Heating Plant operation in Bor. Only 1% of variations is explainned by regression analysis, which shows that many other factors affect the amount of soot concentration, although the level of significance is $p = 0.001$. The usual level of significance is $p < 0.05$.
- There is a positive linear correlation of very small strength ($R = 0.117$) between the concentration of soot and periods without the use of fossil fuels for heating the flats and houses. However, 14% of variations is explained by regression analysis, which shows that many other factors affect the amount of soot concentration, although the level of significance is $p = 0.115$. The usual level of significance is $p < 0.05$.

Measuring point Institute is located 1,900 m in direction SSW of the pollution source, and it is not in the direction of dominant winter winds, but in its vicinity there is very busy traffic line, so this explains higher correlation in the summer period than in the winter period when the number of cars is reduced.

EFFECT OF WIND DIRECTION ON CONCENTRATION LEVELS OF SOOT IN THE AIR

Analysis of the dominant wind direction is used to assess the impact of pollution sources on the level of imission of pollutants in certain areas. For this analysis, data on dominant wind direction are presented graphically in the form of polar diagrams - wind roses [18], and data on pollution in the form of pollution rose [19, 20].

Figures 7 to 10 show the roses of soot pollution (μg/m^3) and wind roses (%) for the observed period in the Bor municipality. Dominant wind directions were west (NW, WNW, W), eastern (ENE, E, SE), and at least was the wing from the south direction (S, SSW). Wind direction has proven to be one of the most important factors that has effect on dispersion of pollutants from the pollution sources.

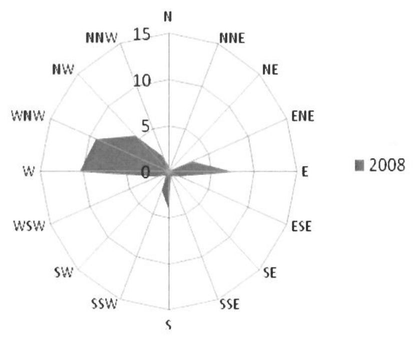

Figure 7 *Wind rose (%) for 2008*

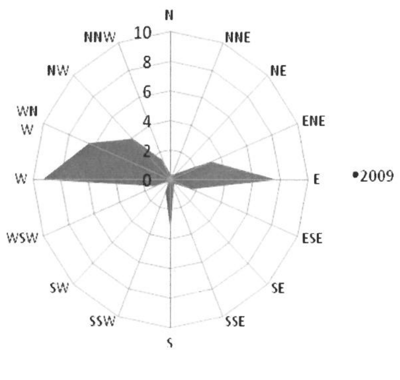

Figure 8 *Wind rose (%) for 2009*

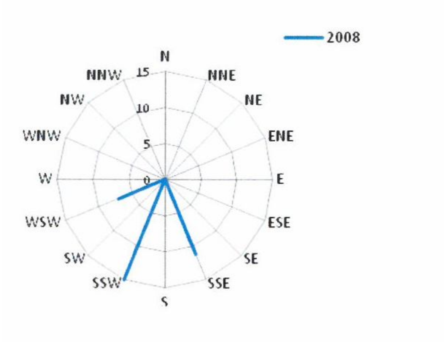

Figure 9 *Rose of soot pollution (μg/m^3) during 2008*

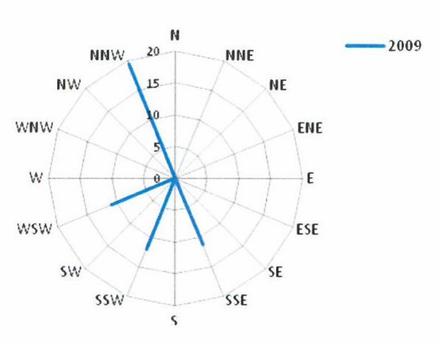

Figure 10 *Rose of soot pollution (μg/m^3) during 2009*

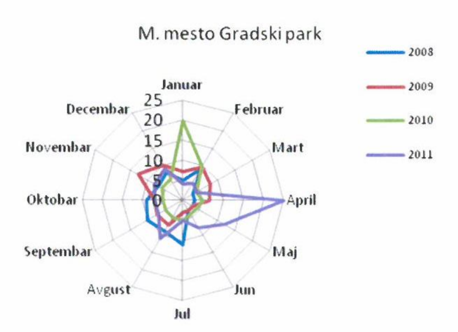

Figure 11 *Soot concentration by months for 2008 and 2011 at the measuring point Town Park*

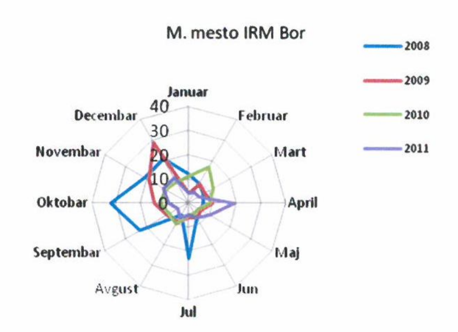

Figure 12 *Soot concentration by months from 2008 to 2011 at the measuring point MMI Bor*

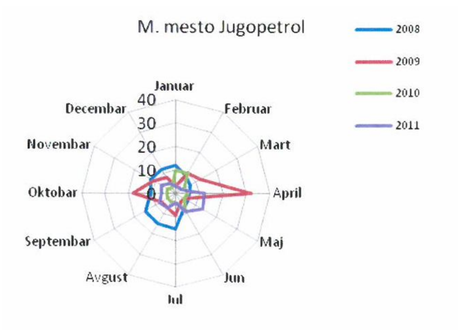

Figure 13 *Soot concentration by months for 2008 and 2011 at the measuring point Jugopetrol*

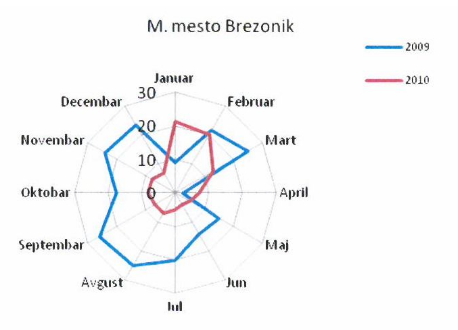

Figure 14 *Soot concentration by months for 2009 and 2010 at the measuring point Brezonik*

Figures 11 and 14 shows the average monthly concentrations of soot at the measuring points in Bor in the form of polar diagrams. Based on these diagrams, it can be concluded that the soot concentrations rarely exceeded maximum allowable concentration of 15 $\mu g/m^3$.

At the measuring point Institute, in the period from 2008 to 2011, the increased soot concentration above maximum allowable limit was only in 2008 from July to December. In mid July 2008, a fire broke out in the area of the airport, which is about five kilometers from Bora as well as a forest fire on Crni vrh, so that was probably the cause of increased soot concentration in this period.

In 2009, at the measuring point Brezonik, the soot concentrations were increased in February and March, as well as in the period from July to December 2009, and due to lack of other data, the other years were not analyzed. Change of meteorological conditions, change of wind directions (Figure 8) and a sharp drop in atmospheric pressure have caused the increased soot concentrations in the settlement Brezonik.

CONCLUSION

In order to find areas with similar levels of pollution in the Bor municipality, the collected data on soot concentration were processed by multivariate statistical methods: regression, correlation and analysis of variance.

One-factor analysis of variance and regression analysis showed that at monthly level at the measuring point Mining and Metallurgy Institute Bor:

- There is a positive linear correlation of mean strength of $R = 0.142$ and $R = 0.313$ between the soot concentration and meteorological parameters. However, a very small percentage of variations are explained by regression analysis of maximum 9.8%, indicating that the addition of meteorological parameters, there are a lot of factors that affect the amount of soot concentrations. The significance level of p is in the range between 0.016 and 0.282. The usual level of significance is $p < 0.05$. Based on this, it can be concluded that there is no statistically significant correlation between soot particles and other meteorological parameters: air humidity, atmospheric pressure, wind speed and amount of precipitation.
- The effect of heating season, i.e. the use of fossil fuels for heating households on soot concentration in the air has shown that there is a positive linear correlation of a very small strength ($P=0.038$). Only 1% of variation is explained by the regression analysis, which shows that many other factors affect the amount of soot concentration, although the significance level is $p=0.001$. The usual level of significance is $p < 0.05$. Soot concentration depends on the direction of dominant winds.
- There is a positive linear correlation of small strength ($R = 0.117$) between the soot concentration and period without use of fossil fuels for heating of flats and houses. However, 14% of variations is explained by regression analysis, indicating that a lot of factors affect the amount of soot concentrations, significance level is $p=0.115$. The usual level of significance is $p < 0.05$. In summer period, the soot concentration is increased at this measuring points due to the increased number of vehicles as well as the winds that blow in this period and which are W and WNW.
- Based on the obtained statistical data, it can be concluded that there is no single source of suspended soot particles, whose concentration is the most affected by humidity from meteorological parameters. Regression model has explained less than 10% of variations of soot concentrations, which means that the remaining 90% of variations were not identified.

One-factor analysis of variance and regression analysis are given at annual level (from 2005 to 2011) at the measuring point Mining and Metallurgy Institute Bor:

- there is no statistically important correlation between the soot concentration and meteorological parameters,
- there is no statistically important correlation between the soot concentration and use of fossil fuels for heating.

Based on statistical indexes, it can be concluded that the meteorological parameters do not affect the level of soot imission in suspended particles (PM). However, small number of imission measurements could be the main reasons of a lack of correlations.

Based on the six-year average concentrations of soot at the measuring points in the urban area, it is concluded that the mean values of soot concentrations around the measuring points Brezonik, Jugopetrol, Institute and Town Park are below maximum allowable limit of 15 μg/m^3 and range from 7.83 to 10.03 μg/m^3. In 2009, at the measuring point Brezonik, the mean annual average was above maximum allowable limit and it was 19.41 μg/m^3, as well as at the measuring point Institute in 2008, the mean annual average was at maximum allowable limit.

However, as the number of samples from 2005 to 2009 is not the same for all measuring points and as the measurements are carried out only a week, and emission of pollutants from the Mining and Smelting Complex is almost constant with minor interruptions and oscillations in production, as well as winter when the Heating Plant is in operation, the certain measuring points may have a lower average than it is normally, while the other places occur as polluted on the basis of a small number of measurements of imissions.

In the Bor municipality, the dominant winds are of west and north-west direction (NW, WNW, W), while the winds of the east direction (ENE, E, ESE) have smaller frequency, and the winds of south direction (S, SSW) have the smallest frequency as shown in the polar diagrams of wind rose for 2008 and 2009. Based on a polar diagram of rose of soot pollution in 2008, the highest level of pollution was recorded at the measuring point Brezonik, Institute and Jugopetrol, as well as in the settlement Metalurg and Local Community Sloga. In 2009, the highest level of contamination was recorded at the measuring points Brezonik, Institute and Jugopetrol, in the settlement Metalurg and Local Community Sloga, which are in the direction of dominant winds, or that are located in close proximity to the pollution sources. The mean annual values of soot concentrations are within normal limits. The increased soot concentration in the settlement Metalurg, Brezonik and Local Community Sloga probably comes from the use of fossil fuels for heating of houses.

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UČEŠĆE ČAĐI U UKUPNOM ZAGAĐENJU VAZDUHA NA TERITORIJI OPŠTINE BOR SA STATISTIČKOM OBRADOM PODATAKA**

Izvod

Za efektivno upravljanje kvalitetom vazduha, jedan od glavnih uslova je identifikacija izvora zagađenja, određivanje njihovog udela u ukupnom zagađenju, kao i sprovođenje mera za kontrolu i redukovanje zagađenja. Cilj rada je da se na osnovu prikupljenih podataka izvede zaključak koliko čađ utiče na nivo zagađenja u Opštini Bor. Rezultati koji su prikazani u radu dobijeni su na osnovu obrađenih dnevnih i srednjih godišnjih vrednosti koncentracija čađi za navedene godine. Analiza uzoraka je rađena na refraktometru u 24-časovnom kontinuitetu, 7 dana u mesecu na određenom mernom mestu. Za statističku obradu podataka korišćen je statistički softver SPSS (Statistical Package for the Social Sciences) verzija 17.0. Na osnovu rezultata koji su dobijeni primenom softvera došlo se do zaključka da postoji mala korelacije između metroloških parametara i koncentraciju čađi u opštini Bor, kao i da ne postoji povećana koncentaracije na mernim mestima uprkos pirometalurškoj preradi koncetrata bakra u RTB Bor. Veliki značaj na povećanu konctraciju čađi ima upotreba fosilnih goriva za zagrevanje domaćinstva, što u Boru nije sličaj jer se više od 90% domaćinstva zagreva daljinskim sistemom grejanja.

Ključne reči: *čađ, zagađenje, opština Bor, statistički softver SPSS*

UVOD

POSMATRANO PODRUČJE

Opština Bor se nalazi u Istočnoj Srbije, prostire se na površini od 856 km^2, i u njoj živi oko 50.000 stanovnika, prema popisu iz 2011. godine. [1, 2] Bor se nalazi na nadmorskoj visini od 378 m, i pripada kontinentalnom klimatskom području. Prosečna godišnja količina padavina je 688 mm, snežni pokrivač zadržava se 60 dana, a srednja godišnja temperature je 10,2 °C. Područje Bora se nalazi u oblasti velike učestalosti vetrova, ali su vetrovi umerenog intenziteta. Dominantni vetrovi u posmatranom području su WNW (9,9 %), W (8,2 %) i NW (7,7 %), kao i pravca E (7,6 %), vetar iz južnog pravca manje učestalosti (4,4 %). Osnovni meterološki parametri su dati u tabeli 1. [3 - 9] Strandardna devijacija je prikazana da bi se videlo koliko elementarnih uzoraka u proseku odstupaju od aritmetičke sredine uzorka.

* *Institut za rudarstvo i metalugiju Bor*

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Tabela 1. *Meteorološka osmatranja za period od 2005-2010. godine sa meteorološke stanice kod Instituta za rudrastvo i metalurgiju u Boru*

Meteorološki parametri		Godina					
		2005.	2006.	2007.	2008.	2009.	2010.
Temperatura (°C)							
	Minimalna	-2,7	-3,6	-0,9	-1,9	0,9	-3,0
	Maksimalna	22,0	21,6	24,7	23,2	21,9	22,9
	Srednja vrednost	9,9	10,1	11,7	11,4	11,3	10,5
	SD	8,5	8,3	8,3	8,1	7,9	8,45
Vlažnost vazduha (%)							
	Minimalna	64	60	43	54	52	65
	Maksimalna	84	81	86	84	86	83
	Srednja vrednost	75,3	70,5	68	69	67	76
	SD	6,27	7,06	12,93	9,76	10,95	7,41
Atmosferski pritisak (mbar)							
	Minimalna	965,7	965,8	967,4	949,5	966,6	964,1
	Maksimalna	978,5	981,5	976,7	980,4	975,1	972,5
	Srednja vrednost	971,9	972,7	971,6	971,1	971,0	969,4
	SD	3,3	4,6	2,7	7,6	3,8	3,46
Brzina vetra (m/s)							
	Minimalna	0,1	0,3	0,4	0,3	0,2	0,3
	Maksimalna	0,8	0,7	0,8	1,0	1,0	2,2
	Srednja vrednost	0,45	0,45	0,55	0,6	0,5	0,8
	SD	0,25	0,13	0,17	0,19	0,28	0,80
Maksimalni udar vetra (m/s)							
	Minimalna	4,4	8,2	11,3	10,3	7,8	5,3
	Maksimalna	17	17,0	18,4	19,6	19,4	16,8
	Srednja vrednost	12,6	13,6	14,0	16,5	13,9	12,2
	SD	3,8	3,1	2,4	2,8	3,5	4,73

SD – standardna devijacija

IZVORI ZAGAĐENJA

Primarni izvori zagađenja u Boru su rudarstvo i metalurgija. Zagađenje potiče iz procesa proizvodnje i prerade rude bakra, a izvor zagađenja su i raskrivke sa površinskog kopa i flotacijska jalovišta.

Sekundarni izvor zagađenja predstavlja čađ koja nataje sagorevanjem fosilnih goriva. Jedna količina čađi u vazduhu potiče od saobraćaja i emisija je prisutna tokom cele godine, dok je druga količina čađi je karakterističana za zimsku (grejnu) sezonu i potiče iz centralne gradske toplane, koja kao gorivo koristi ugalj.

MERNA MESTA

Raspored mernih mesta zavisi od tipa naselja, meteroloskih i topografskih faktora područja, položaja industrijskih objekata, rasporeda glavnih saobraćajnica, kao i od karaktera i količine emitovanih gasova. Monitoring kvaliteta vazduha na području opštine Bor obavlja se na sledećim mernim mestima:

1. Gradski park: merno mesto je udaljeno 800 m u pravcu WSW od Rudarsko-topioničkog basena Bor kao dominantnog izvora zagađenja. Nalazi se u urbanoj zoni grada (MZ Stari centar). Merno mesto smešteno je u starom delu grada u kome se nalaze glavni poslovni, trgovinski i administrativni objekti grada.

2. Institut za rudarstvo i metalurgiju Bor: merno mesto je udaljeno 1.900 m u pravcu SSW u urbanoj zoni grada. Merno mesto nalazi se u najgušće naseljenom delu grada. U blizini mernog mesta nalazi se nekoliko škola, prometne saobraćajnice i sportsko-rekreacioni centar.

3. Jugopetrol: merno mesto je udaljeno u pravcu SSE, 2.500 m od izvora zagađenja. U oblast oko ovog mernog mesta živi najmanji broj stanovnika. Nalazi se u zoni predgrađa koja je ujedno i industrijska zona. Oblast je značajna po tome što se nalazi na udaru vetrova sa najvećom učestalošću.

4. Brezonik: merno mesto je udaljeno 2.000 m u pravcu NNW u zoni predgrađa. [10]

ZAGAĐENJE VAZDUHA

Pojam zagađenja vazduha predstavlja određeni sadržaj štetnih supstanci u vazduhu. Od količine i vrste tih supstanci zavisi šteta koju mogu naneti zdravlju ljudi i životinja, kao i biljkama i materijalima. Zagađujuće materije mogu biti u čvrstom, tečnom ili gasovitom stanju. Čvrsta čestica je pojam koji se koristi za opisivanje čestica koje su suspendovane u vazduhu.

Suspendovane čestice predstavljaju zagađujuće materije koje se razlikuju po veličini, masi, površini, hemijskom sastavu, mehanizmu formiranja i poreklu. Njihova koncentracija u vazduhu je funkcija izvora emitovanja, reakcija u atmosferi i meteoroloških uslova. Suspendovane čestice predstavljaju mešavinu veoma finih čvrstih čestica i kapi tečnosti koje se sastoje od brojnih komponenata, uključujući kiseline (nitrate i sulfate), organske materije, metale, nemetale, čađ, čestice zemlje i prašine. [11]

Prema veličini čvrste čestica mogu se podeliti na: **grube čestice** (2,5-10 μm) koje nastaju mehanički resuspenzijom prašine, erozijom i obradom zemljišta, ili formiranjem iz industrijskih procesa, kao što su proizvodnja cementa, betona, keramike i rudarstvo. Karakteristični elementi koji se koncentrišu u ovoj frakciji su Al, Si, Ca, Fe i Na; **fine čestice** (<2,5 μm) koje potiču od antropogenih aktivnosti, kao što su: sagorevanje, različiti industrijski procesi, saobraćaj. Čestice prečnika <1 μm nastaju kondenzacijom metala ili organskih materija iz procesa sagorevanja; i **ultrafine čestice** (0,01 – 0,1 μm) u atmosferi se nalaze u obliku aerosola. Ultrafine čestice najčešće potiču od sagorevanja dizel goriva, benzina i drugih organskih goriva, sastoje se od čestica ugljenične čađi i pomešane su sa organskim jedinjenjima.

Čestice koje imaju prečnik veći od 50 μm u vazduhu ostaju nekoliko minuta i talože se blizu izvora zagađenja. Manje čestice PM_{10} mogu ostati u vazduhu nekoliko dana i pod uticajem vetra mogu se rasejati na velikom području oko glavnog izvora zagađenja. Fine čestice veličine od 0,1 do 2,5 μm ostaju u atmosferi beskonačno, pri čemu sprečavaju prolaz sunčeve svetlosti i smanjuju vidljivost. One se uglavnom iz vazduha uklanjaju kišom ili sudarom sa drugim česticama. [12]

Prema poreklu suspendovane čestice mogu se podeliti na: **primarne** čestice koje se emituju direktno iz izvora zagađenja (npr. gradilišta, neasfaltirani putevi, dimnjaci, požari, itd.) i **sekundarne** čestice koje nastaju složenim mehanizmima u atmosferi nakon emitovanja iz izvora zagađenja (npr. čestice emitovane iz elektrana, industrije ili izduvni gasovi iz saobraćaja).

ČAĐ

Čađ nastaje sagorevanjem fosilnih goriva. To su fine, male čestice veličine oko

5 µm, koje lebde u vazduhu i ponašaju se kao gas. Sadrže toksične i kancerogene materije, lako prodiru u disajne puteve i oštećuju ih.

Čađ u suspendovanim česticama predstavlja veliku opasnost po zdravlje ljudi. Izloženost pojedinim štetnim materijama može dovesti do genetskih promena, smanjenja imunološke sposobnosti organizma, a najčešće dolazi do pogoršanja postojećih bolesti, kao što su astma i hronična opstruktivna bolest pluća. Pojedine bakterije i otrovni gasovi imaju sposobnost da se povežu sa česticama čađi, što dodatno pojačava njihov štetni uticaj na zdravlje. [13]

GODIŠNJI NIVO KONCENTRACIJE ČAĐI U BORSKOJ OPŠTINI

U tabeli 2. prikazane su srednje godišnje koncentracije čađi na mernim mestima u urbanoj zoni Bor u periodu od 2005. do 2011. godine. Na mernim mestima Gradski park i Jugopetrol 2005. i 2006. godine nisu vršena merenja, kao na mernom mestu Brezonik 2008. godine. U predgrađu ne vrši se merenje koncentracija čađi. U urbanoj zoni merenja se vrše na četiri merna mesta. Najveći broj merenja, u toku petogodišnjeg perioda, izvršen je na mernom mestu Institut, a zatim na mernim mestima Jugopetrol, Brezonik i Gradski park.

Tabela 2. *Koncentracija čađi na mernim mestima u opštini Bor u periodu od 2005. do 2011. godine*

Merno mesto	Koncentracija čađi							Ukupan broj uzoraka (N)	Srednja vrednost
	2005	2006	2007	2008	2009	2010	2011		
Brezonik	7	5	6	/	19,41	9	13,8	949	10,03
Gradski park	/	/	4	7	10,93	7	10,2	883	7,83
Institut	7	8	7	15	12	8,4	9,4	988	9,54
Jugopetrol	/	/	6	11	11,05	5	6,7	957	7,95

** sve koncentracije izražene u µg/m³*

U urbanoj sredini najzagađenjije je područje Brezonika (m. mesto Brezonik), dok je na drugim područjima nivo zagađenja približno isti i ispod granice od 15 µg/m^3. Ukupan broj uzoraka koji su korišćeni u statističkoj analizi prikazan je u tabeli 2.

EKSPERIMENALNI DEO

ANALIZA UZORAKA

Refrektometar je aparat koji služi za određivanje sadržaja čađi u atmosferskom vazduhu refrektometrijskom metodom. Sadržaj čađi u uzorku vazduha dobija se određivanjem refleksije crne mrlje na belom filter papiru i upoređivanjem sa internacionalnom standardnom krivom. Metoda po kojoj je određivana količina čađi u vazduhu je: Određivanje indeksa crnog dima; opseg 6.2-372.1 SRPS ISO 9835:1993.

Merenja u okviru kontrole kvaliteta vazuha vrše se u 24-časovnom kontinuitetu, 7 dana u mesecu na određenom mernom mestu, nakon čega se mobilna merna stanica prenosi na drugo merno mesto.

DESKRIPTIVNA STATISTIČKA ANALIZA

Deskriptivna statistička analiza predstavlja skup metoda kojima se vrši izračunavanje, prikazivanje i opisivanje osnovnih karakteristika statističkih serija. Ona obuhvata sledeće radnje:

1. grupisanje i sređivanje statističkih podataka,
2. prikazivanje statističkih podataka i izračunavanje, i
3. određivanje osnovnih mera statističkih serija.

Grupisanje podataka se vrši prema vrednostima ili modalitetima posmatranih obeležja. Kao krajnji rezultat grupisanja javlja se statistička serija, koja predstavlja uređeni skup varijacija obeležja posmatrane statističke mase.

U cilju pronalaženja područja sa sličnim nivoima zagađenja u borskoj opštini prikupljeni podaci u radu su obrađeni multivarijacionim statističkim metodama: regresionom i korelacionom analizom, jednofaktorskom analizom varijanse (ANOVA). Podaci koji predstavljaju koncentracije čađi i meteorološki podaci obrađeni su u statističkom programu SPSS ststistics version 17.0 [14, 15, 16].

MULTIVARIJACIONA ANALIZA

Regresiona, korelaciona i analiza varijanse

Regresiona analiza je vid multivarijacione analize koji opisuje oblik veze između dve ili više promenljivih. Prost regresioni model obuhvata samo dve promenljive: jednu nezavisnu i jednu zavisnu. Zavisna promenljiva je promenljiva čije varijacije treba da objasnimo na osnovu kretanja objašnjavajuće promenljive. Regresioni model opisuje linearnu međuzavisnost između dve promenljive naziva se linearni regresioni model. [17]

Korelaciona analiza je drugi vid multivarijacione analize i upotrebljava se za opisivanje jačine, tj. stepena slaganja varijacija i smera veze između dve promenljive. Povezanost promenljivih opisuje p-vrednost (engl. significance value) i koeficijent korelacije, koje možemo dobiti jednofaktorskom analizom varijanse (engl. one-way ANOVA). Analiza varijanse poredi promenljivost rezultata (varijansu) između raznih grupa sa promenljivoću unutar svake grupe.

- Pokazatelj (količnik) F predstavlja varijansu između grupa podeljenu varijansom unutar grupa, što je veća vrednost količnika F to je veća promenljivost između grupa.
- Količnik t (ili t-test) predstavlja odnos razlike između dve srednje vrednosti grupe podeljenu sa varijabilitetom grupe, što je veća t-vrednost rezultati su značajniji.
- p-vrednost ne pokazuje jačinu veze, već sa koliko poverenja treba posmatrati dobijene rezultate. Na značajnost rezultata analize utiče veličina uzorka. Za male uzorke podataka (N = 30), mogu se izračunati umerene korelacije. Uobičajeni nivo značajnosti je $p< 0,05$.
- Koeficijent korelacije (R) je pokazatelj stepena kvantitativnog slaganja između promenljivih i kreće se u opsegu od $-1 \leq R \leq 1$. Za R = 0 nema korelacije između promenjivih.
- Koeficijent determinacije (R^2) predstavlja statistički kriterijum na osnovu kojeg se dobija odgovor na pitanje da li izabrana promenljiva dobro objašnjava varijacije zavisne promenljive u prostom linearnom modelu. [17] Parametar R^2 pokazuje koliki je deo varijacija zavisne promenljive objašnjen regresionim modelom. Kreće se u opsegu od $0 \leq R^2 \leq 1$.

UTICAJ METEOROLOŠKIH PARAMETARA NA KONCENTRACIJU ČAĐI

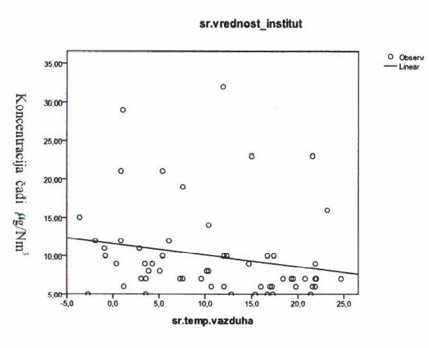
Dijagram rasturanja je grafički prikaz parova promenljivih koji nam govori o prirodi, jačini i smeru saganja između dve promenljive. [17]

Tabelom 3. i na slici 1, 2, 3 i 4 prikazani su rezultati regresione analize na mesečnom nivou za podatke sa automatske merne stanice postavljene od strane Agencije za zaštitu životne sredne (SEPA) na mernom mestu Institut za rudarstvo i metalurgiju. Merenja su sprovedena u periodu od početka 2005. do kraja 2010. godine.

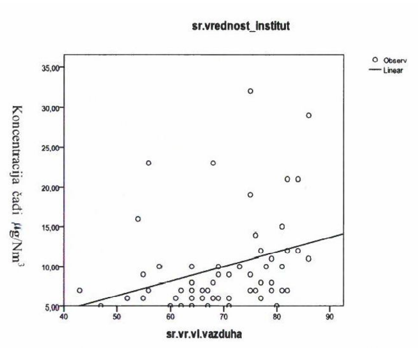
U tabeli 3. prikazani su rezultati analize varijanse za koncentracije čađi (μg/m^3) temperature (°C), vlažnosti vazduha (%), atmosferskog pritiska (mbar) i brzine vetra (m/s), u periodu od 2005. do 2010. godine na mernom mestu Institut za rudarstvo i metalurgiju. Podaci sa mernog mesta Institut izabrani su za analizu, jer se meteorološka stanica u opštini Bor nalazi jedino na ovom mernom mestu.

Tabela 3. *Korelacije između koncentracije čađi i meteoroloških parametara u periodu od 2005. do 2010. godine na mernom mestu IRM Bor (ANOVA)*

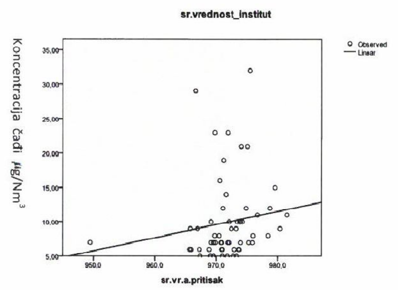
Korelacija	R	R^2	F	*p*-vrednost	*t*
Čađ -Temperatura vazduha	0.205	0.042	2.491	0.120	-1,578
Čađ - Vlažnost vazduha	0.313	0.098	6.178	0.016	2,486
Čađ - Atmosferski pritisak	0.148	0.022	1.283	0.262	1,132
Čađ - Brzina vetra	0.142	0.020	1.181	0.282	-1,087



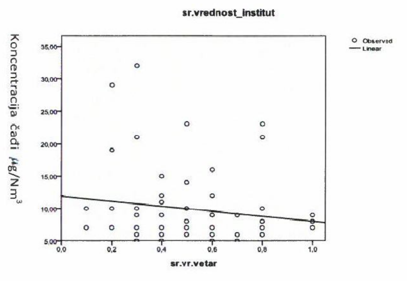
Sl. 1. *Korelacije između koncentracije čađi i srednje temperature vazduha od 2005. do 2010. godine na mernom mestu IRM Bor*



Sl. 2. *Korelacije između koncentracije čađi i srednje vrednosti vl. vazduha od 2005. do 2010. godine na mernom mestu IRM Bor*



Sl. 3. *Korelacije između koncentracije čađi i srednje vrednosti atmosferskog pritiska od 2005. do 2010. god. na mernom mestu IRM Bor*



Sl. 4. *Korelacije između koncentracije čađi i srednje vrednosti jačine vetra od 2005. do 2010. godine na mernom mestu IRM Bor*

Na osnovu rezultata regresione analize možemo zaključiti sledeće:

- Postoji pozitivna linearna koleracija srednje jačine (R=0,205) između koncetracije čađi i temperature vazduha. Međutim, samo 4,2% varijacija je objašnjeno regresionom analizom, što pokazuje da pored temperature postoji još mnogo faktora koji utiču na visinu koncentracije čađi, iako je nivo značajnosti p = 0,120. Uobičajeni nivo značajnosti je p<0,05.

- Postoji pozitivna linearna koleracija srednje jačine (R=0,313) između koncentracije čađi i vlažnosti vazduha. Međutim, samo 9,8% varijacija je objašnjeno regresionom analizom, što pokazuje da pored vlažnosti vazduha postoji još mnogo faktora koji utiču na visinu koncentracije čađi, iako je nivo značajnosti p=0,016. Uobičajeni nivo značajnosti je p<0,05.
- Postoji pozitivna linearna koleracija male jačine (R=0,148) između koncentracije čađi i atmosferskog pritiska vazduha. Samo 2,2% varijacija je objašnjeno regresionom analizom, što pokazuje da pored atmosferskog pritiska vazduha postoji još mnogo faktora koji utiču na visinu koncentracije čađi, iako je nivo značajnosti p = 0,262. Uobičajeni nivo značajnosti je p<0,05.
- Postoji pozitivna linearna koleracija male jačine (R = 0,142) između koncentracije čađi i brzine vetra. Ali, samo 2,0% varijacija je objašnjeno regresionom analizom, što pokazuje da pored brzine vetra postoji još mnogo faktora koji utiču na visinu koncentracije čađi, iako je nivo značajnosti p=0,282. Uobičajeni nivo značajnosti je p<0,05.

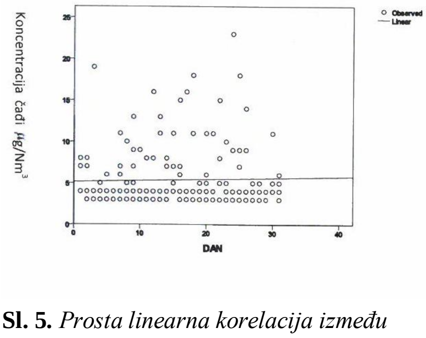
Uticaj meteoroloških parametara: temperature (°C), vlažnosti vazduha (%), atmosferskog pritiska (mbar) i brzine vetra (m/s) na koncentraciju čađi, pokazale su slabu korelaciju i nedovoljan nivo značajnosti za rezultate analize.

UTICAJ GREJNE SEZONE NA KONCENTRACIJU ČAĐI

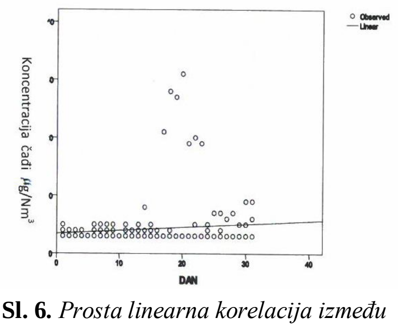
U tabeli 4. i na slici 5. i 6. prikazani su rezultati analize varijanse za koncentracije čađi ($\mu g/m^3$) u periodima od oktobra 2009. do marta 2010. godine i u periodu od aprila do septembra 2010. godine na mernom mestu Institut za rudarstvo i metalurgiju Bor. Ovi periodi su korisćeni za analizu, jer za 2009. i 2010. godinu postoje najviše podataka o koncetraciju čađi.

Tabela 4. *Korelacije između koncentracije čađi i grejne sezone*

Korelacija	R	R^2	F	*p*-vrednost	*t*
Čađ– sezona grejanja	0,038	0,001	0,258	0,001	3,48
Čađ – sezona bez grejanja	0,117	0,014	2,505	0,115	1,583



Sl. 5. *Prosta linearna korelacija između koncentracije čađi i zimskog perioda grejanja u periodu od oktobra 2009. do marta 2010. godine na mernom mestu IRM Bor*



Sl. 6. *Prosta linearna korelacija između koncentracije čađi i letnjeg perioda bez grejanja u periodu od aprila do septembra 2010. godine na mernom mestu IRM Bor*

Na osnovu rezultata regresione analize možemo zaključiti sledeće:

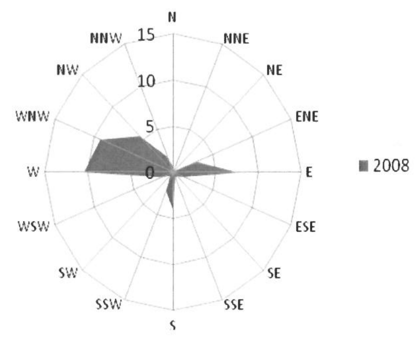
- Postoji pozitivna linearna koleracija veoma male jačine (R = 0,038) između koncetracije čađi i sezone grejanja tj. upotrebe fosilnih goriva za rad Toplane u Boru. Samo 1% varijacija je objašnjeno regresionom analizom, što pokazuje da mnogo drugih faktora utiču na visinu koncentracije čađi, iako je nivo značajnosti p = 0,001. Uobičajeni nivo značajnosti je p<0,05.
- Postoji pozitivna linearna koleracija male jačine (R=0,117) između koncentracije čađi i perioda kada se ne upotrebljavaju fosilna goriva za grejanje stanova i kuća. Međutim, 14% varijacija je objašnjeno regresionom analizom, što pokazuje da mnogo drugih faktora koji utiču na visinu koncentracije čađi, nivo je značajnosti p=0,115. Uobičajeni nivo značajnosti je p<0,05.

Merno mesto Institut je udaljeno 1.900 m u pravcu SSW od izvora zagađenja, i nije u pravcu dominantnih zimskih vetrova, ali u njegovoj blizini je veoma prometna saobraćajnica, tako da to objašnjava veću korelaciju u letnjem period nego u zimskom kada je broj automobila smanjen.

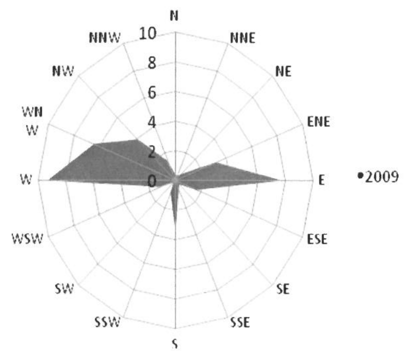
UTICAJ PRAVCA VETRA NA NIVO KONCENTRACIJE ČAĐI U VAZDUHU

Analiza dominantnog pravca vetra koristi se za procenu uticaja izvora zagađenja na visinu imisije zagađujućih materija u određenim područjima. Za ovu analizu podaci o dominantnom pravcu vetra grafički se prikazuju u obliku polarnog dijagrama - ruže vetrova [18], a podaci o zagađenju u vidu ruže zagađenja [19, 20]

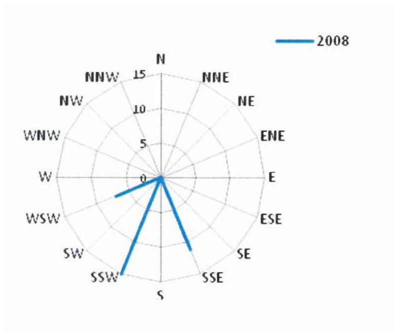
Na slikama 7 do 10, prikazane su ruže zagađenja čađi ($\mu g/m^3$) i ruže vetrova (%) za posmatrani period u borskoj opštini. Dominantni pravci vetrova bili su zapadnog (NW, WNW, W), istočnog (ENE, E, ESE), a u najmanje je bilo vetra iz južnog pravca (S, SSW). Pravac vetra se pokazao da je jedan od najvažnih faktora koji utiču na disperziju zagađujućih materija od izvora zagađenja.



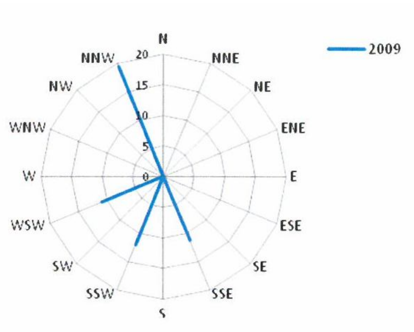
Sl. 7. *Ruža vetrova (%) za 2008. god.*



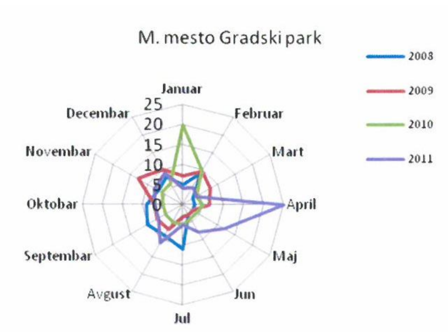
Sl. 8. *Ruža vetrova (%) za 2009. god.*



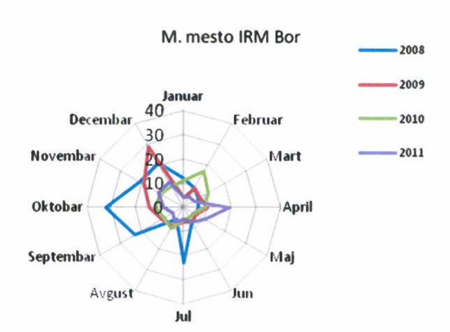
Sl. 9. *Ruža zagađenja čađi (μg/m^3) u toku 2008. god.*



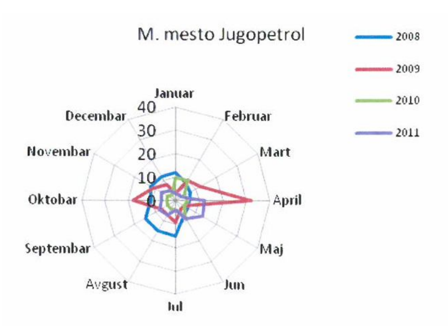
Sl. 10. *Ruža zagađenja čađi (μg/m^3) u toku 2009. god.*



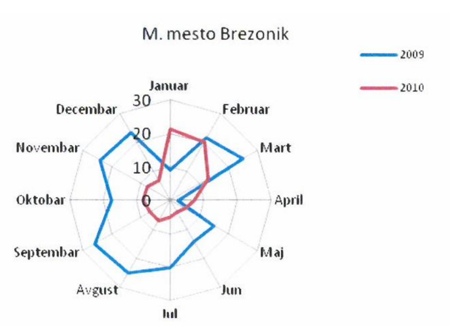
Sl. 11. *Koncentracija čađi po mesecima za 2008. i 2011. godine na mernom mestu Gradski park*



Sl. 12. *Koncentracija čađi po mesecima od 2008. do 2011. godine na mernom mestu IRM Bor*



Sl. 13. *Koncentracija čađi po mesecima za 2008. i 2011. godine na mernom mestu Jugopetrol*



Sl. 14. *Koncentracija čađi po mesecima za 2009. i 2010. godine na mernom mestu Brezonik*

Na slikama 11 do 14 prikazane su srednje mesečne koncentracije čađi na mernim mestima u Boru u vidu polarnog dijagrama. Na osnovu ovih dijagrama može se zaključiti da su koncentracije čađi retko prelazile maksimalno dozvoljenu koncentra-ciju od 15 µg/m^3.

Na mernom mestu Institut u periodu od 2008. do 2011. godine, samo u toku 2008. godine bilo je povećane koncentracije čađi iznad maksimalne dozvoljene granice, i to od meseca jula do decembra. Sredinom jula 2008. godine izbio je požar na području aerodroma koji je oko pet kilometara od Bora, kao i šumski požar na Crnom vrhu, pa je to verovatno uzrok povećanoj koncentraciji čađi u tom periodu.

Na mernom mestu Brezonik u 2009. godini koncenracije čađi bile su povećane u februaru i martu, kao i u periodu od jula do decembra 2009. godine, zbog nedostatka podatka ostale godine nisu analizirane. Promena meteroloških uslova, promena pravca vetrova (slika 8) i nagli pad atmosferskog pritiska je prouzrokovao povećane koncentracije čađi u naselju Brezonik.

ZAKLJUČAK

U cilju pronalaženja područja sa sličnim nivoima zagađenja u borskoj opštini prikupljeni podaci o konentraciji čađi obrađeni su multivarijacionim statističkim metodama: regresiona, korelaciona i analiza varijanse.

Jednofaktorska analiza varijanse i regresiona analiza pokazali su da na mesečnom nivou na mernom mestu Institut za rudarstvo i metalurgiju Bor:

- Postoji pozitivna linearna koleracija srednje jačine od R=0,142 do R=0,313 između koncetracije čađi i metroloških parametara. Međutim, veoma mali procenat varijacija je objašnjeno regresionom analizom najviše 9,8%, što pokazuje da pored metroloških parametara postoji još mnogo faktora koji utiču na visinu koncentracije čađi. Nivo značajnosti p je u granicama između 0,016 i 0,282. Uobičajeni nivo značajnosti je p<0,05. Na osnovu ovoga može se zaključiti da ne postoji statistički značajna korelacija između čestica čađi i ostalih meteoroloških prametara: vlažnosti vazduha, atmosferskog pritiska, brzine vetra i količine padavina.
- Uticaj grejne sezone tj. upotreba fosilnih goriva za grejanje domaćinstva na koncentraciju čađi u vazduhu pokazao je da postoji pozitivna linearna koleracija veoma male jačine (R=0,038). Samo 1% varijacija je objašnjeno regresionom analizom, što pokazuje da mnogo drugih faktora utiču na visinu koncentracije čađi, iako je nivo značajnosti p = 0,001. Uobičajeni nivo značajnosti je p<0,05. Koncentracija čađi zavisi od smera dominstnih vetrova.
- Postoji pozitivna linearna koleracija male jačine (R = 0,117) između koncentracije čađi i perioda kada se ne uptrebljavaju fosilna goriva za grejanje stanova i kuća. Međutim, 14% varijacija je objašnjeno regresionom analizom, što pokazuje da mnogo drugih faktora koji utiču na visinu koncentracije čađi, nivo je značajnosti p=0,115. Uobičajeni nivo značajnosti je p<0,05. U letnjem period na ovom mernom mestu je povećana koncen-tracija čađi zbog povećanog broja vozila kao i vetrova koji duvaju u tom period koji su W i WNW.
- Na osnovu dobijenih statističkih podataka, možemo zaključiti da, nepostoji jedinstveni izvor suspendovanih čestica čađi, na čiju koncentraciju od meteoroloških parametara najviše ima vlažnost vazduha. Regresionim modelom objašnjeno manje od 10% varijacija koncentracije čađi, što znači da ostalih 90% varijacije nismo uspeli da identifikujemo.

Jednofaktorska analiza varijanse i regresiona analiza pokazali su da na godišnjem nivou (od 2005. do 2011. godine) na mernom mestu Institut za rudarstvo i metalurgiju Bor:

- ne postoji statistički značajna korelacija između koncentracije čađi i metroloških parametara,
- ne postoji statistički značajna korelacija između koncentracije čađi i upotrebe fosilnih goriva za zagrevanje.

Na osnovu statističkih pokazatelja, možemo zaključiti da meteorološki parametri ne utiču na visinu imisije čađi u suspendovanim česticama (PM). Međutim, mali broj merenja imisije tokom mogu biti glavni razlozi nepostojanja korelacija.

Na osnovu šestogodišnjeg proseka koncentracije čađi na mernim mestima u urbanoj zoni, zaključujemo da su srednje vrednosi koncentracije čađi oko mernih mesta Brezonik, Jugopetrol, Institut i Gradski park ispod maksimalne dozvoljene granice od 15 $\mu g/m^3$ i iznose od 7,83 do 10,03 $\mu g/m^3$. Na mernom mestu Brezonik u 2009. godini srednji godišnji prosek bio iznad maksimalno dozvoljene granice i iznosio je 19,41 $\mu g/m^3$, kao i na mernom mestu Institut u 2008. godini srednji godišnji prosek je bio na maksimalno dozvoljenoj granici.

Međutim, kako broj uzoraka od 2005. do 2009. godine nije isti za sva merna mesta i kako se merenja obavljaju samo nedeljno, a emitovanje zagađujućih materija iz Rudarsko-topioničarskog kompleksa je skoro konstantno sa manjim prekidima i oscilacijama u proizvodnji, kao i u zimskom periodu kada je u radu Toplana određena merna mesta možda imaju niži prosek nego što inače jeste, dok se druga mesta javljaju kao zagađena na osnovu manjeg broja merenja imisije.

U Borskoj opštini dominantni su vetrovi zapadnog i severozapadnog pravca (NW, WNW, W), dok manju učestalost beleže vetrovi istočnog pravca (ENE, E, ESE), a u najmanju učestalost imaju vetrovi južnog pravca (S, SSW) što je prikazano na polarnim dijagramima ruže vetrova za 2008. i 2009. godinu. Na osnovu polarnog dijagrama ruže zagađenja čađi u 2008. godini možemo da zaključimo da najviši nivo zagađenja postoji na mernim mestima Institut i Jugopetrol, kao i u MZ Sloga i naselje Metalurg. U 2009. godini najviši nivo zagađenja je zabeležen na mernom mestu Brezonik, na mernim mestima Institut i Jugopetrol, u naselju Metalurg i MZ Sloga koja su u pravcu dominantnih vetrova ili koja se nalaze u neposrednoj blizini izvora zagađenja srednje godišnje vrednosti koncentracije čađi su u granicama normalnih vrednosti. U naselju Metalurg, Brezonik i MZ Sloga povećana koncentracija čađi verovatno potiče i od upotrebe fosilnih goriva za zagrevanje domova.

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THE EFFECT OF GRINDING FINENESS ON THE RESULTS OF FLOTATION CONCENTRATION OF ORE FROM THE COPPER DEPOSIT VELIKI KRIVELJ***

Abstract

One of the influential parameters on the process of flotation concentration is a coarseness of particles and openness of mineral resources. In the process of flotation concentration of ore from the deposit Veliki Krivelj, the grinding fineness since the opening of the mine in 1982 has been maintained at values around 58% -0.074 mm. Since then, the operation descended into the deeper parts of deposit, the copper content decreased in the ore and it was assumed that the optimal fineness of ore grinding was changed. This paper presents the results of testing the fineness of grin-ding on recovery and copper content of the basic copper concentrate and the impact of regrinding on recovery and copper content in the purified copper concentrate on a sample of ore from the deposits Veliki Krivelj. The laboratory experiments flotation concentration were carried out, the balances of concentration were made and it is concluded that finer grinding is necessary for better concentration. The optimal regrinding degree of basic concentrate was also determined.

Keywords: *flotation, optimal grinding fineness, copper ore*

INTRODUCTION

The Copper Mine Veliki Krivelj was put into operation in 1982 (Mitrovic Z., Jovanovic R., 2007). The copper deposit Veliki Krivelj belongs to the porphyry deposits of large scale. It is estimated that the balance reserves of copper ore in this deposit are in cut-off grade of 0.15% Cu, categories B+C1 474,291,085 t with 1,533,821 t of copper (Bugarin M., Maksimović M., Ljubojev V., 2012).

Flotation concentration is a process of separation that takes place due to differences in physical and chemical properties of mineral surfaces (Barry WA, Napier-Munn, T., 2006). It is mainly used for concentration of metallic ores, cleaning of solid fuel or enrichment of non-metallic minerals, but it can be also applied for separation of solids from liquids or non-mineral particles from each other). Grains of various sizes are not just flotablen even though they have the same composition of mineral surface (Gaudin A. M., 1957). Grinding has a significant impact on technological results (Bulatović S. M., 2007).

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Optimal grinding fineness of the ore from the Veliki Krivelj deposit was determined in the stage of laboratory testing that preceded the design of site and opening of the mine. Today, 30 years since the opening of the mine, the grinding fineness in the site is maintained as at the beginning of industrial processing at the level of about 58% -0.074 mm. Some of the technological parameters have been retained to this day, although the exploitation went down into the deeper parts of the ore body, and the copper content is reduced in the ore. It is supposed that some other features essential to the process flotation concentration primarily were changed, primarily the grindability and optimum grinding fineness.

The authors of the paper have considered that it is important to determine the effect of grinding fineness on technological results in the basic flotation, and also the effect of regrinding the primary concentrate on technological results in the purification the basic concentrate on a sample of ore from the deposit Krivelj, which is currently being processed. In the Flotation Plant Veliki Krivelj, regrinding of basic copper concentrate goes to a fineness of 85 - 90% -0.074 mm. Regrinding of the basic copper concentrate is also an important technological process that can contribute to increasing the recovery and copper content in the purified concentrates. Taking into account the estimated reserves of this deposit and the trend of copper value on the world market, any increase in technological results would be significant.

A sample of ore from Veliki Krivelj for testing was taken from production, from a line in front of the rod mill in the Flotation Plant Veliki Krivelj in November 2012.

EXPERIMENTAL PART

Characterization of sample

In the Laboratory for mineral processing of the Mining and Metallurgy Institute, a sample is marked VK (Veliki Krivelj), shortened and ground to a size -3.35 mm. Samples were excluded for chemical analysis and experiments of flotation concentration. Chemical analysis of the sample VK was carried out on three independent samples on copper and sulfur. Table 1 shows the results of chemical analysis. Table 2 presents some characteristic sizes for the sample VK.

Table 1 *Chemical analysis of the sample VK*

First sample		Second sample		Third sample	
Chemical element	**Content**	**Chemical element**	**Content**	**Chemical element**	**Content**
Cu	0.18%	**Cu**	0.24%	**Cu**	0.22%
S	3.47%	**S**	2.51%	**S**	3.04%

Table 2 *Characteristic sizes for the sample VK*

Density	2,820 kg/m^3
Natural pH	7.45

Grinding

An ellipsoidal ball mill with a capacity of 15.2 l with batch mass of balls at the start of testing of 13.34 kg was used for testing the grinding. For each grinding experiment, 820 g of sample was taken.

Grinding kinetics

For testing the grinding kinetics, the sample was ground with a solid content of 70%, for a period of 3, 5, 7 and 9 minutes. Grinding product is sieved on a series of sieves and the grain size analysis results are shown in Table 3.

Table 3 *Grain size distribution of grinding products for various grinding times*

Mesh size, mm	3 min			5 min			7 min			9 min		
	m%	D%	R%	m%	D%	R%	m%	D%	R%	m%	D%	R%
-0,600+0,425	2,0	100,0	2,0									
-0,425+0,300	6,4	98,0	8,4									
-0,300+0,212	10,0	91,6	18,4	3,4	100,0	3,4						
-0,212+0,150	11,4	81,6	29,8	7,6	96,6	11,0	4,8	100,0	4,80	2,6	100,0	2,6
-0,150+0,106	10,0	70,2	39,8	10,4	89,0	21,4	9,4	95,2	14,2	5,8	97,4	8,4
-0,106+0,075	6,8	60,2	46,6	10,6	78,6	32,0	11,2	85,8	25,4	10,6	91,6	19,0
-0,075+0,053	5,4	53,4	52,0	8,4	68,0	40,4	9,8	74,6	35,2	10,4	81,0	29,4
-0,053+0,038	6,0	48,0	58,0	7,0	59,6	47,4	8,6	64,8	43,8	10,0	70,6	39,4
-0,038+0	42,0	42,0	100,0	52,6	52,6	100,0	56,2	56,2	100,0	60,6	60,6	100,0

Figure 1 presents the grinding kinetics.

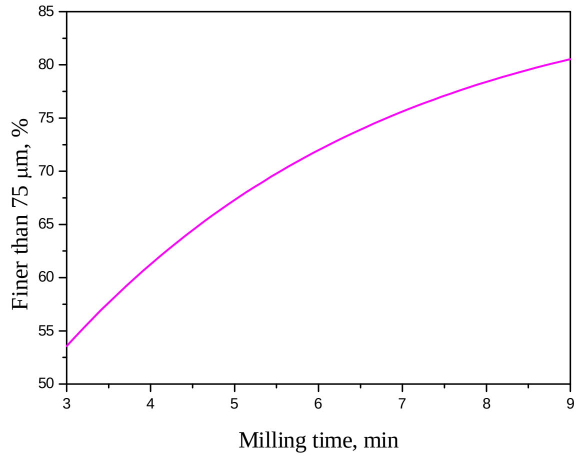

Figure 1 *Grinding kinetics*

Testing the effect of grinding fineness on the results of basic flotation

The effect on grinding fineness on the basic flotation results was tested by grinding, and then flotation in a Denver D-12 flotation machine, in a chamber volume 2.4 l with 820 g of sample. Concentration products were analyzed chemically, and then the concentration balance was calculated for each experiment.

A series of experiments was done that included the grinding fineness of 55-80% -0.075 mm. Experiments were carried out according to the scheme shown in Figure 2. The obtained results of concentration are shown in Table 4. Based on the results in Table 4, dependence of copper recovery and content in the concentrate was carried out on grinding fineness, and it is shown in Figure 3.

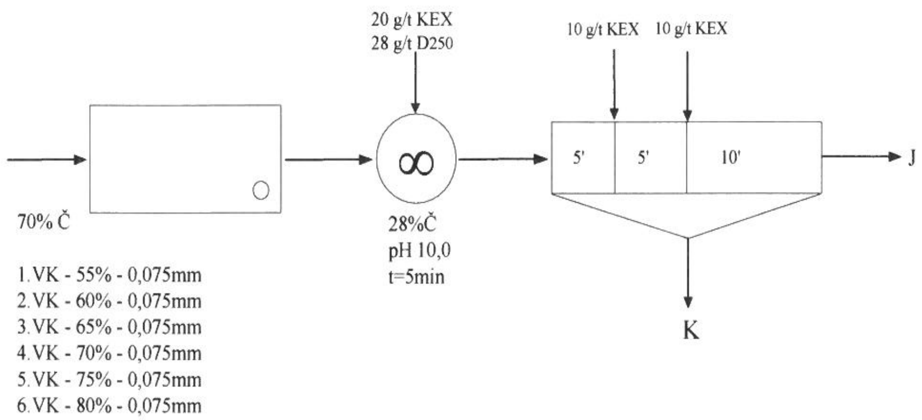

Figure 2 *Scheme of testing the effect of grinding fineness*

Table 4 *Results of the basic flotation of copper minerals*

PRODUCT	MASS m, %	CONTENT		DISTRIBUTION	
		Cu, %	S, %	Cu, %	S, %
Sample 1. VK 55% - 0,075 mm					
U	100,00	0,1843	3,5096	100,00	100,00
K	10,49	1,50	31,75	85,40	94,90
J	89,51	0,03	0,2	14,60	5,10
Sample 2. VK 60% - 0,075 mm					
U	100,00	0,2169	2,9674	100,00	100,00
K	10,93	1,74	25,52	87,69	94,00
J	89,07	0,03	0,2	12,31	6,00
Sample 3. VK 65% - 0,075 mm					
U	100,00	0,2154	3,1449	100,00	100,00
K	11,99	1,65	23,44	91,83	89,37
J	88,01	0,02	0,38	8,17	10,63

Sample 4. VK 70% - 0,075 mm					
U	100,00	0,2123	2,8124	100,00	100,00
K	11,72	1,66	22,49	91,66	93,72
J	88,28	0,02	0,2	8,34	6,28
Sample 5. VK 75% - 0,075 mm					
U	100,00	0,2175	3,1000	100,00	100,00
K	11,90	1,68	24,57	91,91	94,32
J	88,10	0,02	0,2	8,09	5,68
Sample 6. VK 80% - 0,075 mm					
U	100,00	0,2319	3,6072	100,00	100,00
K	12,61	1,70	27,22	92,45	95,15
J	87,39	0,02	0,2	7,55	4,85

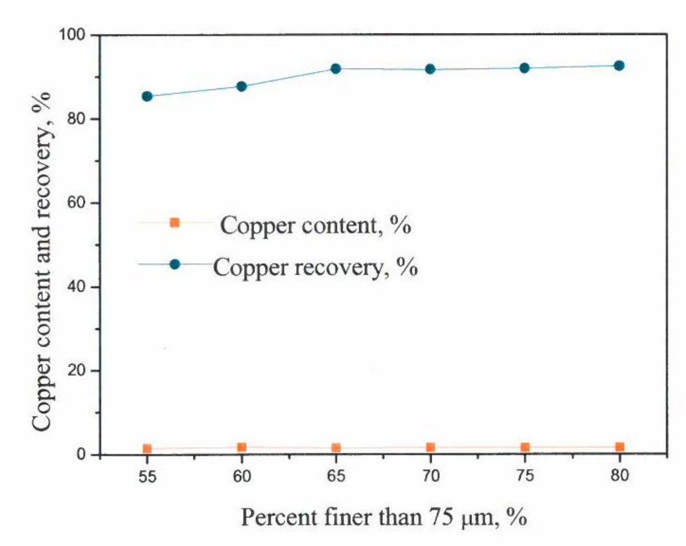

Figure 3 *Dependence of copper recovery and content in the basic concentrate on grinding fineness*

Regrinding

An elliptical ball mill, capacity 15.2 L, with a mass batch of balls of 3,755 kg at the beginning of testing, was used for testing of regrinding. For each experiment of regrinding, it was necessary to grind the four samples of 820 g mass. After that, the two basic flotation processes were carried out (where the mass of samples in each basic flotation was 1.640 g) in a Denver flotation machine D-12 in a chamber, volume of 4.6 l, under the same conditions, and them the basic regrinding concentrate was obtained in a ball mill at different time intervals. The regrinding product was once purified in a flotation machine Denver D-12 in the chamber of 2.4 l, and the concentration products were chemically analyzed, after which the concentration balance was calculated.

Testing the regrinding kinetics

A scheme, according to which the regrinding kinetics was tested, is shown in Figure 4. The results of grain size analysis of regrinding products are shown in Table 6, and regrinding kinetics in Figure 5.

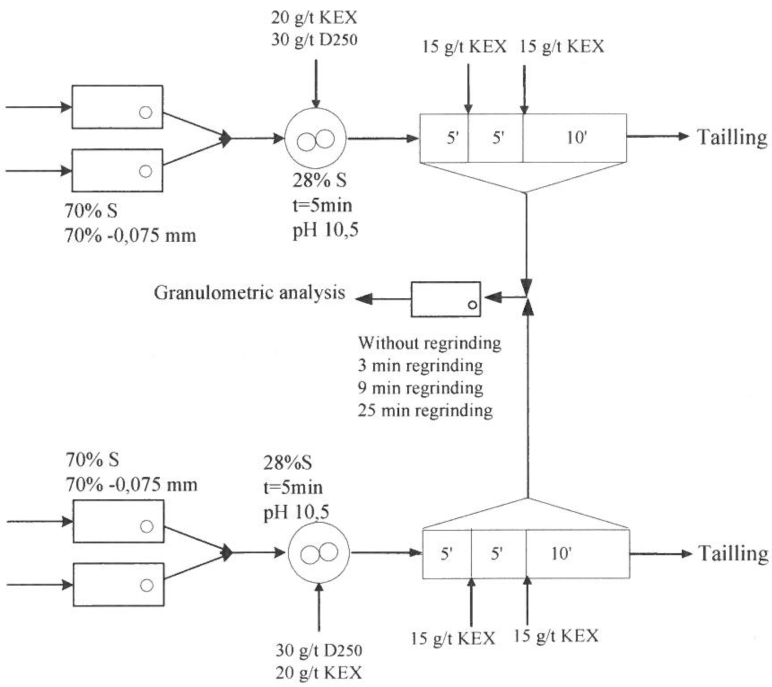

Figure 4 *Scheme of testing the regrinding kinetics*

Table 6 *Grain size distribution of regrinding products for various regrinding times*

Mesh size, mm	Without regrinding		3 min.		9 min.		25 min.	
	m %	D%	m %	D %	m %	D %	m %	D %
-0.300+0.212	2.00	100.00						
-0.212+0.150	6.67	98.00	2.57	100.00				
-0.150+0.106	11.89	91.33	7.38	97.43	3.32	100.00	0.86	100.00
-0.106+0.075	11.22	79.44	10.81	90.05	7.00	96.68	3.86	99.14
-0.075+0.053	8.22	68.22	9.81	79.24	9.84	89.68	6.72	95.28
-0.053+0.038	7.00	60.00	8.62	69.43	9.84	79.84	8.72	88.56
-0.038+0	53.00	53.00	60.81	60.81	70.00	70.00	79.84	79.84

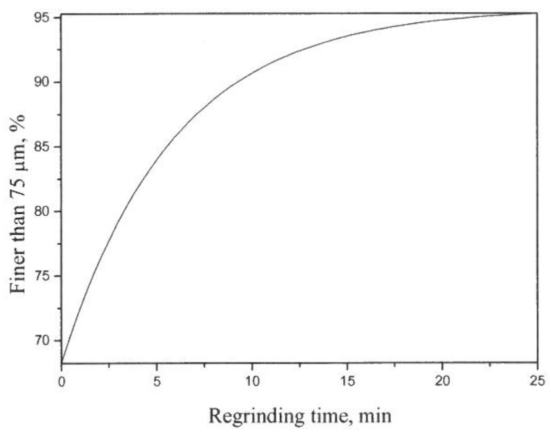

Figure 5 *Regrinding kinetics*

The effect of regrinding fineness on the results of flotation concentration

The effect of grinding fineness on the results of flotation concentration was tested in four experiments, and the scheme according to which the experiments were carried out is shown in Figure 6. The results of regrinding effect on purification the copper concentrate are shown in Table 7, and Figure 7 shows the dependence of copper recovery and content in the purified copper concentrate from regrinding fineness.

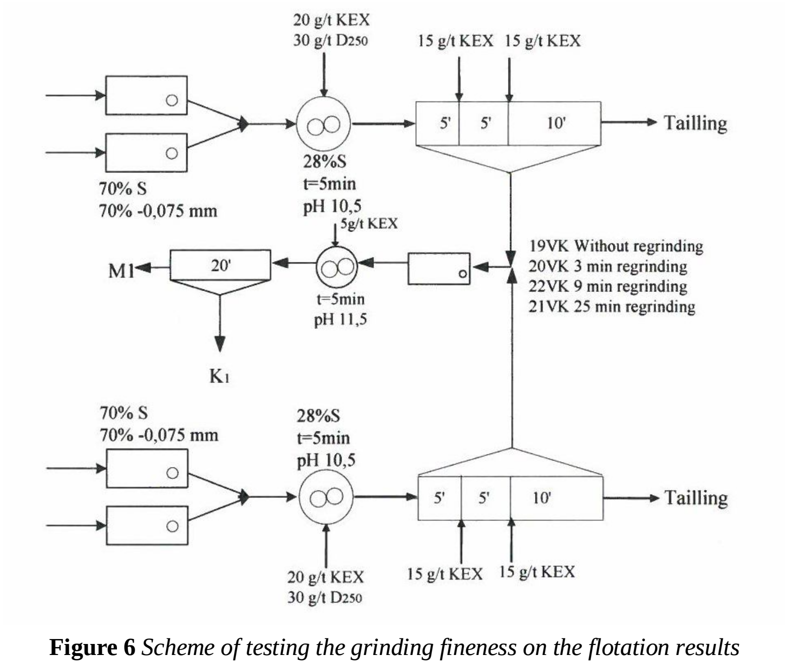

Figure 6 *Scheme of testing the grinding fineness on the flotation results*

Table 7 *The effect of regrinding fineness on the results of purification the copper concentrate*

PROD.	MASS m, %	CONTENT				DISTRIBUTION			
		Cu, %	S, %	Au, g/t	Ag, g/t	Cu, %	S, %	Au, g/t	Ag, g/t
Sample 19 VK - 68.22 % -0.075 mm; without regrinding									
U	100.00	0.1855	2.8081	0.073	0.80	100.00	100.00	100.00	100.00
J	90.36	0.010	0.27	0.016	0.713	4.85	8.69	19.25	80.58
Ko	9.64	1.83	26.60	0.612	1.612	95.15	91.31	80.75	19.42
M_1	7.49	0.14	26.89	0.5	1.50	5.66	71.71	51.30	14.04
K_1	2.15	7.72	25.60	1.0	2.00	89.49	19.60	29.45	5.38
Sample 20 VK - 79.24 % -0.075 mm; 3 minutes									
U	100.00	0.1864	3.1504	0.080	0.80	100.00	100.00	100.00	100.00
J	89.44	0.012	0.2	0.019	0.671	5.74	5.68	21.24	75.05
Ko	10.56	1.66	28.14	0.597	1.89	94.26	94.32	78.86	24.95
M_1	8.55	0.06	28.99	0.384	1.70	2.74	78.68	41.07	18.17
K_1	2.01	8.49	24.52	1.50	2.70	91.52	15.65	37.69	6.78
Sample 22 VK - 89.68 % -0.075 mm; 9 minutes									
U	100.00	0.1988	3.0517	0.073	0.80	100.00	100.00	100.00	100.00
J	90.69	0.012	0.36	0.020	0.68	5.48	10.70	24.85	77.09
Ko	9.31	2.02	29.27	0.589	1.969	94.52	89.30	75.15	22.91
M_1	7.78	0.14	29.89	0.414	1.80	5.48	76.20	44.16	17.50
K_1	1.53	11.57	26.13	1.478	2.828	89.03	13.10	30.99	5.41
Sample 21 - 95.28 % -0.075 mm; 25 minutes									
U	100.00	0.1980	2.8367	0.073	0.80	100.00	100.00	100.00	100.00
J	90.35	0.012	0.2	0.017	0.706	5.45	6.37	21.04	79.73
Ko	9.65	1.94	27.52	0.597	1.681	94.55	93.63	78.96	20.27
M_1	8.31	0.15	27.92	0.403	1.50	6.31	81.79	45.92	15.58
K_1	1.34	13.04	25.06	1.80	2.80	88.23	11.84	33.04	4.69

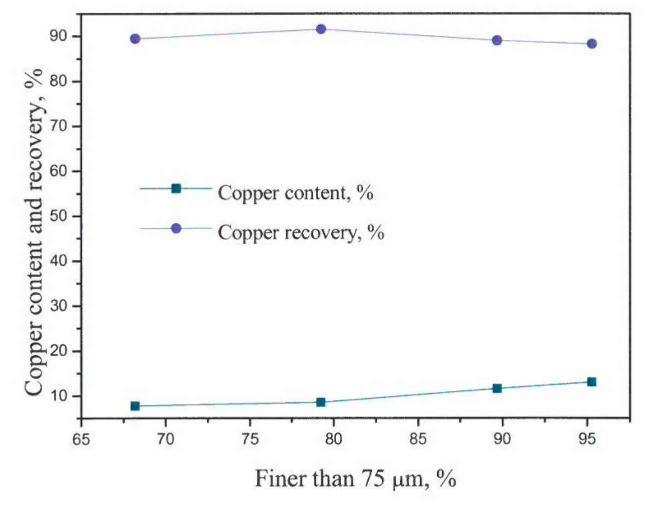

Figure 7 *The effect of regrinding fineness on the results of concentration*

CONCLUSION

Optimal grinding fineness in the process of flotation concentration of the ore from the Veliki Krivelj deposit is determined on the basis of laboratory tests that preceded the design of the site and opening of the mine. Today, almost 30 years since opening of the mine, the grinding fineness in the site is maintained as at the beginning of production. To determine whether this important parameter corresponds to the ore being processed today, testing was carried out on a sample of ore, taken from production. A sample of the ore Veliki Krivelj is marked VK, shortened and ground to a size -3.35 mm. Samples were excluded for chemical analysis and flotation concentration experiments and the tests were carried out on them.

The mean content of the most important elements in the sample, calculated from the chemical analysis was: 0.2133% Cu; 3.0067% S; 0.0733 g/t Au; 0.5667 g/t Ag. The mean content of the most important elements in the sample VK, when it is calculated over the concentration products of all experiments: 0.2095% Cu; 3.1998% S; 0.0709 g/t Au; 0.6614 g/t Ag. The density of the sample VK was 2,820 kg/m^3; the natural pH 7.20. During laboratory technological tests on a sample VK, the following conclusions were made:

- Minimum grinding fineness to be achieved on a sample VK, in terms of technological results is 65% -0.075 mm,
- Regrinding of the basic concentrate has little effect on copper recovery in concentrate from the first purification, but copper content in concentrate increases. The results indicate that the regrinding of basic concentrate is preferably up to 80-90% -0,075 mm do not go over 90% -0.075 mm because, in this case, the copper recovery decreases.

The results of laboratory experiments have shown that minimum grinding fineness to be achieved on a sample VK is 65% -0.075 mm. This increases the copper recovery in the basic concentrate for about 4%. Further increasing the grinding fineness would lead to an increase of copper recovery by another 1%.

The authors of testing think that the responsible in RTB Bor should consider the possibility of increasing the grinding fineness of the ore from the deposit Veliki Krivelj, because it will surely have positive financial effects. Complex economic analysis could exactly point out to which fineness should be adopted, because it is a compromise between a few essential items in production:

- increasing the power consumption to finer grinding,
- increasing the amount of copper in concentrate with increasing the grinding fineness, and
- capacity reduction of the mill sections, because it is only possible to realize finer grinding in given conditions.

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UTICAJ FINOĆE MLEVENJA NA REZULTATE FLOTACIJSKE KONCENTRACIJE RUDE LEŽIŠTA BAKRA VELIKI KRIVELJ[***]

Izvod

Jedan od uticajnih parametara na proces flotacijske koncentracije je krupnoća čestica i otvorenost mineralne sirovine. U procesu flotacijske koncentracije rude ležišta Veliki Krivelj finoća mlevenja se od otvaranja rudnika 1982. godine održava na vrednosti oko 58% -0,074 mm. Od tada se sišlo u dublje partije ležišta, opao je sadržaj bakra u rudi pa se pretpostavilo da se promenila i optimalna finoća mlevenja rude. U radu su prikazani rezultati ispitivanja uticaja finoće mlevenja na iskorišćenje i sadržaj bakra u osnovnom koncentratu bakra i uticaj domeljavanja na iskorišćenje i sadržaj bakra u prečišćenom koncentratu bakra na uzorku rude ležišta Veliki Krivelj. Urađeni su laboratorijski eksperimenti flotacijske koncentracije, obračunati bilansi koncentracije i donet je zaključak da je za bolje rezultate koncentracije neophodno finije mlevenje. Takođe je utvrđen optimalni stepen domeljavanja osnovnog koncentrata.

Ključne reči: *flotacija, optimalna finoća mlevenja, ruda bakra*

UVOD

Rudnik bakra Veliki Krivelj pušten je u rad 1982. godine (Mitrović Z., Jovanović R., 2007.). Ležište bakra Veliki Krivelj pripada porfirskim ležištima velikih razmera. Procenjuje se da su bilansne rezerve rude bakra u ovom ležištu u graničnom sadržaju od 0,15 % Cu, kategorije B+C1 474. 291.085 t u kojima ima 1.533.821 t bakra (Bugarin M., Maksimović M., Ljubojev V., 2012.).

Flotacijska koncentracija je proces razdvajanja koji se odvija zahvaljujući razlikama u fizičko hemijskim osobinama mineralnih površina (Barry W. A., Napier-Munn T., 2006.). Uglavnom se primenjuje za koncentraciju metaličnih ruda, za čišćenje čvrstih goriva ili za obogaćivanje nemetaličnih minerala, ali može da se primeni i za izdvajanje čvrstih čestica iz tečnosti ili razdvajanje nemineralnih čestica jednih od drugih). Zrna različite krupnoće, nisu jednako flotabilna čak iako imaju isti sastav mineralne površine (Gaudin A. M., 1957.). Mlevenje značajno utiče na tehnološke rezultate (Bulatović S. M., 2007.).

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Optimalna finoća mlevenja na rudi ležišta Veliki Krivelj određena je u fazi laboratorijskih ispitivanja koja su prethodila projektovanju pogona i otvaranju rudnika. Danas, 30 godina od otvaranja rudnika, finoća mlevenja u pogonu održava se kao i na početku industrijske prerade na nivou oko 58 % -0,074 mm. Neki od tehnoloških parametara zadržani su do danas, iako se tokom eksploatacije sišlo u dublje partije rudnog ležišta, i smanjio se sadržaj bakra u rudi. Pretpostavlja se da su se promenile i neke druge karakteristike rude bitne za proces flotacijske koncentracije pre svega meljivost i optimalna finoća mlevenja.

Autori rada su smatrali da je bitno utvrditi uticaj finoće mlevenja na tehnološke rezultate u osnovnom flotiranju a takođe i uticaj domeljavanja osnovnog koncentrata na tehnološke rezultate u prečišćavanju osnovnog koncentrata na uzorku rude ležišta Veliki Krivelj, koja se trenutno prerađuje. U Flotaciji Veliki Krivelj, domeljavanje osnovnog koncentrata bakra ide do finoće od 85 - 90% -0,074 mm. Domeljavanje osnovnog koncentrata bakra je takođe važan tehnološki postupak koji može da doprinese povećanju iskorišćenja i sadržaja bakra u prečišćenom koncentratu. Imajući u vidu procenjene rezerve u ovom ležištu i trend vrednosti bakra na svetskom tržištu svako povećanje tehnoloških rezultata bilo bi značajno.

Uzorak rude za ispitivanja Veliki Krivelj izuzet je iz proizvodnje, sa trake ispred mlina sa šipkama u pogonu Flotacije Veliki Krivelj u novembru 2012. godine.

EKSPERIMENTALNI DEO

Karakterizacija uzorka

U Laboratoriji za PMS, Instituta za rudarstvo i metalurgiju uzorak je označen oznakom VK, skraćen i usitnjen do krupnoće -3,35 mm. Izuzeti su uzorci za hemijsku analizu i eksperimente flotacijske koncentracije. Hemijska analiza uzorka VK je urađena na tri nezavisna uzorka na bakar i sumpor. U tablici 1 prikazani su rezultati hemijske analize. U tablici 2 prikazane su neke karakteristične veličine za uzorak VK.

Tabela 1. *Hemijska analiza uzorka VK*

Prvi uzorak		**Drugi uzorak**		**Treći uzorak**	
Hemijski element	**Sadržaj**	**Hemijski element**	**Sadržaj**	**Hemijski element**	**Sadržaj**
Cu	0,18%	**Cu**	0,24%	**Cu**	0,22%
S	3,47%	**S**	2,51%	**S**	3,04%

Tabela 2. *Karakteristične veličine za uzorak VK*

Gustina	2.820 kg/m^3
Prirodna pH	7,45

Mlevenje

Za ispitivanje mlevenja, korišćen je laboratorijski elipsoidni mlin sa kuglama zapremine 15,2 l sa masom šarže kugli na početku ispitivanja od 13,34 kg. Za svaki eksperiment mlevenja uzeto je 820 g uzorka.

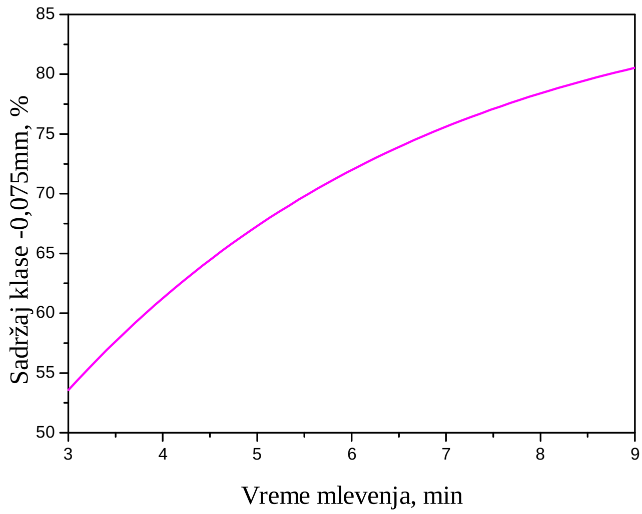
Kinetika mlevenja

Za ispitivanje kinetike mlevenja, uzorak je mleven pri sadržaju čvrstog od 70%, u trajanju od 3, 5, 7 i 9 minuta. Proizvod mlevenja je prosejan na seriji sita, a rezultati granulometrijske analize su prikazani u tabeli 3.

Tabela 3. *Granulometrijski sastav proizvoda mlevenja za različita vremena mlevenja*

Otvor sita, mm	3 min			5 min			7 min			9 min		
	m%	D%	R%	m%	D%	R%	m%	D%	R%	m%	D%	R%
-0,600+0,425	2,0	100,0	2,0									
-0,425+0,300	6,4	98,0	8,4									
-0,300+0,212	10,0	91,6	18,4	3,4	100,0	3,4						
-0,212+0,150	11,4	81,6	29,8	7,6	96,6	11,0	4,8	100,0	4,80	2,6	100,0	2,6
-0,150+0,106	10,0	70,2	39,8	10,4	89,0	21,4	9,4	95,2	14,2	5,8	97,4	8,4
-0,106+0,075	6,8	60,2	46,6	10,6	78,6	32,0	11,2	85,8	25,4	10,6	91,6	19,0
-0,075+0,053	5,4	53,4	52,0	8,4	68,0	40,4	9,8	74,6	35,2	10,4	81,0	29,4
-0,053+0,038	6,0	48,0	58,0	7,0	59,6	47,4	8,6	64,8	43,8	10,0	70,6	39,4
-0,038+0	42,0	42,0	100,0	52,6	52,6	100,0	56,2	56,2	100,0	60,6	60,6	100,0

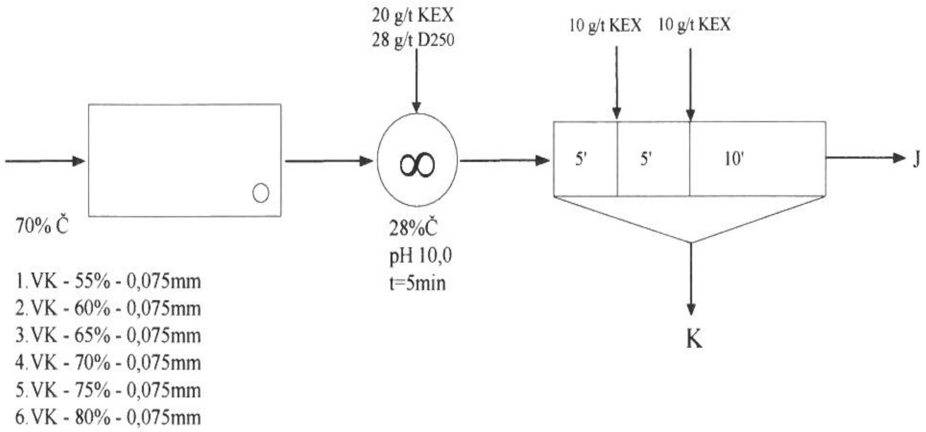
Na slici 1 prikazana je kinetika mlevenja.



Sl. 1. *Kinetika mlevenja*

Ispitivanje uticaja finoće mlevenja na rezultate osnovnog flotiranja

Uticaj finoće mlevenja na rezultate osnovnog flotiranja ispitan je mlevenjem, a zatim flotiranjem u Denver D-12 flotacijskoj mašini, u komori zapremine 2,4 l, sa 820 g uzorka. Proizvodi koncentracije su hemijski analizirani, a zatim je za svaki eksperiment računat bilans koncentracije. Izvedena je serija eksperimenata koja je obuhvatila finoću mlevenja od 55-80 % -0,075 mm. Eksperimenti su izvedeni prema šemi prikazanoj na slici 2. Dobijeni rezultati koncentracije prikazani su u tablici 4. Na osnovu rezultata iz tablice 4. urađena je zavisnost iskorišćenja i sadržaja bakra u koncentratu od od finoće mlevenja i prikazana na slici 3.

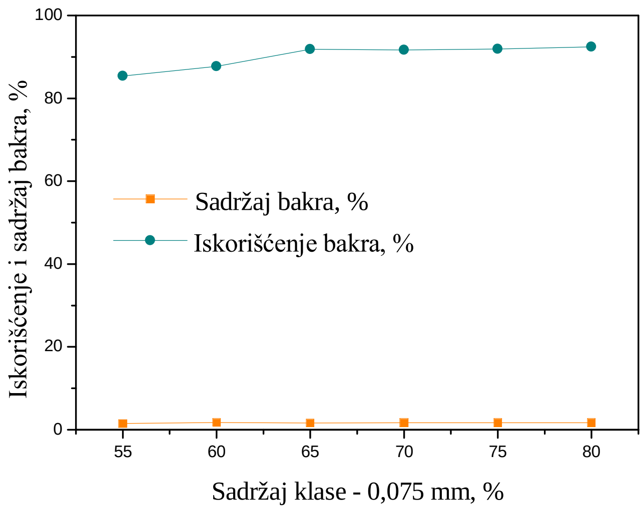


Sl. 2. *Šema ispitivanja uticaja finoće mlevenja*

Tabela 4. *Rezultati osnovnog flotiranja minerala bakra*

PRODUKT	MASA m, %	SADRŽAJ		RASPODELA	
		Cu, %	S, %	Cu, %	S, %
Uzorak 1. VK 55% - 0,075 mm					
U	100,00	0,1843	3,5096	100,00	100,00
K	10,49	1,50	31,75	85,40	94,90
J	89,51	0,03	0,2	14,60	5,10
Uzorak 2. VK 60% - 0,075 mm					
U	100,00	0,2169	2,9674	100,00	100,00
K	10,93	1,74	25,52	87,69	94,00
J	89,07	0,03	0,2	12,31	6,00
Uzorak 3. VK 65% - 0,075 mm					
U	100,00	0,2154	3,1449	100,00	100,00
K	11,99	1,65	23,44	91,83	89,37
J	88,01	0,02	0,38	8,17	10,63

Uzorak 4. VK 70% - 0,075 mm					
U	100,00	0,2123	2,8124	100,00	100,00
K	11,72	1,66	22,49	91,66	93,72
J	88,28	0,02	0,2	8,34	6,28
Uzorak 5. VK 75% - 0,075 mm					
U	100,00	0,2175	3,1000	100,00	100,00
K	11,90	1,68	24,57	91,91	94,32
J	88,10	0,02	0,2	8,09	5,68
Uzorak 6. VK 80% - 0,075 mm					
U	100,00	0,2319	3,6072	100,00	100,00
K	12,61	1,70	27,22	92,45	95,15
J	87,39	0,02	0,2	7,55	4,85



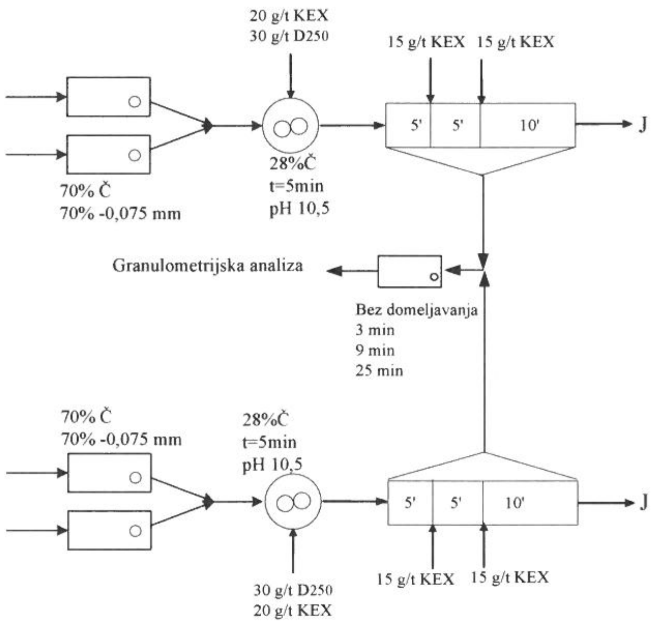
Sl. 3. *Zavisnost iskorišćenja i sadržaja bakra u osnovnom koncentratu od finoće mlevenja*

Domeljavanje

Za ispitivanje domeljavanja korišćen je laboratorijski elipsoidni mlin sa kuglama zapremine 15,2 l, sa masom šarže kugli na početku ispitivanja od 3,755 kg. Za svaki eksperiment domeljavanja, bilo je potrebno samleti po četiri uzorka mase 820 g. Nakon toga, izvršena su po dva osnovna flotiranja (pri čemu je masa uzoraka u svakom osnovnom flotiranju iznosila 1.640 g) u flotacijskoj mašini Denver D-12 u komori zapremine 4,6 l prema istim uslovima, a zatim je dobijeni osnovni koncentrat domeljavan u mlinu sa kuglama u različitim vremenskim intervalima. Proizvod domeljavanja je jednom prečišćen u flotacijskoj mašini Denver D-12 u komori od 2,4 l, a proizvodi koncentracije hemijski analizirani nakon čega je računat bilans koncentracije.

Ispitivanje kinetike domeljavanja

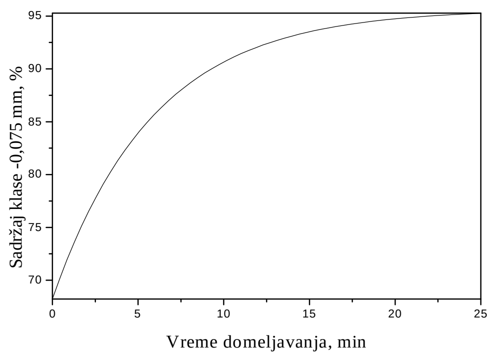
Šema prema kojoj je ispitana kinetika domeljavanja prikazana je na slici 4. Rezultati granulometrijske analize proizvoda domeljavanja prikazani su u tablici 6, a kinetika domeljavanja na slici 5.



Sl. 4. *Šema ispitivanja kinetike domeljavanja*

Tabela 6. *Granulometrijski sastav proizvoda domeljavanja za različita vremena domeljavanja*

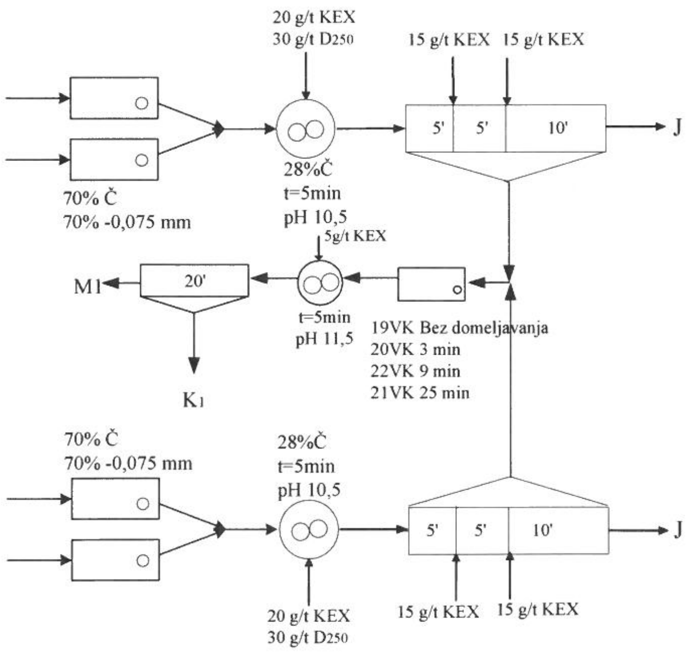
Otvor sita, mm	Bez dom.		3 min.		9 min.		25 min.	
	m %	D%	m %	D %	m %	D %	m %	D %
-0,300+0,212	2,00	100,00						
-0,212+0,150	6,67	98,00	2,57	100,00				
-0,150+0,106	11,89	91,33	7,38	97,43	3,32	100,00	0,86	100,00
-0,106+0,075	11,22	79,44	10,81	90,05	7,00	96,68	3,86	99,14
-0,075+0,053	8,22	68,22	9,81	79,24	9,84	89,68	6,72	95,28
-0,053+0,038	7,00	60,00	8,62	69,43	9,84	79,84	8,72	88,56
-0,038+0	53,00	53,00	60,81	60,81	70,00	70,00	79,84	79,84



Sl. 5. *Kinetika domeljavanja*

Uticaj finoće domeljavanja na rezultate flotacijske koncentracije

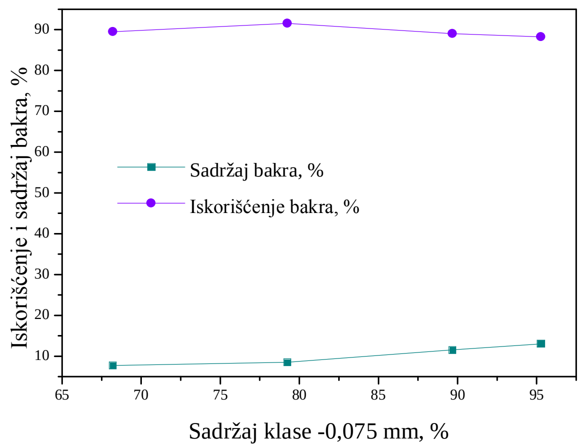
Uticaj finoće domeljavanja na rezultate flotacijske koncentracije ispitan je kroz četiri eksperimenta, a šema prema kojoj su eksperimenti izvedeni prikazana je na slici 6. Rezultati uticaja domeljavanja na prečišćavanje koncentrata bakra prikazani su u tablici 7 i na slici 7 prikazana je zavisnost iskorišćenja i sadržaja bakra u prečišćenom koncentratu bakra od finoće domeljavanja.



Sl. 6. *Šema ispitivanja uticaja finoće domeljavanja na rezultate flotiranja*

Tabela 7. *Uticaj finoće domeljavanja na rezultate prečišćavanja koncentrata bakra*

PROD.	MASA m, %	SADRŽAJ				RASPODELA			
		Cu, %	S, %	Au, g/t	Ag, g/t	Cu, %	S, %	Au, g/t	Ag, g/t
Uzorak 19.VK - 68,22 % -0,075 mm; Bez domeljavanja									
U	100,00	0,1855	2,8081	0,073	0,80	100,00	100,00	100,00	100,00
J	90,36	0,010	0,27	0,016	0,713	4,85	8,69	19,25	80,58
Ko	9,64	1,83	26,60	0,612	1,612	95,15	91,31	80,75	19,42
M_1	7,49	0,14	26,89	0,5	1,50	5,66	71,71	51,30	14,04
K_1	2,15	7,72	25,60	1,0	2,00	89,49	19,60	29,45	5,38
Uzorak 20 VK - 79,24 % -0,075 mm; 3 minuta									
U	100,00	0,1864	3,1504	0,080	0,80	100,00	100,00	100,00	100,00
J	89,44	0,012	0,2	0,019	0,671	5,74	5,68	21,24	75,05
Ko	10,56	1,66	28,14	0,597	1,89	94,26	94,32	78,86	24,95
M_1	8,55	0,06	28,99	0,384	1,70	2,74	78,68	41,07	18,17
K_1	2,01	8,49	24,52	1,50	2,70	91,52	15,65	37,69	6,78
Uzorak 22 VK - 89,68 % -0,075 mm; 9 minuta									
U	100,00	0,1988	3,0517	0,073	0,80	100,00	100,00	100,00	100,00
J	90,69	0,012	0,36	0,020	0,68	5,48	10,70	24,85	77,09
Ko	9,31	2,02	29,27	0,589	1,969	94,52	89,30	75,15	22,91
M_1	7,78	0,14	29,89	0,414	1,80	5,48	76,20	44,16	17,50
K_1	1,53	11,57	26,13	1,478	2,828	89,03	13,10	30,99	5,41
Uzorak 21 - 95,28 % -0,075 mm; 25 minuta									
U	100,00	0,1980	2,8367	0,073	0,80	100,00	100,00	100,00	100,00
J	90,35	0,012	0,2	0,017	0,706	5,45	6,37	21,04	79,73
Ko	9,65	1,94	27,52	0,597	1,681	94,55	93,63	78,96	20,27
M_1	8,31	0,15	27,92	0,403	1,50	6,31	81,79	45,92	15,58
K_1	1,34	13,04	25,06	1,80	2,80	88,23	11,84	33,04	4,69



Sl. 7. *Uticaj finoće domeljavanja na rezultate koncentracije*

ZAKLJUČAK

Optimalna finoća mlevenja u procesu flotacijske koncentracije na rudi ležišta Veliki Krivelj određena je na bazi laboratorijskih ispitivanja koja su prethodila projektovanju pogona i otvaranju rudnika. Danas, gotovo 30 godina od otvaranja rudnika, finoća mlevenja u pogonu održava se kao i na početku proizvodnje. Da bi se utvrdilo da li ovaj važan parametar odgovara rudi koja se danas prerađuje izvršena su ispitivanja na uzorku rude izuzetom iz proizvodnje. Uzorak rude Veliki Krivelj je označen oznakom VK, skraćen i usitnjen do krupnoće -3,35 mm. Izuzeti su uzorci za hemijsku analizu i eksperimente flotacijske koncentracije i na njima izvršena ispitivanja.

Srednji sadržaj važnijih elemenata u uzorku, izračunato iz hemijske analize je: 0,2133% Cu; 3,0067 % S; 0,0733 g/t Au; 0,5667 g/t Ag. Srednji sadržaj važnijih elemenata u uzorku VK, kada se izračuna preko proizvoda koncentracije svih eksperimenata je: 0,2095% Cu; 3,1998 % S; 0,0709 g/t Au; 0,6614 g/t Ag. Gustina uzorka VK iznosila je 2.820 kg/m^3, prirodna pH 7,20. Tokom laboratorijskih tehnoloških ispitivanja na uzorku VK došlo se do sledećih zaključaka:

- Minimalna finoća mlevenja koju treba ostvariti na uzorku VK, sa aspekta tehnoloških reziltata je 65% -0,075 mm
- Domeljavanje osnovnog koncentrata nema velikog uticaja na iskorišćenje bakra u koncentratu prvog prečišćavanja, ali se sadržaj bakra u koncentratu povećava. Rezultati ukazuju da je domeljavanje osnovnog koncentrata poželjno i to do 80-90 % -0,075 mm. Ne treba ići preko 90% -0,075 mm jer u tom slučaju opada iskorišćenje bakra

Rezultati laboratorijskih eksperimenata pokazuju da je minimalna finoća mlevenja koju treba ostvariti na uzorku VK 65% -0,075 mm. Time se povećava iskorišćenje bakra u osnovnom koncentratu za oko 4%. Dalje povećanje finoće mlevenja dovelo bi do povećanja iskorišćenja bakra za još oko 1%.

Autori ispitivanja smatraju da bi odgovorni u RTB Bor trebali da razmotre mogućnost povećanja finoće mlevenja rude ležišta Veliki Krivelj, jer će to sigurno imati pozitivne finansijske efekte. Kompleksnija ekonomska analiza bi mogla tačno da pokaže do koje finoće treba ići, jer je to kompromis između nekoliko bitnih stavki u proizvodnji:

- povećanja potrošnje energije na finije mlevenje,
- povećanja količine bakra u koncentratu sa povećanjem finoće mlevenja i
- smanjenja kapaciteta mlinskih sekcija, jer je samo tako u datim uslovima moguće finije mlevenje.

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DEVELOPMENT THE MODEL OF ASSESSMENT THE OH&S RISKS FOR THE WORK PLACE DRILLER IN THE PROCESS OF GEOLOGICAL EXPLORATORY DRILLING

Abstract

This work gives a model of OH&S risk assessment for the workplace driller in the process of implementation the geological exploratory works. Model of OH&S risk assessment for the workplace driller is based on ISO 31010 Standard and fulfilling the requirements of OHSAS 18001 and legal regulations. In this case, a partially adjusted and optimized Kinny method was used. Model of OH&S risk assessment provides a reasonable basis for development and implementation the system of occupational health and safety management in accordance with BS OHSAS 18001: 2008, since it is practically applied and tested in the organizations dealing with geological exploratory drilling, such as "Geops Balkan Drilling Services" Ltd., Drillex International Ltd., International Drilling Service Ltd. and Stara Planina Resources Ltd.

Keywords: *OH&S risk, driller, geology, exploratory drilling*

1 INTRODUCTION

Safety and health at work is a very important part of work at every employer - regardless the type of activity of the employer. By the systematic approach to the safety and health at work, the importance of prevention in all phases of work is given. Assessment of OH&S risk tends to control the risk in order to eliminate the dangers and hazards of injury, occupational diseases and illnesses related to work and to establish the system of occupational health and safety at work (OHSAS). Achieving the quality in management the system of health and safety at work is impossible without complying with the basic legal requirements of assessment the OH&S risks.

Organization whose activity is geological exploratory drilling is expected to be confronted with significant OH&S risks. If OH&S risks are not adequately assessed and placed under the control, they may affect in a negative way the achievement of organization objectives. The goals of organization can refer to a range of activities, from strategic initiatives through to operations and can be reflected in the non-compliances with the regulations and other requirements. Considering that the technological process of exploratory drilling, consisted of operations involving a significant number of hazardous materials to the potential OH&S risks, may be even greater.

Management of OH&S risk involves the application of logical and systematic methods for identifying, analyzing and assessment the OH&S risks during the process of exploratory drillings, monitoring and review of risks to the aim of effective and efficient

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management of integrated quality management systems (ISO 9001), environmental protection (ISO 14001) and occupational health and safety at work (OHSAS 18001).

The aim of this research is to evaluate the OH&S risks in the process of geological exploratory drilling with finding the answers to the following basic questions:

- What can happen in the process of exploratory drilling and why (hazard identification)?
- What are the probabilities of danger and hazards?
- Can it be managed by the assessed OH&S risks and whether it requires further treatment of reduction the OH&S risks?
- How to make the planning of measures to protect the health and safety at work that may affect the probability reduction of danger and hazard occurrence?

In accordance with determined aim of research, the following research hypothesis is set:

a) Based on a systemic approach it is possible to make a positive identification, risk analysis and assessment of OH&S risks and to establish the mechanisms to control the assessed OH&S risks.

Based on the identification of problems, set objective and hypotheses of research, the following research tasks have resulted, namely:

1) to perform a system analysis, and define the model and methods of assessment the OH&S risks;
2) to identify the hazards, determine the probability of occurrence and potential consequences;
3) to assess the OH&S risks for a specific job position;
4) to define a Plan of measures to control the increased OH&S risks.

In order to fulfill the tasks of research and achieving the objective of testing the proposed hypotheses of research, the known methods are used are that have contributed to improving the methodology of research, namely:

1) descriptive method (method of observation and description) through the analysis of available data;
2) method of analysis the theory and practice;
3) method of general system theory or systematic approaches and system analysis;
4) method of the process modeling, and development the flow charts.

2 THEORETICAL APPROACH, SELECTED METHODOLOGICAL APPROACH AND METHODS OF ASSESSMENT THE OH&S RISKS

2.1 Theoretical approach to assessment the OH&S risks

To meet the requirements of the Standard OHSAS 18001 as well as the requirements of legislation, it is necessary for all hazards and dangers that occur and/or may be occured at the workplace **driller in the process of exploratory drillings** to carry out the assessment of OH&S risks. For the purpose of effective and efficient assessment of OH&S risks, it is necessary to use the appropriate method that will provide the proactive, but not reactive assessment results [10]. The effectiveness and efficiency of the OH&S system can not be only achieved by y assessment the OH&S risks, but it is necessary that after the assessment of OH&S risks of organizations, to provide conditions that the results of the assessment OH&S risks are taken into account in establishing the OH&S management system and to define the management plan with increased OH&S risks.

In the world and in the Republic of Serbia, the most widely used tool for establishment, maintenance and upgrading the occupational health and safety at work system is the Standard OHSAS 18001. OH&S system is a structured process for overcoming the OH&S risks. The afforementioned standard has precisely provided the requirements of some key elements of occupational health and safety at work, such as: identifying the hazards and dangers that may arise where the compulsory taking into account the behavior and abilities of employees, management, communication, cooperation and consulting with employees.

To manage with OH&S risks means finding one acceptable combination that allows actions to improve safety and health at work and elimination of all dangers and hazards that lead into question the optimal functioning of OH&S system. Management of OH&S risks can be achieved with assumptions that include the following:

- timely identification of all dangers and hazards;
- making a list of dangers and hazards that affect the OH&S system;
- analysis of previous data on consequences of injuries at work, occupational diseases and diseases related to work;
- analysis of individual dangers and hazards and their grouping by similarity;
- analysis of interdependence the individual dangers and hazards and their potential consequences;
- assessment of OH&S risks for the established list of dangers and hazards;
- establishment an environment that fosters a tradition of teamwork;
- development of methods and techniques for assessment and management the OH&S risks;
- establishment an optimal level of safety at work;
- adoption of goals, plans and programs for management of assessed OH&S risks.

For effective control OH&S risks risks, it is necessary to know to manage the information, based on which the conclusions and decisions are made, i.e. it is necessary to pay attention to the quality of information which is contained in the Act on assessment the OH&S risks.

Assessment of OH&S risks risks in the business process is in no case a constant, but a dynamic value that changes from moment to moment. Every time some elements of dangers and hazards is changed, the level of OH&S risks is also changed. There is a standard that defines the process of risk assessment ISO 31010: 2010 [8].

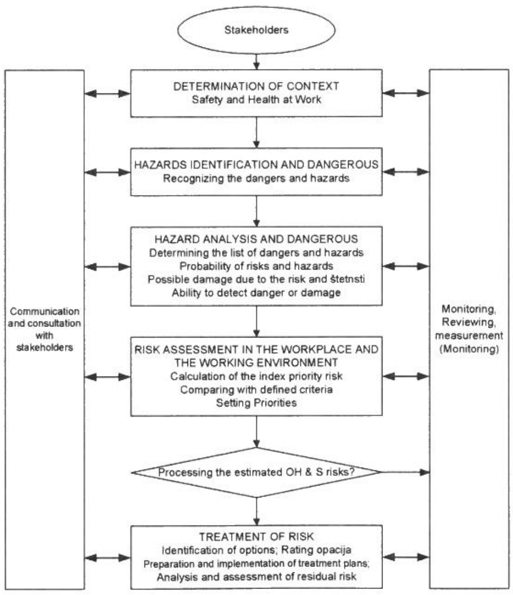

Figure 1 *Block diagram of assessment process the OH&S risks* [8], [12]

2.2 Selected method of assessment the OH&S risks

The Kinny method is one of the methods by which it is possible to assess the OH&S risks. OH&S risks change over time in three basic categories, which are analyzed by the Kinny method, as follows:

- probability of dangers and hazards;
- severity of consequences that may result from the occurrence of dangers and hazards;
- frequency of incidence the dangers and hazards.

Based on identification of danger at the workplace and working environment and statistical data processing about dangerous events (occupational injuries), hazardous materials and critical points of the process, the assessment of OH&S can be done.

The process of hazard and danger identification and evaluation the impact can achieve the following:

- to identify all dangers and hazards that may impact the workplace and working environment;
- to analyze the impacts of hazards and dangers at the workplace and working environment;
- to establishe an evaluation system of any dangers and hazards;
- to determine the significance of any dangers and hazards.

Parameters of analysis are numerically evaluated, and the final assessment of OH&S risks at the workplace and work environment is expressed numerically. The default setting of the Kinny method in assessment the risks at the workplace and work environment is essentially simple and easy to understand. The essence of the method consists in realization the following activities:

a) determining the all potential dangers and hazards that are/or may incur as the result of work process;
b) determining the possible causes of each danger and hazard;
c) analysis of each danger and hazard in order to determine using the analytical methods:
   - probability of occurrence the potential danger and hazard;
   - serious consequences which employee suffers in occurrence of danger and hazard ;
   - frequency of danger and hazard occurrence.
d) evaluating the level of risk is is made by the product of three factors:
   - probability of dangers and hazards - V;
   - serious consequencies due to occurrence of dangers and hazards - P;
   - frequency of occurrence the dangers *and hazards - U;*

Evaluation of the risk **R** is done according to the formula:

R = V x P

Table 1 *Matrix of risk assessment by Kinny method [11]*

Identified danger or hazard	**ASSESSMENT OF OH&S RISKS R = V x P**		
	Probability v	**Consequence P**	**Risk level R**
x			
y			
z			

2.2.1 Criteria for probability assessment **-** *V*

Table 2 *Description of criteria for probability assessment of occurrence the dangers and hazards [11]*

RANK	DESCRIPTION OF CRITERIA FOR PROBABILITY ASSESSMENT - V
0.1	*Hardly conceivable*
0.2	*Practically unbelievable*
0.5	*There is, but only very unlikely*
1	*Unlikely, but possible in limited cases*
3	*Little as possible*
6	*It is quite possible*
10	*Predictably, the expected*

2.2.2 Criteria for assessment of consequencies **-** *P*

Table 3 *Description of criteria for assessment of consequencies in occurrence of dangers and hazards [11]*

RANK	DESCRIPTION OF CRITERIA FOR ASSESSMENT OF CONSEQUENCIES - P
1	*Illness, injury which requires first aid and any other treatment*
2	*Medical treatment by a physician*
3	*Severe-disability, serious individual injury with hospitalization and lost days*
6	*Very serious individual-fatal accidents*
10	*Catastrophic-with multiple fatalities*

2.2.3 Criteria for assessment the frequency of occurrence the dangers and hazards **-** *U*

Table 4 *Description of criteria for assessment the frequency of occurrence the dangers and hazards [11]*

RANK	DESCRIPTION OF CRITERIA FOR FREQUENCY - U
1	*Exposed rarely (annually)*
2	*Exposed monthly*
3	*Exposed weekly*
6	*Exposed daily*
10	*Exposed permanent, continuous*

2.3.4 Criteria for classification the risk level (R)

Table 5 *Criteria for determining the risk level [11]*

Total score	Risk class	Classification of risk level	Description the classification of risk level
>0.1 <20	**R I**	**Negligible risk**	*No action is required.*
>20 <70	**R II**	**Low risk**	*There is no need for additional r activities in the management of operation.* *An economically cost-effective solution or improvement without additional investmen could be considered. It is necessary to monitor the situation in order to possess information on implementation the prescribed activities.*
>70 <200	**R III**	**Medium risk**	*Efforts are needed to reduce the risk, but the costs of prevention have to be carefully planned and limited to a certain level.* *It is necessary to define a deadline for implementation of improvements.* *For those events where extremely dangerous consequence can be occurred, it is necessary to further verify the probability of occurrence of such events in order to define the required level of activity to mitigate risk.*
>200 <400	**R IV**	**High risk**	*One must not start with a given activity, while the level of risk is not reduced.* *Significant resources are needed to reduce the risk.* *If the risk is applied to all started activities, it is necessary to take urgent actions to reduce the level of risk.*
>400 <1000	**R V**	**Extremely high risk**	*Activity must not be commenced nor continued until the level of risk is reduced to an acceptable level. If investing the limited resources it is not possible to reduce the level of risk to an acceptable level, the activity must remain prohibited.*

2.2.5 Categorization and characterization of risk

Table 6 *Criteria for categorization and characterization of risks [11]*

Assessment the risk level	Categorization of risk level	Risk characterization
R I	**Negligible risk**	***Acceptable risk***
R II	**Low risk**	***Acceptable risk***
R III	**Medium risk**	***Increased risk***
R IV	**High risk**	***Unacceptable risk***
R V	**Extremely high risk**	***Unacceptable risk***

Table 7 *Description of risk characterization [11]*

Risk characterization	Description of risk characterization
Acceptable risk	*Risk for which there is assessment and presumption that it will not result in:* *- occupational injuries and illnesses related to work,* *- inconsistency with legislation and / or deviation from the prescribed work organization, and* *- deviation from the prescribed policy of the health protection and safety at work system in organization.*
Acceptable risk	
Increased risk	*Risk for which there is assessment and presumption that it will cause in the certain circumstances:* *- occupational injuries and illnesses related to work,* *- partly inconsistency with legislation and / or deviation from the prescribed work organization, and* *- occasional deviation from the prescribed policy and objectives of the system of health protection and safety at work.*
Unacceptable risk	*Risk for which there is assessment and presumption that it directly cause:* *- occupational injuries and illnesses related to work, inconsistency with legislation;* *- deviation from the prescribed work organization, and* *- deviation from the prescribed policys and objectives of the system of health protection and safety at work.*

3 RESEARCH RESULTS - PRACTICAL EXAMPLE OF ASSESSMENT THE OH&S RISK

Job position code III GROUP	IDENTIFYING AND DETERMINING THE DANGERS AND HAZARDS AND RISK ASSESSMENT AT THE JOB POSITION: DRILLER - GEOLOGICAL EXPLORATORY DRILLING
1 GENERAL DATA ON JOB POSITION	
1.1 Name of work organization:	**"GEOPS BALKAN DRILING SERVICES" LTD.**
1.2 Sector:	Conduction the geological exploratory drilling
1.3 Service:	/
1.4 Department:	/

2 DATA ON THE WORK PROCESS:
2.1 Jobs by job classification and work tasks (description): **Driller - Geological exploratory drilling:**
Works are done using the appropriate machines and methods for exploration of mineral resources. Drilling is carried out in geological surveyed areas in order to find the solid mineral resources. Geotechnical drilling machine is mounted ana special vehicle with caterpillars on which all working and driving parts of the machine are also installed, and the same are arranged and secured in a safe manner. Commanding of machine is done properly with the control board. Drilling a hole is carried out through the drive motor with reduction gear and system for drilling with diamond tools which are mounted on a special tube. Installation and removal of diamond tools on the machine is performed. Clamping of drilling tools and installation of extensions are performed appropriately performed. Extraction of geological cores via the pneumatic system and the system of ropes and drums and are also performed in a safe manner. Monitorinf and taking the appropriate measures for cooling the drilling through cooling system that is driven by a suitable pump. Monito-ring the operation of generators to supply electricity.
Periodical jobs: If necessary, driving a motor vehicle from the place of work to the base and vice versa.

3 PODACI O RADNOM I POMOĆNOM PROSTORU				
3.1 Structures:	Bisiness premises in Bor, Danila Kiša 6/28			
3.2 Workspace:	Actual site in the exploration area Brestovac - Metovnica			
3.3 Group of elements of work space	**3.3.1 Elements of work space**	**3.3.2 Prescribed requirements**	**3.3.3 Assessment the state of workspace**	
			Satisfies✓	**Unsatisfies ×**
1) Size and height of work premises	Free floor space	2 m^2 per worker	/	
	Free air space	10 m^3 per worker	/	
	Height of workroom	minimum 2.5 m	/	
2) Floors	Floor level	above the level of surrounding land	/	
	Material of floor	resistant to abrasion, water airtight	/	
	Method of making	flat smooth but not slippery	/	
	Condition and maintenance	regularly	/	
3) Walls and ceiling	Material and making	thermal, acoustic insulation	/	
	Processing and color	plastered and painted	/	
	Condition and maintenance	light surface/regularly	/	
4) Doors	Opening direction and width	depending on the purpose of room	/	
	Number and arrangement	at 30 to 50m min one door	/	
5) Windows	Surface of windows	min 12.5 % of floor area	/	
	Incidence angle of light	minimum 24^o	/	
	Principle and method of opening	easily	/	
6) Heating	Method of heating	steam heating	/	
	Arrangement of heating bodies	properly	/	
	Condition and maintenance	according to the maintenance plan	/	
7) Microclimate	Room temperature	$18\text{-}22^o$ C	/	
	Relative room humidity	65-80 %	/	
	Airflow speed	0,3 m/s (air conditioned)	/	
8) Lighting	General illumination	classic properly executed	/	
	Local illumination	not required	/	
9) Others	Sanitary facilities	properly executed	/	
	Changing rooms	not required	/	
	First aid cabinet	there is prescribed equipment	/	
3.4 Auxiliary workspace:	/			
3.5 Note:	Work is performed in open space			

4 AVAILABLE MEANS AND EQUIPMENT FOR WORK	
4.1 Machines	Geological drilling machines CHRISTENSEN CS 14; CHRISTENSEN CS 10; CHRISTENSEN CS 14 - CE C 20;
4.2 Devices	Compressors, pumps, etc.
4.3 Facilities	/
4.4 Installations	Compressed air
4.5 Tools and accessories	Different types of tools for tightening of pipes that are used for geological drilling
4.6 Other tools forf work	Combined passenger – freight car

5 MATERIALS, RAW MATERIALS AND OTHER SUBSTANCES THAT ARE USED IN THE OPERATION PROCESS	
5.1 Materials	Different types of raw materials such as oil and grease; AMC CR650 RD
5.2 Raw materials	Samples of minerals obtained in geological drilling
5.3 Other substances	/

6 QUALIFICATION AND TRAINING	
6.1 Specific professional training:	Yes, training for machine operation
6.2 Training for health and safety at work::	Yes, training was carried out
6.3 Training for fire protection:	Yes, training was carried out

7 EQUIPMENT AND MEANS FOR PERSONAL PROTECTION AT WORK		Score of condition
7.1 Means for head protection:	Safety helmet	Satisfies
7.2 Means for body protection:	Protective suit; Protective identification vest	Satisfies
7.3 Means for hands protection:	Protective gloves	Satisfies
7.4 Means for legs protection:	Safety shoes with steel drips; Protective rubber boots with steel drips	Satisfies
7.5 Means for eyes protection:	Safety glasses	Satisfies
7.6 Means for hearing protection:	Wear ear muffs; Earplugs and others.	Satisfies
7.7 Equipment for safe operation:	Safety harness for working at height	Satisfies

8 WORK ORGANIZATION			
8.1 Conditions for entering employment:			
Degree of education	From II to VI		
Educational profile	All professions		
Work experience	Preferably		
Special knowledge, skills and ability	Ability of driving a motor vehicle		
8.2 General information about executors:			
Total number of employees at the workplace/group:	>4	Men: Yes	Women: No
Professional invalids works at the workplace:	No	Men:/	Women: /

8.3 General requirements of the workplace:			
Engagement according to the place of activities	In the work premises	Office	0%
		Ancillary work facilities	0%
	Work in the open	Field work	100 %
		Worksite	100 % periodically
		Work with means of transport	Yes, periodically
Execution of tasks	Work in shifts	Yes	
	Work at night	Yes	
	Organizes and manages	Yes	

9 ANALYSIS OF THE CURRENT STATE OF SAFETY AND HEALTH AT WORKPLACE		
9.1. Element of safety at work	**9.2. Compliancy with requirements**	
	Yes ✓	**No ×**
Applicable and professional findings on executed reviews and testing of means for work	✓	
Applicable and professional findings on executed reviews and testing the conditions of work	✓	
Reports on previous and periodical medical examinations of employees	✓	
Data on occupational injuries	✓	
Data on occupational diseases and diseases related to work	✓	
Means and equipment for personal protection at work	✓	
Analysis of taken measures to prevent occupational injuries	✓	
Safety instructions for work	✓	
Required documentation for use and maintenance, or packaging, transportation, use, storage, destruction and others	✓	
Fire protection	✓	

10 IDENTIFYING THE DANGERS AT WORKPLACE				
10.1 Grouping of dangers				
Group of dangers	**Code**	**Subgroup of dangers**	**Dangers ✓YES / ×NO**	
1) Mechanical dangers that occur using the work equipment such as:	(01)	Insufficient security due to rotating or moving parts,	✓	
	(02)	Free movement of parts or materials that can cause injury of employee,	✓	
	(03)	Internal transport and movement of working machines or vehicles, as well as moving some equipment for work,	✓	
	(04)	Use of dangerous instruments of work which can produce an explosion or fire,	✓	
	(05)	Inability or limitations of timely removal from the place of work, exposure to closure, mechanical shock, match, etc.,	✓	
	(06)	Other factors that may occur as mechanical sources of danger,	✓	

2) Dangers arising in connection with the characteristics of the workplace, such as:	(07)	Dangerous surfaces (floors and all kinds of treads, surfaces with which an employee comes in contact, and which have sharp edges, spikes, rough surfaces, protruding parts, etc.)	✓	
	(08)	Work at height or in depth, in terms of regulations on safety and health at work,	✓	
	(09)	Work in confined, restricted or danger area (between two or more fixed parts, between moving parts or vehicles, work indoors, which is insufficiently illuminated and ventilated,etc.)		×
	(10)	Possibility of slipping or tripping (wet or slippery surfaces),	✓	
	(11)	Physical instability of workplace,		×
	(12)	Possible consequences or disturbances due to the mandatory use of means or equipment for personal protection at work,	✓	
	(13)	Impacts due to the performance of work processes using inappropriate or unadjusted methods,		×
	(14)	Other dangers that may occur in connection with the characteristics of workplace and work methods (using the mans and equipment for personal protection at work that burden the employee, etc.);	✓	
3) Dangers that occur using electricity, such as:	(15)	Risk of direct contact with parts of electrical installations and equipment under voltage		×
	(16)	Risk of indirect contact		×
	(17)	Risk of thermal effects that are developed by electrical equipment and installations (overheating, fire, explosion, electric arc or sparks, etc.),		×
	(18)	Danger of local lightning strike and consequences of atmospheric discharge	✓	×
	(19)	Danger of harmful effects of electrostatic charge,		×
	(20)	Other dangers that may occur related to the use of electricity.		×

11 IDENTIFYING THE HAZARDS AT WORKPLACE

11.1 Grouping of hazards

Group of hazards	Code	Subgroups of hazards	Hazards ✓YES	/ ×NO
1) Hazards arising or occurring in the work process, such as:	(21)	Chemical hazards, dust and fumes (inhalation, ingestion, penetration into the body through the skin, burns, poisoning, etc.)	✓	
	(22)	Physical hazards (noise and vibration),	✓	
	(23)	Biological hazards (infections, exposure to microorganisms and allergens)		×
	(24)	Adverse impacts microclimate (high or low temperature, humidity and air velocity)		×
	(25)	Inadequate – insufficient illumination,	✓	
	(26)	Harmful effects of radiation (heat, ionizing or non-ionizing, laser, ultrasound),		×
	(27)	Adverse climatic effects (work outdoors),	✓	
	(28)	Hazards generated using hazardous substances in the production, transport, packaging, storage or destruction;		×
	(29)	Other hazards that occur in the work process, and that may be the cause of injury of the employee at work, occupational disease or illnesses related to work,	✓	

2) Hazards arising from psychological and psycho-physiological efforts related causally to the workplace and jobs that an employee performs, such as:	(30)	Efforts or physical stresses (manual handling of loads, pushing or pulling the loads, various long-term increased physical activities and etc.),	✓	
	(31)	Unphysiological position of the body (prolonged standing, sitting, squatting, kneeling, etc.)	✓	
	(32)	Efforts for various tasks that cause psychological stresses (stress, monotony, etc.),	✓	
	(33)	Responsibility in receiving and transferring of information, use the appropriate knowledge and skills, responsibility in rules of conduct, responsibility for rapid changes in work procedures, work intensity, spatial causality of the workplace, conflict situations, working with clients and money, lack of motivation to work, responsibility in management, etc .;	✓	
3) Hazards related to the work organization, such as:	(34)	Overtime working hours (overtime work), shift work, part-time, night work, standby in case of intervention,	✓	
4) Other hazards occurring at workplaces, such as:	(35)	Hazards caused by other persons (violence to persons working at the counters, security persons, etc.)		×
	(36)	Work with animals,		×
	(37)	Work in an atmosphere with high or low pre-ssure		×
	(38)	Work near water or under the water surface,		×
	(39)	Other dangers and hazards.		×

12 DETERMINING THE LIST OF DANGERS AND HAZARDS AT THE WORKPLACE	
12.1 Determined list of hazards	
01.1	Danger of occupational injuries caused by rotating or moving parts of the machine for geological drilling and explorations
02.1	Danger of occupational injuries caused by movement of parts during geological drilling and explorations
03.1	Danger of occupational injuries caused by movement of machines and vehicles as well as the equipment used in geological drilling and explorations
04.1	Danger of occupational injuries caused by the use of compressors and diesel generators that produce high pressures and that can cause explosions and fires
05.1	Danger of occupational injuries caused by inability or limitations for timely removal from the place of work on the machine for geological drilling and explorations
06.1	Danger of occupational injuries caused by potential traffic accidents in the management of intermittent of passenger car or light truck on categorized and uncategorized roads and transportation of working staff from the base to the place of work and vice versa;
07.1	Danger of occupational injuries caused by the type of treads and edges, rough surfaces and protruding parts on the machines for geological drilling and explorations
08.1	Danger of occupational injuries caused by work at height in servicing and maintenance the machines for geological drilling and explorations
	Danger of ocupational injuries caused by the possibility of slipping or tripping (wet or slippery surfaces) on the machines and / or explorated area on which the geological drillings are carried out

12.1	Danger of occupational injuries caused by mandatory use the means or equipment for personal protection at work (ear muffs, goggles, gloves, etc.).
14.1	Danger of occupational injuries caused by difficulty of precision work and difficulty of movement due to the mandatory use of personal protective equipment at work
18.1	Danger of occupational injuries caused by natural disasters and lightning and consequences of atmospheric discharge.
12.2 Specified list of hazards	
21.1	Hazard on health caused by chemical hazards caused by operation of diesel generators, work with muds containing chemicals and dusts that occur in geological drilling
22.1	Hazard on health caused by noise from the operation of diesel generators and machines for geological drilling and exploration
25.1	Hazard on health caused by insufficient illumination during night work
27.1	Hazard on health caused by adverse climate impacts in working outdoors during geological drilling and exploration
29.1	Hazard on health caused by hazards arising from the use of oils, lubricants, diesel fuel, and others.
30.1	Hazard on health caused by physical efforts and stresses during manual transfer of pipes, tools and equipment for geological drilling
31.1	Hazard on health caused by non-physiological body position during prolonged standing, squatting or kneeling in control and operation of machines for geological drilling and exploration
32.1	Hazard on health caused by the efforts of psychophysical stresses in monitoring and control the operation of machines for geological drilling and exploration,
33.1	Hazard on health caused by responsibility in receiving and transferring the information, using the appropriate knowledge and skills to work on machines for geological drilling and exploration,
34.1	Hazard on health caused by prolonged work as well as work at night for geological drilling and exploration.

13 ASSESSMENT OF OH&S RISK						
13.1	**Risk assessment for determined specified hazards**	**V**	**T**	**U**	**R-Risk**	**Specified measures for risk assessment**
01.1	Danger of occupational injuries caused by rotating or moving parts of the machine for geological drilling and explorations	6	3	6	108	Instructions for safe operation in geological drilling
02.1	Danger of occupational injuries caused by movement of parts during geological drilling and explorations	6	3	6	108	Use of technical protective devices; Instructions for safe operation in geological drilling
03.1	Danger of occupational injuries caused by movement of machines and vehicles as well as the equipment used in geological drilling and explorations	3	3	6	54	Instructions for safe operation in geological drilling;

04.1	Danger of occupational injuries caused by the use of compressors and diesel generators that produce high pressures and that can cause explosions and fires	3	3	6	54	Instructions for safe operation on the machine
05.1	Danger of occupational injuries caused by inability or limitations for timely removal from the place of work on the machine for geological drilling and explorations	6	3	6	108	Instructions for safe operation on machines
06.1	Danger of occupational injuries caused by potential traffic accidents in the management of intermittent of passenger car or light truck on categorized and uncategorized roads and transportation of working staff from the base to the place of work and vice versa;	6	3	6	108	Protective measures in the use of motor vehicles
07.1	Danger of occupational injuries caused by the type of treads and edges, rough surfaces and protruding parts on the machines for geological drilling and explorations	3	3	6	54	General instructions for safe operation; Instructions – safety measures at the site
08.1	Danger of occupational injuries caused by work at height in servicing and maintenance the machines for geological drilling and explorations	6	3	6	108	Instructions for safe work at height
10.1	Danger of ocupational injuries caused by the possibility of slipping or tripping (wet or slippery surfaces) on the machines and/or explorated area on which the geological drillings are carried out	3	3	6	54	Instructions – safety measures at the site ; Protective measures against slipping, tripping and falling
12.1	Danger of occupational injuries caused by mandatory use the means or equipment for personal protection at work (ear muffs, goggles, gloves, etc.).	3	3	6	54	Protection measures in the use of PPE
14.1	Danger of occupational injuries caused by difficulty of precision work and difficulty of movement due to the mandatory use of personal protective equipment at work	3	3	6	54	Protection measures in the use of PPE
18.1	Danger of occupational injuries caused by natural disasters and lightning and consequences of atmospheric discharge.	1	3	1	3	Operating Instructions for geological drillings

13.2	Risk assessment for determined specified hazards	V	T	U	R-Risk	Specified measures for risk assessment
21.1	Hazard on health caused by chemical hazards caused by operation of diesel generators, work with muds containing chemicals and dusts that occur in geological drilling	6	3	6	108	Use of personal protective equipment
22.1	Hazard on health caused by noise from the operation of diesel generators and machines for geological drilling and exploration	6	3	6	108	Use of personal protective equipment
25.1	Hazard on health caused by insufficient illumination during night work	3	3	6	54	Instructions – safety measures at the site
27.1	Hazard on health caused by adverse climate impacts in working outdoors during geological drilling and exploration	6	3	6	108	Use of personal protective equipment
29.1	Hazard on health caused by hazards arising from the use of oils, lubricants, diesel fuel, and others.	6	3	6	108	Use of personal protective equipment
30.1	Hazard on health caused by physical efforts and stresses during manual transfer of pipes, tools and equipment for geological drilling,	6	3	6	108	Use of personal protective equipment
31.1	Hazard on health caused by non-physiological body position during prolonged standing, squatting or kneeling in control and operation of machines for geological drilling and exploration,	6	3	6	108	Use of personal protective equipment
32.1	Hazard on health caused by the efforts of psychophysical stresses in monitoring and control the operation of machines for geological drilling and exploration,	3	2	6	36	Proper use the prescribed work breaks (daily, weekly, yearly)
33.1	Hazard on health caused by responsibility in receiving and transferring the information, using the appropriate knowledge and skills to work on machines for geological drilling and exploration,	3	2	6	36	Proper use the prescribed work breaks (daily, weekly, yearly)
34.1	Hazard on health caused by prolonged work as well as work at night for geological drilling and exploration.	3	2	6	36	Proper use the prescribed work breaks (daily)

13.3 Comment on assessed dangers and hazards:

Based on identified, analyzed and defined specific dangers and hazards at work place and working environment **Driller-Geological exploratory drilling**, the assessed probabilities of occurrence the occupational injuries, damage to health and diseases in relation to the work and assessment the severity of injury, damage to health and diseases in relation with, the **MEDIUM RISK (R III)** was assessed of occupational injuries, damage to health and diseases related to work.

13.4 Opinion of occupational health service:

Professional team of occupational health service has reviewed the assessed dangers and hazards for the work place **Driller-Geological exploratory drilling** and thinking that the **indications exists** for proclamation the work place with increased risk.

13.5 The final conclusion of the Team for assessment the OH&S risk:

Based on the assessed specific dangers, theTeam for assessment the OH&S risks brings:
THE FINAL CONCLUSION
For the work place **Driller-Geological exploratory drilling,** the **RISK LEVEL R III – MEDIUM RISK** was established for occupational injuries, damage to health and diseases in relation to the work. Based on the final conclusion on assessment the OH&S risks, the mentioned work place is categorized as the work place with **INCREASED RISK.**
For establishing the mechanism of control/management with increased OH&S risks, it is needed to define the **MANAGEMENT PLAN OF ASSESSED OH&S RISKS.**

14 PLAN OF MANAGEMENT THE ASSESSED OH&S RISKS

Risk	List of increased OH&S risks for the workplace driller - geological exploration drilling	Hierarchy of management the increased OH&S risks					Priority
		1 Measures of complete risk elimination:	2 Measure of risk replacement (substitution)	3 Measures of technical (engineering) risk control:	4 Measures of signaling the warnings or administrative control risk:	5 Measures for application the PPE and equipment for BNR	
108	Risk of occupational injuries caused by rotating or moving parts of the machine for geological drilling and exploration	Not applicable	Mandatory application the technical protection devices with rotating or moving parts	Mandatory daily and weekly inspection and periodic testing	Mandatory application the procedures, instructions. Mandatory training for safe operation. Mandatory periodic medical examination	Mandatory use of personal protective equipment and equipment for safe operation	High
108	*x*						
54	*y*						
36	*z*						

CONCLUSION

Institutional changes that have occurred in the Republic of Serbia in the field of health and safety at work have inevitably caused the need for development and improvement of tools for decision making in planning and management the system of health and safety at work. Making decisions based on the previously presented models and methods of assessment the OH&S risks is a flexible approach that is proactive and provides identification, determining the prio-rities and documentation on OH&S risks, as well as implementation the Plan of measures for control the assessed OH&S risks.

Based on a detailed identification and hazard analysis of dangers and hazards for the work place *Driller - geological exploratory drilling* in the organization *"Geops Balkan Drilling Services" Ltd.,* it can be concluded that the optimized method Kinny and methodological approach to the assessment OH&S risks has fulfilled its purpose and gave the satisfactory results.

Management of OH&S risks in accordance with this methodological approach is very reliable and useful tool for decision makers in fulfilling the policy and objectives in terms of health and safety at work.

The optimized model of assessment the OH&S risks based on the Kinny method, applied in this paper, is practically tested in the other similar organizations such as: *Drillex International Ltd., International Drilling Service Ltd.* and *Stara Planina Resources Ltd.* Based on this model, the efficient and effective management of occupational health and safety at work was established in accordance with SRPS OHSAS 18001: 2008.

From practical application the optimized model for assessment the OH&S risks in management of OH&S system, it can be concluded that in the most stages of geological exploratory drilling the increased OH&S risk is present, but that the same can be managed only if the planned measures are applied under the Plan of measures to control the assessed OH&S risks.

Thus proposed methodological procedure for assessment the OH&S risks can be of great use to the other organizations that use this method of risk assessment or deal with similar activities. Assessment of OH&S risks and establishing the control mechanisms of management is of great use in a system design of management the occupational health and safety at work. The proposed valuation model of OH&S risksenables that the information about OH&S risk are adequately processed and use in decision making at the relevant levels of the organization dealing with works on geological exploratory drillings.

Active and comprehensive assessment of OH&S risk as it is defined in this paper, the management organization that deals with geological exploratory drillings can:

- accept and approve the management policy by assessed OH&S risk;
- inform all stakeholders in the process of geological exploratory drillings;
- define the mechanisms of control the assessed OH&S risks that correspond to the performances of organization;
- provide the compliance with legal regulations and subordinate legilastion as well as the legal acts of organization;
- provide the distribution of needed resources for managing theassessed OH&S risk.

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RAZVOJ MODELA PROCENE OH&S RIZIKA ZA RADNO MESTO BUŠAČ U PROCESU IZVOĐENJA GEOLOŠKIH ISTRAŽNIH BUŠENJA

Izvod

U radu je kreiran model procene OH&S rizika za radno mesto bušač u procesu izvođenja geoloških istražnih radova. Model procene OH&S rizika za radno mesto bušač bazira se na standardu ISO 31010 i ispunjenju zahteva standarda OHSAS 18001 i zakonske regulative. U ovom slučaju korišćena je delimično prilagođena i optimizovana Kinny metoda. Model procene OH&S rizika daje realne osnove za razvoj i implementaciju sistema menadžmenta zaštite zdravlja i bezbednosti na radu u skladu sa SRPS OHSAS 18001:2008, s obzirom da je praktično primenjen i proveren u organizacijama koje se bave geološkim istražnim bušenjima kao što su "Geops Balkan Driling Services" d.o.o, Drillex International d.o.o, International Drilling Service d.o.o kao i Stara Planina Resources d.o.o

Ključne reči: *OH&S rizik, bušač, geologija, istražna bušenja*

1. UVOD

Bezbednost i zdravlje na radu je veoma značajan segment rada kod svakog poslodavca – bez obzira na vrstu delatnosti koju poslodavac obavlja. Sistemskim pristupom bezbednosti i zdravlja na radu daje se značaj prevenciji u svim fazama rada. Procenom OH&S rizika teži se kontrolisanju rizika radi otklanjanja opasnosti i štetnosti od povreda na radu, profesionalnih oboljenja i oboljenja u vezi sa radom i da bi se uspostavio – sistem upravljanja zaštitom zdravlja i bezbednošću na radu (OHSAS). Postizanje kvaliteta u upravljanju sistemom zaštite zdravlja i bezbednosti na radu nije moguće bez usklađivanja sa osnovnim zakonskim obavezama procene OH&S rizika.

Organizacije čija je delatnost geološko istražno bušenje za očekivati je da će se suočiti sa značajnim OH&S rizicima. Ukoliko OH&S rizici nisu adekvatno procenjeni i stavljeni pod konrolom mogu u negativnom smislu uticati na ostvarivanje ciljeva organizacije. Ciljevi organizacije se mogu odnositi na niz aktivnosti, od strateških inicijativa pa sve do operacija, a mogu se ogledati i u neusaglašenostima sa zakonskom regulativom i drugim zahtevima. S obzirom, da se tehnološki proces geoloških istražnih bušenja sastoji od operacija u kojima učestvuje značajan broj opasnih materija to potencijalni OH&S rizici mogu biti i veći.

Upravljanje OH&S rizikom podrazumeva primenu logičkih i sistematskih metoda za identifikaciju, analizu i procenu OH&S rizika tokom procesa geoloških

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istražnih bušenja, praćenje i preispitivanje rizika u cilju efektivnog i efikasnog upravljanja integrisanim sistemima menadžmenta kvalitetom (ISO 9001), zaštitom životne sredine (ISO 14001) i zaštitom zdravlja i bezbednosti na radu (OHSAS 18001).

Cilj ovog istraživanja je procena OH&S rizika u procesu geološkog istražnog bušenja uz pronalaženje odgovora na sledeća osnovna pitanja:

- Šta se u procesu geoloških istražnih bušenja može desiti i zašto (identifikacija opasnosti)?
- Koje su to verovatnoće pojave opasnosti i štetnosti?
- Da li se procenjenim OH&S rizicima može upravljati i da li se zahteva dalji tretman smanjenja OH&S rizika?
- Kako izvršiti planiranje mera zaštite zdravlja i bezbednosti na radu koje mogu da utiču na smanjenje verovatnoće pojave opasnosti i štetnosti?

U skladu sa utvrđenim ciljem istraživanja, postavljena je se sledeća hipoteza istraživanja:

a) Na osnovu sistemskog pristupa moguće je izvršiti identifikaciju, analizu opasnosti i procenu OH&S rizika i uspostaviti mehanizme za kontrolu procenjenih OH&S rizika.

Na osnovu identifikacije problema, postavljenog cilja i hipoteze istraživanja proistekli su sledeći zadaci istraživanja i to:

1) izvršiti sistemsku analizu, i definisati model i metodu procene OH&S rizika;
2) izvršiti identifikaciju opasnosti, utvrditi verovatnoću pojave i potencijalnih posledica;
3) izvršiti procenu OH&S rizika za konkretno radon mesto.
4) definisati Plan mera za kontrolu povećanih OH&S rizika.

U cilju ispunjenja zadataka istraživanja i postizanja cilja i provere postavljene hipoteze istraživanja korišćene su poznate metode koje su doprinele poboljšanju metodologiji istraživanja, a to su:

1) deskriptivna metoda (metoda zapažanja i opisivanja) kroz analizu dostupnih podataka;
2) metoda analize teorije i prakse;
3) metoda opšte teorije sistema odnosno sistemskoh pristupa i sistemske analize;
4) metoda modeliranja procesa, i izrade dijagrama toka.

2. TEORIJSKI PRISTUP, IZABRANI METODOLOŠKI POSTUPAK I METODA PROCENE OH&S RIZIKA

2.1. Teorijski pristup procene OH&S rizika

Da bi se ispunili zahtevi standarda OHSAS 18001 kao i zahtevi zakonske regulative potrebno je da za sve opasnosti i štetnosti koje se javljaju i/ili se mogu javiti na radnom mestu **bušač u procesu geoloških istražnih bušenja** izvrši procena OH&S rizika. Radi efektivne i efikasne procene OH&S rizika, neophodno je koristiti odgovarajuću metodu koja će dati proaktivne, a ne reaktivne rezultate procene [10]. Efektivnost i efikasnost OH&S sistema se ne može postići samo procenom OH&S rizika, već je neophodno da nakon izvršene procene OH&S rizika organizacija obezbediti uslove da se rezultati procene OH&S rizika uzmu u obzir prilikom uspostavljanja OH&S sistema i definiše plan upravljanja povećanih OH&S rizicima.

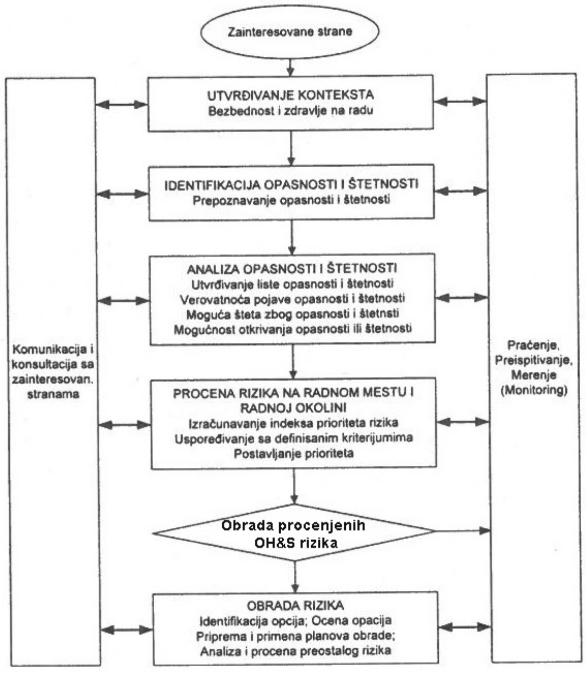
U svetu, a i u R. Srbiji je najčešće upotrebljeni alat za uspostavljanje, održavanje i unapređivanje sistema upravljanja zaštitom zdravlja i bezbednošću na radu standard OHSAS 18001. OH&S sistem je strukturiran proces za savlađivanje OH&S rizika. Navedenim standardom su precizno dati zahtevi nekih ključnih elemenata sistema upravljanja zaštitom zdravlja i bezbednošću na radu kao što su: prepoznavanje opasnosti i štetnosti koje mogu nastati gde se obavezno uzimaju u obzir ponašanja i sposobnosti zaposlenih, vođenje, komunikacija, sarađivanje i savetovanje sa zaposlenima.

Upravljati OH&S rizicima znači pronaći onu prihvatljivu kombinaciju koja omogućava akcije povećanja bezbednosti i zdravlja na radu i otklanjanja svih opasnosti i štetnosti koje dovode u pitanje optimalno funkcionisanje OH&S sistema. Upravljanje OH&S rizicima moguće je ostvariti uz pretpostavke koje podrazumevaju sledeće:

- pravovremeno identifikovanje svih opasnosti i štetnosti;
- utvrđivanje liste opasnosti i štetnosti koje imaju uticaj na OH&S sistem;
- analiza ranijih podataka o posledicama nastanka povreda na radu, profesionalnih oboljenja i oboljenja u vezi sa radom;
- analiza pojedinačnih opasnosti i štetnosti njihovo grupisanje po srodnosti;
- analiza međuzavisnosti pojedinačnih opasnosti i štetnosti i njihovih eventualnih posledica;
- procena OH&S rizika za utvrđenu listu opasnosti i štetnosti;
- formiranje okruženja koje neguje tradiciju timskog rada;
- razvoj metoda i tehnika za procenu i upravljanjeOH&S rizicima;
- uspostavljanje optimalnog nivoa bezbednosti na radu;
- donošenje ciljeva, planova i programa za upravljanje procenjenim OH&S rizicima.

Za efikasnu kontrolu OH&S rizika, potrebno je znati upravljati informacijama na osnovu kojih se donose zaključci i odluke, tj. potrebno je obratiti pažnju na kvalitet informacija kojima se raspolažu iz Akta o proceni OH&S rizika.

Procena OH&S rizika u poslovnom procesu nije ni u kom slučaju neka konstanta, već dinamička veličina koja se menja od trenutka do trenutka. Svaki puta kada se promeni neki od elemenata opasnosti i štetnosti, menja se i nivo OH&S rizika. Postoji standard koji definiše proces procene rizika ISO 31010: 2010 [8].



Sl. 1. *Blok dijagram procesa procene OH&S rizika*[8], [12]

2.2. Izabrana metoda procene OH&S rizika

Jedna od metoda kojom je moguće izvršiti procenu OH&S rizika je Kinny metoda. OH&S rizici se tokom vremena menjaju kroz tri osnovne kategorije koje analizira metoda Kinny i to:

- verovatnoća pojave opasnosti i štetnosti;
- težina posledica koje mogu nastati kod pojave opasnosti i štetnosti;
- učestalost pojavljivanja opasnosti i štetnosti.

Na osnovu identifikacije opsanosti štetnosti na radnom mestu i radnoj okolini i statističke obrade podataka o opasnim događajima (povredama na radu), opasnim materijama i kritičnim tačkama procesa može se izvršiti procena OH&S rizika.

Postupkom identifikacije opasnosti i štetnosti i vrednovanja uticaja postiže se sledeće:

- identifikuju se sve opasnosti i štetnosti koje mogu imati uticaja na radno mesto i radnu okolinu;
- analiziraju se uticaji opasnosti i štetnosti na radno mesto i radnu okolinu;
- utvrđuje se sistem vrednovanja svake opasnosti i štetnosti;
- određivanja značaja svake opasnosti i štetnosti.

Parametri analize se numerički vrednuju, pa je i konačna procena OH&S rizika na radnom mestu i radnoj okolini izražena numerički. Osnovna postavka metode Kinny u funkciji procene rizika na radnom mestu i radnoj okolini je u suštini jednostavna i laka za razumevanje. Suština metode sastoji se u realizaciji sledećih aktivnosti:

a) utvrđivanje svih potencijalnih opasnosti i štetnosti koje su/ili mogu nastati kao posledica procesa rada;
b) utvrđivanje mogućih uzroka nastanka svake opasnosti i štetnosti;
c) analiza svake opasnosti i štetnosti sa ciljem da se analitičkim metodama utvrde:
   - verovatnoća pojave potencijalne opasnosti i štetnosti;
   - težina posledica koje koje zaposleni trpi kod pojave opasnosti i štetnosti;
   - učestalost pojavljivanja opasnosti i štetnosti.
d) vrednovanje nivoa rizika čine proizvod tri faktora i to:
   - verovatnoća pojave opasnosti i štetnosti - V;
   - težina posledice zbog pojave opasnosti i štetnosti - P;
   - učestalost pojavljivanja opasnosti i štetnosti - U;

Vrednovanje rizika **R** vrši se po formuli:

R = V x P

Tabela 1. *Matrica procene rizika po Kinny metodi [11]*

Identifikovana opasnost ili štetnost	PROCENA OH&S RIZIKA R = V x P		
	Verovatnoća V	Posledica P	Nivo rizika R
x			
y			
z			

2.2.1. Kriterijum za procenu verovatnoće - V

Tabela 2. *Opis kriterijuma za procenu verovatnoće pojave opasnosti i štetnosti [11]*

RANG	OPIS KRITERIJUMA ZA PROCENU VEROVATNOĆE - V
0,1	*Jedva pojmljivo*
0,2	*Praktično neverovatno*
0,5	*Postoji, ali samo malo verovatno*
1	*Mala verovatnoća, ali moguća u ograničenim slučajevima*
3	*Malo moguće*
6	*Sasvim moguće*
10	*Predvidivo, očekivano*

2.2.2. Kriterijum za procenu posledica - P

Tabela 3. *Opis kriterijuma za procenu posledica kod pojave opasnosti i štetnosti [11]*

RANG	OPIS KRITERIJUMA ZA PROCENU POSLEDICA - P
1	*Bolest, povreda koja zahteva prvu pomoć i nikakav drugi tretman*
2	*Medicinski tretman od strane lekara*
3	*Ozbiljne-invalidnost, ozbiljna pojedinačna povreda sa hospitalizacijom i izgubljenim danima*
6	*Veoma ozbiljne-pojedinačne nesreće sa smrtnim ishodom*
10	*Katastrofalne-sa višestrukim smrtnim ishodima*

2.2.3. Kriterijum za procenu učestalosti pojavljivanja opasnosti i štetnosti - U

Tabela 4. *Opis kriterijuma za procenu učestalost pojavljivanja opasnosti i štetnosti [11]*

RANG	OPIS KRITERIJUMA ZA UČESTALOST - U
1	*Izlaže se retko (godišnje)*
2	*Izlaže se mesečno*
3	*Izlaže se nedeljno*
6	*Izlaže se dnevno*
10	*Izlaže se trajno, kontinualno*

2.3.4. Kriterijumi za klasifikaciju nivoa rizika (R)

Tabela 5. *Kriterijumi za određivanje nivoa rizika [11]*

Ukupna ocena	Klasa rizika	Klasifikacija nivoa rizika	Opis klasifikacije nivoa rizika
>0,1 <20	R I	Zanemarljivo mali rizik	*Ne zahteva se nikakva akcija.*
>20 <70	R II	Mali rizik	*Nema potrebe za dodatnim aktivnostima pri upravljanju operacijom.* *Može se razmotriti ekonomski isplativije rešenje ili unapređenje bez dodatnih ulaganja. Potrebno je pratiti situaciju, kako bi posedovali informacije o sprovođenju propisanih aktivnosti.*
>70 <200	R III	Srednji rizik	*Potrebno je uložiti napor kako bi se smanjio rizik, ali troškovi prevencije moraju biti pažljivo planirani i ograničeni do izvesnog nivoa.* *Potrebno je definisati rok za sprovođenje unapređenja.* *Kod onih događaja kod kojih mogu nastupiti izuzetno opasne posledice, potrebno je dodatno proveriti verovatnoću nastanka takvog događaja kako bi se definisao potreban nivo aktivnosti na ublažavanju rizika.*
>200 <400	R IV	Veliki rizik	*Ne sme se započeti sa datom aktivnošću dok nivo rizika ne bude snižen.* *Potrebna su znatna sredstva kako bi se rizik smanjio.* *Ako se rizik odnosi na sve započete aktivnosti, potrebno je preduzeti hitne akcije na smanjenju nivoa rizika.*
>400 <1000	R V	Ekstremno veliki rizik	*Aktivnost ne sme biti započeta ni nastavljena, sve dok se nivo rizika ne smanji na prihvatljivi nivo.* *Ako ulaganjem ograničenih sredstava nije moguće smanjiti nivo rizika na prihvatljiv nivo, aktivnost mora ostati zabranjena.*

2.2.5. Kategorizacija i karakterizacija rizika

Tabela 6. *Kriterijumi za kategorizaciju i karakterizaciju rizika [11]*

Procena nivoa rizika	Kategorizacija nivoa rizika	Karakterizacija rizika
R I	Zanemarljivo mali rizik	*Prihvatljiv rizik*
R II	Mali rizik	*Prihvatljiv rizik*
R III	Srednji rizik	*Povećani rizik*
R IV	Veliki rizik	*Neprihvatljiv rizik*
R V	Ekstremno veliki rizik	*Neprihvatljiv rizik*

Tabela 7. *Opis karakterizacije rizika [11]*

Karakter rizika	Opis karakterizacije rizika
Prihvatljiv rizik ***Prihvatljiv rizik***	*Rizik za koji postoji procena i pretpostavka da neće uzrokovati:* - *povrede na radu i oboljenja u vezi sa radom,* - *neusaglašenost sa zakonskom regulativom i/ili odstupanje od propisane organizacije rada i* - *odstupanje od propisane politike sistema zaštite zdavlja i bezbednosti na radu u organizaciji.*
Povećani rizik	*Rizik za koji postoji procena i pretpostavka da u određenim okolnostima može uzrokovati:* - *povrede na radu i oboljenja u vezi sa radom,* - *delimičnu neusaglašenost sa zakonskom regulativom i/ili odstupanje od propisane organizacije rada i* - *povremeno odstupanje od propisane politike i ciljeva sistema zaštite zdavlja i bezbednosti na radu.*
Neprihvatljiv rizik ***Neprihvatljiv rizik***	*Rizik za koji postoji procena i pretpostavka da direktno uzrokuje:* - *povrede na radu i oboljenja u vezi sa radom,* - *neusaglašenost sa zakonskom regulativom;* - *odstupanje od propisane organizacije rada i* - *odstupanje od propisane politike i ciljeva sistema zaštite zdravlja i bezbednosti na radu.*

3. REZULTATI ISTRAŽIVANJA - PRAKTIČAN PRIMER PROCENE OH&S RIZIKA

Šifra r.m.	**PREPOZNAVANJE I UTVRĐIVANJE OPASNOSTI I ŠTETNOSTI I PROCENA RIZIKA NA RADNOM MESTU: BUŠAČ - GEOLOŠKIH ISTRAŽNIHBUŠENJA**
III GRUPA	
1. OPŠTI PODACI O RADNOM MESTU	
1.1. Naziv radne organizacije:	**"GEOPS BALKAN DRILING SERVICES" D.O.O**
1.2. Sektor:	Izvođenje geoloških istražnih bušenja
1.3. Služba:	/
1.4. Odeljenje:	/

2. PODACI O PROCESU RADA:
2.1. Poslovi po sistematizaciji poslova i radnih zadataka (opis poslova):   **Bušač - geoloških istražnih bušenja:**
Izvode se radovi primenom odgovarajućih mašina i metoda za istraživanje mineralnih sirovina. Vrše se bušenja na geološki ispitanim područjima u cilju pronalaženja čvrstih mineralnih sirovina. Mašina za istražna bušenja je montirana na specijalnom vozilu sa gusenicama na kome su postavljeni svi radni i pogonski delovi mašine, a isti su rasporedjeni i učvršćeni na bezbedan način. Komandovanje mašinom se vrši na odgovarajući način sa komandnog pulta.   Bušenje rupa se izvodi preko pogonskog motora sa reduktorom i sistema za bušenje sa dijamantskim alatima koji se montiraju na specijalnim cevima. Vrši se montaža i demontaža dijamantskih alata na mašini. Vrši se učvršćivanje alata za bušenje i spajanje nastavaka na odgovarajući način. Vrši vadjenje uzoraka geoloških jezgara preko pneumatskih sistema i sistema užadi i doboša i isto se izvodi na bezbedan način. Nadgleda i preduzima odgovarajuće mere na hladjenju alata za bušenje preko sistema za hladjenje koji se pogoni preko odgovarajuće pumpe. Vrši se nadgledanje rada agregata za snabdevanje električnom energijom.
Povremeni poslovi: Po potrebi upravlja motornim vozilom od mesta rada do baze i obratno.

3. PODACI O RADNOM I POMOĆNOM PROSTORU				
3.1. Objekti:	Poslovni prostor u Boru, ul. Danila Kiša 6/28			
3.2. Radni prostor:	Aktuelno radilište na istražnom prostoru Brestovac - Metovnica			
3.3. Grupa elemenata radnog prostora	**3.3.1. Elementi radnog prostora**	**3.3.2. Propisani zahtevi**	**3.3.3. Ocena stanja radnog prostora**	
			Zadovoljava ✓	**Ne zadovolja. ×**
1) Veličina i visina radne prostorije	Slobodna površina poda	2 m^2 po radniku	/	
	Slobodan vazdušni prostor	10 m^3 po radniku	/	
	Visina radne prostorije	min. 2,5 m	/	
2) Podovi	Nivo poda	iznad nivoa okolnog zemljišta	/	
	Materijal poda	otporan na habanje, vodonep.	/	
	Način izrade	ravan gladak ali ne klizav	/	
	Stanje i održavanje	redovno	/	
3) Zidovi i plafon	Materijal i izvođenje	toplotna, zvučna zaštita	/	
	Obrada i boja	malterisano i obojeno	/	
	Stanje i održavanje	svetla površina / redovno	/	
4) Vrata	Smer otvaranja i širina	u zavisn. od namene prostor.	/	
	Broj i raspored	na 30 do 50m min jedna vrata	/	
5) Prozori	Površina prozorskih otvora	min 12,5 % površine poda	/	
	Upadni ugao svetla	min 24^0	/	
	Princip i način otvaranja	sa lakoćom	/	
6) Zagrevanje	Način zagrevaja	parno grejanje	/	
	Raspored grejnih tela	propisno	/	
	Stanje i održavanje	po planu održavanja	/	
7) Mikroklima	Temperatura prostorije	18-22^0 C	/	
	Relativ. vlažnost prostori.	65-80 %	/	
	Brzina strujanja vazduha	0,3 m/s (klimatizovano)	/	
8) Osvetljenje	Opšta rasveta	klasična propis. izvedena	/	
	Lokalna rasveta	ne zahteva se	/	
9) Ostalo	Sanitarne prostorije	propis. izvedene	/	
	Garderobe	ne zahteva se	/	
	Ormarić za prvu pomoć	propisana oprema i postoji	/	
3.4. Pomoćni radni prostor:	/			
3.5. Napomena:	Rad se izvodi na otvorenom prostoru			

4. RASPOLOŽIVA SREDSTVA I OPREMA ZA RAD	
4.1. Mašine	Mašine za geološka bušenja CHRISTENSEN CS 14; CHRISTENSEN CS 10; CHRISTENSEN CS 14 - CE C 20;
4.2. Uređaji	Kompresori, pumpe i dr.
4.3. Postrojenja	/
4.4. Instalacije	Komprimirani vazduh
4.5. Alat i pribor	Različite vrste alata za pritezanje cevi koje se koriste za geološka bušenja
4.6. Druga sredstva za rad	Kombinovani putničko - teretni automobil

5. MATERIJALI, SIROVINE I DRUGE SUPSTANCE KOJE SE KORISTE U PROCESU RADA	
5.1. Materijali	Različite vrste repromaterijala kao što su: ulja i maziva; AMC CR650 RD
5.2. Sirovine	Uzorci mineralnih sirovina koji se dobijaju pri geološkom bušenju
5.3. Druge supstance	/

6. OSPOSOBLJAVANJE I OBUKE	
6.1. Specifično stručno osposobljavanje:	Da, obuka za rukovanje mašinom
6.2. Obuka za zaštitu zdravlja i bezbednost na radu:	Da, obuka je izvršena
6.3. Obuka za zaštitu od požara:	Da, obuka je izvršena

7. OPREMA I SREDSTVA ZA LIČNU ZAŠTITU NA RADU		Ocena stanja
7.1. Sredstva za zaštitu glave:	Zastitni šlem	Zadovoljava
7.2. Sredstva za zaštitu tela:	Zaštitno odelo; Zaštni identifikacioni prsluk	Zadovoljava
7.3. Sredstva za zaštitu ruku:	Zaštitne rukavice	Zadovoljava
7.4. Sredstva za zaštitu nogu:	Zaštitne cipele sa čeličnom kapnom; Zaštitne gumene čizme sa čelič.kap.	Zadovoljava
7.5. Sredstava za zaštitu očiju:	Zaštitne naočare	Zadovoljava
7.6.Sredstava za zašt. sluha:	Zaštitni antifoni; Čepići za uši i dr.	Zadovoljava
7.7. Oprema za bezbedan rad:	Sigurnosni pojas za rad na visini	Zadovoljava

8. ORGANIZACIJA RADA			
8.1. Uslovi za zasnivanje radnog odnosa:			
Stepen stručne spreme	Od II do VI		
Obrazovni profil	Svih struka		
Radno iskustvo	Poželjno je		
Posebno znanje, veštine i sposobnost	Sposobnost upravlanja motornim vozilom		
8.2. Opšti podaci o izvršiocima:			
Ukupan broj zaposlenih na radnom mestu/grupi:	>4	Muškarci: da	Žene: ne
Na radnom mestu rade invalidi rada:	Ne	Muškarci:/	Zene: /

8.3. Opšti zahtevi radnog mesta:			
Angažovanje prema mestu aktivnosti	U radnim prostorijama	Kancelarija	0%
		Pom. radne prostorije	0%
	Rad na otvorenom	Terenski rad	100 %
		Radilište	100 % povremeno
		Rad sa prevoznim sredstvom	Da, povremeno
Izvršavanje zadataka	Radi u smenama	Da	
	Radi noću	Da	
	Organizuje i rukovodi	Da	

9. ANALIZA POSTOJEĆEG STANJA BEZBEDNOSTI I ZDRAVLJA NA RADNOM MESTU		
9.1. Element bezbednosti na radu	9.2. Usklađenost sa zahtevima	
	Da ✓	Ne ×
Važeći stručni nalazi o izvršenim pregledima i ispitivanjima sredstava za rad	✓	
Važeći stručni nalazi o izvršenim pregledima i ispitivanjima uslova rada	✓	
Izveštaji o prethodnim i periodičnim lekarskim pregledima zaposlenih	✓	
Podaci o povredama na radu	✓	
Podaci o profesionalnim bolestima i oboljenjima u vezi sa radom	✓	
Sredstva i oprema za ličnu zaštitu na radu	✓	
Analiza preduzetih mera radi sprečavanja povreda na radu	✓	
Uputstva za bezbedan rad	✓	
Propisana dokumentacija za upotrebu i održavanje, odnosno pakovanje, transport, korišćenje, skladištenje, uništavanje i dr.	✓	
Zaštita od požara	✓	

10. PREPOZNAVANJE OPASNOSTI NA RADNOM MESTU				
10.1. Grupisanje opasnosti				
Grupa opasnosti	Šifra	Podgupa opasnosti	Opasnosti ✓IMA	/×NEMA
1) Mehaničke opasnosti koje se pojavljuju korišćenjem opreme za rad kao što su:	(01)	Nedovoljna bezbednost zbog rotirajućih ili pokretnih delova,	✓	
	(02)	Slobodno kretanje delova ili materijala koji mogu naneti povredu zaposlenom,	✓	
	(03)	Unutrašnji transport i kretanje radnih mašina ili vozila, kao i pomeranja određene opreme za rad,	✓	
	(04)	Korišćenje opasnih sredstava za rad, koja mogu proizvesti eksplozije ili požar,	✓	
	(05)	Nemogućnost ili ograničenost pravovremenog uklanjanja sa mesta rada, izloženost zatvaranju, mehaničkom udaru, poklapanju, i sl.,	✓	
	(06)	Drugi faktori koji mogu da se pojave kao mehanički izvori opasnosti.	✓	

2) Opasnosti koje se pojavljuju u vezi sa karakteristikama radnog mesta kao što su:	(07)	Opasne površine (podovi i sve vrste gazišta, površine sa kojima zaposleni dolazi u dodir, a koje imaju oštre ivice-rubove, šiljke, grube površine, izbočene delove, i sl.)	✓	
	(08)	Rad na visini ili u dubini, u smislu propisa o bezbednosti i zdravlju na radu,	✓	
	(09)	Rad u skučenom, ograničenom ili opasnom prostoru (između dva ili više fiksiranih delova, između pokretnih delova ili vozila, rad u zatvorenom prostoru koji je nedovoljno osvetljen ili provetravan, i sl.),		×
	(10)	Mogućnost klizanja ili spoticanja (mokre ili klizave površine),	✓	
	(11)	Fizička nestabilnost radnog mesta,		×
	(12)	Moguće posledice ili smetnje usled obavezne upotrebe sredstava ili opreme za ličnu zaštitu na radu,	✓	
	(13)	Uticaji usled obavljanja procesa rada korišćenjem neodgovarajućih ili neprilagođenih metoda rada,		×
	(14)	Druge opasnosti koje se mogu pojaviti u vezi sa karakteristikama radnog mesta i načinom rada (korišćenje sredstava i opreme za ličnu zaštitu na radu koja opterećuju zaposlenog, i sl.);	✓	
3) Opasnosti koje se pojavljuju korišćenjem električne energije, kao što su:	(15)	Opasnost od direktnog dodira sa delovima električne instalacije i opreme pod naponom,		×
	(16)	Opasnost od indirektnog dodira,		×
	(17)	Opasnost od toplotnog dejstva koje razvijaju električna oprema i instalacije (pregrevanje, požar, eksplozija, električni luk ili varničenje, i dr),		×
	(18)	Opasnosti usled udara groma i posledica atmosferskog pražnjenja	✓	×
	(19)	Opasnost od štetnog uticaja elektrostatičkog naelektrisanja,		×
	(20)	Druge opasnosti koje se mogu pojaviti u vezi sa korišćenjem električne energije.		×

11. PREPOZNAVANJE ŠTETNOSTI NA RADNOM MESTU				
11.1.Grupisanje štetnosti				
Grupa štetnosti	**Šifra**	**Podgupa štetnosti**	**Štetnosti ✓IMA / ×NEMA**	
1) Štetnosti koje nastaju ili se pojavljuju u procesu rada, kao što su:	(21)	Hemijske štetnosti, prašina i dimovi (udisanje, gušenje, unošenje u organizam, prodor u telo kroz kožu, opekotine, trovanje, i sl.),	✓	
	(22)	Fizičke štetnosti (buka i vibracije),	✓	
	(23)	Biološke štetnosti (infekcije, izlaganje mikroorganizmima i alergenima),		×
	(24)	Štetni uticaji mlkroklime (visoka ili niska temperatura, vlažnost i brzina strujanja vazduha),		×
	(25)	Neodgovarajuća - nedovoljna osvetljenost,	✓	
	(26)	Štetni uticaji zračenja (toplotnog, jonizujućeg ili nejonizujućeg, laserskog, ultrazvučnog),		×
	(27)	Štetni klimatski uticaji (rad na otvorenom),	✓	
	(28)	Štetnosti koje nastaju korišćenjem opasnih materija u proizvodnji, transportu, pakovanju, skladištenju ili uništavanju,		×
	(29)	Druge štetnosti koje se pojavljuju u radnom procesu, a koje mogu da budu uzrok povrede na radu zaposlenog, profesionalnog oboljenja ili oboljenja u vezi sa radom.	✓	

2) Štetnosti koje proističu iz psihičkih i psihofizioloških napora koji se uzročno vezuju za radno mesto i poslove koje zaposleni obavlja, kao što su:	(30)	Napori ili telesna naprezanja (ručno prenošenje tereta, guranje ili vučenje tereta, razne dugotrajne povećane telesne aktivnosti i sl.),	✓	
	(31)	Nefiziološki položaj tela (dugotrajno stajanje, sedenje, čučanje, klečanje i sl.),	✓	
	(32)	Napori pri obavljanju određenih poslova koji prouzrokuju psihološka opterećenja (stres, monotonija i sl.),	✓	
	(33)	Odgovornost u primanju i prenošenju informacija, korišćenje odgovarajućeg znanja i sposobnosti, odgovornost u pravilima ponašanja, odgovornost za brze izmene radnih procedura, intenzitet u radu, prostorna uslovljenost radnog mesta, konfliktne situacije, rad sa strankama i novcem, nedovoljna motivacija za rad, odgovornost u rukovođenju, i sl.;	✓	
3) Štetnosti vezane za organizaciju rada, kao štosu:	(34)	Rad duži od punog radnog vremena (prekovremeni rad), rad u smenama, skraćeno radno vreme, rad noću, pripravnost za slučaj intervencija,	✓	
4) Ostale štetnosti koje se pojavljuju na radnim mestima, kao što su:	(35)	Štetnosti koje prouzrokuju druga lica (nasilje prema licima koja rade na šalterima, lica na obezbeđenju, i sl.),		×
	(36)	Rad sa životinjama,		×
	(37)	Rad u atmosferi sa visokim ili niskim pritiskom,		×
	(38)	Rad u blizini vode ili ispod površine vode,		×
	(39)	Ostale opasnosti i štetnosti.		×

12. UTVRĐIVANJE LISTE OPASNOSTI I ŠTETNOSTI NA RADNOM MESTU	
12.1. Utvrđena lista opasnosti	
01.1	Opasnost od povreda na radu uzrokovana od rotirajućih ili pokretnih delova na mašini za geološka bušenja i istraživanja
02.1	Opasnost od povreda na radu uzrokovana od kretanja delova pri izvođenju geoloških bušenja i istraživanja
03.1	Opasnost od povreda na radu uzrokovana od kretanja radnih mašina i vozila kao i opreme koja se koristi pri geološkim bušenjima i istraživanjima
04.1	Opasnost od povreda na radu uzrokovana od korišćenje kompresora i dizel agregata koji proizvode velike pritiske i koji mogu uzrokovati eksplozije i požare
05.1	Opasnost od povreda na radu uzrokovana od nemogućnost ili ograničenost pravovremenog uklanjanja sa mesta rada na mašini za geološka bušenja i istrživanja
06.1	Opasnost od povreda na radu uzrokovana od potencijalnih saobraćajnih udesa pri povremenom upravljanju putničkim ili poluteretnim vozilom na kategorisanim i nekategorisanim putevima i prevozu radnog osoblja od baze do mesta rada i obratno;
07.1	Opasnost od povreda na radu uzrokovana od vrsta gazišta i rubova, grubih površina i izbočenih delova koji se nalaze na mašinama za geološka bušenja i istraživanja;
08.1	Opasnost od povreda na radu uzrokovana radom na visini pri opsluživanju i održavanju mašina za geološka bušenja i istraživanja

10.1	Opasnost od povreda na radu uzrokovana mogućnost klizanja ili spoticanja (mokre ili klizave površine) na mašinama i/ili na istražnom prostoru na kome se vrše geološka bušenja.
12.1	Opasnost od povreda na radu uzrokovana od usled obavezne upotrebe sredstava ili opreme za ličnu zaštitu na radu (antifoni; naočare; rukavice i sl.)
14.1	Opasnost od povreda na radu uzrokovana otežanom preciznošću rada i otežanom kretanju usled obaveznog korišćenja opreme za ličnu zaštitu na radu.
18.1	Opasnost od povreda na radu uzrokovana od prirodnih nepogoda i udara groma i posledica atmosferskog pražnjenja.
12.2. Utvrđena lista štetnosti	
21.1	Štetnost po zdravlje uzrokovan hemijskim štetnostima uzrokovana radom dizel agregata, radom sa isplakama koje sadrže hemijske supstance i prašina koje se javljaju pri geološkim bušenjima.
22.1	Štetnost po zdravlje uzrokovana bukom od rada dizel agregata i mašina za geološka bušenja i istraživanja.
25.1	Štetnost po zdravlje uzrokovana nedovoljnom osvetljenošću u toku noćnog rada
27.1	Štetnost po zdravlje uzrokovana štetnim klimatskim uticajima pri radu otvorenom prostoru u toku geoloških bušenja i istraživanja.
29.1	Štetnost po zdravlje uzrokovana štetnostima koje nastaju korišćenjem ulja, maziva, dizel goriva i sl.
30.1	Štetnost po zdravlje uzrokovana naporima i telesnim naprezanjima pri ručnom prenošenju cevi, alata i pribora za geološka bušenja.
31.1	Štetnost po zdravlje uzrokovana nefiziološkim položajem tela pri dugotrajnom stajanju, čučanju ili klečanju pri nadzoru i opsluživanju mašina za geološka bušenja i istraživanja.
32.1	Štetnost po zdravlje uzrokovana naporima psihofizičkih opterećenja u nadgledanju i kontoli rada mašina za geološka bušenja i istraživanje.
33.1	Štetnost po zdravlje uzrokovana odgovornošću u primanju i prenošenju informacija, korišćenju odgovarajućeg znanja i sposobnosti za rad na mašinama za geološka bušenja i istraživanja.
34.1	Štetnost po zdravlje uzrokovana produženim radom kao i radom noću pri geološkim bušenjima i istraživanjima.

13. PROCENA OH&S RIZIKA						
13.1	**Procena rizika za tvrđene konkretne opasnosti**	**V**	**T**	**U**	**R-Rizik**	**Mere kon. pro.riz.**
01.1	Opasnost od povreda na radu uzrokovana od rotirajućih ili pokretnih delova na mašini za geološka bušenja i istraživanja.	6	3	6	108	Uputstvo za bezbedan rad pri geološkim bušenjima.
02.1	Opasnost od povreda na radu uzrokovana od kretanja delova pri izvođenju geoloških bušenja i istraživanja.	6	3	6	108	Primena tehničkih zaštitnih naprava. Uputstvo za bezbedan rad pri geološkim bušenjima.

03.1	Opasnost od povreda na radu uzrokovana od kretanja radnih mašina i vozila kao i opreme koja se koristi pri geološkim bušenjima i istraživanjima.	3	3	6	54	Uputstvo za bezbedan rad pri geološkim bušenjima; Uputstvo – mere bezbednosti na radilištu.
04.1	Opasnost od povreda na radu uzrokovana od korišćenje kompresora i dizel agregata koji proizvode velike pritiske i koji mogu uzrokovati eksplozije i požare.	3	3	6	54	Uputstvo za bezbedan rad na mašinama
05.1	Opasnost od povreda na radu uzrokovana od nemogućnost ili ograničenost pravovremenog uklanjanja sa mesta rada na mašini za geološka bušenja i istrživanja.	6	3	6	108	Uputstvo za bezbedan rad na mašinama
06.1	Opasnost od povreda na radu uzrokovana od potencijalnih saobraćajnih udesa pri povremenom upravljanju putničkim ili poluteretnim vozilom na kategorisanim i nekategorisanim putevima i prevozu radnog osoblja od baze do mesta rada i obratno.	6	3	6	108	Mere zaštite pri upotrebi motornih vozila
07.1	Opasnost od povreda na radu uzrokovana od vrsta gazišta i rubova, grubih površina i izbočenih delova koji se nalaze na mašinama za geološka bušenja i istraživanja.	3	3	6	54	Opšte uputstvo za bezbedan rad; Uputstvo – mere bezbednosti na radilištu
08.1	Opasnost od povreda na radu uzrokovana radom na visini pri opsluživanju i održavanju mašina za geološka bušenja i istraživanja.	6	3	6	108	Uputstvo za bezbedan rad na visini
10.1	Opasnost od povreda na radu uzrokovana mogućnost klizanja ili spoticanja (mokre ili klizave površine) na mašinama i/ili na istražnom prostoru na kome se vrše geološka bušenja.	3	3	6	54	Uputstvo – mere bezbednosti na radilištu; Mere zaštite od klizanja, saplitanja i padanja
12.1	Opasnost od povreda na radu uzrokovana usled obavezne upotrebe sredstava ili opreme za ličnu zaštitu na radu (antifoni; naočare; rukavice i sl.).	3	3	6	54	Mere zaštite pri upotrebi LZS
14.1	Opasnost od povreda na radu uzrokovana otežanom preciznošću rada i otežanom kretanju usled obaveznog korišćenja opreme za ličnu zaštitu na radu.	3	3	6	54	Mere zaštite pri upotrebi LZS
18.1	Opasnost od povreda na radu uzrokovana od prirodnih nepogoda i udara groma i posledica atmosferskog pražnjenja.	1	3	1	3	Uputstvo za rad pri geološkim bušenjima
13.2	**Procena rizik za tvrđene konkretne štetnosti**	**V**	**T**	**U**	**R-Rizik**	**Mere kon. pro.riz.**

21.1	Štetnost po zdravlje uzrokovan hemijskim štetnostima uzrokovana radom dizel agregata, radom sa isplakama koje sadrže hemijske supstance i prašina koje se javljaju pri geološkim bušenjima.	6	3	6	108	Primena ličnih zaštitnih sredstava
22.1	Štetnost po zdravlje uzrokovana bukom od rada dizel agregata i mašina za geološka bušenja i istraživanja.	6	3	6	108	Primena ličnih zaštitnih sredstava
25.1	Štetnost po zdravlje uzrokovana nedovoljnom osvetljenošću u toku noćnog rada.	3	3	6	54	Uputstvo – mere bezbed. na radilištu
27.1	Štetnost po zdravlje uzrokovana štetnim klimatskim uticajima pri radu otvorenom prostoru u toku geoloških bušenja i istraživanja.	6	3	6	108	Primena ličnih zaštitnih sredstava
29.1	Štetnost po zdravlje uzrokovana štetnostima koje nastaju korišćenjem ulja, maziva, dizel goriva i sl.	6	3	6	108	Primena ličnih zaštitnih sredstava
30.1	Štetnost po zdravlje uzrokovana naporima i telesnim naprezanjima pri ručnom prenošenju cevi, alata i pribora za geološka bušenja.	6	3	6	108	Primena ličnih zaštitnih sredstava
31.1	Štetnost po zdravlje uzrokovana nefiziološkim položajem tela pri dugotrajnom stajanju, čučanju ili klečanju pri nadzoru i opsluživanju mašina za geološka bušenja i istraživanja.	6	3	6	108	Primena ličnih zaštitnih sredstava
32.1	Štetnost po zdravlje uzrokovana naporima psihofizičkih opterećenja u nadgledanju i kontoli rada mašina za geološka bušenja i istraživanje.	3	2	6	36	Propisno koristiti propisane pauze u radu (dnevne, nedeljne, godišnje)
33.1	Štetnost po zdravlje uzrokovana odgovornošću u primanju i prenošenju informacija, korišćenju odgovarajućeg znanja i sposobnosti za rad na mašinama za geološka bušenja i istraživanja.	3	2	6	36	Propisno koristiti propisane pauze u radu (dnevne, nedeljne, godišnje)
34.1	Štetnost po zdravlje uzrokovana produženim radom kao i radom noću pri geološkim bušenjima i istraživanjima.	3	2	6	36	Propisno koristiti propisane pauze u radu (dnevne)

13.3. Komentar procenjenih opasnosti i štetnosti:

Na osnovu identifikovanih, analiziranih i utvrđenih konkretnih opasnosti i štetnosti na radnom mestu i radnoj okolini **Bušač-Geološka istražna bušenja**, procenjene verovatnoće nastanka povreda na radu, oštećenja zdravlja i oboljenja u vezi sa radom i procene težine povrede na radu, oštećenja zdravlja i oboljenja u vezi sa, procenjen je **SREDNJI RIZIK** (**R III**) od povreda na radu, oštećenja zdravlja i oboljenja u vezi sa radom.

13.4. Mišljenje službe medicine rada:
Stručni tim medicine rada sagledao je procenjene opasnosti i štetnosti zaradno mesto **Bušač-Geološka istražna bušenja** i mišljenja je da **postoje indikacije** za proglašenje radnog mesta sa povećanim rizikom.
13.5. Konačan zaključakTima za procenu OH&S rizika:
Na osnovu procenjenih konkretnih opasnosti i štetnosti Tim za procenu OH&S rizika donosi: **KONAČAN ZAKLJUČAK** Za radno mesto **Bušač-Geološka istražna bušenja** utvđen je **NIVO RIZIKA R III - SREDNJI RIZIK** od povreda na radu, oštećenja zdravlja i oboljenja u vezi sa radom. Na osnovu konačnog zaključka o proceni OH&S rizika navedeno radno mesto kategoriše se kao radno mesto sa **POVEĆANIM RIZIKOM.** Za uspostavljanje mehanizama kontrole/upravljanja povećanim OH&S rizicima neophodno je definisati **PLAN UPRAVLJANJA PROCENJENIM OH&S RIZICIMA.**

14. PLAN UPRAVLJANJA PROCENJENIM OH&S RIZICIMA							
Rizik	Lista povećanih OH&S rizika za radno mesto Bušač-Geološka istražna bušenja	Hijerarhija upravljanja povećanim OH&S rizicima					Prioritet
		1. Mere potpunog otklanjanja rizika:	2. Mere zamene (substitucije) rizika:	3. Mere tehničke (inženjerske) kontrole rizika:	4. Mere signalizacije upozorenja ili administrativne kontole rizika:	5. Mere primene LZS i opreme za BNR	
108	Opasnost od povreda na radu uzrokovana od rotirajućih ili pokretnih delova na mašini za geološka bušenja i istraživanja	Nije primenljivo	Obavezna primena tehničkih zaštitnih naprava kod rotirajućih i pokretnih delova	Obavezan dnevni i nedeljni pregled i periodično ispitivanje	Obavezna primena procedura, uputstava. Obavezna obuka za bezbedan rad. Obavezan periodični lekarski pregled	Obavezna primena ličnih zaštitnih sredstava i opreme za bezbedan rad	Veliki
108	*x*						
54	*y*						
36	*z*						

ZAKLJUČAK

Institucionalne promene koje su se desile u Republici Srbiji u oblasti zaštite zdravlja i bezbednosti na radu neminovno su uslovile potrebu za razvojem i poboljšanjem alata za donošenje odluka pri planiranju, i upravljanju sistemom zaštite zdravlja i bezbednosti na radu. Donošenje odluka na osnovu prethodno prikazanog modela i metoda procene OH&S rizika je fleksibilni pristup koji je proaktivan i obezbedjuje identifikaciju, određivanje prioriteta i dokumentovanost OH&S rizika, kao i primenu Plana mera za kontrolu procenjenih OH&S rizika.

Na osnovu detaljne identifikacije i analize opasnosti i štetnosti za radon mesto *Bušač - Geološka istražna bušenja* u organizaciji *"Geops Balkan Driling Services" d.o.o,* može se zaključiti da je optimizovana metoda Kinny i metodološki pristupak procene OH&S rizika ispunio svoju svrhu i dao zadovoljavajuće rezultate.

Upravljanje OH&S rizicimau skladu sa ovim metodološkim postupkom je vrlo pouzdan i koristan alat za donosioce odluka u ispunjavanju politike i ciljeva u pogledu zaštite zdravlja i bezbednosti na radu.

Optimizovani model procene OH&S rizika na bazi Kinny metode primenjen u ovom radu je praktično ispitan u i drugim sličnim organizacijama kao što su: *Drillex International d.o.o, International Drilling Service d.o.o kao i Stara Planina Resources d.o.o.* Na osnovu ovog modela je uspostavljen efikasan i efektivan sistem upravljanja zaštitom zdravlja i bezbednosti na radu u skladu sa SRPS OHSAS 18001:2008.

Iz praktične primene optimizovanog modela za procenu OH&S rizika pri upravljanju OH&S sistemom može se zaključiti da je u većini faza geološkog istražnog bušenja prisutan povećani OH&S rizik ali da se istim može upravljati samo ako su primenjene planirane mere iz Plana mera za kontrolu procenjenih OH&S rizika.

Ovako predloženi metodološki postupak procene OH&S rizika može biti od velike koristi i u drugim organizacija koje koriste ovu metodu procene rizika ili se bave sličnom delatnošću. Procena OH&S rizika i uspostavljanje kontrolnih mehanizama upravljanja je od velike koristi i pri projektovanju sistema upravljanja zaštitom zdravlja i bezbednošću na radu. Predloženi model procene OH&S rizika omogućava da se informacije o OH&S riziku adekvatno procesuiraju i koriste u donošenju odluka na releventnim nivoima organizacije koja se bavi izvođenjem radova na geološkim istražnim bušenjima.

Aktivnom i sve obuhvatnom procenom OH&S rizika kako je to definisano ovim radom menadžment organizacije koja se bavi geološkim istražnim bušenjem može da:

- prihvata i odobrava politiku upravljanja procenjenim OH&S rizikom;
- obaveštava sve zainteresovane strane u procesu izvođenja geoloških istražnih bušenja;
- definiše mehanizme kontrole procenjenog OH&S rizika koji odgovaraju performansama organizacije;
- obezbeđuje usaglašenost sa zakonskom i podzakonskom regulativom kao i sa pravnim aktima organizacije;
- obezbeđuje raspodelu potrebnih resursa za potrebe upravljanja procenjenim OH&S rizikom.

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TREATMENT OF WASTE SULFURIC ACID COPPER ELECTROLYTE[*****]

Abstract

The aim of this paper was to investigate the possibility of using the copper anodes with high nickel content for electrolytic treatment of waste sulfuric acid copper electrolyte. Nickel content in each anode was about 10 wt. %. Lead, antimony, and tin content was within the limits ranged from 0.1 to 1.4 wt. %. Copper mass content in anodes was in the range from 86 to 90 wt. %, and was mathematical deference to 100 wt. %. Electrolytic processing was done in galvanostatic conditions at the current density of 250 A/m^2, electrolyte temperature of 63 ± 2 ° C, duration of each test of 72 h. The mass of each anode was about 7 kg. The waste sulfuric acid electrolyte with concentration of 30 g dm^3 Cu^{2+} ions and 225 g/dm^3 SO_4^{2-} ions was used as the working solution. Changing the anode mass, changing the content of copper and nickel ions in the working solution and the mass of obtained cathode deposit were the subject of discussion in this paper. The difference in weight of anode at the beginning and end of the process confirmed that the anodes are dissolved during the process. A significant reduction of Cu^{2+} ions concentration was achieved as well as an increase in concentration of Ni^{2+} ions in the working solution. Mass of cathode deposit, obtained during electrolytic refining of anode with the smallest impurity content, was greater than the mass of dissolved correspondent anode for about 2%. Mass of cathode deposit, obtained by refining the anode with the content of Pb + Sn + Sb from 1.5 to 3.5 wt. %, was less than the mass of dissolved correspondent anode by about 2 %.

Keywords: *anode, electrolyte refining, waste electrolyte, copper, nickel*

INTRODUCTION

High purity copper production in the industrial conditions is carried out by two independent processes: electrolytic refining and elecrowining. Electrolytic refining process is used for purifying the flame refined copper obtained by pyrometallurgical processing of copper ore or copper waste. Electrowining is used to extract the copper from the copper solution obtained after hydrometallurgical treatment [1, 2].

Under the influence of direct current, copper is deposited directly on cathode from the copper solution during the electrowining process. Lead alloyed with Sb, Ag, Sn and

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Ca is commonly used as an insoluble anode where the oxygen appears according to the following reaction, [1]:

$H_2O \rightarrow H^+ + (OH)^- \rightarrow 1/2O_2 + 2H^+ + 2e$;

$E^o = +1.23$ V.

The commercial copper anode with copper content from 98.0 to 99.5 wt. % and working solution with copper concentration from 35 to 50 g/dm^3 and free sulfuric acid concentration from 150 to 250 g/dm^3, are used in the commercial copper electrolytic refining process [3,4].

In addition to copper as the base metal, the other impurities are present in copper anode. These impurities have the impact on structure characteristics of anode material, and could change its properties. During the constant galvanostatic pulse, the impurities could be dissolved on anode with the possibility to: remain dissolved into the base electrolyte, to become a part of the anode slime forming the "floating slime" and eventually to precipitate onto the cathode. The impurities could cause the anode passivation, contamination of cathode deposit and electrolyte contamination. In the industrial environments, the control of impurities in the electrolyte is achieved by continuous discharging a part of electrolyte from circulation system with the aim to control the content of copper and other elements. The choice of treatment methods depends on type and contamination level. The chemical methods, solvent extraction, membrane processes, ion exchange, electrochemical methods are commonly used [5,6].

Large quantities of solid wastes, generated in the copper smelting process, are needed to be recycled with the goal of recovering the useful components. The recycling process is cheaper than the copper production process from raw materials, and the mineral resources could be kept. The anodes, produced from secondary materials, are generally rich in nickel, lead, antimony and tin, and have a low content of selenium, tellurium and silver [7]. The aim of this paper was to examine the possibility of application the copper anode with high copper content to recover the copper from waste sulfuric acid copper electrolytes. The anode chemical composition has to provide the reduction of copper content to minimum and to significantly increase the nickel content. By the proposed process, copper from electrolyte and anode could be valorized in the form of copper cathodes, and nickel from anode would be converted into the working solution, what would create the conditions for further treatment with the aim of nickel valorization as the final product.

EXPERIMENTAL PROCEDURE

Induction furnace, power up to 15 kW, was used for preparation the suitable mixture for obtaining the anode materials with nickel content of 10 wt.% and different contents of lead, tin and antimony, wherein total maximum content of these elements was up to 3.5 wt.%. The mixture was prepared by melting the anode copper (99.2 wt. % Cu) and pure metal components of nickel, lead, antimony and tin. The detailed procedure of preparing the mixture and melting process of copper anodes with Ni content of 7.5 wt. % is shown in an earlier paper by the same author [8]. When the oxygen content was less than 200 ppm, the melt was cast into suitable steel moulds at temperature of 1300 ^oC. After natural cooling, the anodes are prepared for the electrolysis process by mechanical finishing on the lathe, Figure 1, removing about 2 mm of material from the surface and by drilling the holes for connection with the electrode holder and electrical contacts. Final preparation of anode consisted of polishing the surface with abrasive paper from 600 to 1200, marking, measuring, hanging on the electrode holder, and rinse with distilled water just before immersing in the electrolytic cell and degreasing with ethanol. The mass of each anode was about 7 kg. The final anode shape is shown in Figure 2, which shows three holes with threaded for anode connection with electrode holder and current supplier.

Figure 1 *Copper anode mechanical finishing*

Figure 2 *Final copper anode*

Current density for all experiments was 250 A/m^2. Direct current is provided from an external DC power source, Heinzinger TNB-10-500, feature 50 A and 10 V. The starting cathode is made of stainless steel, and the reference electrode was copper.

Anode samples for chemical analysis were taken from the bottom, middle and top of the anode in order to determine the distribution of characteristic elements. RFA method (PANalytical Axios) was used for chemical analysis. The chemical composition of electrolyte is determined by method of simultaneous optical emission spectrometry with inductively coupled plasma (ICP-OES), SPECTRO Ciros VISION.

RESULTS AND DISSCUTION

Each of the anodes was analyzed on 26 elements, in accordance with the existing software. The results of chemical analysis of samples taken from the bottom, middle and top of anode A1 are shown in Table 1. The average values of the elements content were obtained by mathematical calculation. Copper content was the difference up to 100 wt. %.

Table 1 *Chemical composition of anode A1*

Element	Content, wt. %			
	Sampling position			Average content
	Bottom	Middle	Top	
Ni	10.02	9.78	9.79	9.86
Pb	0.143	0.143	0.138	0.14
Sn	0.09	0.093	0.091	0.092
Sb	0.071	0.074	0.073	0.073
Zn	< 0.0015	< 0.0015	< 0.0015	< 0.0015
P	0.0055	0.0054	0.0056	0.0055
Mn	< 0.0005	< 0.0005	< 0.0005	< 0.0005

Fe	0.016	0.016	0.014	0.015
Si	0.022	0.027	0.020	0.024
Mg	< 0.0002	< 0.0002	< 0.0002	< 0.0002
Cr	0.0003	0.0003	0.0004	0.0003
Te	0.012	0.012	0.010	0.012
As	0.021	0.021	0.021	0.021
Cd	0.0014	0.0014	0.0013	0.0014
Bi	0.0035	0.0034	0.0033	0.0034
Ag	0.061	0.062	0.063	0.062
Co	< 0.0015	< 0.0015	< 0.0015	< 0.0015
Al	< 0.0010	< 0.0010	< 0.0010	< 0.0010
S	0.0045	0.0047	0.0046	0.0046
Be	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Zr	< 0.0003	< 0.0003	< 0.0003	< 0.0003
Au	0.0018	0.0018	0.0019	0.0018
B	< 0.0005	0.0005	< 0.0005	< 0.0005
C	0.0016	0.011	0.0016	0.0047
Ti	0.002	0.0019	0.002	0.002
Se	0.0055	0.0055	0.0054	0.0055

There is no major difference of Ni, Pb, Sn, Sb content and content of other impurities, compared to the anode sampling position (table 1). These results confirmed the homogeneous distribution of impurities within the anode. The same conclusion is applied to anodes A2 and A3. Therefore, complete tables for these two anodes will not be shown, but only the average content values for characteristic elements will be shown: Ni, Pb, Sn, Sb and Cu (Table 2). Content of oxygen in all anodes was less than 100 ppm.

Table 2 *The average content of characteristic elements in anodes A1-A3*

Anode	Content, wt. %				
	Ni	**Pb**	**Sn**	**Sb**	**Cu**
A1	9.86	0.14	0.092	0.073	89.7
A2	10.04	0.385	0.41	0.382	88.6
A3	10.41	1.38	1.2	0.92	85.9

By measuring the anode mass at the beginning and end of experiment (after 72 h), the values of dissolved anode mass are obtained, 1,752 g for anode A1, 1,367 g for anode A2 and 1,785 g for anode A3.

Starting electrolyte was the waste sulfuric acid copper electrolyte with the following chemical composition (g/dm^3): Cu - 30; Ni - 20.5; As - 4; Pb - 0004; Sn - 0:01; Sb - 0.3 and SO_4^{2-} - 225.

Concentration of copper and nickel ions was controlled every 24 hours during the each test duration of 72 h. The values of Cu^{2+} and Ni^{2+} concentration changes in comparison to the starting values, expressed in percentages, are shown in Table 3.

Table 3 *Cu^{2+} i Ni^{2+} ions concentration changes*

Time	Anode					
	A1	**A2**	**A3**	**A1**	**A2**	**A3**
	Concentration changes of Cu^{2+} ion, %			**Concentration changes of Ni^{2+} ion, %**		
start	100	100	100	100	100	100
24 h	69.43	64.62	58.77	151.53	139.02	143.41
48 h	48.41	32.00	26.15	207.14	163.41	206.83
72 h	13.38	20.92	4.31	235.71	212.68	236.10

Observing the data for the working electrolyte composition changing, it could be seen that the concentration of Cu^{2+} ions in the electrolyte during the process is decreased. The largest decreasing, in the amount of 95.7 % was observed for the anode with the lowest copper content (85.9% wt.) and maximal content of impurities Pb + Sn + Sb (3.5 wt.%). Decreasing the concentration of Cu^{2+} ion is accompanied by Ni^{2+} ion concentration increasing in electrolyte to the value of about 140%. These results are in agreement with the results obtained by an electrolytic refining of copper anodes with 7.5 wt. % Ni and total sum of Pb + Sn + Sb up to 3 wt. % [8.9].

Decreasing the concentration of copper ions in the electrolyte has confirmed that copper is deposited on cathode and by electrowining process from solution. The ratio of obtained cathode deposits and dissolved masses of corresponding anode demonstrates that these values are very close (Figure 3).

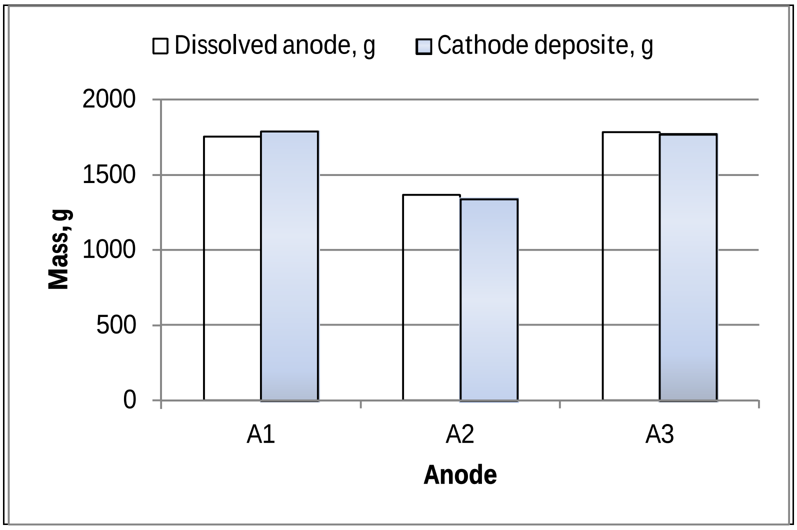

Figure 3 *The mass ratio of disolved anode and cathode deposite*

Mass of the obtained cathode deposit was about 2 wt. % greater than the mass of dissolved anode with lowest total impurity content and the highest copper content (anode A1). Mass of cathode deposits, obtained by electrolytic refining of anodes with total content of Pb, Sn and Sb content in the range from 1.5 to 3.5 wt. % was less than the mass of dissolved anode by about 2%.

CONCLUSION

By the process of electrolytic refining of copper anode with nickel content of 10 wt. % in the waste sulfuric acid copper electrolyte, the copper concentration was decreased, increased the concentrations of nickel ions and produced cathode copper. Compared to the chemical composition of copper anode from commercial copper production, chemical composition of this anode is significantly different. Very high content of nickel and increased content of lead, antimony and tin is also specific characteristic of these anodes (total value of Pb, Sn And Sb was up to 3.5 wt. %). During the anode electrolytic refining, in the working solution with copper content of 30 g/dm^3, concentration of Cu^{2+} ion is significantly decreased (more than 95%) and concentration of Ni^{2+} ion is increased up to 140%.

Reduction of copper contents in the solution is confirmed by weight of the obtained cathode deposits, which is very close to the weight of the soluble anode. Thus, the weight of cathode deposit was about 2 wt. % greater than the weight of dissolved anode with the highest copper content (anode A1). Masses of cathode deposits, obtained by refining the anodes with total content of Pb, Sn, and Sb from 1.5 to 3.5 wt. % (anodes A2 and A3), were slightly less than the weight of dissolved anode (approximately 2 wt.%).

Considering the fact that recycling process is cheaper than copper production from the primary raw materials, in addition to saving the mineral resources, it is reasonable to expect the positive economic effects.

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TRETMAN OTPADNOG SUMPORNO-KISELOG ELEKTROLITA BAKRA*****

Izvod

Cilj ovog rada bio je da se ispita mogućnost korišćenja bakarnih anoda sa visokim sadržajem nikla za elektrolitičku preradu otpadnog sumporno-kiselog elektrolita bakra. Sadržaj nikla u anodama bio je oko 10 mas. %, a sadržaj olova, antimona i kalaja kretao se u granicama od 0.1 do 1.4 mas. %. Maseno učešće bakra u anodama bilo je u opsegu od 86 do 90 mas. % i predstavljalo je razliku do 100 mas. %. Elektrolitička prerada je rađena u uslovima galvanostatskog režima rada, pri gustini struje od 250 A/m^2, temperaturi elektrolita od 63±2^{o}C, u trajanju od 72 h. Masa svake anode bila je oko 7 kg. Otpadni sumporno-kiseli elektrolit sa sadržajem Cu^{2+} jona od 30 g/dm^3 i sadržajem SO_4^{2-} jona od 225 g/dm^3 korišćen je kao radni rastvor. Promena mase anoda, promena sadržaja jona bakra i nikla u radnom rastvoru i masa dobijenog katodnog taloga bili su predmet diskusije u ovom radu. Razlika u masi anoda na početku i kraju procesa potvrdila je da su se anode tokom procesa rastvarale. Postignuto je značajno smanjenje koncentracije Cu^{2+} jona i povećanje koncentracije Ni^{2+} jona u radnom rastvoru. Masa katodnog taloga dobijenog elektriliti̇čkom rafinacijom anode sa najmanjim sadržajem nečistoća bila je veća od mase rastvorene korespodentne anode za oko 2 % dok su mase katodnih taloga dobijenih rafinacijom anoda sa sadržajem Pb+Sn+Sb od 1.5 - 3.5 mas. % bile manje od masa rastvorenih anoda za oko 2 %.

Ključne reči: *anoda, elekrolitička rafinacija, otpadni elektrolit, bakar, nikl*

UVOD

Dobijanje bakra visoke čistoće u industrijskim uslovima odvija se kroz dva nezavisna procesa: elektrolitičkom rafinacijom i elektroekstrakcijom. Proces elektrolitičke rafinacije koristi se za prečišćavanje plameno rafinisanog bakra dobijenog pirometalurškom preradom rude bakra ili bakarnog otpada, a proces elektroekstrakcije bakra za izdvajanje bakra iz rastvora dobijenog nakon hidrometalurškog tretmana [1, 2].

Procesom elektroekstrakcije, pod dejstvom jednosmerne struje bakar se iz rastvora taloži direktno na katodi. Olovo legirano sa Sb, Ag, Sn i Ca najčešće se koristi kao nerastvorna anoda na kojoj se

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tokom procesa izdvaja kiseonik prema sledećoj reakciji [1]:

$H_2O \rightarrow H^+ + (OH)^- \rightarrow 1/2O_2 + 2H^+ + 2e$;

$E^o = +1,23$ V.

U standardnom procesu elektrolitičke rafinacije bakra koriste se komercijalne anode sa sadržajem bakra od 98.0 do 99.5 mass % i osnovni radni rastvor koncentracije Cu od 35 -50 g/dm^3 i H_2SO_4 od 150 - 250 g/dm^3 [3,4]. U anodama su, pored bakra kao osnovnog metala, prisutne i druge nečistoće koje utiču na strukturu anodnog materijala i samim tim menjaju njena svojstva. Za vreme trajanja konstantnog galvanostatskog pulsa, primese mogu da se rastvore iz anode uz mogućnost da: ostanu rastvorene u osnovnom elektrolitu, pređu u nerastvoran talog, formiraju "lebdeći mulj" i eventualno se istalože na katodi, čime mogu da izazovu pasivaciju anode, zaprljanje katodnog taloga i elektrolita. U industrijskim uslovima, kontrola sadržaja nečistoća u elektrolitu postiže se kontinualnim izvođenjem dela elektrolita iz cirkulacionog sistema radi izdvajanja bakra i drugih nečistoća, a izbor metode za njegovo prečišćavanje zavisi od vrste i stepena onečišćenja. Najčešće se koriste različite hemijske metode, solventna ekstrakcija, membranski procesi, jonska izmena, elektrohemijske metode [5,6].

Velike količine čvrstih otpadnih materijala koje nastaju u procesu topljenja bakra potrebno je reciklirati u cilju izdvajanja korisnih komponenti. Proces reciklaže jeftiniji je od procesa proizvodnje bakra iz primarnih sirovina, a postiže se i očuvanje mineralnih resursa. Anode dobijene iz sekundarnih sirovina generalno su bogate niklom, olovom, antimonom i kalajem, a zabeležen je nizak sadržaj selena, telura i srebra [7]. Cilj ovog rada bio je da se bakarne anode sa visokim sadržajem nikla (10 mas. %) primene za izdvajanje bakra iz otpadnog elektrolita bakra. Hemijski sastav anoda trebao je da omogući da se u otpadnom rastvoru sadržaj bakra svede na minimum i da se značajno poveća koncentracija nikla. Predloženim postupkom bakar iz rastvora i anode bio bi valorizovan u formi katodnog bakra, a nikl iz anode bio bi preveden u radni rastvor čime bi se stvorili uslovi za dalji tretman u cilju valorizacije nikla do krajnjeg proizvoda.

EKSPERIMENTALNA PROCEDURA

Indukciona peć snage do 15 kW, korišćena je za pripremu odgovarajuće smeše za dobijanje bakarnih anoda sa sadržajem nikla od 10 mas.% i različitim sadržajem olova, kalaja i antimona, pri čemu je ukupan maksimalan sadržaj ovih elemenata iznosio do 3,5 mas. %. Smeša je pripremana topljenjem anodnog bakra i čistih metalnih komponenti nikla, olova, antimona i kalaja. Detaljna procedura pripreme smeše i procesa topljenja za bakarne anode sa sadržajem Ni od 7,5 mas. % prikazana je u ranijem radu istog autora [8]. Rastop je izlivan u odgovarajuće čelične kalupe na temperaturi od 1300°C, tek kada je sadržaj kiseonika bio ispod 200 ppm. Nakon prirodnog hlađenja, anode su pripremane za proces elektrolize mehaničkom obradom na strugu, slika 1., skidanjem oko 2 mm materijala sa površine i bušenjem otvora za elektrodni nosač i električne kontakte. Finalna priprema anoda sastojala se od poliranja površina abrazivnim papirima krupnoće od 600 do 1200, obeležavanja, merenja, kačenja na elektrodni nosač, ispiranja destilovanom vodom a neposredno pre ulaganja u ćeliju i odmašćivanja etanolom. Masa svake anode bila je oko 7 kg. Finalni izgled anode prikazan je na slici 2. na kojoj se vide tri otvora sa navojem za kačenje anode na elektrodni nosač i povezivanje sa strujnim snabdevačem.

Sl. 1. *Priprema bakarnih anoda*

Sl. 2. *Bakarne anode*

Gustina struje taloženja za sve eksperimente iznosila je 250 A/m^2. Jednosmerna struja obezbeđena je sa spoljnjeg izvora jednosmerne struje, HEINZINGER TNB-10-500, karakteristika 50 A i 10 V. Polazna katoda je od nerđajućeg čelika, a referentna elektroda od bakra.

Uzorci za hemijsku analizu anode uzimani su sa dna, sredine i vrha anode u cilju utvrđivanja raspodele karakterističnih elemenata. RFA metoda (PANalytical-Axios) korišćena je za hemijsku analizu. Hemijski sastav elektrolita određen je metodom simultano optičke emisione spektrometrije sa indukovano kuplovanom plazmom (ICP-OES), SPECTRO CIROS VISION.

REZULTATI I DISKUSIJA

Svaka anoda analizirana je, saglasno postojećem softveru, na 26 elemenata. Rezultati hemijskih analiza za uzorke uzete sa dna, sredine i vrha anode A1 prikazani su u tabeli 1. Srednje vrednosti sadržaja elemenata, dobijene su matematičkim putem. Sadržaj bakra predstavlja razliku do 100 mas. %.

Tabela 1. *Hemijski sastav bakarne anode A1*

Element	Sadržaj, mas. %			
	Pozicija uzorkovanja anoda			Srednja vrednost
	Dno	Sredina	Vrh	
Ni	10,02	9,78	9,79	9,86
Pb	0,143	0,143	0,138	0,14
Sn	0,09	0,093	0,091	0,092
Sb	0,071	0,074	0,073	0,073
Zn	< 0,0015	< 0,0015	< 0,0015	< 0,0015
P	0,0055	0,0054	0,0056	0,0055
Mn	< 0,0005	< 0,0005	< 0,0005	< 0,0005

Fe	0,016	0,016	0,014	0,015
Si	0,022	0,027	0,020	0,024
Mg	< 0,0002	< 0,0002	< 0,0002	< 0,0002
Cr	0,0003	0,0003	0,0004	0,0003
Te	0,012	0,012	0,010	0,012
As	0,021	0,021	0,021	0,021
Cd	0,0014	0,0014	0,0013	0,0014
Bi	0,0035	0,0034	0,0033	0,0034
Ag	0,061	0,062	0,063	0,062
Co	< 0,0015	< 0,0015	< 0,0015	< 0,0015
Al	< 0,0010	< 0,0010	< 0,0010	< 0,0010
S	0,0045	0,0047	0,0046	0,0046
Be	< 0,0001	< 0,0001	< 0,0001	< 0,0001
Zr	< 0,0003	< 0,0003	< 0,0003	< 0,0003
Au	0,0018	0,0018	0,0019	0,0018
B	< 0,0005	0,0005	< 0,0005	< 0,0005
C	0,0016	0,011	0,0016	0,0047
Ti	0,002	0,0019	0,002	0,002
Se	0,0055	0,0055	0,0054	0,0055

Iz tabela se vidi da nema velikih odstupanja u sadržaju Ni, Pb, Sn i Sb, kao ni u sadržaju ostalih primesa, posmatrano u odnosu na pozicije uzorkovanja anoda, čime je potvrđena homogena raspodela nečistoća unutar anode. Isti zaključak važi i za anode A2 i A3 tako da neće biti prikazane kompletne tabele za ove dve anode već samo vrednosti srednjih sadržaja za karakteristične elemente: Ni, Pb, Sn, Sb i Cu (tabela 2). Sadržaj kiseonika u svim anodama bio je manji od 100 ppm.

Tabela 2. *Srednje vrednosti sadržaja karakterističnih elemenata u anodama A1-A3*

Anoda	**Hemijski sadržaj, mas %**				
	Ni	**Pb**	**Sn**	**Sb**	**Cu**
A1	9,86	0,14	0,092	0,073	89,7
A2	10,04	0,385	0,41	0,382	88,6
A3	10,41	1,38	1,2	0,92	85,9

Merenjem masa anoda na početku i kraju eksperimenta dobijena je vrednost rastvorene mase anoda koja iznosi: 1752 g za anodu A1, 1.367 g za anodu A2 i 1.785 g za anodu A3.

Polazni elektrolit predstavljao je otpadni sumporno-kiseli elektrolit bakra sledećeg hemijskog sastava (g/dm^3): Cu – 30; Ni – 20.5; As – 4; Pb – 0.004; Sn – 0.01; Sb – 0.3 i SO_4^{2-} – 225.

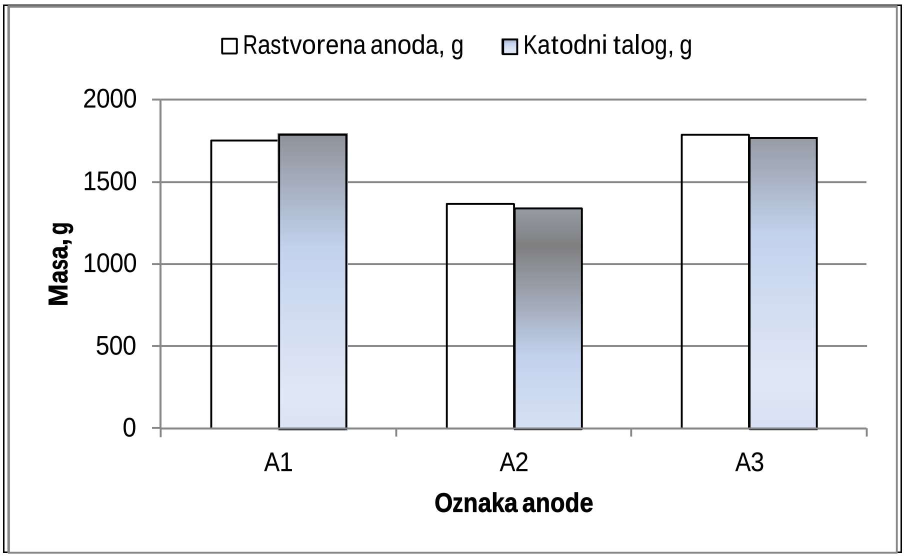
Koncentracija jona bakra i nikla kontrolisana je tokom svakog eksperimenta, na svakih 24 h za ukupno vreme trajanja od 72 h. Vrednosti promene koncentracije Cu^{2+} i Ni^{2+} jona u odnosu na polazne vrednosti, izražene u procentima, prikazane su u tabeli 3.

Tabela 3. *Promena koncentracije Cu^{2+} i Ni^{2+} jona u elektrolitu*

Vreme	Oznaka anoda					
	A1	A2	A3	A1	A2	A3
	Promena koncentracije Cu^{2+} jona, %			Promena koncentracije Ni^{2+} jona, %		
Start	100	100	100	100	100	100
24 h	69,43	64,62	58,77	151,53	139,02	143,41
48 h	48,41	32,00	26,15	207,14	163,41	206,83
72 h	13,38	20,92	4,31	235,71	212,68	236,10

Posmatrajući podatke za promenu sastava radnog elektrolita, vidi se da se koncentracija Cu^{2+} jona u elektrolitu tokom procesa smanjuje. Najveće smanjenje, u vrednosti od 95.7 %, registrovano je kod anode koju karakteriše najniži sadržaj bakra (85,9 mas. %) i najviši sadržaj nečistoća Pb+Sn+Sb (3.5 mas. %). Smanjenje sadržaja Cu^{2+} jona praćeno je povećanjem sadržaja Ni^{2+} jona u elektrolitu do vrednosti od oko 140 %. Dobijeni rezultati su u saglasnosti sa rezultatima dobijenim elektrolitičkom rafinacijom bakarnih anoda sa 7,5 mas. % Ni i sadržajem Pb+Sn+Sb do vrednosti od 3 mas. % [8,9].

Smanjenje koncentracije bakarnih jona u elektrolitu potvrđuje da se bakar taloži na katodi i procesom elektroekstrakcije iz rastvora. Odnos dobijene mase katodnog taloga i rastvorene mase odgovarajuće anode pokazuje da su ove vrednosti veoma bliske (sl. 3).



Sl. 3. *Odnos masa rastvorenih anoda i masa katodnih taloga*

Kod anode sa najnižim sadržajem ukupnih nečistoća i najvišim sadržajem bakra (anoda A1) masa dobijenog katodnog taloga bila je za oko 2 mas. % veća od mase rastvorene anode. Mase katodnih taloga dobijenih rafinacijom anoda sa sadržajem Pb+Sn+Sb od 1,5 - 3,5 mas. % bile su manje od masa rastvorenih anoda za oko 2 %.

ZAKLJUČAK

Elektrolitičkom rafinacijom bakarnih anoda sa sadržajem nikla od 10 mas. %, u otpadnom sumporno - kiselom elektrolitu bakra, smanjena je koncentracija jona bakra, povećana koncentracija jona nikla i dobijen katodni bakar. U poređenju sa hemijskim sastavom bakarnih anoda koje se koriste u komercijalnom procesu dobijanja katodnog bakra, hemijski sastav ovih anoda je bitno različit. Osim jako visokog sadržaja nikla, za ove anode je karakterističan i povećani sadržaj olova, antimona i kalaja (zbirna vrednost do 3,5 mas. %). Tokom procesa elektrolitičke rafinacije ovih anoda, u radnom rastvoru sa sadržajem bakra od 30 g/dm^3, značajno je smanjena koncentracija Cu^{2+} jona (više od 95 %) i povećana koncentracija Ni^{2+} jona (oko 140 %), posmatrano u odnosu na polazne vrednosti.

Smanjenje sadržaja bakra u rastvoru potvrđeno je dobijenom masom katodnog taloga koja je veoma bliska masi rastvorene anode. Tako je masa katodnog taloga bila za oko 2 mas. % veća od mase anode sa najvećim sadržajem bakra (anoda A1) koja je rastvorena tokom procesa. Mase katodnih taloga dobijenih rafinacijom anoda sa ukupnim sadržajem Pb, Sn i Sb od 1,5 do 3,5 mas. % (anode A2 i A3) bile su neznatno manje od masa rastvorenih anoda (oko 2 mas. %).

Imajući u vidu činjenicu da je proces reciklaže jeftiniji od procesa proizvodnje bakra iz primarnih sirovina, pored očuvanja mineralnih resursa realno je očekivati i pozitivne ekonomske efekte.

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TECHNOLOGICAL INVESTIGATIONS OF SULPHIDE OXIDATION FROM FLOTATION TAILINGS IN ORDER TO INCREASE THE DEGREE OF COPPER LEACHING[***]

Abstract

The off-balance resources present the environmental problem and potential resource for copper extraction. This paper presents the results obtained using different reagents for the process of sulphide form oxidation of copper from flotation tailings. For the investigation in this paper work, the samples of flotation tailings were taken from the Old Flotation Tailing Dump of the Mining and Smelting Complex Bor in Eastern Serbia. Experimental testing was carried out in order to increase the leaching degree of copper with addition of oxidants during leaching. Using the $Fe_2(SO_4)_3$ as an oxidant, the achieved copper leaching degree was 76.8%. The effect of thermal destruction of sulfide copper from flotation tailings in the presence of concentrated sulfuric acid was also investigated. After leaching of calcine with water, the degree of copper leaching was attained of 92%. Solutions after leaching are suitable for the SX-EW process of obtaining the copper.

Keywords: *flotation tailings, oxidation, leaching, copper*

INTRODUCTION

The most commonly used method in the world for copper valorization from off-balance mine resources is the hydrometallurgical process. The method consists of the following stages: comminuting, leaching, solvent extraction and electrolytic copper extraction. Hydrometallurgical treatment is applied in the countries (USA, Chile, Australia, and Peru), which have readily available off-balance deposits with low content of copper and with more oxide forms of [1.2]. Copper, present in the off-balance resources in the municipality of Bor, created during centuries of mining and processing of copper ore, presents an important economic resource if it is valorized in an appropriate way with affordable and sustainable technology. Otherwise, it presents the major generator of contaminated mine water that directly flow into the basin of the Bor River, with a significant impact on the quality of water downstream of the river Timok, and further to the Danube River [3-8].

The world experiences show that copper can be cost-effectively valorized from flotation tailings. One example is the old flotation tailing dump of the Miami mine in Arizona. In this mine, there was the flotation tailing dump that were deposited in about 34 million tons of tailings with the average copper content of 0.33%, out of which oxide

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copper is around 50%. Flotation tailings was treated by the conventional method of agitation acid leaching at pH = 1.5 with the processing capacity of about 450 t/h of tailings. Total copper leaching for leaching time of about 26 h was 57%. Total costs, from mining tailings to electrolysis to produce one ton of cathode copper from flotation tailings in this mine, amounted to 740 $/t of copper cathodes [9].

The old Bor flotation tailing dump is located on the border of urban and industrial part of town, and beneath it a collector of municipal waste water is situated. Due to the immediate close of the town center, it is also one of the sources of negative environmental impact that is reflected in dissemination of fine dust into the environment during windy periods and acidified water runoff.

Disposal of tailings in the Bor Flotation Plant from 1933 to 1987 was done in the valley of the Bor River. According to data [10], around $27x10^6$ t of tailings was deposited in the tailing dump with the average copper content of about 0.2%, which means that this waste material contains about 54,000 t of copper. Based on this, with the quantitative and qualitative point of view, the flotation tailings deposited in the old Bor flotation tailing dump, present an exceptional raw material for further revaluation of copper.

The laboratory tests of acid agitation leaching of copper were carried out from the old Bor flotation tailings during 2007 in the Mining and Metallurgy Institute Bor [11] implemented by Mitsui Mineral Development Engineering Co., Ltd (MINDECO). Within these studies, the exploration drilling of flotation tailings was done and the new representative sample was formed from extracted nuclei on which further laboratory testing was carried out. Investigations have included leaching experiments wherein the grade of copper leaching reached 60% [12] which indicates that only oxide coper ore reacts in the leaching solution without addition of oxidant. From leaching solution, copper was extracted by the method of solvent extraction and electrolysis, therefore the complete L-SX-EW method.

In order to increase the degree of copper extraction from flotation tailings, technological testing of sulphide oxidation from flotation tailings was carried out in order to increase the degree of copper leaching. Testing was carried out on a sample formed from the cores of drill holes from depths of 14 from surface of tailing dump. The physicochemical characterization of a sample of tailings was carried out. The effect of the following oxidants was carried out on the leaching degree of copper: iron(III) sulfate and concentrated sulphuric acid. Copper sulfides are transferred into the forms soluble in acidic aqueous solutions under the oxidative conditions.

EXPERIMENTAL TESTING WITH DISCUSSION OF THE RESULTS

The samples of tailings from depth of 14 m were used for testing with four different locations marked with B-1, B-2, B-3 and B-4, whose chemical characterization is shown in Table 1.

Table 1 *Chemical characterization of the samples of flotation tailing from depth of 14 m*

Content, mass %	Samples			
	B-1	**B-2**	**B-3**	**B-4**
Cu, total	0.46	0.44	0.39	0.58
Cu, ox	0.27	0.27	0.27	0.27
Fe	10.18	10.94	6.37	17.28
S	9.7	11.08	7.50	18.58

The leaching test and TCLP (Toxicity Characteristic Leaching Procedure) test were carried out on a composite sample of flotation tailings from depth of 14 m testing results are shown in Table 2.

Table 2 *Results of carried out leaching test and TCLP test on a sample of flotation tailings from depth of 14 m*

Element	Unit measure	Content		
		Leaching test	TCLP test	MDK of water for III and IV class*
Cu	mg/l	196	89	0.1
Fe	mg/l	256	105	1.0
Pb	mg/l	<0.1	<0.1	0.1
Zn	mg/l	12	5,8	1.0
Mn	mg/l	2,7	1,4	/
Ag	mg/l	<0.02	<0.02	/
As	mg/l	<0.1	<0.1	0.05
Hg	mg/l	<1	<1	0.001

**Regulations on Hazardous Substances in Water (Official Gazette of SRS, No.31/82)*

Based on the results of leaching test (conducted according to the standard procedure SRPS EN 12457-2) and the TCLP test (conducted according to the standard procedure of EPA Test Method 1311), where the concentrations of heavy metals are several hundred times higher than the legally prescribed MDK values, it can be concluded that the tailing dump present the major environmental problem for the surrounding waterways. The stage content of flotation tailings is present in Figure 1.

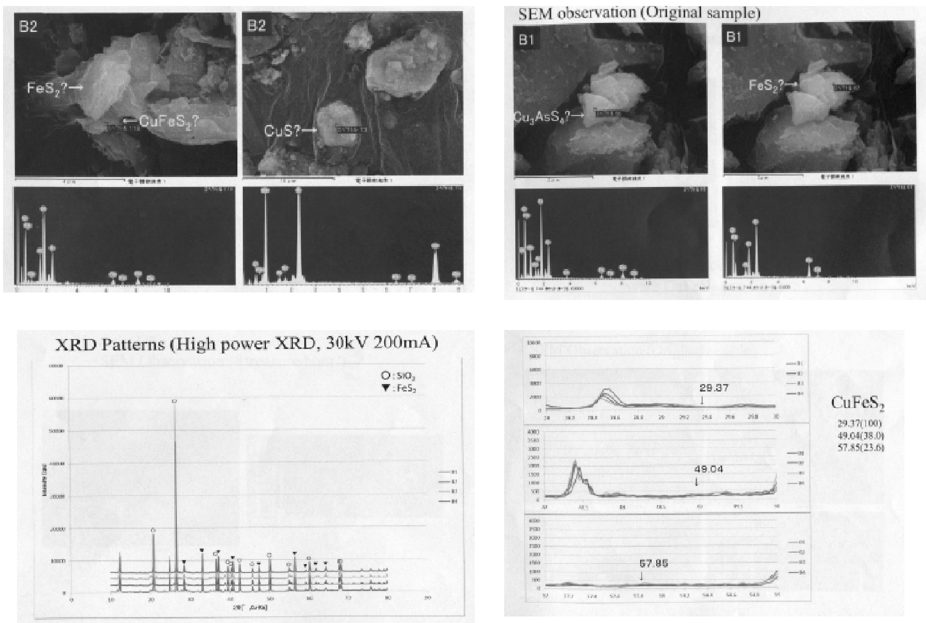

Figure 1 *Stage composition of flotation tailings (High power XRD, 30 kV 200 mA) recorded at the Akita University, Japan*

Experimental testing the leaching process composite sample of flotation tailings in order to determine the optimal parameters of copper extraction were performed on a laboratory scale. Samples from flotation tailing dump were treated by the agitation leaching method. The mine water from the accumulation Robule (mine waste water) was used as leaching solution with the following chemical composition: Cu-69,10 mg/dm^3; Pb<0.05 mg/dm^3; Zn-26.30 mg/dm^3; Cd-0.12 mg/dm^3; Ni-0.34 mg/dm^3; Cr <0.02 mg/dm^3; Se<0.020 mg/dm^3; As<0.010 mg/dm^3; Fe-739.00 mg/dm^3; suspended matters - 12.00 mg/dm^3; SO_4^{2-} - 8243,10 mg/dm^3.

The content of metals in mine water from the accumulation Robule is above the legally prescribed maximum allowed values, and the measured pH value of 3.5 indicates the acidic character of waste water. Before leaching, pH value of mine waste water was corrected to pH = 1 with concentrated sulphuric acid.

The leaching process of copper was analyzed from flotation tailings with mine waste water in the following conditions: time: 4 h, temperature: 80°C, the ratio of solid: liquid = 1:2.5, pH of leaching solution = 1, degree of copper leaching was attained of about 60% as it is exactly the participation of copper oxide forms regarding to the total copper content [13,14]. The experiments were carried out in a laboratory glass reactor with mechanical stirring.

Sulphide and other copper compounds (CuS, Cu_3AsS_4, $CuFeS_2$), present in the flotation tailings in the given conditions of leaching stay in the unchanged form, i.e. there is no their chemical degradation, what is shown in Figure 2.

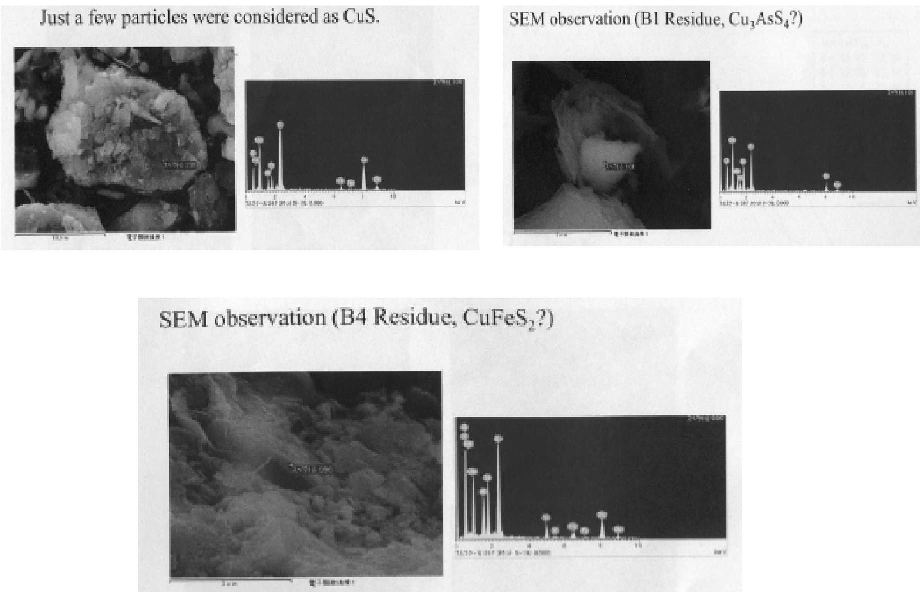

Figure 2 *Stage composition of flotation tailings after leaching (High power XRD, 30 kV 200 mA) recorded at the Akita University Japan*

The next series of experiments was aimed at increasing the degree of copper leaching that would be achieved by degradation of sulphide compounds of copper in tailings with addition of oxidants during leaching or thermal destruction of sulphide from tailings in the presence of an oxidant (sulphatization roasting) and subsequent leaching of the obtained calcine.

Leaching of flotation tailings with addition of $Fe_2(SO_4)_3$ as oxidant

Testing the effect of $Fe_2(SO_4)_3$ as an oxidant in the leaching process a composite sample of flotation tailings was carried out at room temperature with the concentration of sulfuric acid in leach solution of 0.1 M (pH=1) in the ratio S:L=1:2.5. Leaching experiments were carried out with different concentrations of Fe^{3+} ions in the sulfur-acidic solution ranged from 1 g/dm^3 to 10 g/dm^3.

Dependence of copper leaching degree on concentration of iron (III) sulfate at different leaching times (2-120 min) is given in Table 5.

Table 5 *Effect of iron (III) sulfate concentration on copper leaching*

Time (min)	1 g/dm^3 Fe^{3+}	2 g/dm^3 Fe^{3+}	7 g/dm^3 Fe^{3+}	10 g/ dm^3 Fe^{3+}
	Leaching degree of copper, %			
2	52	52	56	52
5	56	60	60	56
10	60	64	64	60
30	64	66	68	60
60	64	66	68	60
120	64	66	68	60

It can be concluded from the obtained results that the effect of concentration Fe^{3+} ions in sulfur-acidic leaching solution, or more precisely, has very little impact on copper leaching degree. The achieved results of copper leaching have approximate values and differ only by ± 4%. Leaching solution with concentration of oxidants of 7 g/l Fe^{3+} was used for further testing, where some better copper leaching results were achieved. The effect of temperature on copper leaching degree was tested at the following conditions: time: 120 min; temperature: room, 50^{o}C and 80^{o}C; S:L = 1:2.5; leaching solution: 0.1M H_2SO_4 (pH=1); concentration oxidant: 7 g/dm^3 Fe^{3+}. Testing results of the effect of temperature on copper leaching degree in the presence of oxidants are given in Table 6.

Table 6 *Temperature effect on copper leaching degree*

Temperature	Leaching degree of copper, %
Room	68.0
50^{o}C	70.7
80^{o}C	76.8

Based on the obtained results, it can be concluded that the highest degree of copper leaching was achieved at temperature of 80^{o}C with addition of $Fe_2(SO4)_3$ as the oxidant in concentration of 7 g/dm^3 Fe^{3+} in the leaching time of 120 min.

Destruction of sulphide from flotation tailings at increased temperature with addition of H_2SO_4 as oxidant

The experimental testing of sulphatization process of flotation tailings were carried out. For thermal treatment of destructive sulphide in the presence of sulphuric acid, a tubular furnace with temperature control was used as an oxidant. Prior to the sulphatization roasting, the sample of tailings was mixed with addition of concentrated sulphuric acid in the ratio: 1: 0.5 by weight. The impurities are present in the Bor flotation tailings that affect that dissociation of copper sulphate to the oxide forms beginning at lower temperature. Experimental studies of sulphatization process of the Bor flotation tailings at temperature of 700°C have shown that copper sulphate dissociates to a large extent to the oxides insoluble in water. After a series of experiments, the optimum roasting temperature of sulphatization roasting of flotation tailings was determined at 630°C. The process of sulphatization roasting was carried out on the sample of 100 g of flotation tailings at two degrees: I degree: at temperature of 250°C for a period of 2 h and II degree: at temperature of 630°C for a period of 2 h. By XRD analysis on device EXPLORER GNR, the following mineralogical composition of a calcine sample was determined: quartz SiO_2 – 94.6 % and hematite Fe_2O_3 – 15.4 %. After sulphatization roasting, the obtained calcine was leached with water for disolving the formed copper sulphates. The attained percentage of copper leaching was 92 %. After process of sulphatization roasting and calcine leaching with water, the solid residue was obtained with chemical chatacterization given in Table 7.

Table 7 *Chemical composition of solid residue obtained after thermal treatment and leaching process with water*

Element	Content,%	Element	Content,%
Cu	0.034	Ag	<0.002
SiO_2	66.74	Hg, g/t	<0.1
Fe	10.89	Pb	<0.01
As	<0.003	Zn	0.0006
Mn	<0.0005		

Solid residure, obtaiend after leaching of calcine with water was undergone to the TCLP (Toxicity Characteristic Leaching Procedure) test.

Table 8 *Results of carried out TCLP test on a sample of solid residue obtained after leaching of calcine with water*

Element	Unit measure	Results of analyses	MDK of water for III and IV class*
Cu	mg/l	<0.1	0.1
Fe	mg/l	<0.2	1.0
Pb	mg/l	<0.1	0.1
Zn	mg/l	0.18	1.0
As	mg/l	<0.1	0.05
Hg	mg/l	<0.001	0.001

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The results of TCLP test, given in Tabeli 8, indicate that the metal concentrations are below MDK values, what points aout a fact that the solid residue, formed after copper extraction, is possible to store without a negative impact on the human environment because it belngs to the category of non-hazardous waste.

CONCLUSION

Based on the obtained results, it can be said that the leaching of flotation tailings with sulhuric acid solution in the presence of an oxidant significantly increases the degree of copper leaching compared. By the use of $Fe_2(SO_4)_3$ as an oxidant in concentration of 7 g/dm^3 Fe^{3+} at leaching temperature of 80^{o}C and leaching time of 120 min, the attained degree of copper leaching was 76.8 %. The process of sulphide destruction and copper leaching from flotation tailings sample with concentrated sulphuric acid at 630°C and leaching of calcine with water has resulted into copper leaching degree of 92%. Solutions, after leaching, contain about 2 g/dm^3 Cu and less than 1 g/dm^3 and Fe and they are suitable for SX-EW process for obtaining the commercial quality copper. The additional effect of the sulphatization process of tailings is the complete destruction of sulphide what realizes the embedded precious metals in pyrite: gold and silver and provides the possibility of their valorization from tailings. The advantage of use the sulphatization procedure is the possibility of solid residue storage resulting from the process of thermal treatment and leaching of tailings with no risk of harm the human environment.

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