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

IZRADA NUMERIČKOG MODELA STRUJANJA PODZEMNIH VODA U ZONI UTICAJA RUDNIKA RTB-a KORIŠĆENJEM SOFTVERSKOG PAKETA SPRING**

Izvod

Numerički model strujanja podzemnih voda razvijen je za borsku oblast u cilju utvrđivanja potencijalnog uticaja odloženog rudničkog otpada iz pogona RTB Bor (kopovska odlagališta i flotacijska jalovišta u okolini Bora) na kvalitet podzemnih voda. Svi parametri i prostorno-vremenska dinamika uzimanja uzoraka podzemnih voda definisani su standardom ISO 5667-11, kojim se utvrđuje program uzimanja uzoraka i rukovanje uzorcima za fizičko i hemijsko ispitivanje istih.

Ključne reči: *podzemne vode, SPRING softver, rudnička jalovina, zagađenje*

UVOD

Zagađenje voda u Republici Srbiji potiče od različitih privrednih grana (industrija, energetika, poljoprivreda, saobraćaj, rudarstvo itd.), kao i od neprečišćenih komunalnih otpadnih voda. Na pogoršanje kvaliteta vode u Republici Srbiji utiču, pored komunalnih i industrijskih i poljoprivredne aktivnosti, rečni saobraćaj, poplave, kao i prekogranično zagađenje. Značajno mesto u zagađenju voda zauzimaju prostori deponovane jalovine nastale u procesu rudarsko – prerađivačke industrije (flotacijska jalovišta Bora, Majdapeka, Rudnika, Velikog Majdana, Zajače, Raške, Vranja i dr.), deponije nastale pri metalurškoj preradi mineralnih sirovina i deponije pepela nastale pri energetsko-toplotnoj proizvodnji (termoelektrane).

HIDROGEOLOŠKI MODEL TRANSPORTA

Numerički model strujanja podzemnih voda razvijen je za borsku oblast, u cilju procene potencijalnog priliva podzemnih voda u oblasti površinskih kopova i jame

* *Institut za rudarstvo i metalurgiju Bor*
** *Ovaj rad je proistekao iz Projekta broj TR: 37001 „Uticaj rudarskog otpada iz RTB-a Bor na zagađenje vodotokova sa predlogom mera i postupka za smanjenje štetnog dejstva na životnu sredinu“ koji je finansiran sredstvima Ministarstva prosvete, nauke i tehnološkog razvoja Republike Srbije.*

Bor, kao i u cilju utvrđivanja potencijalnog uticaja kopovskih odlagališta i flotacijskih jalovišta RTB Bor koja su u okruženju, na kvalitet podzemnih voda.

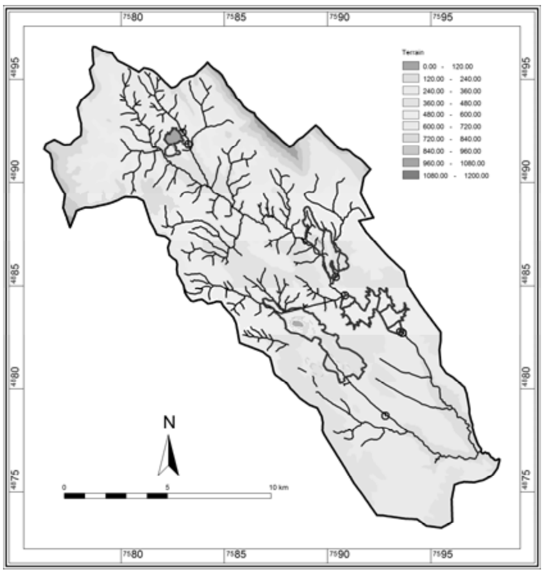
Izbor softverskog modela

Konceptualni model podzemnih voda preveden je u numerički model strujanja podzemnih voda, u cilju procene vrednosti brzine i pravca strujanja podzemnih vode. Izabran softverski paket "SPRING" za 3D numeričko modeliranje strujanja podzemnih voda, zasnovan na metodi konačnih elemenata, razvijen od strane Delta h Ingenieurgesellschaft mbH, Germany (König 2010). Program je prvi put objavljen 1970. godine i od tada je prošao kroz nekoliko revizija. "SPRING" je široko prihvaćen softverski program od strane naučnika iz oblasti zaštite životne sredine i naučnih udruženja. Ovaj softverski paket koristi metodu konačnih elemenata prilikom rešavanja jednačina kojom je prikazano strujanja podzemnih voda. To znači da je domen modela predstavljen brojem čvorova i elemenata.

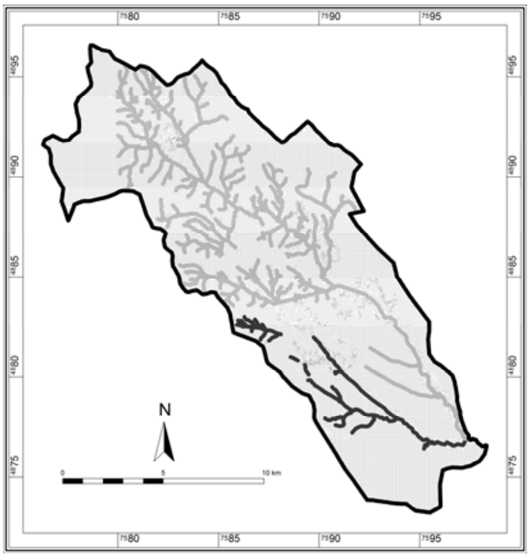
Hidrauličke osobine, svojstva ovih čvorova, elemenata i jednačina, razvijaju se za svaki čvor, a na osnovu susednih čvorova. Niz iteracija je zatim pokrenuto za rešavanje sistema diferencijalnih jednačina matričkom metodom. Model je pokazao da ima "konvergentne" rezultate, kada se greške smanjuju do prihvatljivog opsega. "SPRING" je u stanju da simulira stacionarno i nestacionarno strujanje podzemnih voda u izdani nepravilnih dimenzija, kao i prilikom zatvorenog ili otvorenog strujanja, ili kombinacije ova dva. Mogući su različiti modeli slojeva podzemnih voda različitih debljina.

Geometrijska struktura

Za mapiranje slivova relevantnih voda i kvantifikaciju uticaja ovih voda na situaciju podzemnih voda u borskoj oblasti, kreiran je regionalni dvodimenzionalni model. Prilikom formiranja mreže uzeti su u obzir: geološka struktura, nadmorska visina (Slika 1), površinske vode (Slika 2) sa svojim nivoima vode, bušotine izrađene u prethodnom periodu u cilju geoloških istraživanja i lokacija pijezometara za monitoring podzemnih voda.



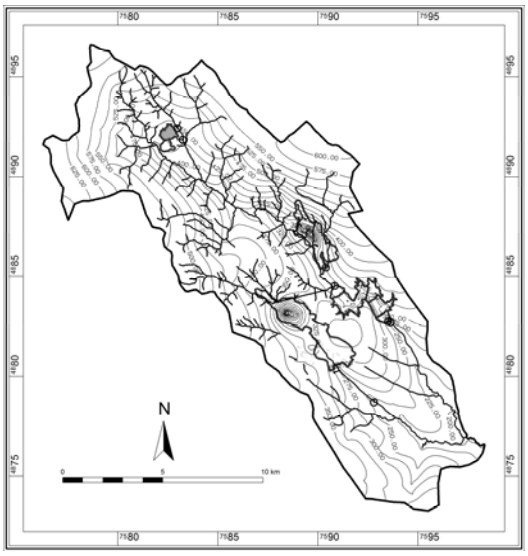
Sl. 1. *Visina površine terena čitave oblasti modeliranja*



Sl. 2. *Tok površinskih voda u domenu modela*

Pravac kretanja podzemnih voda

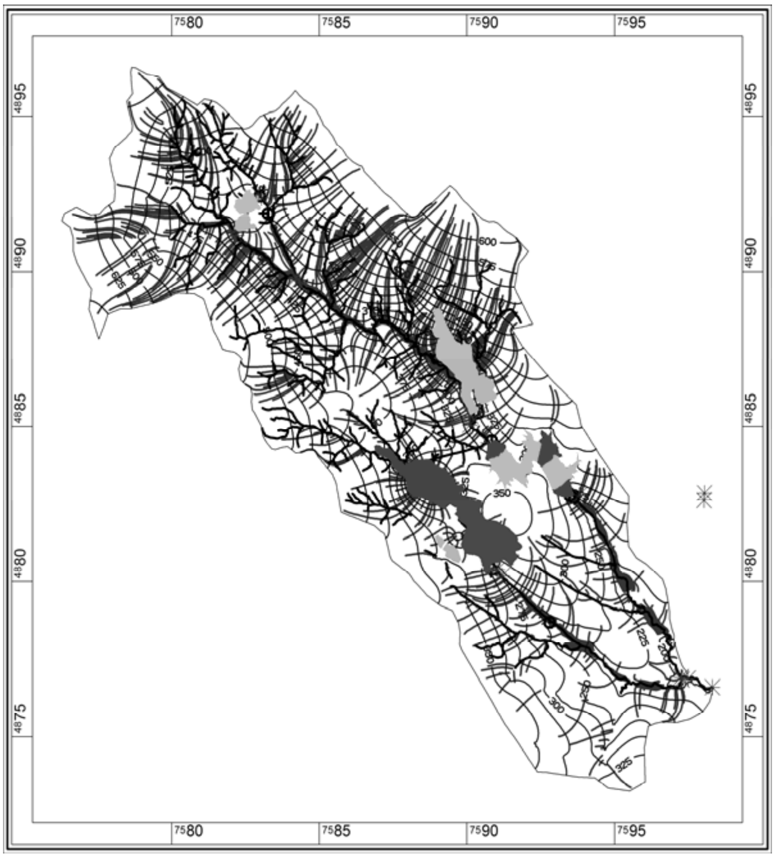
Po modelu kontura lokalnih podzemnih voda, jasno se vidi da je veliki uticaj rudnika bakra, flotacijskih jalovišta i odlagališta rudničke jalovine. Konture regionalnih stacionarnih podzemnih voda su, kao što se očekuje, u bliskoj vezi sa topografijom. Podzemne vode teku od viših ka nižim terenima, gde se pojavljuju kao izvorišta od kojih nastaju potoci i reke (Sl.3).



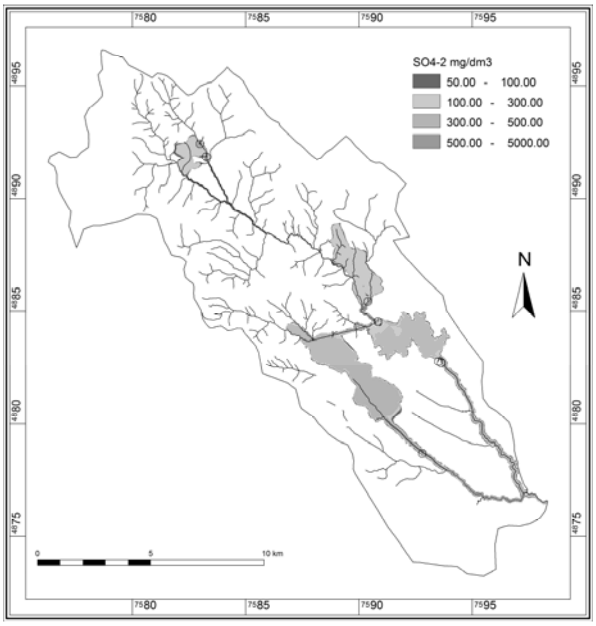
Sl. 3. *Model kontura podzemnih voda za čitavu oblast modeliranja*

Zagađenje u podzemnim vodama

3D model stacionarnih podzemnih voda korišćen je kao osnova za transportni model primenom "SPRING"-a. Jalovišta, deponije i površinski kopovi su smatrani kao potencijalni izvori zagađenja i ubačeni su u domen modela kao oblasti dreniranja sa izvorom konstantne koncentracije. U ovom tekstu se razmatra samo, transport potencijalnih zagađivača pretpostavljen kao advekcioni - disperzivni (longitudinalna disperzivnost 50 m) bez zadržavanja ili transformacija. Uticaji potencijalnih izvora zagađenja na kvalitet podzemnih voda su stoga ograničeni. Slike 4 i 5 pokazuju proračunate koncentracije SO_4^{-2} [mg/dm³] u borskoj oblasti u podzemnim i površinskim vodama.

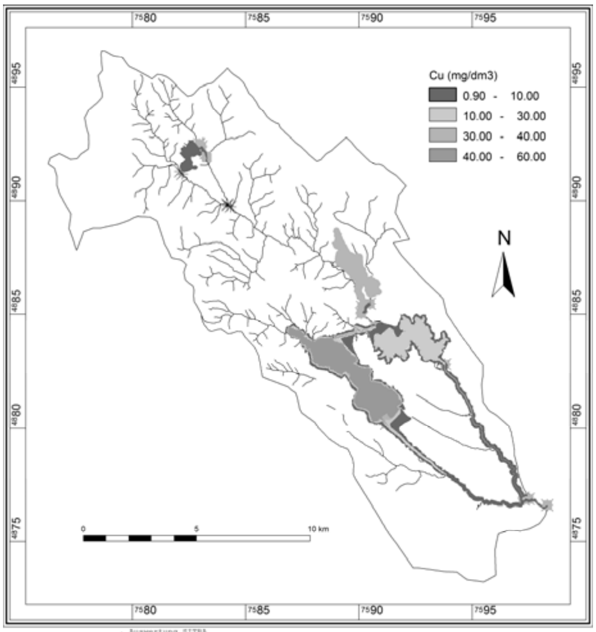


Sl. 4. *Proračunate linije pravca kretanja*



Sl. 5. *Proračunate koncentracije* SO_4^{-2} *[mg/dm³]*

Slika 6 pokazuje proračunate koncentracije Cu [mg/dm³] u borskoj oblasti u površinskim i podzemnim vodama.



Sl. 6. *Proračunata koncentracija Cu [mg/dm³]*

Uzorkovanje i ispitivanje kvaliteta podzemnih voda

Svi parametri i prostorno-vremenska dinamika uzimanja uzoraka podzemnih voda definisani su standardom ISO 5667-11, kojim se utvrđuje program uzimanja uzoraka i rukovanje uzorcima za fizičko i hemijsko ispitivanje istih (Tabela 1).

Tabela 1. *Uzimanje uzoraka podzemnih voda, terenska osmatranja i merenja*

Opis aktivnosti	Metoda/Standard	Prostorno-vremenska dinamika
Uzimanje uzoraka	ISO 5667-11:1997 Water quality -- Sampling -- Part 11: Guidance on sampling of groundwaaters	7 lokaliteta: na području RBB Bor; Dinamika: april-juni 2012.

REZULTATI I DISKUSIJA

Fizičko-hemijsko ispitivanje podzemnih voda na području borskog rudnika je uključivalo određivanje sledećih elemenata: hroma, selena, gvožđa, bakra, olova, nikla, kadmijuma, cinka, arsena, sadržaja suspendovanih materija i sulfata. Rezultati fizičko hemijskih ispitivanja uzoraka podzemnih voda prikazani su u Tabelama 2a i 2b.

Tabela 2a i 2b. *Rezultati fizičko-hemijskih ispitivanja uzoraka podzemnih voda iz posmatranih pijezometara koji su uzorkovani 18.05.2012. godine*

Parametar	T (^oC) vazduha	T (^oC) vode	Boja/miris	El.provod. µS/cm	pH	Cu (mg/dm^3)	Pb (mg/dm^3)	Zn (mg/dm^3)
P1	20	13.7	mutna/bez	3452	**5.82**	<0.1	<0.1	0.5
P2	20	11.9	mutna/bez	3812	6.15	<0.1	<0.1	**16.1**
P3	20	12.7	mutna/bez	5858	**4.45**	**3.6**	<0.1	**1.1**
P4	20	16.0	mutna/bez	1777	**5.21**	**5.1**	<0.1	**2.9**
P5	23	14.4	mutna/bez	2751	6.83	<0.1	<0.1	0.73
P8	23	17.8	mutna/bez	3032	6.67	<0.1	<0.1	<0.1
B3	22	17	mutna/bez	3081	7.39	<0.1	<0.1	<0.1

Parametar	Cd (mg/dm^3)	Ni (mg/dm^3)	Cr (mg/dm^3)	Se (mg/dm^3)	As (mg/dm^3)	Fe-uk (mg/dm^3)	Sus.mater. (mg/dm^3)	SO_4^{-2} (mg/dm^3)
P1	<0.1	<0.1	<0.1	<0.2	<0.1	**132.7**	363.0	2837.2
P2	<0.1	<0.1	<0.1	<0.2	<0.1	**64.4**	1977.0	2806.3
P3	<0.1	**0.5**	<0.1	<0.2	<0.1	<0.1	2225.0	3392.8
P4	<0.1	**0.37**	<0.1	<0.2	<0.1	**36.9**	899.0	1204.3
P5	<0.1	<0.1	<0.1	<0.2	<0.1	0.1	2264.0	1641.1
P8	<0.1	<0.1	<0.1	<0.2	<0.1	**2.1**	6770.0	1276.0
B3	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	62.0	1944.8

Tabele 2a i 2b - Lokacije posmatranih pijezometara

***P1** - Desna obala Valja Luterice – drenažna šahta;*
***P2 -** Desna obala Valja Luterice – drenažno jezero;*
***P3 -** Podnožje odlagališta Saraka potok;*
***P4** - Borska reka uzvodno od Slatine;*
***P5** - Kriveljska reka posle izlaza iz tunela;*
***P8** - Telo brane III;*
***B2** - Ulaz u tunel Kriveljske reke*

Pravilnik koji propisuje maksimalno dozvoljenu količinu opasnih i štetnih materija u zemljištu i vodi koje mogu da oštete ili promene proizvodnu sposobnost zemljišta i koje dolaze ispuštanjem iz fabrika i izlivanjem iz deponija, dat je u Službenom listu Socijalističke Republike Srbije br. 23/94. U tabeli 3 prikazani su podaci o maksimalno dozvoljenim količinama opasnih i štetnih materija u vodi.

***Tabela 3.** Maksimalno dozvoljena količina opasnih i štetnih materija*

Broj	Parametar	MDK u vodi (mg/L)
1.	Kadmijum	Do 0.01
2.	Olovo	Do 0. 1
3.	Živa	Do 0.001
4.	Arsen	Do 0.05
5.	Hrom	Do 0.5
6.	Nikl	Do 0. 1
7.	Fluor	Do 1.5
8.	Bakar	Do 0.1
9.	Cink	Do 1.0
10.	Bor	Do 1.0

Opasne materije, u smislu ovog pravilnika su: kadmijum, olovo, živa, arsen, hrom, nikl i fluor, a štetne materije su: bakar, cink i bor.

Za analizu kvaliteta podzemnih voda u zoni uticaja rudnika i odložene jalovine RTB Bor, uzeti su kao hemijski parametri prvenstveno teški metali i pH vrednost.

Smanjena pH vrednost odnosno povećana kiselost ispod donje granice od 6 pH jedinica, u posmatranom periodu uočena je na mernim mestima P1, P3 i P4, pri čemu je najniža izmerena pH vrednost iznosila 4,45 u zoni odlagališta Saraka (pijezometar P3).

U Tabeli 2a i 2b boldirane su sve vrednosti onih elemenata čije se koncentracije nalaze iznad dozvoljenih granica. Povećane sadržaje imaju bakar, cink, gvožđe i nikl. Sadržaj bakra u posmatranom periodu se kretao od 3.6 mg/dm^3 (P3) do

5,1 mg/dm^3 (P4), cinka od 1,1 mg/dm^3 (P3) do 16,1 mg/dm^3 (P2), gvožđa 2,1 mg/dm^3 (P8) do 132,7 mg/dm^3 (P1) i nikla od 0,37 mg/dm^3 (P4) do 0,5 mg/dm^3 (P3). Ukoliko uporedimo izmerene koncentracije i maksimalno dozvoljene koncentracije (MDK) uočavamo da su one kod nekih elemenata višestruko povećane, na primer za bakar 51 put, za cink 16 puta, za gvožđe 132 puta i za nikl do 5 puta. Sadržaj hroma, kadmijuma, selena i arsena se u posmatranom periodu kretao ispod MDK.

ZAKLJUČAK

Ogromne količine odloženog rudničkog otpada u opštini Bor nastalog tokom vekovne eksploatacije i prerade rude bakra, konstantno zagađuje kako površinske tako i podzemne vodotokove. Kao krajnji rezultat i posledica zagađenja imamo neupotrebljive vodotokove Borske i Kriveljske reke koji se ne mogu koristiti čak ni za navodnjavanje poljoprivrednog zemljišta, jer je kvalitet vode u njima van svake kategorije. Ono što je takođe veoma ozbiljno je da su i posledice po podzemne vode u zoni uticaja rudničkog otpada RTB Bor katastrofalne. Svi bunari i izvorišta u selima Veliki i Mali Krivelj, Slatina i Oštrelj, koji se nalaze u bližoj okolini Kriveljske i Borske reke su veoma zagađeni i ne mogu se koristiti, kako za piće tako i za napajanje domaćih životinja. Ovo isto važi i za bunare i izvorišta u bližoj okolini odlagališta kopovske raskrivke i flotacijske jalovine. Numeričko modeliranje ima za cilj da nam omogući kvalitetan grafički prikaz uticaja zagađenja kako na podzemne tako i na površinske vodotokove, sa definisanim zonama rasprostiranja zagađenja i njihovom krajnjem dometu. Na taj način se u potpunosti može sagledati sveobuhvatan uticaj koje zagađenja generisana rudničkim otpadom imaju na površinske i podzemne vode u njihovom okruženju.

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Mile Bugarin, Ljubiša Obradović*, Vladan Marinković**

DEVELOPMENT THE NUMERICAL MODEL OF GROUND WATER FLOW IN THE IMPACT ZONE OF RTB MINE USING THE SOFTWARE PACKAGE SPRING**

Abstract

The numerical model of ground water flow was developed for the Bor area in order to determine the potential impact of disposed mine waste from the site of RTB Bor (open pit and flotation tailing dumps in the vicinity of Bor) on the ground water quality. All parameters and spatial-temporal dynamics of ground water sampling are defined by the Standard ISO 5667-11, which establishes a program of sampling and handling of samples for physical and chemical analysis the same.

Keywords: *ground water, SPRING software of mine waste, pollution*

INTRODUCTION

Water pollution in the Republic of Serbia comes from various economic sectors (industry, energy, agriculture, transportation, mining, etc.), as well as from untreated municipal wastewater. The deterioration of water quality in the Republic of Serbia is influenced, in addition to the municipal and industrial activities and agricultural activities, by the water transport, floods, and cross-border pollution. An important place in the water pollution is occupied by the areas of deposited tailings produced in the process of mining - processing industry (flotation tailing dumps of Bor, Majdanpek, Mine, Veliki Majdan, Zajača, Raška, Vranje, etc.), the waste dumps incurred in the metallurgical treatment of mineral resources and ash landfills resulting from the energy-thermal production (thermal power plants).

HYDROGEOLOGICAL MODEL OF TRANSPORTATION

Numerical ground water flow model was developed for the Bor area in order to assess the potential groundwater inflow in

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the area of open pits and pit Bor, as well as to determine the potential impact of open pit dumps and flotation tailing dumps of RTB Bor, which are in the environment, on the ground water quality.

Selection of software model

A conceptual model of ground water has been translated into a numerical model of ground water flow in order to assess the value of speed and direction of ground water flow. The selected software package SPRING for 3D numerical modeling of ground water flow, based on the finite element method, was developed by the delta h Ingenieurgesellschaft mbH, Germany (König 2010). The program was first published in the 1970 and since then it has gone through several revisions. SPRING is a software program widely accepted by scientists in the field of environmental protection and scientific societies. This software package uses the finite element method in solving the equation that shows the flow of ground water. This means that the model domain is represented by the number of nodes and elements.

Hydraulic characteristics, properties of these nodes, elements and equations, are developed for each node, based on the neighboring nodes. A series of iterations was then run to solve the system of differential equations using the matrix method. Model showed that it has the "convergence" results when the errors are reduced to an acceptable range. SPRING is able to simulate steady and unsteady flow of ground water in the aquifers of irregular sizes, as well as in the closed or opened flow, or a combination of these two. There may be different models of ground water layers of different thicknesses.

Geometric structure

To map the relevant water basins and quantify the impact of this water on the ground water situation in the Bor area, a regional two-dimensional model was created. During formation the network, the followings are taken into account: geological structure, altitude (Figure 1), surface water (Figure 2) with their levels of water, drill holes made in the previous period for geological explorations and locations of piezometers for ground water monitoring.

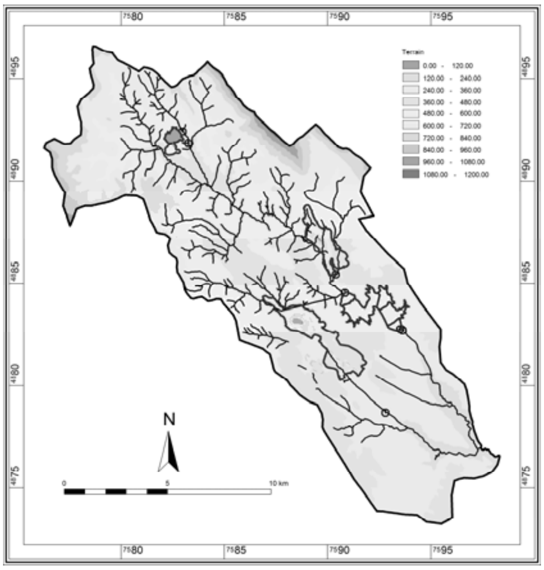

Fig. 1. *Field surface height of the entire modeling area*

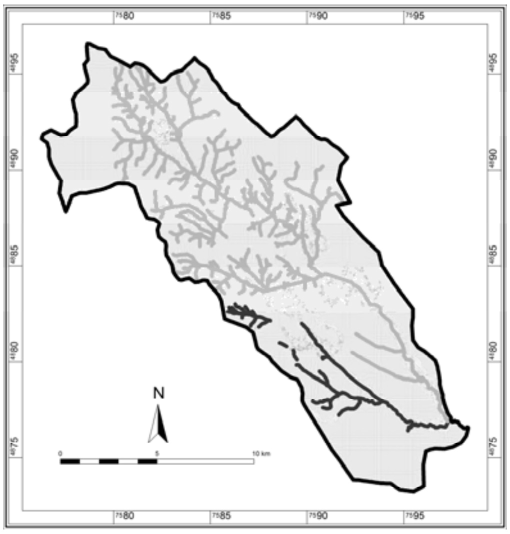

Fig. 2. *Surface water floe in the area of model*

Ground water directions

According to the model local ground water contours, it is clear that the copper mine, flotation tailing dumps and mine waste dumps have the major impact. The contours of regional stationary ground water, as it is expected, are closely related to the topography. Ground water flows from higher to lower terrains where they appear as sources which crate streams and rivers (Figure 3).

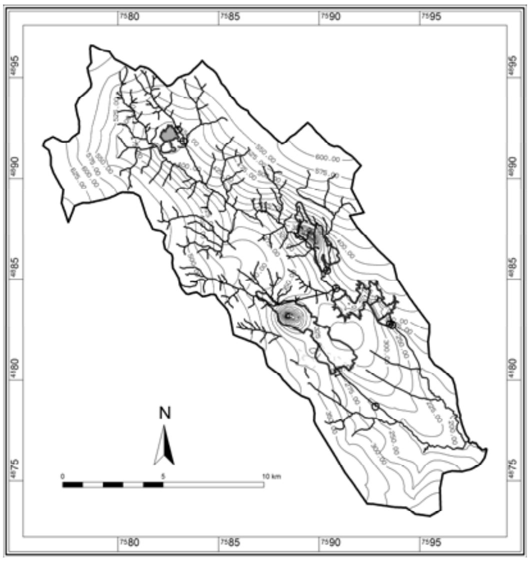

Fig. 3. *Model of ground water contours for the entire area of modeling*

Pollution of groundwater

3D model of stationary ground water was used as the basis for the transport model using SPRING. Tailing dumps, landfills and open pits are considered as potential sources of pollution and they are inserted into the model domain as drainage areas with a source of constant concentration. This paper discusses only the transport of potential pollutants assumed to advection-dispersion (longitudinal dispersion 50 m) without stopping or transformation. The effects of potential pollution sources to the ground water quality are therefore limited. Figures 4 and 5 show the calculated concentration of SO_4^{-2} [mg/dm³] in the Bor area in the ground and surface water.

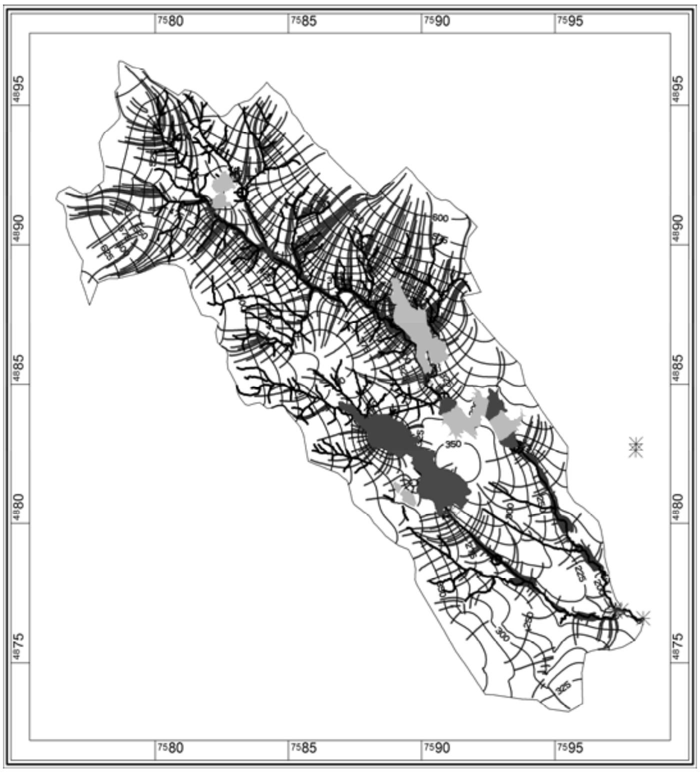

Fig. 4. *Calculated lines of movement direction*

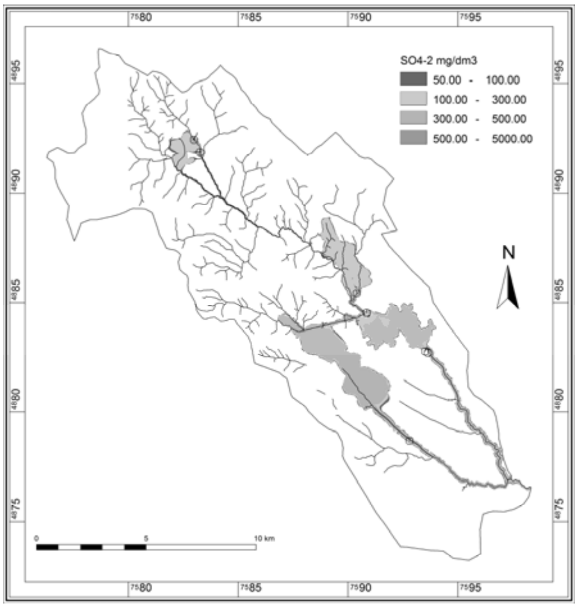

Fig. 5. *Calculated concentrations of* SO_4^{-2} *[mg/dm³]*

Figure 6 shows calculated concentrations of Cu [mg/dm³] in the Bor area in the ground and surface water.

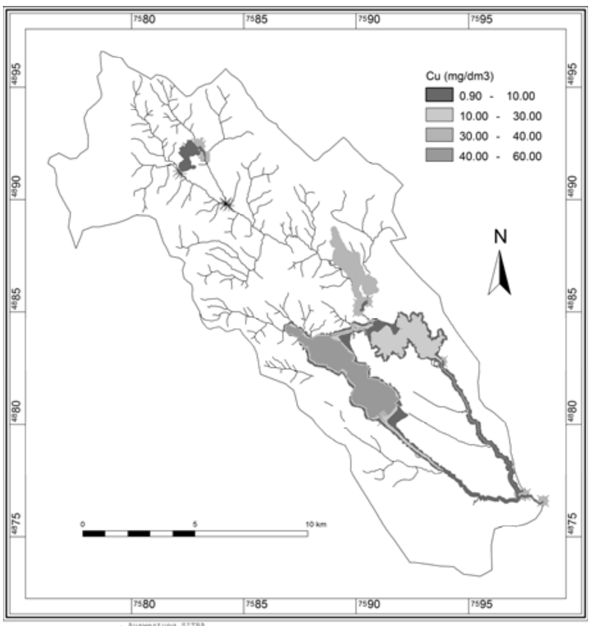

Fig. 6. *Calculated concentration of Cu [mg/dm³]*

Sampling and testing the groundwater quality

All parameters and spatial-temporal dynamics of ground water sampling are defined by the Standard ISO 5667-11, which establishes a program of sampling and handling of samples for physical and chemical analysis of the same (Table 1).

Table 1. *Groundwater sampling, field observations and measuring*

Activity description	Method/Standard	Prostorno-vremenska dinamika
Sampling	ISO 5667-11:1997 Water quality -- Sampling -- Part 11: Guidance on Sampling of Ground Water	7 locaities: in the area of RBB Bor; Dynamics: April-June 2012

RESULTS AND DISCUSSION

Physical-chemical testing of ground water in the area of Bor mine included determining the following elements: chromium, selenium, iron, copper, lead, nickel, cadmium, zinc, arsenic, content of suspended solids and sulfates. The results of physical and chemical testing of ground water samples are present in Tables 2a and 2b.

Tables 2a and 2b. *Results of physical- chemical testing of ground water samples from the observed piezometers, sampled on May 18, 2012*

Parameter	T (^{o}C) air	T (^{o}C) water	Colour/smell	El.conduct. µS/cm	pH	Cu mg/dm^3	Pb mg/dm^3	Zn mg/dm^3
P1	20	13.7	muddy / without	3452	**5.82**	<0.1	<0.1	0.5
P2	20	11.9	muddy / without	3812	6.15	<0.1	<0.1	**16.1**
P3	20	12.7	muddy / without	5858	**4.45**	**3.6**	<0.1	**1.1**
P4	20	16.0	muddy / without	1777	**5.21**	**5.1**	<0.1	**2.9**
P5	23	14.4	muddy / without	2751	6.83	<0.1	<0.1	0.73
P8	23	17.8	muddy / without	3032	6.67	<0.1	<0.1	<0.1
B3	22	17	muddy / without	3081	7.39	<0.1	<0.1	<0.1

Parameter	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)	Suspended matters (mg/dm^3)	SO_4^{-2} (mg/dm^3)
P1	<0.1	<0.1	<0.1	<0.2	<0.1	**132.7**	363.0	2837.2
P2	<0.1	<0.1	<0.1	<0.2	<0.1	**64.4**	1977.0	2806.3
P3	<0.1	**0.5**	<0.1	<0.2	<0.1	<0.1	2225.0	3392.8
P4	<0.1	**0.37**	<0.1	<0.2	<0.1	**36.9**	899.0	1204.3
P5	<0.1	<0.1	<0.1	<0.2	<0.1	0.1	2264.0	1641.1
P8	<0.1	<0.1	<0.1	<0.2	<0.1	**2.1**	6770.0	1276.0
B3	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	62.0	1944.8

Tables 2a and 2b – Locations of the observed piezometers

P1 *- The right bank of Valja Luterica - drainage manhole;*
P2 *- The right bank of Valja Luterica - drainage lake;*
P3 *- Bottom of the waste dump Saraka Stream;*
P4 *- The Bor River upstream from Slatina;*
P5 *- The Krivelj River after exit of the tunnel;*
P8 *- The body of Dam III;*
B2 *- The entrance into the tunnel of the Krivelj river.*

The Rulebook that prescribes maximum allowable quantity of hazardous and harmful substances in soil and water that might damage or change the production capacity of soil and that come from factory discharges and spillages from land fills, is given in the Official Gazette of the Socialist Republic of Serbia No. 23/94. Table 3 presents the data on maximum allowable quantities of hazardous and harmful substances in water.

Table 3. *Maximum allowable quantities of hazardous and harmful substances*

No.	Parameter	MDK in water (mg/L)
1.	Cadmium	Up to 0.01
2.	Lead	Up to 0. 1
3.	Mercury	Up to 0.001
4.	Arsenic	Up to 0.05
5.	Chrome	Up to 0.5
6.	Nickel	Up to 0. 1
7.	Fluorine	Up to 1.5
8.	Copper	Up to 0.1
9.	Zinc	Up to 1.0
10.	Boron	Up to 1.0

Hazardous substances, in terms of this regulation are: cadmium, lead, mercury, arsenic, chromium, nickel and fluorine, and harmful substances are: copper, zinc and boron.

For the analysis of ground water quality in the area of impacts the mine and disposed tailings of RTB Bor, primarily heavy metals and pH value were taken as chemical parameters.

Decreased pH value and increased acidity below the lower limit of 6 pH units in the reporting period was observed at the measuring points P1, P3, and P4, with the lowest measured pH value of 4.45 in the area of Saraka landfill (piezometer P3).

Table 2a and 2b present the bolded all values of those elements whose concentrations are above the permissible limits. Copper, zinc, iron and nickel have the increased contents. Content of copper in the observed period ranged from 3.6 mg/dm^3 (P3) to 5.1 mg/dm^3 (P4), zinc from 1.1 mg/dm^3 (P3) to 16.1 mg/dm^3 (P2), iron from 2.1 mg/dm^3 (P8) to 132.7 mg/dm^3 (P1) and nickel from 0.37 mg/dm^3 (P4) to 0.5 mg/dm^3 (P3). If the measured concentrations and maximum permissible concentrations (MPC) are compared, it is seen that they are several times increased in some elements, for example 51 times for copper, 16 times for zinc, 132 times for iron and up to 5 times for nickel. Content of chromium, cadmium, selenium and arsenic in the observed period was under MPC.

CONCLUSION

Huge amounts of disposed mine waste in the municipality of Bor, created during centuries of mining and processing of copper ore, constantly pollute both surface and ground waterways. As the final result and consequence of pollution, there are unusable waterways of the Bor and Krivelj River that cannot be used even for irrigation of agricultural land, because the water quality in them is out of any category. It is also very serious that the consequences for ground water in the impact zone of mine waste of RTB Bor are disastrous. All wells and springs in the villages of Veliki and Mali Krivelj, Slatina and Oštrelj, which are located in the vicinity of the Krivelj and Bor River are heavily polluted and they can be used both for drinking and watering of domestic animals. This is also true for wells and springs in the vicinity of the open pit overburden and tailing dump. Numerical modeling is intended to allow a high quality graphic display of the pollution impact both on ground water and surface water courses, with defined areas of pollution spreading and their ultimate range. In this way, a completely comprehensive impact can be seen of pollution, generated by mine waste on the surface and ground water in their environment.

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MOGUĆA REŠENJA PROMENE METODE PODETAŽNOG ZARUŠAVANJA RADI POBOLJŠANJA EFEKATA OTKOPAVANJA RUDNIH LEŽIŠTA**

Izvod

Metodu podetažnog zarušavanja, ma koliko ona bila savremena, prati pojava brojnih problema zbog kojih se često u praksi postižu nepovoljni rezultati, kako tehnički, tako i ekonomski. U slučaju kada se iz objektivnih ili subjektivnih razloga ne postižu očekivani rezultati njene primene, treba razmisliti o promeni metode ili bar njenoj modifikaciji u cilju poboljšanja uslova otkopavanja i postizanja povoljnijih ekonomskih rezultata, o čemu se govori u ovom radu.

Ključne reči: *podzemno otkopavanje, metoda podetažnog zarušavanja, varijante metode, iskorišćenje i osiromašenje rude.*

UVOD

U više ranijih radova govoreno je o problemima koji se javljaju pri primeni metode podetažnog zarušavanja, a koji se u najvećoj meri manifestuju na dva glavna pokazatelja metode: iskorišćenje i osiromašenje rude. Poznato je da se kod ove metode javlja nešto veći obim pripreme, da se vrlo veliki problemi javljaju pri nedovoljno preciznoj izradi podetažnih hodnika, isto tako i zbog nekih grešaka u izvodjenju radova na bušenju i miniranju.

O pomenutim problemima je govoreno na bazi iskustava na primeni ove metode pri otkopavanju nekoliko rudnih tela u borskoj jami, u kojoj se ova metoda primenjuje od sredine prošlog veka. Uticaj nekih od njih, ispitivani su i na modelima u laboratorijskim uslovima, što je doprinelo očiglednom upoznavanju zakonitosti odvijanja procesa istakanja minirane rude i štetnog uticaja nekih nepovoljnih pojava pri primeni metode podetažnog zarušavanja.

Na bazi teoretskih i laboratorijskih istraživanja predloženo je nekoliko novih varijanti metode podetažnog zarušavanja, koje mogu doprineti otklanjanju nepovoljnih uticaja opisanih problema, koji se javljaju u praksi primene ove metode.

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PREDLOG NEKIH MOGUĆIH REŠENJA IZMENE KONSTRUKCIJE METODE PODETAŽNOG ZARUŠAVANJA

U literaturi se sreće veći broj različitih konstrukcija metoda podetažnog zarušavanja, a ovde se razmatraju samo one koje su uporedive sa primenjenom «švedskom varijantom».

Da bi se realno sagledao uticaj obima pripremnih radova, korisno je odrediti pokazatelj pripreme (koeficijent pripreme) za klasičnu varijantu – «švedsku varijantu» podetažnog zarušavanja, koja se u rudnim telima borske jame («Tilva Roš» i «P_2A) primenjuje sa sledećim parametrima (slika 1):

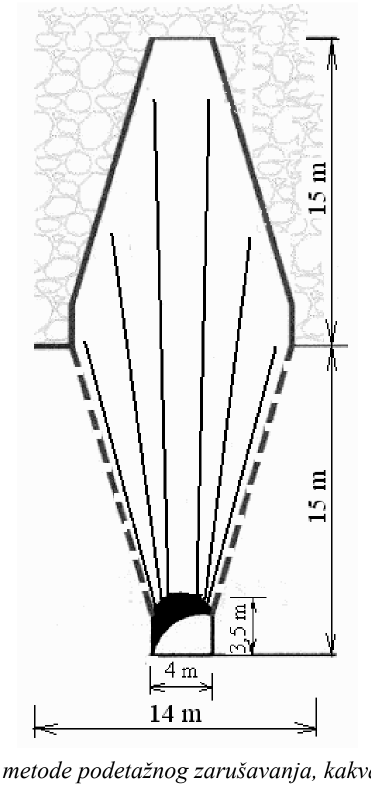
- visina izmedju podetaža H = 15 m,
- rastojanje izmedju podetažnih hodnika B = 14 m,
- parametri podetažnog hodnika: širina b = 4 m, visina h = 3,5 m, poprečni presek $P_h = 12,5\ m^2$

Površina bloka rude, koji se minira, je:

$P_b = B \cdot H - P_h = 14 \text{ x } 15 - 12,5 = 197,5\ m^2$.

Pri zapreminskoj masi rude $\gamma_r = 2,8\ t/m^3$, količina rude u bloku, na 1 m dužni podetažnog hodnika iznosi:

$Q_{r1} = P_b \cdot 1 \cdot \gamma_r = 197,5 \text{ x } 2,8 = 553$ t,



Sl. 1. *Parametri metode podetažnog zarušavanja, kakva se primenjuje u rudnim telima Borskog ležišta*

Za izračunavanje koeficijenta pripreme uzima se i ruda dobijena iz podetažnog hodnika, pa je količina rude na 1 m hodnika

Q_{r1} = 14 x 15 x 1 x 2,8 = 588 t,

a dobijene rovne rude ili rudne mase:

$$Q_{rm} = \frac{Q_r \cdot K_{ir}}{1 - K_{or}} = \frac{588 \cdot 0{,}8}{1 - 0{,}1} = 522{,}67 \text{ t}$$

($\frac{K_{ir}}{1 - K_{or}} = K_{rm}$ -koeficijent rudne mase)

Uzimajući u obzir samo dužinu prečnog podetažnog hodnika, parcijalni koeficijent pripreme iznosi:

K_p = 1 / 522,67 = 0,00191 m/t

Za moćnost pojasa miniranja od 4 m, količina rude, koja se minira, iznosi:

$Q_r = P_b \cdot m \cdot \gamma_r$ = 197,5 x 4 x 2,8 = 2.212 t

Kada se radi o mogućim varijantama metode podetažnog zarušavanja, kojima bi moglo da se zameni primenjeno podetažno zarušavanje u pomenutim rudnim telima Borskog ležišta, ima se u vidu pre svega potreba da se racionalizacija postigne sa stanovišta:

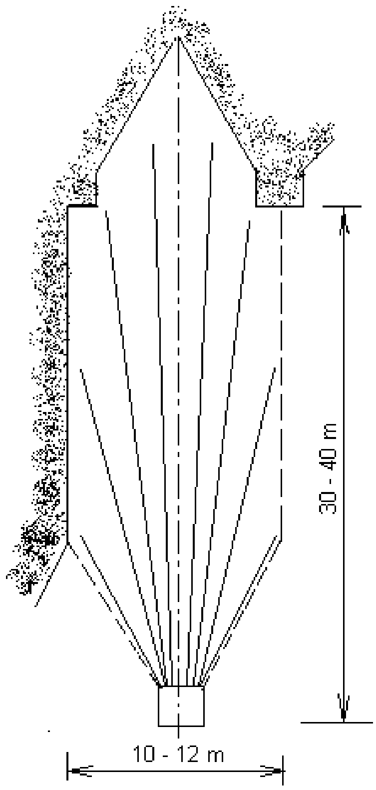
- smanjenja obima pripreme u rudnim telima,
- povećanja veličine bloka rude koja se otkopava,
- racionalnijeg korišćenja opreme za bušenje, utovar i odvoz rude,
- obezbedjenja uslova za smanjenje gubitaka i osiromašenja rude.

Smanjenje koeficijenta pripreme postiže se, pre svega, povećanjem visine izmedju podetaža, odnosno povećanjem veličine bloka rude koji se otkopava, dok se za prevazilaženje većeg broja drugih nedostataka metode podetažnog zarušavanja, može postići prelazom na varijante metoda otkopavanja sa miniranjem rude u pojasima veće moćnosti. O nekim od tih varijanti se nadalje govori.

1. Varijanta metode podetažnog zarušavanja sa većom visinom podetaža

Ova varijanta je razvijana paralelno sa najšire primenjivanom «švedskom varijantom» posebno u nekim švedskim rudnicima (Kiruna, Malmberget, Grengesberg i dr., /3/). Metoda, prikazana na slici 2, se karakteriše znatno većom visinom izmedju podetaža, tačnije primenom ove varijante mogla bi se priprema izvoditi na svakoj drugoj podetaži. Medjutim, kod ove varijante oblik bloka rude u poprečnom preseku nije sličan preseku kod «švedske varijante», pa se kod nje ne sreće veće podudaranje preseka bloka sa površinom elipsoida točenja. To znači da je mogućnost postizanja iskorišćenja i osiromašenja rude manja u odnosu na «švedsku varijantu», ali se opravdanje za njenu primenu može naći u značajnom smanjenju pripreme, povećanju količine rude koja se odjednom minira, racionalnijoj primeni mehanizacije, većoj proizvodnosti otkopa, većoj produktivnosti rada i dr.

Kod ove metode se koeficijent pripreme još više smanjuje jer se i osnovni podetažni hodnici izradjuju na duplo većem visinskom rastojanju u odnosu na «švedsku varijantu». Površina bloka koja se minira, kao i pojas minirane rude u direktnoj su zavisnosti od položaja prečnog podetažnog hodnika, a uticaj odstupanja lokacije hodnika u odnosu na hodnike gornje podetaže je manji, budući da je količina rude iznad gornjeg podetažnog nivoa srazmerno manja. Zbog toga je negativan uticaj greške u izradi podetažnih hodnika neuporedivo manji u odnosu na taj uticaj kod «švedske varijante».



Sl. 2. *Podetažno zarušavanje sa većom visinom podetaža*

Za proračun uporednih pokazatelja, usvajaju se sledeći parametri metode:

- visina izmedju podetaža 30 m,
- širina bloka (rastojanje izmedju podetažnih hodnika) 12 m,
- širina pojasa miniranja 4 m.

Površina bloka rude je:

$P_b = B \cdot H - P_h =$

$= 12 \text{ x } 30 - 12{,}5 = 347{,}5 \text{ m}^2$

Količina rude koja se minira iznosi:

$Q_r = P_b \cdot m \cdot \gamma_r = 347{,}5 \text{ x } 4 \text{ x } 2{,}8 = 3.892 \text{ t}$

Računajući i rudu iz podetažnog hodnika, količina je:

Količina rude na 1 m hodnika iznosi:

$Q_{r1} = P_b \cdot 1 \cdot \gamma_r =$

$=12 \text{ x } 30 \text{ x } 1 \text{ x } 2{,}8 = 1.008 \text{ t/m}$

Koeficijent pripreme (parcijalni) je:

$$K_{ph} = \frac{L_p}{Q_{rm}} = \frac{1}{Q_{r1} \cdot K_{rm}} =$$

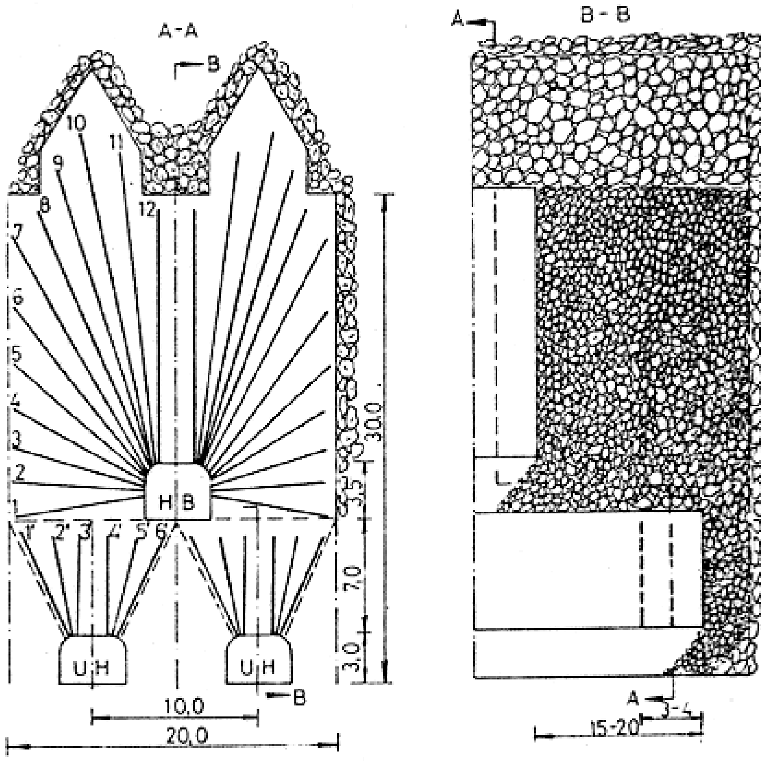
$$= \frac{1}{1008 \cdot 0{,}87} = 0{,}00114 \quad \text{m/t}$$

2. Varijanta podetažnog zarušavanja sa posebnim hodnikom za bušenje

Ova varijanta podetažnog zarušavanja se sreće u ruskoj literaturi, a bazirana je na principima miniranja rude u stešnjenoj sredini u pojasima velike moćnosti, /8/.

Zbog toga se u okviru pripreme izradjuje poseban hodnik za bušenje, (slika 3), iz koga se bušenje minskih bušotina za osnovno obaranje rude izvodi sa većom nezavisnošću od radova na utovaru rude. Hodnik za bušenje se može raditi za svaki utovarni hodnik, za dva utovarna hodnika (kao na slici), izuzetno i za tri hodnika.

Za usvojeni primer na slici 3, priprema se izvodi izradom posebnog hodnika za bušenje na medjusobnom rastojanju koje odgovara dvostrukoj širini rudnog bloka sa jednim utovarnim hodnikom, (do 20 m). Za tu širinu bloka se na podetažnom nivou izradjuju dva hodnika za utovar rude. Visina bloka može biti 30 – 40 m, odnosno da bude jednaka polovini usvojene visine izmedju horizonata.



Sl. 3. *Varijanta metode podetažnog zarušavanja sa posebnim hodnikom za bušenje*

Princip otkopavanja se sastoji u sledećem. Iz hodnika za bušenje buše se duboke minske bušotine sa lepeznim rasporedom («polulepeze»), kojima se ruda minira u pojasima, koji odgovaraju dužini bloka miniranoj sa 2 – 3 reda minskih bušotina, izuzetno i više ukoliko za to postoje povoljni uslovi. Na taj način se znatno bolje koriste pogodnosti miniranja rude u stešnjenoj sredini: racionalnije korišćenje opreme za bušenje, bolje usitnjavanje rude, smanjen broj miniranja i dr.

Minirana ruda se utovara iz utovarnih hodnika pošto se prethodno izbuše 2 – 3 reda kraćih minskih bušotina i miniranjem omogući istakanje rude oborene i iz hodnika za bušenje. Obezbedjenje uslova za istakanje rude iz narednog pojasa istakanja postiže se miniranjem nešto šireg pojasa iz utovarnih hodnika, budući da se, pri istakanju, istače i deo rude iza vertikalne ravni novog pojasa miniranja.

Pokazatelji metode izračunati su za sledeće parametre:

- visina izmedju podetaža 30 m,
- širina bloka (rastojanje izmedju hodnika bušenja) 20 m,
- širina pojasa miniranja 4 m.

Površina bloka koja se otkopava:

P_b = 20 x 30 – 3 x 12,5 = 562,5 m^2

Količina rude u pojasu:

Q_r = 562,5 x 4 x 2,8 = 6.300 t

Količina rude na 1 m podetažnih hodnika

Q_{r1} = 562,5 x 1 x 2,8 = 1.575 t/m.

Količina rude sa rudom iz podetažnih hodnika

Q_{ru} = 20 x 30 x 1 x 2,8 =1.680 t/m

Koeficijent pripreme je:

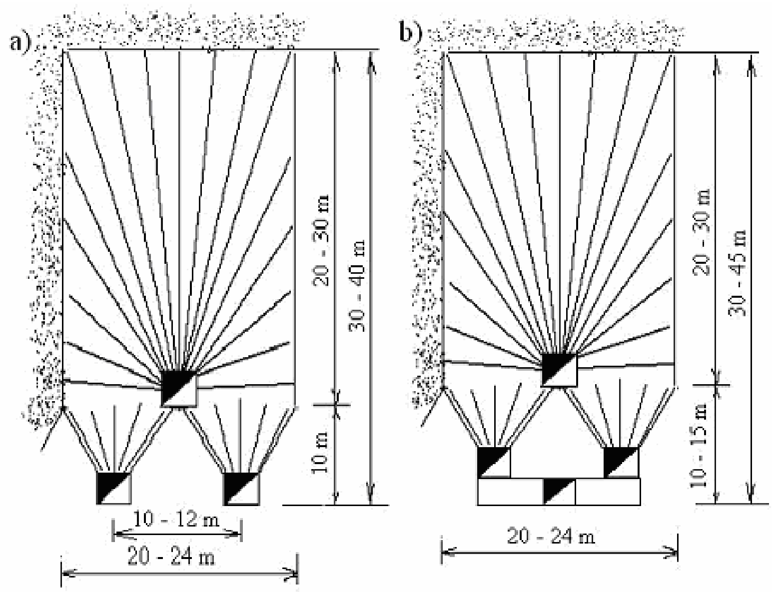
$$K_p = \frac{3}{1680 \cdot 0{,}87} = 0{,}00205 \quad \text{m/t}$$

Ovoj metodi se može zameriti to što se ne primenjuje istakanje rude iz pojasa veće moćnosti, kada se već ruda tako obara. Na taj način ostaje problem prethodnih varijanti podetažnog zarušavanja da se ruda istače iz pojasa relativno male širine pri čemu se pri svakom istakanju javlja osiromašenje rude sa vertikalnog kontakta izmedju rude i jalovine. Taj nedostatak se može otkloniti izradom posebnih hodnika za utovar rude, kojima se stvaraju uslovi istakanja rude iz pojasa velike moćnosti, kada, takodje, postoji samo jedan vertikalni kontakt izmedju minirane rude i jalovine. To, samim tim, omogućava dobijanje rudne mase sa manjim osiromašenjem.

3. Varijanta podetažnog zarušavanja sa posebnim hodnicima za utovar rude

Prelaz na varijante sa istakanjem rude iz pojasa velike moćnosti omogućava se izradom posebnih utovarnih hodnika, iz kojih se ruda može istakati istovremeno iz više «ispusnih otvora» - bočnih utovarnih mesta ili niša, (slika 4), /8/. Ovaj se princip može primeniti i kod varijante podetažnog zarušavanja sa romboidalnim oblikom bloka rude, medjutim, ovde se ona ne razmatra budući da se i kod ove varijante javlja problem zbog neprecizno izradjenih podetažnih hodnika.

Na slici 4, uporedjenja radi, prikazana je i prethodna varijanta da bi se uočile osnovne razlike kod varijante sa posebnim utovarnim hodnikom. Novina je samo u izradi utovarnog hodnika i bočnih utovarnih niša kojima se pristupa do «ispusnih otvora», koji su u podu hodnika podsecanja. Kao što je prikazano utovarni hodnici kod prethodne varijante, kod ove su hodnici transejnog podsecanja, pa se ovde može govoriti o pripremi dna bloka, koja može biti i drugojačija, ali je ovde usvojena ova, koja u potpunosti odgovara situaciji na prethodnoj slici. Utovarne niše su kratki hodnici, koji se izradjuju bočno iz utovarnog hodnika do hodnika podsecanja. Izradjuju se na medjusobnom rastojanju 8 – 10 m. Dužina im je 10 m ili nešto veća ukoliko se izradjuju ukoso radi lakšeg ulaska utovarno - transportne mašine. Na slici nisu prikazane prostorije gornje podetaže, pa se može pretpostaviti njihovo postojanje, mada se pri obaranju rude taj deo bloka ne buši niti minira.



Sl. 4. *Mogućnost modifikacije metode u cilju prelaska na istakanje rude iz pojasa velike moćnosti: a) varijanta sa posebnim hodnikom bušenja (kao na sl.3), b) varijanta sa izradom i posebnog hodnika za utovar rude*

Za izračunavanje pokazatelja metode, usvojeni su parametri kao kod prethodne varijante:

- visina izmedju podetaža 30 m,
- širina bloka (rastojanje izmedju hodnika bušenja) 20 m,
- širina pojasa miniranja 4 m.

Površina bloka koja se otkopava:

$P_b = 20 \times 30 - 4 \times 12{,}5 = 550\ m^2$

Količina rude u pojasu:

$Q_r = 550 \times 16 \times 2{,}8 = 24.640$ t

Količina rude na 1 m podetažnih hodnika

$Q_{r1} = 550 \times 1 \times 2{,}8 = 1.540$ t.

Dužina pripremnih hodnika, osim 4 podetažna, uvećava se za dužinu utovarnih niša (usvaja se njihovo medjusobno rastojanje 8 m):

$L_{un} = 2 \times 5 / 8 = 1{,}25$ m/m.

Ukupna dužina pripremnih prostorija je:

$L_p = 4 \times 1 + 1{,}25 = 5{,}25$ m.

Koeficijent pripreme iznosi:

$$K_p = \frac{5{,}25}{1540 \cdot 0{,}9} = 0{,}00379 \quad \text{m/t}$$

Varijanta podetažnog zarušavanja sa posebnim hodnicima za bušenje i utovar rude ima povećani obim pripreme, što treba da buse opravdano drugim tehničkim i ekonomskim pokazateljima. Ova varijanta stvara mogućnosti korišćenja prednosti primene miniranja u stešnjenoj sredini, pri čemu se velika moćnost minirane rude ne mora po svaku cenu obezbediti masovnim miniranjem većeg broja redova minskih bušotina, već se ono može obavljati višekratnim miniranjem sa delimičnim istakanjem rude posle svakog miniranja u cilju povećanja rastresitosti rude. Medjutim, konačno istakanje minirane rude se izvodi istovremenim utovarom rude iz više «ispusnih otvora» na dužini bloka najmanje 15 – 20 m. Tada se osiromašenje rude, koje u najvećoj meri dolazi sa jalovinom sa vertikalnog kontakta, javlja sa jednog kontakta na pomenutoj dužini bloka.

4. Varijanta podetažnog zarušavanja rudnih blokova velike visine

U cilju racionalizacije pripreme, a za slučaj otkopavanja vrlo velikih rudnih tela, kakav je slučaj sa rudnim telom «Borska Reka» u borskom ležištu, predložena je varijanta sa većom visinom podetaža, koja je jednaka polovini visine izmedju horizonata, koja je u pomenutom rudnom telu usvojena na 80 m. Kao što se sa slike 5 vidi, kod ove varijante izostavljena je i izrada posebnog hodnika za bušenje minskih bušotina, koje se u ovom slučaju buše iz hodnika podsecanja. Usvojena je visina izmedju podetaža 40 m, a rastojanje izmedju hodnika bušenja je 12 m, pri čemu je širina rudnog bloka 24 m. Usvojeno je da se utovarne niše rade na medjusobnom rastojanju 10 m, a da se miniranje obavlja u bloku dužine 20 m.

Za pomenute parametre izračunati su sledeći pokazatelji metode:

- površina rudnog bloka iznosi:

$P_b = 24 \times 40 = 960 \text{ m}^2$

- površina bloka koja se minira

$P_{bm} = 960 - 3 \times 12{,}5 - 0{,}1 \times 12 \times 3{,}5 =$

$= 918{,}3 \text{ m}^2$,

- količina rude koja se odjednom minira

$Q_r = 918{,}3 \times 20 \times 2{,}8 = 51.424{,}8 \text{ t}$

- na 1 m dužine bloka nalazi se ruda

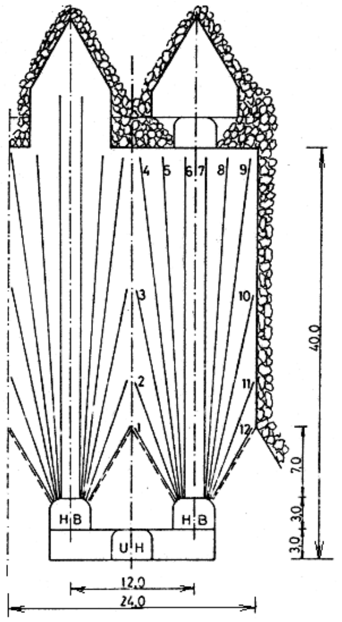
$Q_{r1} = 960 \times 1 \times 2{,}8 = 2.688 \text{ t}$.

Koeficijent pripreme iznosi:

$$K_p = \frac{4{,}2}{2688 \cdot 0{,}9} = 0{,}00174 \text{ m/t.}$$

UPOREDJENJE POKAZATELJA RAZMATRANIH VARIJANTI PODETAŽNOG ZARUŠAVANJA

Napred razmatrane varijante analizirane su samo kroz nekoliko osnovnih tehničkih pokazatelja, koji daju uvid u mogućnosti otkopavanja, kada se, pre svega, radi o veličini rudnih blokova i količinama rude koje se obaraju jednim miniranjem. To u principu ne mora da omogući konačan uvid u prednosti metode otkopavanja i izbor najpovoljnije, budući da su od velikog značaja i ekonomski pokazatelji koji se dobijaju kao posledica promene razmatranih tehničkih parametara i pokazatelja.



Sl. 5. *Varijanta podetažnog zarušavanja sa većom visinom bloka i miniranjem rude u pojasima velike moćnosti*

Uporedjenje najznačajnijih proračunatih pokazatelja dato je u tabeli iz koje se najjasnije uočavaju značajne promene površine blokova rude, kao i količine rude, koja se dobija jednim miniranjem. Za donošenje konačnog suda o prioritetu pojedinih varijanti metode treba imati u vidu uticaj pojedinih problema koji se javljaju pri njihovoj primeni, kao i promene najznačajnijih pokazatelja ovih metoda, a to su iskorišćenje i osiromašenje rude. Sa stanovišta ovih pokazatelja najinteresantnije je uporedjenje prvih dveju varijanti. Pri tome druga varijanta ima bitno smanjen koeficijent pripreme, ali ova metoda daje nešto lošije pokazatelje iskorišćenja i osiromašenja rude, budući da se kod prve varijante javlja najbolje podudaranje oblika bloka rude i elipsoida točenja rude.

Medjutim, ako se imaju u vidu probleme koji se javljaju pri nepreciznoj izradi podetažnih hodnika, tada se druga varijanta može smatrati prioritetnom.

Uporedjenje najznačajnijih proračunatih pokazatelja dato je u tabeli iz koje se najjasnije uočavaju značajne promene površine blokova rude, kao i količine rude, koja se dobija jednim miniranjem. Za donošenje konačnog suda o prioritetu pojedinih varijanti metode treba imati u vidu uticaj pojedinih problema koji se javljaju pri njihovoj primeni, kao i promene najznačajnijih pokazatelja ovih metoda, a to su iskorišćenje i osiromašenje rude. Sa stanovišta ovih pokazatelja najinteresantnije je uporedjenje prvih dveju varijanti. Pri tome druga varijanta ima bitno smanjen koeficijent pripreme, ali ova metoda daje nešto lošije pokazatelje iskorišćenja i osiromašenja rude, budući da se kod prve varijante javlja najbolje podudaranje oblika bloka rude i elipsoida točenja rude.

Medjutim, ako se imaju u vidu probleme koji se javljaju pri nepreciznoj izradi podetažnih hodnika, tada se druga varijanta može smatrati prioritetnom.

Tabela 1. *Uporedjenje osnovnih parametara i pokazatelja razmatranih varijanti podetažnog zarušavanja*

Naziv varijante	**Širina x visina bloka, m**	**Površina bloka miniranja m^2**	**Količina minirane rude t**	**Količina rude na 1 m PH, t**	**Koeficijent pripreme m/t**
1. Švedska varijanta	14 x 15	197,5	2.212	588	0,00191
2. Varijanta sa većom visinom podetaže	12 x 30	347,5	3.892	1.008	0,00114
3. Varijanta sa posebnim hodnikom bušenja	20 x 30	562,5	6.300	1.680	0,00205
4. Varijanta sa posebnim utovarnim hodnikom i velikom moćnošću pojasa minirane rude	20 x 30	550	24.640	1.540	0,00379
5. Varijanta sa većom visinom podetaže i velikom moćnošću pojasa	24 x 40	918,3	51.424,8	2.688	0,00174

ZAKLJUČAK

Primena podetažnog zarušavanja u borskoj jami, konkretno njene «švedske varijante», sprovodi se sa pojavom većeg broja problema, koji su posebno analizirani, a koji su doveli do postizanja nezadovoljavajućih rezultata, pre svega sa stanovišta niskog iskorišćenja i velikog osiromašenja rude. Bez obzira na značajno suženje mogućnosti dalje primene ove metode, a za neke buduće prilike, potrebno je imati u vidu mogućnosti promena primenom drugih načina otkopavanja, medju kojima su i razmatrane varijante u ovom radu. Izbor rešenja će, pored navedenih mogućnosti, zavisiti i od usavršavanja tehnologije izrade prostorija pripreme, kao i od tehnike i tehnologije bušenja dubokih minskih bušotina, budući da se i obaranje rude miniranjem javlja sa više odgovarajućih problema.

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Živorad Milićević, Igor Svrkota*, Dejan Petrović**

POSSIBLE VARIATIONS OF SUBLEVEL CAVING METHOD IN ORDER TO IMPROVE THE EFFECTS OF MINING**

Abstract

Application of sublevel caving method is often followed by numerous problems, causing unfavorable technical and economical results. In cases when the results differ from the expected ones, the method modification or even complete change should be taken into consideration, in order to improve the excavation parameters and economic results, which is the topic of this paper.

Keywords: *underground mining, sublevel caving, method variations, ore recovery, ore dilution*

INTRODUCTION

In several previous papers the problems were mentioned occurring in application the sublevel caving method. The majority of problems reflect on two main method parameters: ore recovery and dilution. This method requires extended development works and very accurate drifting geometry, as well as drilling and blasting.

These problems occurred in application the sublevel caving method in Jama Bor, where it is in use since the middle of last century, in several ore bodies. Some of method parameters were analyzed on laboratory models, which helped in understanding the ore drawing process and influence level of some parameters.

Based on theoretical and laboratory researches, several new variants of the sublevel caving method were proposed in order to avoid problems in its application.

SUGGESTIONS FOR POSSIBLE METHOD DESIGN VARIATIONS

There are many different designs of sublevel caving method, but here are analyzed only those which are comparable to the Swedish variant. In order to gain a comparable parameter, a development ratio will be determined. At first, a development ratio will be determined for the Swedish variant and its applied design in

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Jama Bor, for the ore bodies Tilva Ros and P_2A. Design parameters for this method are the following:

- Height between sublevels, H = 15 m;
- Spacing between sublevel drifts, B = 14 m;
- Sublevel drift dimensions: width b = 4 m; height h = 3.5 m; cross section area P_h = 12.5 m^2.

Area of blasting for a single ringdrill

P_b = B x H – P_h = 197.5 m^2.

For ore density of γ_r = 2.8 t/m^3, quantity of ore per 1 m of sublevel drift is:

Q_{rl} = P_b x 1 m' x γ_r = 553 t

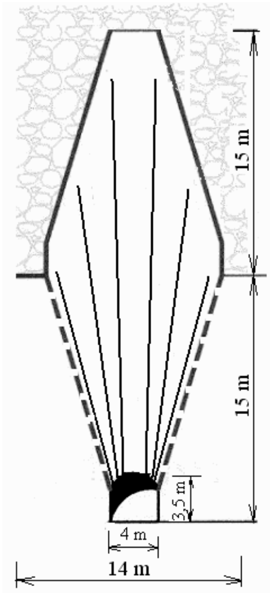

Fig. 1. *Geometry of the Swedish variant of sublevel caving method, applied in Jama Bor*

For calculation a development ratio, it is also needed to add the ore gained from a sublevel drift, so total ore quantity is:

Q_{rl} = 14 x 15 x 1 x 2.8 = 588 t

And quantity of bulk ore is:

$$Q_{rm} = \frac{Q_r \cdot K_{ir}}{1-K_{or}} = \frac{588 \cdot 0{,}8}{1-0{,}1} = 522{,}67 \ \text{t},$$

where:

K_{ir} – ore recovery ratio,

K_{or} – ore dilution ratio.

Considering only across the strike drift length, a partial development ratio is:

K_p = 1 / 522.67 = 0.00191 m/t

For ringdrill blasting thickness of 4 m, quantity of ore is:

Q_r = P_b x m x γ_r = 2,212 t

When the possible variants of sublevel caving methods, applicable to the ore bodies in Jama Bor, are considered, the goal is to gain the following improvements:

- Reduction of development works in the ore bodies;
- Increase of blasting area;
- More rational use of drilling, loading and hauling equipment;
- Reduction of ore dilution.

Reduction of development works is usually achieved by increase the height between sublevels, thus increasing quantity of ore gained by single blasting. Other improvements require more serious changes in method design, or transition to variants of sublevel caving with excessive blasting zone thickness. Some of these variants will be analyzed bellow.

1. Sublevel caving method with increased sublevel height

This variant was developed along with the most common Swedish variant of sublevel caving, especially in the Swedish mines, such as Kiruna, Malmberget, Grengesberg, etc. [3]. This method, shown in Figure 2, has significantly increased sublevel height. In fact, this variant enables using of development works for two sublevels. However, designed ringdrill block differs from the Swedish variant, which means that it differs from ideal drawing ellipsoid, too.

This leads to the excessive ore dilution. On the other hand, this variant provides reduction of development works, increase the quantity of ore gained by single blasting, more rational use of equipment, better stope production, increased productivity, etc.

Design parameters for this method are the following:

- Height between sublevels, H = 30 m;
- Spacing between sublevel drifts, B = 12 m;
- Ringdrill blasting thickness, 4 m.

Area of blasting for a single ringdrill

$P_b = B \cdot H - P_h = 347.5\ m^2$

For ringdrill blasting thickness of 4 m, quantity of ore is:

$Q_r = P_b \cdot m \cdot \gamma_r = 3{,}892\ t$

For ore density of $\gamma_r = 2.8\ t/m^3$, quantity of ore per 1 m of sublevel drift is:

$Q_{rl} = P_b \cdot 1\ m' \cdot \gamma_r = 1{,}008\ t$

And quantity of bulk ore is:

$$Q_{rm} = \frac{Q_r \cdot K_{ir}}{1 - K_{or}} = \frac{1008 \cdot 0{,}8}{1 - 0{,}1} = 877\ t,$$

where:

K_{ir} – ore recovery ratio,

K_{or} – ore dilution ratio.

Considering only across the strike drift length, partial development ratio is:

$K_p = 1 / 877 = 0.00114\ m/t$

Development ratio is even more reduced since the main sublevel drifts are also driven at double vertical spacing regarding to the Swedish variant. Area of blasting block, as well as its thickness depends on layout of across the strike sublevel drift, while influence of drift correct positioning is lower, since quantity of ore above the drift is lower. This means that negative influence of drift disposition is lower than in the Swedish variant.

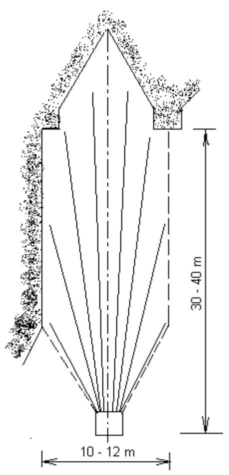

Fig. 2. *Sublevel caving with increased sublevel height*

2. Sublevel caving method with additional drilling drift

This variant of sublevel caving method has been mentioned in the Russian literature. It is based on principles of restricted blasting in thick cuts. Development includes additional drilling drift (Figure 3). This drift enables separation of longhole drilling and loading works. Drilling drift can be driven for each loading drift, for two (Figure 3) or even three of them.

For the variant in Figure 3, development includes the additional drilling drifts, with spacing that matches double width of standard single loading drift stope, up to 20 m. For this block width, there should be two loading drifts in sublevel. Block height should be about 30 – 40 m, e.g. half of level height.

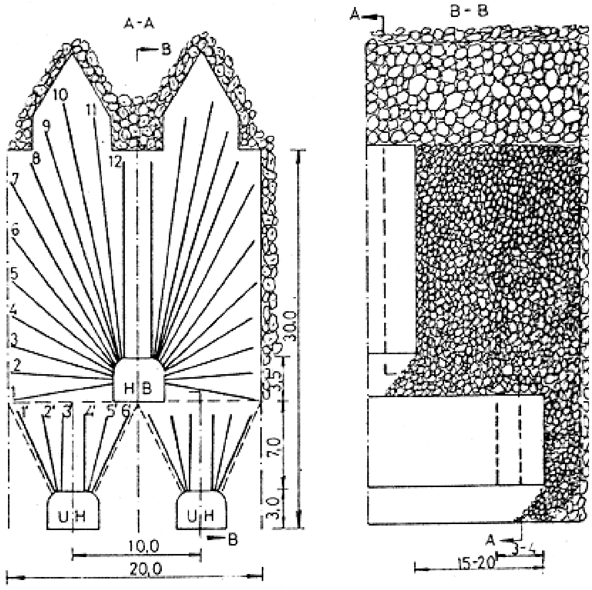

Fig. 3. *Sublevel caving method with additional drilling drift*

Principle of mining is as follows. Long blastholes are drilled from drilling drifts, in a semiring pattern. Ore is blasted in cuts that match block length with two or three lines of blastholes, or even more if conditions are favorable. By this way, the advantages of ore blasting are used in the strained area: more rational use of drilling equipment, better ore fragmentation, reduced blasting works, etc.

Blasted ore is loaded from loading drifts. At the beginning, two or three lines of shorter drill holes are blasted in order to gain the ore from drilling drifts. Regular ore drawing is enabled by blasting a wider zone from loading drifts.

For calculation the method parameters, the following stope geometry is used:

- Sublevel height, 30 m,
- Block width (spacing between drilling drifts) 20 m,
- Blasting zone width 4 m.

Block area

$P_b = 20 \times 30 - 3 \times 12.5 = 562.5 \text{ m}^2$

Quantity of ore in a 4 m wide block

Q_r = 562.5 x 4 x 2.8 = 6,300 t

Quantity of ore per 1 m width

Q_{r1} = 562.5 x 1 x 2.8 = 1,575 t/m.

Quantity of ore including sublevel drifts

Q_{ru} = 20 x 30 x 1 x 2.8 =1,680 t/m

Development ratio

$$K_p = \frac{3}{1680 \cdot 0.87} = 0.00205 \text{ m/t}$$

Problem with this method is that there is still ore drawing from relatively narrow zone, which causes high ore dilution from vertical contact between ore and waste. In case that the loading drifts are added, they could enable much thicker drawing zone, while contact between ore and waste stays only vertical. This would significantly reduce ore dilution.

3. Sublevel caving method with additional loading drifts

Transition to the variants with ore drawing from a wide and thick stope is enabled by additional loading drifts, where ore could be drawn from several lateral draw points (Figure 4), [8]. The same principle could be used in a variant with rhomboid block shape, but this variant would not be considered due to demands on accurate drift geometry.

Figure 4 shows previous variant too, in order to compare them and highlight main difference regarding to the additional loading drift. Loading drift and lateral loading connections are used to provide the access to draw points, which are situated on the bottom of undercut drifts. As it can be seen in Figure 4, the loading drifts in previous variant (a) are now trench undercut drifts (b). So in this variant, there is a classic block development, which may also differ, but in this case the one is shown which is the most similar to the previous variant. Loading connections are actually short drifts, connecting loading drift and undercut drifts. They are driven at 8 – 10 m spacing and they are 10 m long, unless they are slightly inclined, in order to provide easier access for LHD machines. In Figure 4b, there are no drifts from upper sublevel, although that part of block is not supposed to be drilled and blasted.

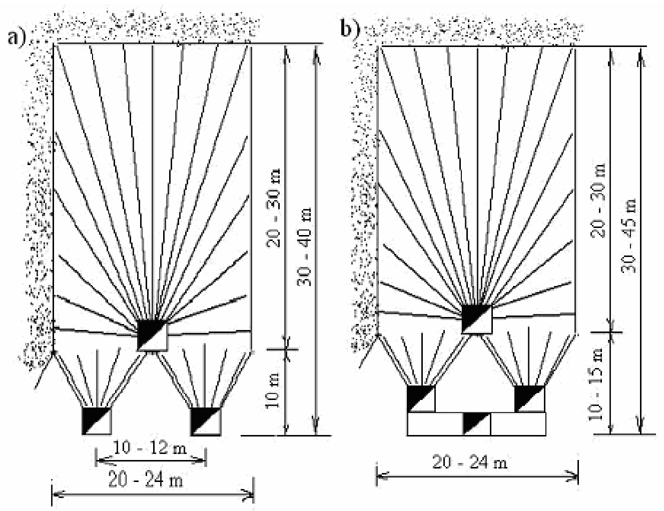

Fig. 4. *Example of transition to ore drawing from thick blocks; a) variant with additional drilling drift (similar to Figure 3); b) variant with additional loading drifts*

In order to calculate the method parameters, the same stope geometry is used as in the previous case:

- Sublevel height, 30 m,
- Block width (spacing between drilling drifts) 20 m,
- Blasting zone width 4 m.

Block area

$P_b = 20 \times 30 - 4 \times 12.5 = 550 \ m^2$

Quantity of ore in a block

$Q_r = 550 \times 16 \times 2{,}8 = 24{,}640$ t

Quantity of ore per 1 m width

$Q_{r1} = 550 \times 1 \times 2.8 = 1.540$ t/m.

Length of development drifts, beside 4 sublevel drifts, is increased by length of loading connections (at 8 m spacing):

$L_{un} = 2 \times 5/8 = 1.25$ m/m

Total length of development drift is:

$L_p = 4 \times 1 + 1.25 = 5.25$ m

Development ratio

$$K_p = \frac{5.25}{1540 \cdot 0.9} = 0.00379 \ \text{m/t}$$

As it can be seen, this variant has higher development ratio, but other technical and economic parameters are better. It provides advantages such as restrained blasting, thick blasting zone, possibility of successive blasting, thus avoiding large amount of explosive blasting at once and partial ore drawing after each blasting in order to increase ore scarification. Also, the final ore drawing is performed from several draw points simultaneously, along 15 – 20 m wide block. Ore dilution in this case comes only from a vertical contact between ore and surrounding rock.

4. Sublevel caving method with increased block height

For massive ore bodies, such as the Borska reka in the underground mine Jama Bor, this method is designed in order to reduce development works. Sublevel height is equal to half of level height. For example, in Jama Bor, level height is 80 m. This method even excludes the additional drilling drift, since drilling is performed from undercut drift (Figure 5). Block geometry is the following: sublevel height 40 m, spacing between drilling drifts 12 m, block width 24 m, block length 20m, with loading connections driven at 10 m spacing.

For this block geometry, method parameters are:

- Block area

$P_b = 24 \times 40 = 960 \ m^2$

- Blasting area

$P_{bm} = 960\text{-}3\text{x}12.5\text{-}0.1\text{x}12 \times 3.5 = 18.3 \ m^2$

- Quantity of ore in a single blasting

$Q_r = 918.3 \times 20 \times 2.8 = 51{,}424.8$ t

- Quantity of ore per 1 m

$Q_{r1} = 960 \times 1 \times 2{,}8 = 2.688$ t

Development ratio

$$K_p = \frac{4.2}{2688 \cdot 0.9} = 0.00174 \,\text{m/t}$$

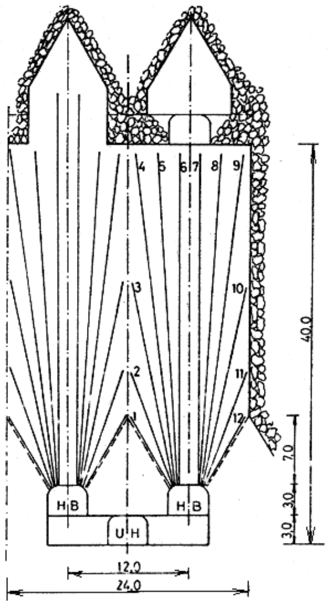

Fig. 5. *Sublevel caving with increased block height*

COMPARISON OF PARAMETERS FOR DIFFERENT VARIANTS OF SUBLEVEL CAVING

Different variants were only analyzed through several basic technical parameters. They can be used in order to compare block dimensions and quantity of ore gained by single blasting. However, the final estimation about optimal variant has to include the economic parameters derived from technical ones, too.

Comparison of the most important technical parameters is given in Table 1. Variations in block areas and ore quantities are obvious. Ore dilution and ore recovery also have to be included in analyses. From this aspect, comparison of the first two variants is very interesting. The second variant provides significantly reduced development ratio, but at the same time ore recovery and dilution are better in the first variant, since block shape is the most similar to ellipsoid.

But, considering the starting premises, that there are constant problems in maintenance of block geometry, the second variant becomes more suitable.

Table 1. *Comparison of the main parameters for different variants of sublevel caving*

Variant	Block width x block height, m	Blasting zone area, m^2	Quantity of blasted ore, t	Quantity of blasted ore per 1 m of sublevel drift, t	Development ratio, m/t
1. Swedish variant	14 x 15	197.5	2,212	588	0.00191
2. Increased sublevel height	12 x 30	347.5	3,892	1,008	0.00114
3. Additional drilling drift	20 x 30	562.5	6,300	1,680	0.00205
4. Additional loading drift and thick blasted ore zone	20 x 30	550	24,640	1,540	0.00379
5. Increased sublevel height and thick blasted ore zone	24 x 40	918.3	51,424.8	2,688	0.00174

As for the third and fourth variant, they are specific in the aspect of development, since they require more development works, for additional loading and drilling drifts. On the other hand, these two methods provide larger blocks and increased quantity of ore gained by single blasting. Their common characteristic is restrained blasting in thick blocks, which is more convenient. Quantities of 24,640 t to 51,424 t of ore gained by single blasting are far beyond 2,212 t, provided by the first variant. Also, the last two variants enable ore drawing from thick blocks, thus providing lower ore dilution. Consequently, lower ore dilution enables higher ore recovery, which is the most important advantage of the last two variants of sublevel caving.

CONCLUSION

Application of the Swedish variant of sublevel caving in Jama Bor is followed by numerous problems. These problems were analyzed in this and several previous papers, along with their consequences, especially poor ore recovery and increased ore dilution. That is why some other variants of sublevel caving were introduced as a possible replacement. The final decision on most suitable variant of sublevel caving, beside parameters analyzed in this paper, also depends on technical issues, related to the drifting technology, long hole drilling and problems related to their operation in Jama Bor.

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TRAJNOST BUŠAĆEG DLETA ZA USLOVE RUDNIKA „ŽUTA PRLINA”

Izvod

Sagledavajući ovu problematiku, ovim radom učinjen je pokušaj, da se za radnu sredinu rudnika Žuta Prlina, eksperimentalno „in situ” pri bušenju kratkih minskih bušotina odredi potrošnja bušećeg pribora. Podaci su grupisani u tri grupe u zavisnosti od pritiska sabijenog vazduha i vode. U svakoj grupi posebno su posmatrani uticaji pojedinih elemenata sečiva dleta i njihov uticaj na potrošnju bušećeg dleta.

Ključne reči: *bušeće dleto, trajnost bušećeg dleta, pritisak sabijenog vazduha, pritisak vode*

UVOD

U dodiru sa stenama i čvrstim mineralnim sirovinama, radni elementi mehanizovanog alata i mašina izloženi su, ne samo mehaničkim naprezanjima, nego i velikom trenju između površina materijala radnog elementa i površine mineralnih sastojaka radne sredine. Ovo se podjednako odnosi na sečiva dleta za perkusivno bušenje, krune za rotaciono bušenje, ozubljene valjke za dubinsko rotaciono bušenje itd. Kao posledica pojačanog trenja među površinama dolazi do odnošenja čestica sa istaknutih delova radnog elementa za bušenje. Tako da za kraće ili duže vreme prvobitni geometrijski oblik i dimenzije radnog elementa se menjaju, tj. dolazi do tupljenja sečiva, smanjenja prečnika radnog elementa, a ovim sporije ili brže opadanje njihove radne sposobnosti.

Radi poboljšanja procesa bušenja teži se da se pored povećanja brzine bušenja smanji habanje i poveća izdržljivost reznih elemenata. Pri tome, jedan od osnovnih uslova za optimalan rad bušeće opreme je poznavanje svojstva i kvaliteta reznih elemenata i njihove izdržljivosti, naročito za slučaj bušenja u abrazivnim stenskim sredinama.

Abrazivnost je veoma važan faktor pri procesu bušenja i može se definisati kao osobina stena da izazivaju habanje (trošenje radnih elemenata pri radu). Pri oceni postupka za određivanje abrazivnosti nailazi se i na teškoće s obzirom na složenost

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problema, to je pre svega činjenica da abrazivnost ne zavisi samo od fizičko-mehaničkih osobina radne sredine već isto tako i od tehničkih činilaca, tj. od mehaničke opreme za bušenje i od režima rada i efikasnosti izvođenja radova u procesu bušenja.

HABANJE SEČIVA

Kod bušenja u steni dolazi do habanja sečiva po visini i prečniku, odnosno povećava se površina sečiva. Povećanje površine sečiva izaziva dodatna opterećenja na dletu, što je često uzrok loma sečiva ili tela monoblok dleta. Da bi se monoblok dleto održalo u dobrom, radnom stanju treba ga oštriti preporučenim postupcima od strane proizvođača čime se ostvaruju uštede u tvrdoj leguri i do 50%. Kod bušenja u jako abrazivnim stenama, kao na primer u kvarcitima, dolazi do pojačanog habanja krajnjih ivica sečiva usled čega se smanjuje prečnik glave monoblok dleta. To izaziva obrazovanje „suprotnog konusa" koji deluje kao klin, pa je sečivo, a i celo monoblok dleto izloženo velikim dodatnim opterećenjima, koja neminovno dovode do loma sečiva ili usadnog dela dleta.

Kod bušenja vrlo tvrdih a žilavih materijala (magnetit, krečnjak) na površini sečiva obrazuje se mreža finih pukotina (dubine oko 0,1 mm) koje nastaju usled dinamičkih naprezanja. Kako se u mekom materijalu tvrda legura gotovo i ne troši to se ova mreža ne gubi nego se u toku rada pukotine sve jače produbljuju, dok ne postignu dubinu za iniciranje efekata zareza i do raslojavanja pločice. Međutim, ako se monoblok dletom, čije sečivo ima izraženu „reptilski kožu", buši u abrazivnoj sredini „reptilska koža" nestaje trenutno, tako da ne može doći do oštećenja sečiva.

Osim prirodnih karakteristika na trajnost bušećeg dleta utiču još i tehnički faktori koji su sadržani u kvalitetu čelika od koga je izgrađeno bušeće dleto, od geometrije i oblika bušeće krune, ojačanja bušeće krune, kvaliteta spoja tvrde legure sa maticom krune, zatim disciplina održavanja krune i temena usadnika bušećeg dleta. Svi ovi činioci utiču na trajnost bušećeg dleta, te je preporučljivo uslovima bušenja prilagoditi oblik, dimenzije i kvalitet bušeće krune, zatim posvetiti pažnju uslovima i režimu rada, kao i pridržavati se upustva proizvođača u vezi kontrole stanja bušećeg dleta i njihovog održavanja.

METODOLOGIJA ISTRAŽIVANJA

Ova istraživanja obavljena su u jami „Žuta Prlina" na horizontima 1080 m i 1130 m. Odabrano je po 5 mernih mesta na svakom horizontu, što ukupno čini 10 mernih mesta. Na svakoj mernoj tački vršeno je bušenje bušećim čekićem RK-28 i potpornom nogom tipa RPH-1300. Ispitivanje je vršeno sa uglovima oštrenja 90°, 100°, 105°, 110° i 120° i različite pritiske sabijenog vazduha i vode, dužina bušećeg dleta iznosila je l = 1,4 m. Ukupna dužina bušenja, za koju se statistički obrađuje promena iznosi 20 x 1,4 što čini na svakoj mernoj tački 28 m. U toku čitavog bušenja radio je isti radnik, po kvalifikaciji VKV rudar. Merenje je vršeno pomoću specijalnog mernog instrumenta sa komparaterom tačnošću od 0,01 mm. Statističkom obradom podataka dobijene su srdenje vrednosti smanjenja kako po visini tako i po prečniku prvo za merni horizont a zatim za rudno telo. Ove vrednosti poslužile su za donošenje zaključka o trošenju monoblok dleta u ispitivanim uslovima.

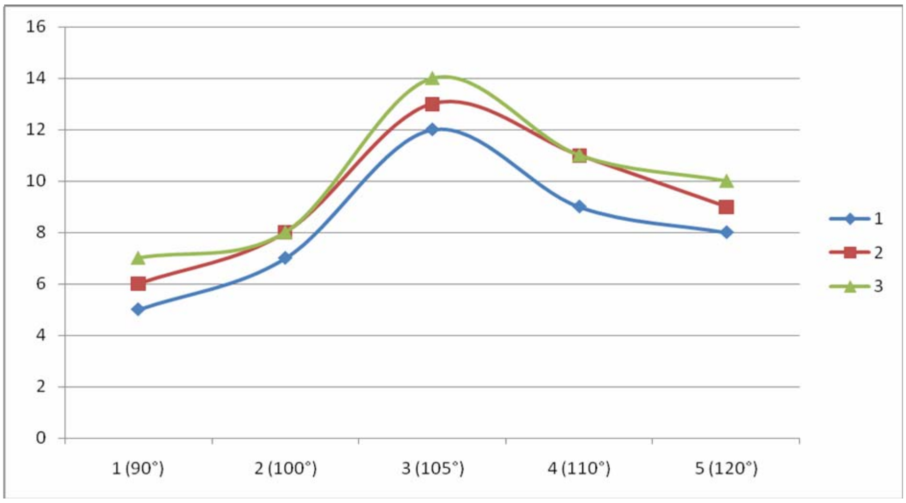
ANALIZA UTICAJNIH ČINILACA NA TRAJNOST BUŠAĆEG DLETA

U radu je obrađena problematika veka trajanja bušećeg dleta, sa posebnim osvrtom na broj oštrenja koja se najčešće javljaju u praksi i rezultate koji se postižu u rudniku gde je obavljeno istrazivanje. Isto tako u radu je data analiza rezultata kojima je utvrdjena zakonitost trošenja bušaćih dleta u zavisnosti od broja izbušenih bušotina.

Ukupna trajnost dleta pri različitim uglovima oštrenja i različitim pritiscima vode i vazduha je različita. Na osnovu eksperimantalnih istraživanja u rudnom telu rudnika „Žuta Prlina" utvrđen je broj oštrenja do granične visine tvrdog metala, koji je na osnovu iskustva pri udarnom bušenju u ovom rudnom telu usvojen da iznosi 7 mm. Na ovaj način određeno je koliki je broj oštrenja, a njime i koliko se ukupno metara bušotina može izbušiti za vek trajanja dleta, posle čega je isto za bušenje neupotrebljivo. Broj oštrenja do potpune istrošenosti dleta za posmatrane uglove oštrenja dleta, dobijeni ovim istraživanjem dati su u tabeli 1 i 2.

Tabela 1. *Pregled broja oštrenja u toku eksperimentalnog bušenja*

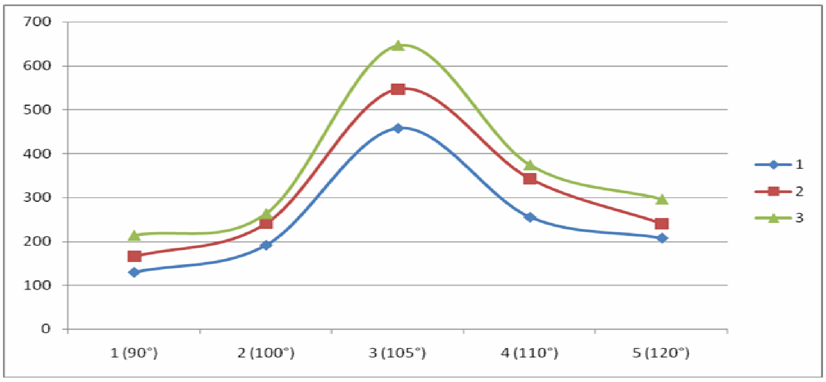
Oznaka	Pritisak vazduha	Broj oštrenja				
	Vode	90°	100°	105°	110°	120°
1.	$\frac{4.5\cdot 10(Pa)}{1\cdot 10(Pa)}$	5	7	12	9	8
2.	$\frac{5\cdot 10(Pa)}{1.5\cdot 10(Pa)}$	6	8	13	11	9
3.	$\frac{6\cdot 10(Pa)}{2\cdot 10(Pa)}$	7	8	14	11	10



Sl. 1. *Grafički prikaz broja oštrenja*

Tabela 2. *Pregled izbušenih metara u toku eksperimentalnog bušenja*

Oznaka	Pritisak vazduha	Dužina izbušenih metara L(m′)				
	Vode	90°	100°	105°	110°	120°
1.	$\frac{4.5 \cdot 10(Pa)}{1 \cdot 10(Pa)}$	130.0	191.8	458.4	255.6	208.0
2.	$\frac{5 \cdot 10(Pa)}{1.5 \cdot 10(Pa)}$	166.2	241.6	547.3	343.2	241.2
3.	$\frac{6 \cdot 10(Pa)}{2 \cdot 10(Pa)}$	213.5	263.2	646.8	374.0	296.0



Sl. 2. *Grafički prikaz izbušenih metara*

ZAKLJUČAK

Pod trajnošću bušaćeg dleta podrazumeva se dužina izbušene bušotine posle koje bušaće dleto postaje neupotrebljivo. Istraživanja u ovom radu pokazuju da od mehaničke karakteristike stenske mase u najvećoj meri zavisi trajnost bušaćeg dleta.

Dobijeni podaci, u pogledu veka trajanja bušaćeg dleta, pokazuju da je moguće planirati sa visokom tačnošću potrošnju bušaćih dleta u zavisnosti od uslova pod kojima se bušenje obavlja. Isto tako vidi se da je moguće utvrditi, posle koliko izbušenih metara bušeće dleto treba podvrći kontroli i oštrenju. Ovi podaci, ne samo da su interesantni za nauku, već su interesantni za proizvođače bušećih dleta i nabavnu službu na rudniku, jer im omogućava da blagovremeno obezbede potrebne količine bušećih dleta u proizvodnji.

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DURABILITY IF DRILLING CHISEL FOR REQUIREMENTS OF THE MINE "ŽUTA PRLINA"

Abstract

Considering this problem, an attempt is done by this paper to determine consumtion of drilling tools for the work environment in the mine Žuta Prlina, experimentally "in site" during the short blast holes drilling. Data are grouped into three groups depending on the pressure of compressed air and water. In each group, particularly the impacts of somel elements of bit blade are observed and their impact on consumption the drill bit.

Keywords: *drill bit, drill bit durability, compressed air pressure, water pressure*

INTRODUCTION

In contact with rocks and solid mineral resources, the operating elements of mechanized tools and machines are exposed, not only to the mechanical stresses, but also to high friction between the material surface of work elements and surface of mineral constituents of the working environment. This equally refers to drill bit blades for percussive drilling, rotary drilling, tooth rollers for deep rotary drilling and so on. As the result of increased friction between the surfaces it leads to removal of particles from important parts of work elements of drilling. So, for short or long period the original geometrical shape and dimensions of the working elements are changed, i.e. it comes to dulling of blades, diameter reduction of the working element, and this results into slower or faster decline work capacity.

To improve the drilling process it tends to, beside higher drilling speed, reduce wear and increase durability of cutting elements. In fact, one of the basic conditions for working optimum of drilling equipment is knowledge of the properties and quality of cutting elements of their endurance, especially in the case of rock drilling in abrasive environments.

Abrasiveness is a very important factor in the process of drilling and can be defined as properties of rocks to cause the wearing out (consumtion of working elements at work). In the evaluation process

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for determination of abrasiveness there are difficulties due to the complexity of the problem, it is primarily the fact that abrasiveness depends not only on the physical and mechanical characteristics of the working environment, but also on technical factors, ie. on mechanical drilling equipment and the mode and efficiency of work within the drilling process.

BLADE WEAR

In rock drilling, the blade is worn in height and diameter, i.e. the blade surface is increased. Increasing the blade surface causes an additional load on the bit, which is often the cause of blade breakage or body of drill bit monoblock. To keep drill bit monoblock in a good working condition, it should be sharpened by recomended instructions of producer which can result in savings in hard alloys and up to 50%. When drilling in very abrasive rocks, such as in quartzite, there is increased wear of blade edges which reduces the diameter of head of drill bit monoblock. This causes creation of "opposite cone" that acts as a wedge, and the blade, and the whole bowl gouge is exposed to a large additional loads, which inevitably lead to blade breakage or threaded parts chisels.

In drilling of very hard and tough materials (magnetite, limestone) on the surface of blade is formed a network of fine cracks (depth of about 0.1mm) that arise due to dynamic stresses. Since solid alloy is almost not spent in a soft material, this network is not lost but during the work these cracks are growing deeper, until they reach a depth of initiation point and the effects of stratification tiles. However, if momoblok is drilled with bit whose blade has a visible "reptilian skin" in abrasive environment, the "reptilian skin" disappears instantly, so it can not damage the blade.

In addition to the natural characteristics, durability of drill bit performance is influenced by technical factors that are contained in the quality of steel which the drill bit is made of, drill geometry and shape of drill bit, reinforcement of drill bit, hard alloy quality connection with the main bit, maintenance the drill bit and head of drill bit. All these factors affect the durability of drill bit, and drilling conditions, it is advisable to adjust the shape, size and quality of drill bits, then pay attention to the conditions and mode, as well to comply with the instructions of manufacturer regarding to the control of drill bit condition and maintenance.

TESTING METHODOLOGY

This testing was performed in the pit Žuta Prlina at levels of 1080 m and 1130 m. Selected by 5 measuring points at each level, making total of 10 stations. At each measuring point the drilling was done with a drill hammer RK-28 and RPH-1300. Testing was performed with sharpening angles of 90^0, 100^0, 105^0, 110^0 and 120^0 and various pressures of compressed air and water, the length of drill bit was l = 1.4 m. Total length of drilling for which the change is statistically processes is 20 x 1.4, what is each measuring point 28 m. The same worker, skilled miner, worked during drilling. Measurement was done using a special measuring device with comparator, accuracy of 0.01 mm. Statistical analysis of data resulted into average values of reduction in height and diameter by the first measurement of level and then the ore body. These values were used to draw conclusions about spending the drill bit monoblock in tested conditions.

ANALYSIS OF INFLUENTIAL FACTORS ON DURABILITY OF DRILL BIT PERFORMANCE

This paper deals with the life of the drill bit, with special reference to the number of sharpening that occurs most frequently in practice and performance of the mine where testing was performed. Also, the paper presents an analysis of the results that verify the way of consumption the drill bits depending on the number of drilled holes.

Total duration of drill bit at different sharpening angles and different pressures of water and air is different. Based on the experimental testing in the ore body of the mine Zuta Prlina, it was identified that a number of sharpening to the limit height of hard metal, which is, based on the experiences of the impact of drilling in this mine, is adopted to 7mm. In this way, the number of sharpening was determined, and how many meters of drill holes could be drilled for the life of bit, after which the same drill is unusable. Number of sharpening to the complete worn out for the observed sharpening angles, obtained in this testing are given in Tables 1 and 2.

Table 1. *Overview of sharpening number during experimental drilling*

Designation	Air pressure / Water	Number of sharpening				
		90^0	100^0	105^0	110^0	120^0
1	$\frac{4.5\cdot 10(Pa)}{1\cdot 10(Pa)}$	5	7	12	9	8
2	$\frac{5\cdot 10(Pa)}{1.5\cdot 10(Pa)}$	6	8	13	11	9
3	$\frac{6\cdot 10(Pa)}{2\cdot 10(Pa)}$	7	8	14	11	10

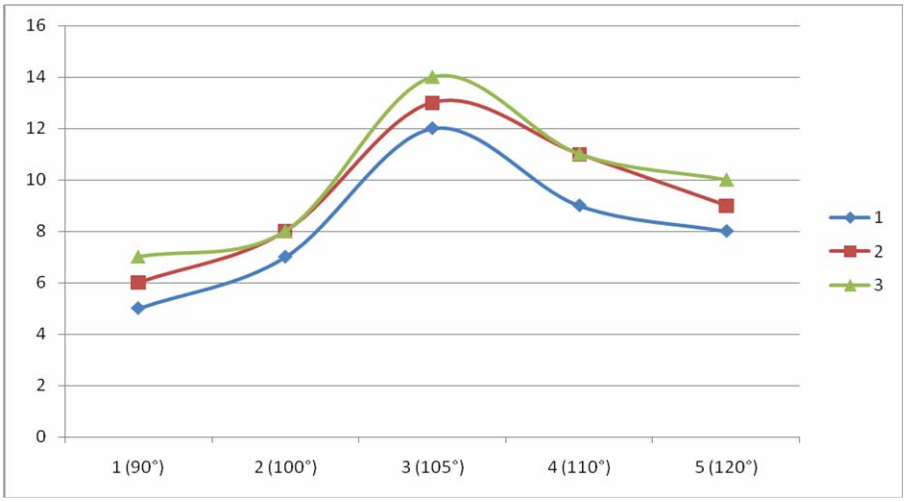

Fig. 1. *Graphic presentation the number of sharpening*

Table 2. *Overview of drilled meters during experimental drilling*

Mark	Air pressure	Length of drilled meters				
	Water	90^0	100^0	105^0	110^0	120^0
1	$\frac{4.5\cdot 10(Pa)}{1\cdot 10(Pa)}$	130.0	191.8	458.4	255.6	208.0
2	$\frac{5\cdot 10(Pa)}{1.5\cdot 10(Pa)}$	166.2	241.6	547.3	343.2	241.2
3	$\frac{6\cdot 10(Pa)}{2\cdot 10(Pa)}$	213.5	263.2	646.8	374.0	296.0

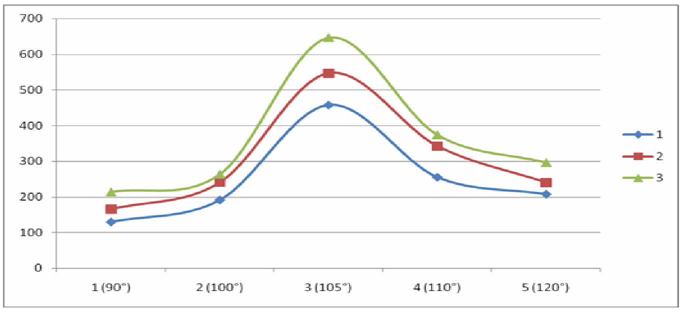

Fig. 2. *Graphic presentation the drilled meters*

CONCLUSION

Term durability of drill bit means the length of the drilled hole after which it becomes unusable. Researches in this paper show that the durability of drill bit depends mainly on mechanical properties of the rock mass.

The obtained data, in terms of the life of drill bit, show that it is possible to plan the consumption of drill bits with high accuracy depending on the conditions under which the drilling is done. It also shows that it is possible to determine, after how many drilled meters the drill bit should be subjected to control and sharpening. These data are not only of interest for the science, but they are interesting for manufacturers of drill bits and acquisition department in the mine, allowing them to provide timely the required amount of drill bit in production.

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KOMPLEKSNA PROCENA VRSTA I VISINE INDUSTRIJSKIH ŠTETA NASTALIH KAO POSLEDICA ODLAGANJA PEPELA I ŠLJAKE IZ TERMOELEKTRANA, TOPLANA I METALURŠKIH POSTROJENJA NA OBRADIVOM I DRUGOM POLJOPRIVREDNOM ZEMLJIŠTU

Izvod

Težnja ka održivom ekonomskom razvoju Republike Srbije, pokazuje izrazite potrebe za svim vidovima energije, a posebno za sve većim količinama tzv. «čiste» energije. Kako Republika Srbija preko 60% prizvodnje električne energije ostvaruje sagorevanjem velikih količina fosilnih goriva, kao nusproizvod javlja se velika količina pepela i elektranske šljake. Sem toga, velika metalurška postrojenja crne i obojene metalurgije kakva su US Steel Smederevo i RTB Bor stvaraju takođe značajne količine nesagorivih materija. Procena vrsta i visine industrijskih šteta koje nastaju na ovaj način prestavlja vrlo složen problem koji zahteva multidisciplinaran pristup. Kako bi se došlo do kvalitetnih rešenja u obzir se moraju uzeti ekološki prihvatljiva i ekonomski održiva rešenja.

Ključne reči: *Poljopoprivredna šteta, rudarska šteta, ekologija, ekonomija, održivi razvoj*

1. UVOD

Ekonomije zemalja zapadnog Balkana nalaze se u različitim fazama tranzicije i pridruživanja Evropskoj Uniji. Dinamika harmonizacije zakonodavstava i ekonomija sa odgovarajućim u Evropskoj Uniji podrazumeva primenu postupaka, procedura i standarda koje su kao preporuku Evropske komisije primenile zemlje u procesu pridruživanja u prethodnom periodu. Jedna od najvažnijih preporuka je usaglašavanje postojećih tehnologija i primena novih, sa akcentom na zaštiti životne sredine i održivom razvoju.

Većina zemalja zapadnog Balkana svoju privrednu aktivnost zasniva na eksploataciji vlastitog mineralno-sirovinskog kompleksa i razvoju izvozno orijentisane prerađivačke industrije. U ovom trenutku rastuća ekonomija Republike Srbije, pokazuje izrazite potrebe za svim vidovima energije, a posebno za sve većim količinama električne energije kao najekonomičnijem vidu pogonske energije. Kako energetika Republike Srbije preko 60% prizvodnje električne energije ostvaruje sagorevanjem velikih količina fosilnih goriva (pretežno lignita niske

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kalorične vrednosti) kao nusproizvod javlja se velika količina pepela i elektranske šljake. Sem toga, gradska naselja koja se pretežno zagrevaju daljinskim sistemom iz toplana stvaraju takođe značajne količine nesagorivih materija.

Stoga, odlaganje ovih materija koje su, kao proizvod sagorevanja, gotovo uvek, u većoj ili manjoj meri otrovne, a ne retko i sa povišenom radioaktivnošću, predstavlja ozbiljan problem, koji zahteva ekološki prihvatljiva i ekonomski održiva rešenja. Rešavanju ovog, veoma značajnog problema do sada se pristupalo u najvećem broju slučajeva parcijalno, i problem je rešavan od slučaja do slučaja. Dosadašnja iskustva u proizvodnji i preradi metala, nemetala i ugljeva, ukazala su na ozbiljnost problema odlaganja otpadnih materija na površini terena, sa svim pratećim posledicama po poljoprivredno zemljište i ukupan ekosistem kao celinu. Obzirom da se radi o godišnjim količinama od nekoliko miliona m^3 ovog materijala, koji je gotovo uvek u izvesnoj meri otrovan, a ne retko i kancerogen, pitanje njegovog odlaganja u prirodi (najčešće na poljoprivrednom zemljištu ili neposredno uz njega u blizini postrojenja u kojima se stvara) i samim tim narušavanje ukupnog ekosiste-ma mora biti tretirano sa odgovarajućom pažnjom.

Izgradnja velikih termoenergetskih kompleksa u konfliktu je sa okolinom po brojnim parametrima: zauzimanje prostora, promene reljefa, izmene ekosistema, izmeštanje stanovništva, zagađivanje vazduha, vode i zemljišta i sl. Zaštita okoline od različitih faza proizvodnje električne energije u termoelektranama je složen problem, pa i rešavanje svih pitanja iz ovog domena zahteva kompleksno sagledavanje problematike za dobijanje validnih rešenja. Treba imati u vidu činjenicu da se najveći deo električne energije kod nas dobija u termoelektranama na lignit čija je specifična potrošnja, s obzirom na kaloričnu moć vrlo velika, a problemi iskopa zbog enormnih količina jalovina, a potom pepela i šljake, posebno izraženi.

Sa druge strane rešavanje problema odlaganja ovog otpada vezano je za obradivo i drugo poljoprivredno zemljište koje se nalazi u neposrednoj blizini ovih postrojenja ili za otvorene otkopane prostore rudnika sa površinskom ili podzemnom eksploatacijom, kao potencijalno najboljim lokacijama za trajno i sigurno odlaganje ovog otpada i rekultivaciju i remedijaciju prostora.

Za procenu rizika po životnu sredinu i zdravlje ljudi, korišćene su i metode date u preporukama i uputstvima Svetske zdravstvene organizacije (WHO), Evropske fondacije za hemijsko inženjerstvo (EFCE), Agencije za zaštitu životne sredine USA (EPA-USA) i Međunarodne organizacije za rad (ILO):

- Environmental Impact Assessment of Urban Development Project, Guidelines and Recommendation, WHO, 1995;
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- Metode za analizu hazarda, Tehničko uputstvo za upravljanje akcidentima, Washington, USA-EPA, 1989.

Inače, zavisno od hemijskog sastava, pepeo može biti podesan materijal za niz raznovrsnih namena:

1) U građevinarstvu i industriji građevinskog materijala:
   - u proizvodnji raznih vrsta opeka;
   - u proizvodnji cementa;
   - u proizvodnji betona;

- u izradi kolovoznih konstrukcija saobraćajnica;
- za temelje manjih stambenih objekata;
- u proizvodnji injekcionih masa za povećanje nosivosti zemljišta; i
- u izradi parkirališta i sportskih terena;

2) U rudarstvu:
   - kao zamena za kreč kao regulator pH vrednosti sredine u flotacijama bakra i drugih obojenih metala itd. [Monevski, Anđelković, 1989.];
   - kao zasipni material ili kao kompozitni elemenat u stvaranju različitih vrsta zasipnih mešavina [Dimovski, 2003.] u količinama koje dostižu više miliona tona.
3) U poljoprivredi:
   - za melioracije zemljišta;
   - za obogaćevinje zemljišta mikrohranivima;
   - za različite popravke jalovinskih zemljišta, uglavnom jalovina rudnika uglja;
   - kao polazni materijal za kompostiranje; i
   - kao delimična zamena za supstrat (kod plasteničko - stakleničke proizvodnje povrća).
4) U šumarstvu, kao podloga za gajenje.

2. EKSPERIMENTALNI DEO

Kako bi se mogla sprovesti procena vrsta i visine industrijskih šteta, kao objekti eksperimentalnih testiranja izabrani su pepelište termoelektrane Nikola Tesla u obrenovcu tzv. TENT A, i otvoreni otkopani prostori površinskih kopova rudarskog basena «Kolubara», otvoreni otkopani prostori površinskih kopova rudarsko-topioničarskog basena Bor i otvoreni otkopani prostori u Jami rudnika bakra Bor i Jami nekog od rudnika uglja sa podzemnom eksploatacijom. Industrijske štete u ovom slučaju možemo uslovno podeliti na dve grupe:

a. Poljoprivredna šteta nastala od neprimenjivanja intenzivne poljoprivredne proizvodnje određenih kultura na prostoriji namenjenoj za deponiju pepela i šljake, u period eksploatacije prostora deponije i ostale relevantne troškove izgradnje i eksploatacije deponije
b. Rudarska šteta nastala od ne otkopane raspoložive korisne mineralne sirovine, i samim time viših stopa amortizacije tehnološke opreme, takođe i oštećenja površine terena i objekata na njoj.

Kao osnova za model eksperimentalnih testiranja obrađena je, kao jedna od alternativa, tehnologija rešavanja ovog problema kroz njegovo vraćanje u utrobu zemlje, u stare otkopa. Na taj način, kako je navedeno,postigao bi se dvojaki efekat:

- dobija se dovoljna količina jeftinog, vrlo kvalitetnog zasipnog materijala, čijom primenom bi se omogućila eksploatacija onih ležišta ili njihovih delova koji do sada nisu mogli biti eksploatisani klasičnim postupcima kako sa stanovišta zaštite objekata na površini terena, tako i ergonomsko-tehničkih karakteristika tehnologije (čvrstoća ovakvog materijala, u mešavini sa drugim raspoloživim materijalima, posle ugradnje u otkope ravna je mršavom betonu posle protoka određenog vremena (3-6 meseci)),
- potpuno (ili u najvećoj meri) rešava se odlaganje ovih materija na siguran način i bez oštećenja ekološkog sistema;

Ako se ima u vidu da su ovi prostori već degradirani samom tehnologijom otkopavanja, koja nema, na sadašnjem nivou tehnološkog razvoja, tehnoekonomski opravdanu alternativu, i da je za odlaganje ovih materija na površini terena potrebna degradacija značajne površine zemljišta, onda je sa stanovišta održivog razvoja ovo jedno od prihvatljivih rešenja, ukoliko se dokaže ekonomska opravdanost.

Na ovom mestu razmotren je kompleksni tehnoekonomski model, [Dimovski, 2012.] tehnološkog rešenja vraćanja pepela i šljake iz termoelektrana, toplana i metalurških postrojenja i raznih drugih otpadnih materija u različitim vrstama mešavina u prazne prostore rudnika sa podzemnom eksploatacijom, na primeru podzemnog proizvodnog sistema u rudnom telu RT «Borska reka» u RTB Bor.

Model obuhvata više različitih međusobno integrisanih i prepletenih aktivnosti koji se u osnovi sastoji u tehnoekonomskom modeliranju:

- Postupak prikupljanja i transporta pepela i šljake do mesta ugradnje
- Pripremu i formiranje odgovarajuće zasipne mešavine
- Transport i ugradnju zasipne mešavine,
- Procena rudarske štete od ne otkopane korisne mineralne sirovine (rude bakra sa plemenitim metalima), pri čemu se stepen iskorišćenja korisne mineralne sirovine kreće oko 50%, dok ostatak ostaje u zaštitnim stubovima i pločama,
- Procena vrednosti mineralne sirovine koja se može otkopati primenom metoda otkopavanja sa ugradnjom zasipnih materijala, kada se stepen iskorišćenja korisne mineralne sirovine penje na preko 90%, i da li vrednost razlike u visini stepena otkopane rude, pokriva troškove koji nastaju ovakvim postupkom.

Vremenski horizont je, radi komparacije, usvojen na 40 godina, za šta postoje potvrđeni resursi korisne mineralne sirovine u RT «Borska reka» od preko 500 miliona tona, i za koje se vreme očekuje rad normalan elektrane sa postojećim kapacitetima i sa postojećom ili neznatno modernizovanom tehnologijom. Primenjeni model kao konstantu u svakoj od razmatranih mogućih rešenja uzima procenjenu visinu štete nastale od neprimenjivanja intenzivne poljoprivredne proizvodnje određenih kultura na prostoriji namenjenoj za deponiju pepela i šljake, u period ekploatacije prostora deponije i ostale relevantne troškove izgradnje i eksploatacije deponija po opisanom tehnološkom postupku. Kao osnovni proizvod, za ekonomsku ocenu u ekonomskom modelu figurira proizvedena električna energija, i eventualno kao dopunski program cena pepela i šljake na komercijalnom tržištu, u slučaju termoelektrana, odnosno količine proizvedenih obojenih metala i ostalih proizvoda u slučaju rudnika u koje se odlažu ove materije.

Kritični parametar izabranih rešenja praktično su troškovi transporta otpadnih materija od mesta nastanka do mesta ugradnje, koji opredeljuju koji od objekata koji stvaraju značajne količine otpadnih materija u Republici Srbiji, može gravitirati određenom mestu njegovog trajnog i ekološki prihvatljivog odlaganja. Kao metod optimizacije izabrana je metoda mrežnog planiranja, kao najpodesnija za ovu analizu.

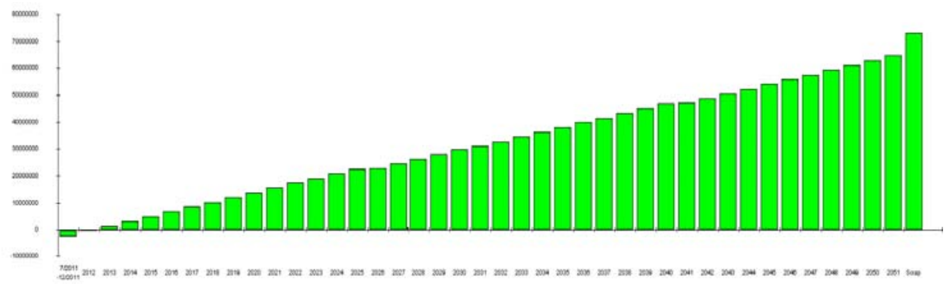
Rezultati ispitivanja dati su u narednim tabelama.

3. PRIKAZ REZULTATA

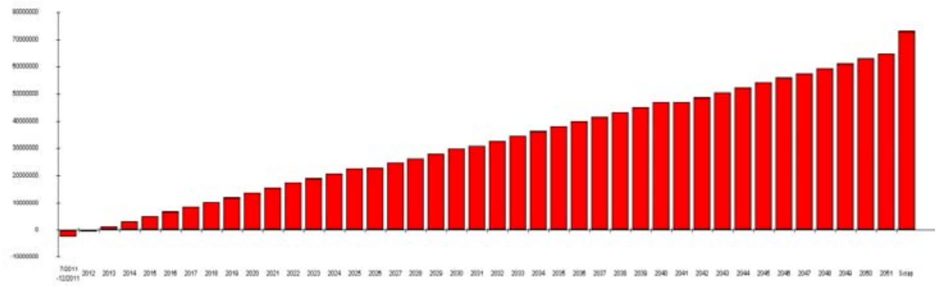
3.1. Procena poljoprivredne štete nastale od neprimenjivanja intenzivne poljoprivredene proizvodnje određenih kultura na prostoriji namenjenoj za deponiju pepela i šljake, u period ekploatacije prostora deponije i ostale relevantne troškove izgradnje i eksploatacije deponije

Kako je površina poljoprivrednog zemljišta koja je zauzeta za potrebe izgradnje deponije pepela u TENT-A procenjena na oko 500 ha, u okviru ovog dela istraživanja koja su primenjena u ovoj disertaciji, ista je podeljena na određene poljoprivredne kulture.

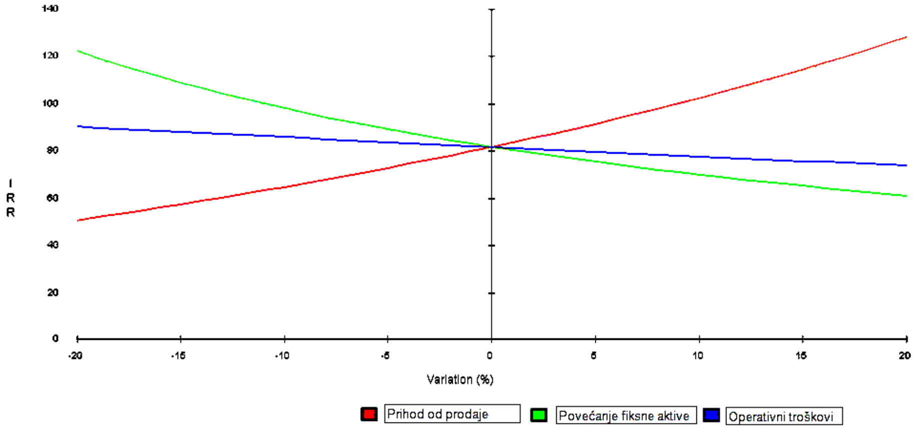
U okviru ekonomskog modela razmotrena je očekivana proizvodnja ovih kultura sa predmetnog zemljišta, tokom godina upotrebe zemljišta u druge svrhe, kako bi se mogla proceniti visina ekonomske štete. Tako je predmetna površina podeljena na 150 ha na kojima bi se sejao kukuruz, 150 ha na kojima bi se sejala pšenica, 75 ha na kojima bi se sejao krompir, 100 ha na kojima bi se sejala šećerna repa i 25 ha na kojima bi se sadi paradajz ili bi se gradili plastenici za paradajz. [Malinović i sar., 2001., Molnar i sar., 1999., Hauarnek i sar., 2001.]. Kao vremenski horizont uzeto je vreme od danas (od početka projekta) pa za 40 godina, odnosno od 2011. godine do kraja 2051. godine. Ako se ima u vidu da rad elektrane traje u kontinuitetu već 40 godina, ukoliko bi se uzele u obzir sve protekle godine, onda se vrednosti ekonomskih parametara dobijene ovom analizom mogu bez većih uopštavanja i aproksimacija udvostučiti. Rezultati modelovanja dati su u narednim tabelama i dijagramima.



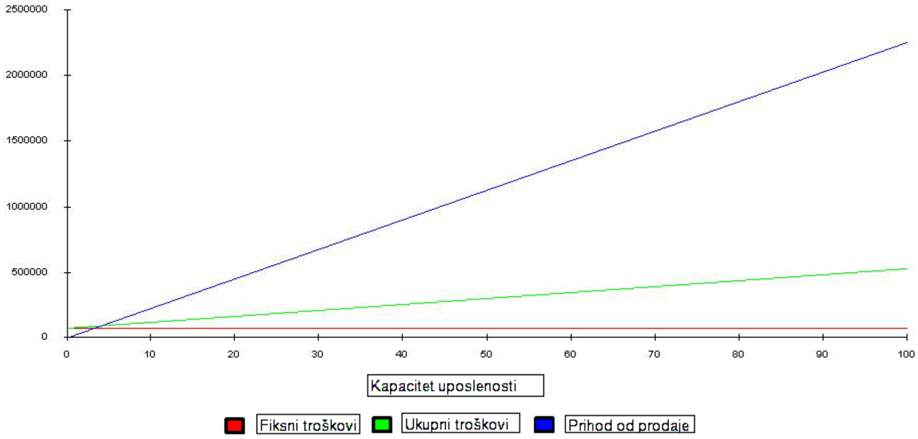
Sl. 1. *Kumulativni «keš flow» za finansijsko planiranje (u evrima)*



Sl. 2. *Kumulativni diskontovani «keš flow» za uslove normalnog povraćaja uloženih sredstava (u evrima)*



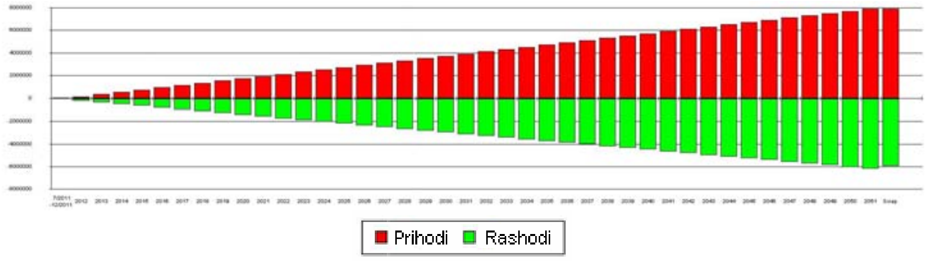
Sl. 3. *Dijagram osetljivosti interne stope povraćaja uloženih sredstava (u evrima)*



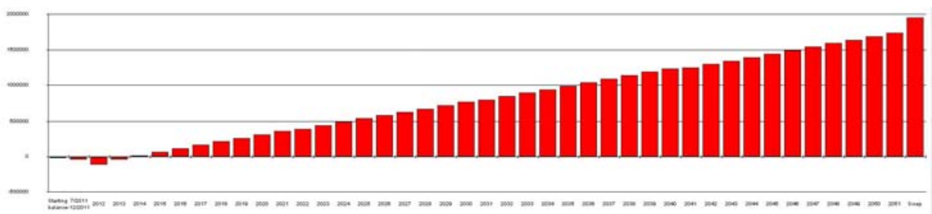
Sl. 4. *Analiza kritične tačke projekta sa uključenim troškovima finansiranja 2013 (u evrima)*

3.2. Procena ekonomskih parametara primene postupka odlaganja pepela i šljake iz termoelektrana, toplana i metalurških postrojenja vraćanjem istih «na mesto nastanka» odnosno u prostore napuštenih rudnika

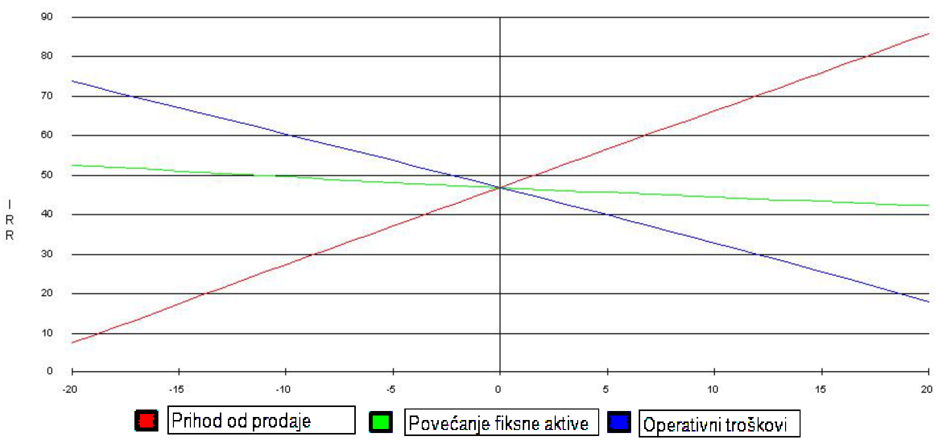
Kako je već u rado navedeno, na ovom mestu razmotren je kompleksni tehno-ekonomski model, tehnološkog rešenja vraćanja pepela i šljake iz termoelektrana, toplana i metalurških postrojenja i raznih drugih otpadnih materija u različitim vrstama mešavina u prazne prostore rudnika sa podzemnom eksploatacijom, na primeru podzemnog proizvodnog sistema u rudnom telu RT «Borska reka» u RTB Bor. Vremenski horizont je, radi komparacije, usvojen na 40 godina, za šta postoje potvrđeni resursi korisne mineralne sirovine u RT «Borska reka» od preko 500 miliona tona, i za koje se vreme očekuje rad normalan elektrane sa postojećim kapacitetima i sa postojećom ili neznatno modernizovanom tehnologijom.



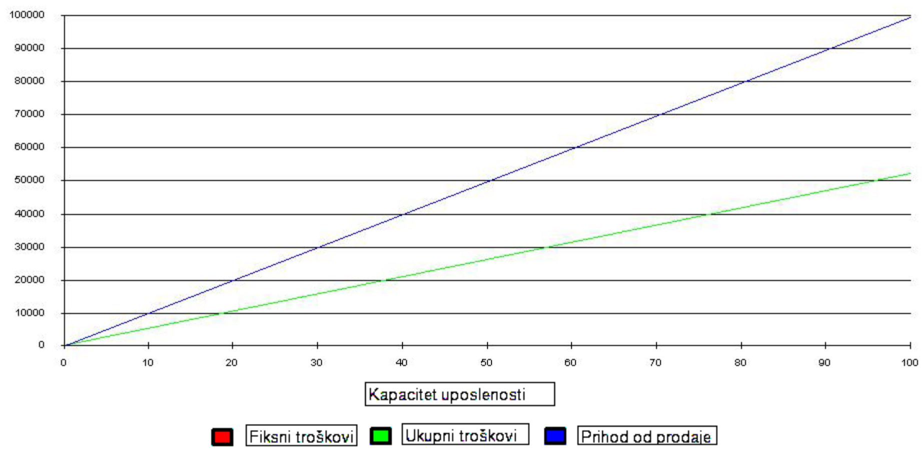
Sl. 5. *Kumulativni «keš flow» za finansijsko planiranje (u hiljadama evra)*



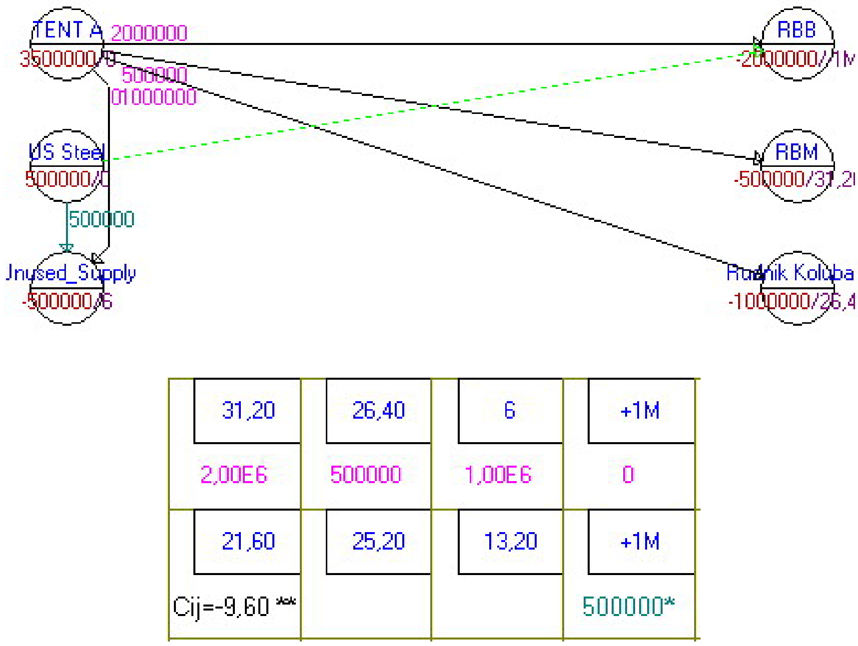
Sl. 6. *Kumulativni diskontovani «keš flow» za uslove normalnog povraćaja uloženih sredstava (u hiljadama evra)*



Sl. 7. *Dijagram osetljivosti interne stope povraćaja uloženih sredstava (u hiljadama evra)*



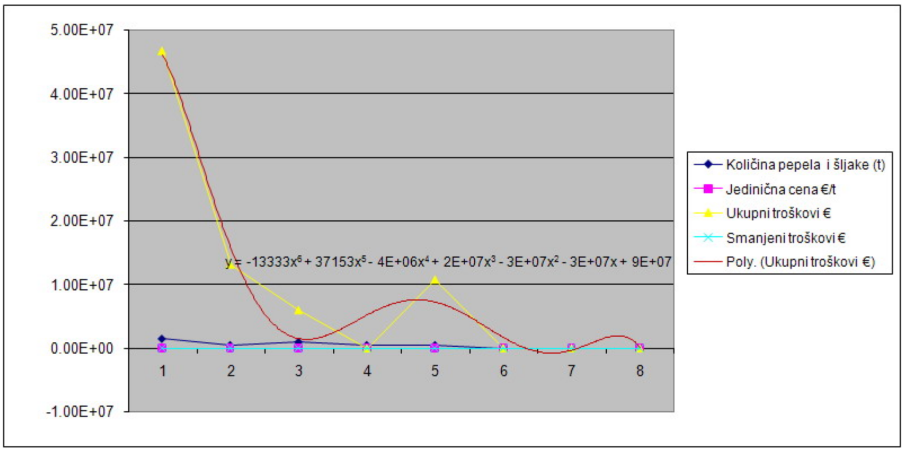
Sl. 8. *Analiza kritične tačke projekta sa uključenim troškovima finansiranja 2013 (u hiljadama evra)*



Sl. 9. *Minimizacija transportnih troškova mrežni plan*

Tabela 1. *Rešenje transporta pepela od TE do Rudnika: Minimizacija (Transportni problem)*

01-17-2012	Od	Do	Količina pepela i šljake (t)	Jedinična cena €/t	Ukupni troškovi €	Smanjeni troškovi €
1	TENT A	RBB	1.50E+06	31.2	4.68E+07	0
2	TENT A	RBM	500000	26.4	1.32E+07	0
3	TENT A	Rudnik Kolubara	1.00E+06	6	6000000	0
4	TENT A	Unused_Supply	500000	0	0	0
5	US Steel	RBB	500000	21.6	1.08E+07	0
6	US Steel	RBM	0	25.2	0	8.4
7	US Steel	Rudnik Kolubara	0	13.2	0	16.8
8	US Steel	Unused_Supply	0	0	0	9.6
	Total	Objective	Function	Value =	7.68E+07	



Sl. 10. *Minimizacija transportnih troškova dijagram*

U analizi su uzeti u obzir kao mogući «proizvođači» pepela i šljake TENT A i metulurško postrojenje US Steel iz Smederева, a kao potencijalna mesta odlaganja Rudnici bakra Bor, Rudnik bakra Majdanpek i Površinski kopovi Kolubara u Lazarevcu. Sa dijagrama (sl. 10.) se može uočiti da su minimalni transportni troškovi primenom železničkog sistema transporta na rastojanju od 50 km i transport do 1000000 t u Kolubaru, a da je projektovanom raspodelom racionalno transportovati ovim vidom transporta 2000000 t pepela i šljake iz TENTA i 500000 t metalurške šljake iz US Steel-a u Rudnik bakra Bor.

4. DISKUSIJA

Analizom rezultata tehno-ekonomskog modela izabrani su kritični parametri modela, koji su podvrgnuti višekriterijskoj optimizaciji. Za optimizaciju korišćen je metod mrežnog planiranja.

Rezultati optimizacije predstavljeni su u tabeli 1 i na slikama br. 9 i 10. Dosadašnja istraživanja ovog problema, u prethodnom periodu, mada obimna i multidisciplinarna, nisu iz određenih razloga bila i sveobuhvatna. Pristupalo se uglavnom namenskim istraživanjima pojedinih segmenata problema, ali nikada do sada nisu uzeti u obzir i stali aspekti ove problematike. Sa jedne strane, verovatno zbog politike termoelektrana i rudarsko-metalurških kompleksa, nije se uzimala u obzir visina šteta koje nastaju ne korišćenjem poljoprivrednog zemljišta na adekvatan način. Pri razmatranju procesa odlaganja otpadnih materija iz procesa sagorevanja razmatran je samo parcijalni aspekt uticaja na životnu sredinu bez razmatranja novih mogućnosti i tehnologija zaštite, a ekonomski interes nije razmatrao i uticaj tzv. «**poljoprivredne štete»,** koja je prvi put uzeta u razmatranje u ovom radu, što predstavlja originalni pristup, za razliku od do sada primenjivanih.

Sa druge strane, nikada do sada nije ozbiljnije razmotrena mogućnost, da se odlagališta štetnih materija potpuno izmeste sa površine terena i da se ista odlože u otvorene otkope rudnika sa podzemnom (ili površinskom) eksploatacijom mineralnih sirovina, i dali vrednost dobiti od **«poljoprivredne štete»,** pokriva troškove primene ovog postupka.

Kao kruna svega u radu je obrađen tehno-ekonomski model kojim je uzeta u obzir i tzv. **«rudarska šteta»** od neotkopane korisne mineralne sirovine, čijom se kvantifikacijom i kompleksnom analizom došlo do saznanja o primenljivosti razmatrenog pristupa sa svim svojim pozitivnim efektima.

5. ZAKLJUČAK

Sa ekonomskog stanovišta, stvarni troškovi primene ovakvog sistema odlaganja, troškovi ekonomske štete od primene ove tehnologije i efekti ekoloških oštećenja su obrađeni u prethodnoj analizi. Direktna ekonomska šteta - **«poljoprivredna šteta»** od neprimenjivanja intenzivne poljoprivredne proizvodnje na prostoru koji je inače upotrebljen kao deponija, koja u do sadašnjem periodu slučajno ili namerno nije uzeta u razmatranje i analizirana na ovakav način, iznosi približno 73 miliona evra, u razmatranom periodu. Ova šteta je mnogo veća ako bi se razmotrili ostali aspekti privredne nadgradnje koji neminovno prate poljoprivrednu proizvodnju. Razmotreno tehnološko rešenje posmatrano sa tehnološkog aspekta i interesa same termoelektrane (ova konstatacija se odnosi i na metalurška postrojenja i toplane) je najmanje poželjno, jer je i najmanje razmatrano u dosadašnjem periodu.

Sa druge strane primena ove tehnologije ima dugu istoriju u rudarstvu Republike Srbije i veliki broj radova i istraživanja je sproveden iz ove oblasti. Međutim sva ova istraživanja odnosila su se isključivo na tehničko-tehnološki aspekt primene bez dubljeg ulaženja u ekološki i posebno ekonomski aspekt njihove primene. Ne bi bila preterana konstatacija da je ovakav kompleksni tehnoekonomski i ekološki pristup pionirski u ovoj oblasti, zbog nepomirljivioh razlika između «proizvođača» i «potrošača» ovih otpadnih materija i ne postojanja regulatornih tela čiji bi zadatak bio međusobna koordinacija između glavnih «stake holdersa».

Primena ovog tehnološkog rešenja podrazumeva aktivnu ulogu države kao vlasnika ovih privrednih entiteta i ključnog **«stake holdersa»**. Kada se detaljno razmotri sam predlog onda se vidi da njegovom primenom svi dobijaju. Sa strane elektrane (Metalurška postrojenja i toplane) oni se trajno oslobađaju viška otpadnih materijala, osim onog dela koji se može plasirati na tržištu (cementna industrija, građevinska industrija i industrija drugog građevinskog materijala), a rudnici dobijaju «besplatno» kvalitetan pucolanski materijal koji u odgovarajućoj smeši sa granuliranom rudničkom jalovinom i jalovim peskom iz preliva hidrociklona u postrojenjima flotacije daje kvalitetan očvršćavajući zasip.

Sa stanovišta rudnika primena ovog sistema zahteva investicije u površinski kompleks za prihvat i pripremu zasipne mešavine na površini terena, podzemnog kompleksa za zasipavanje i sistema za povratne vode. Benefiti rudnika su pored eliminisanja direktne **rudarske štete** od neotkopane raspoložive korisne mineralne sirovine, i samim time viših stopa amortizacije tehnološke opreme, takođe i eliminisanje oštećenja površine terena i objekata na njoj. Investicioni trošak države odnosi se na investicije u železnički transportni sistem i železničku infra-strukturu.

Troškovi ovih investicija pokrili bi se kroz eliminisanje direktne – poljopri-vredne štete i kroz eliminisanje ili smanjivanje rudarskih šteta. Sa ekološkog aspekta on je na osnovu iznetih analiza najpovoljnije rešenje jer se najveći broj uticaja na životnu sredinu u potpunosti eliminiše.

Kako je napred pomenuto, pošto se radi o značajnim investicionim ulaga-njima, ukoliko bi primena ovakvih sistema zaštite bila ultimativna mera definisana određenim zakonskim propisima i pravi-lima (kakva važe u EU), i bila podržana od strane državnih organa i fondova Republike Srbije, stvorili bi se uslovi da se prostor Republike Srbije u potpunosti oslobodi ovih materija.

U čisto ekoonomskom smislu, ukoliko bi se posmatralo kumulativno, ukupni profit Republike Srbije iznosio bi oko **2 milijarde evra u periodu od oko 40 godina, odnosno oko 50 miliona evra godišnje**, ne računajući indirektne efekte od popravljanja stanja životne sredine, boljeg iskorišćenja raspoloživih resursa, novih radnih mesta, investicija u infrastrukturu itd.

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COMPLEX EVALUATION THE TYPE AND AMOUNT OF INDUSTRIAL DAMAGES COMMENCED AS THE CONSEQUENCE OF FLY ASH AND SLAG DUMPING FROM THE THERMO POWER PLANTS, HEATING PLANTS AND METALLURGICAL PLANTS ON ARABLE AND OTHER AGRICULTURAL LAND

Abstract

Tendency for sustainable economic development of the Republic of Serbia shows the extraordinary demands for all types of energy, and especially for increasing amounts of so called «clean» energy. Since the Republic of Serbia more than 60% of the need for energy fulfill from the thermo energy power plants with combustion of huge amount fossil fuel as the «product» remains huge amount of fly ash and slag. Beside this, the big metallurgical plants of iron, steel and stained metals like the US Steel in Smederevo and RTB Bor, also produce a significant amount of incombustible materials. Evaluation the type and amount of industrial damages commenced on the mentioned process is very complex problem which requires a multidisciplinary approach. To reach qualitative solutions, it has to be taken into consideration both ecologically acceptable and economically sustainable solutions.

Keywords: *Agricultural damage, mining damage, ecology, economy, sustainable development*

1. INTRODUCTION

Economies of the West Balkan countries are in different phases of transition and association to EU. Dynamics of harmonization of legal systems and economy with appropriate in the European Union means application of actions, procedures, and standards which are, as the recommendation of European commission, applied by the countries in the process of association informer period. One of the most important is harmonization the existing technologies and application new, with the accent on environmental protection and sustainable development.

Majority of the West Balkan countries their economic activity base on the exploitation own mineral resources complex and development export orientated processing industry. In this moment growing economy of the Republic of Serbia shows ex-

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traordinary needs for any types of energy, and especially for as higher amounts of electrical energy as the most economic type of drive power. Since the energetic industry of the Republic of Serbia more than 60% of production of electric energy realize by combustion of great amount of fossil fuels (mostly lignite coals of low caloric value) as the waste product remains high amount of fly ashes and slag. Beside this, cities, which are heating mostly from distance systems from heating plant, create also significant amounts of unburnt materials.

Therefore, waste dumping of these materials which are, as a product of combustion, almost always, more or less poisoned, and not rarely with increased radioactivity, presents serious problem, which demands ecologically acceptable and economic sustainable solutions. In solving of this, very significant problem until today was approached in the majority number of cases partially, and the problem is solved from the case to case. The existing experiences in production and processing of metals, non metals and coals, shows to the seriousness of problems of dumping the waste materials at the surface of the terrain, with all following consequences on agricultural land and ecosystem as whole. Since, that it is dealing with amounts of few million m^3 of this material, which is almost always, in certain measure poisoned, and not rarely carcinogenic, the question of its dumping in the nature (most commonly on the agricultural land or beside it in the close neighborhood of the power plant facilities where it appear) and with this interruption whole ecosystem must be treated with appropriate attention.

Construction of large thermo power complexes is in conflict with the environment for many parameters: capturing the space, changing the relief, changing the ecosystem, replacing the population, poisoning the atmosphere, water and soil etc. Environmental protection from different phases of production of electrical energy in thermo power plants is a complex problem, and so the solving of all questions from this domain demands complex approach to the problem in purpose to obtain valid solutions. It should have on mind fact that the largest part of produced electric energy in our country is made in thermo power plants which combust lignite, which specific consumption, regard to the caloric value, is very high, and the problem of excavation of enormous amount of waste rocks, and then fly ashes and slag, are especially expressed.

In the other hand solving the problem of dumping of this waste is connected with the arable and the other agricultural land which is located in the close neighborhood of this facilities or with the open caves of mines with open pit or underground exploitation, as potentially best locations for permanent and safe dumping of this waste and remediation and restoration of area.

For the prognosis of risks for living environment and health of human population, were used methods given in recommendations and guides of the World Health Organization (WHO), European Fundation for Chemical Engineering (EFCE), Agency of Environmental Protection of USA (EPA-USA) and International Labour Organization (ILO):

- Environmental Impact Assessment of Urban Development Project, Guidelines and Recommendation, WHO, 1995;
- The Risk Assessment Guidelines, EPA Washington DC, 1986;
- Environmental Impact Assessment, McGraw-Hill International edition, Sigapores,1996;
- Major Hazard Control, WHO, Geneve, 1990;
- Methods for analyze of hazards, Technical guide for control of hazards (ILO), Geneva, 1990;
- Methods of risk analysis, European foundation for chemical (EFCE) Rugby, England, 1985;

- Methods for analyze of hazards, Technical guide for control of accidents, Washington, USA-EPA, 1989. Otherwise, depending onchemical content, ash could be suitable material for several different purposes:

1) In civil engineering and industry of civil construction materials:
   - In production of different types of bricks;
   - In cement production;
   - In concrete production;
   - In building the road constructions;
   - For the foundations of civil objects;
   - In production of injection masses for improvement of soil shipment;
   - In building parking places and sport terrains;
2) In mining:
   - As replacement of lime as regulator of pH value of pulp in the flotation plants of copper and other non ferrous metals etc. [Monevski, Andjelković, 1989];
   - As bacfilling material or as a composite element in creation of different backfilling compounds in the amounts of several million tons. [Dimovski , 2003]
3) In agriculture:
   - For soil meliorations;
   - For enrichment of soil with micro feeders;
   - For different reparations of waste land, mainly waste rocks from coal mining;
   - As the basic material in composting; and
4) In forestry as the base for raising.

2. EXPERIMENTAL PART

In purpose to realize the evaluation of type and amount of industrial damages, as the object of experimental testing is chosen waste dump of thermo power plant Nikola Tesla near the community of Obrenovac, so called TENT A, and mined out open scopes of open pits of mining basin «Kolubara», open pits of Copper Mining and Smelting Company «RTB» Bor and mined open areas of the underground mine «Jama» Bor and mined open areas in some coal mines with underground exploitation. Industrial damages in this case could be divided in two groups:

a. **Agricultural damage** from non application of intensive agricultural production at the place which is otherwise used as waste dump, in the period of exploitation the waste dump area and other relevant costs of building and exploitation of the waste dump.
b. **Mining damage** from unexploitated available mineral resources, and with this higher rate of amortization the technological equipment, also elimination the damages of the terrain surface and constructed objects on it.

As the base for model of experimental testing, one alternative was processed - technology with backfilling «at the place of origin» i.e. in the abandoned mined out areas of mines. In this way, as it is mentioned, it would be double effect:

- Obtaining sufficient amount of cheap, very good quality backfilling material, which application enables exploitation the mineral deposits or their parts which cannot be exploitable by classic mining methods, neither from the viewpoint of protection the object on terrain surface, nor from ergonomic and technical characteristics of mining technology (compressive strength of this material as mixture with other available materials, after the backfilling the open scopes is equal to the poor concrete after the time of 3-6 months,

- ❖ Completely (or mostly) is solving the dumping of this materials by safe manner and without damaging the ecological system;

Having in mind that these areas are already degraded with mining technology itself, which does not have, at the present level of technological development, a techno-economically reliable alternative, and the dumping of these materials on terrain surface demands degradation of significant area of land, then from the viewpoint of sustainable development, this is one of more acceptable solutions, if the economical reliability is proven.

At this place, a complex techno-economical mode [Dimovski, 2012] is considered of technological solution of returning fly ashes and slag from thermo power plants, heating plants and metallurgical facilities and several other waste materials in different types of mixtures in open scopes of mines with underground exploitation, in the underground mining system in the ore body «Borska reka» of the Mining and Smelting Company «RTB» Bor. Model consists of several different, mutually integrated and intertwined activities, which basically consists of techno-economical modeling:

- ➢ Procedure of collecting and transport of fly ash and slag till the place of dumping
- ➢ Processing and mixing of appropriate backfilling mixture
- ➢ Transport and fulfilling backfilling mixture
- ➢ Evaluation of mining damage from unexploitated available mineral resources (copper ore with precious metals), when the recovery ratio of available mineral resources is app. 50%, while the rest remains in pillars and roof plates,
- ➢ Evaluation of value the mineral resources which could be excavated using the mining methods with backfilling, when the recovery ratio of available mineral resources increase up to 90%, and whether value of difference in recovery ratio, cover the costs which appear in the application of such technology.

Time horizon is, in purpose of comparison, adopted for 40 years, for which the proved ore reserves exist in the ore body «Borska reka» of over 500 million metric tons, and for which the normal operation of thermo power plant is expected with existing capacities, and with existing or insignificantly improved technology. The applied models as a constant in any of considered possible solutions take the estimated amount of damage appeared from non application of intensive agricultural production of some plants on the area aimed for the waste dump, in the exploitation period of dump area and the other relevant costs of building and exploitation of dump in accordance to described technological procedure. As a basic product, for the economical appraisal the electric energy is produced in economical model and eventually as the additional program price of fly ash and slag on commercial market, in case of thermo power plants, i.e. the amount of produced non-ferrous metals and other products in case of mines where these materials are dumped.

Critical parameter of chosen solutions, practically, are the transport costs of waste materials from the place of origin to the place of dumping, which determine what objects producing the significant amount of waste materials in the Republic of Serbia can gravitate to the certain place of their permanent and ecologically acceptable dumping. As the optimization method was chosen the method of network planning, as the most suitable for such analysis. The results of modeling are shown in the following tables and diagrams.

3. PRESENTATION OF THE RESULTS

3.1. Evaluation of «agricultural damage» caused from non application of intensive agricultural production of certain cultures at the place which is aimed for fly ash and slag dump, in the period of exploitation the dump area and other relevant costs of construction and exploitation of dump

Since that the area of agricultural land which is captured, in purpose of construction the waste dump, in TENT A, is estimated to 500 ha, inside of this part of explorations which are applied in the paper, same is divided to the certain agricultural products. In the economical model, the expected production of such products is considered from experimental area, in purpose to evaluate the level of economical damage. So, the experimental area is divided to 150 ha on which corn would be sown, 150 ha for wheat, 75 ha for potato, 100 ha for beet and 150 ha for tomato the plastic tents would be built for rising the tomato [Malinović et al., 2001, Molnar et al., 1999, Hauarnek et al., 2001]. As the time horizon is a taken period from today (from the start of project) for 40 years, i.e. from 2011 to the end of 2051. Having on mind that the thermo power plant operates into continuity for 40 years, if the all passed years are taken into consideration, then the values of economic parameters could be doubled, without larger simplifications and approximations. The results of modeling are shown in the following tables and diagrams.

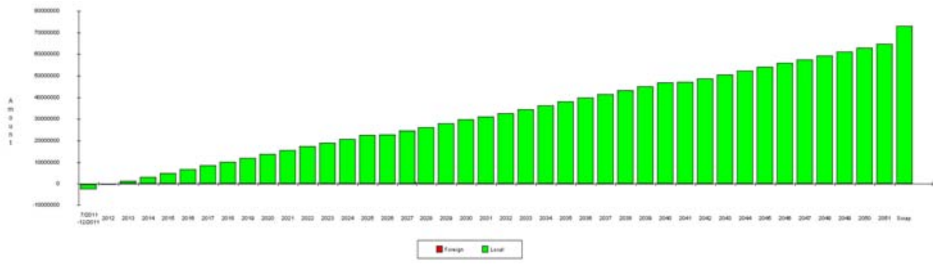

Fig. 1. *Accumulated «cash flow» for financial planning (in euro)*

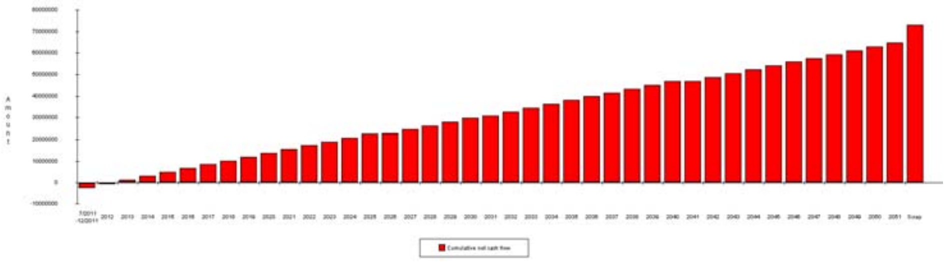

Fig. 2. *Cumulative discounted «cash flow» for normal return of investments (in euro)*

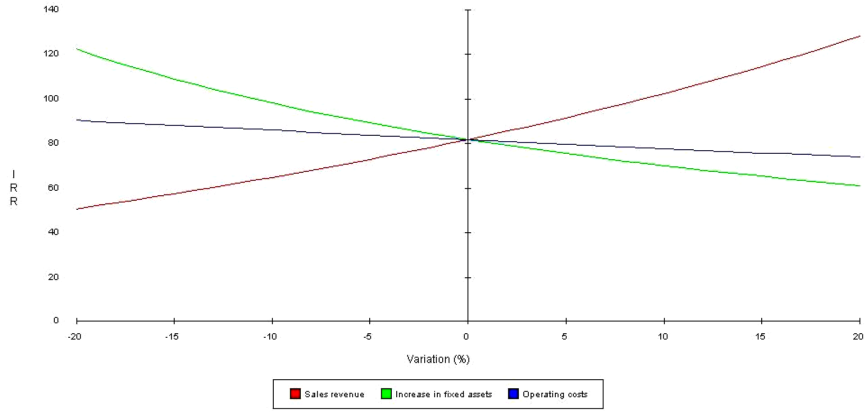

Fig. 3. *Diagram of sensitivity the internal rate of return (in euro)*

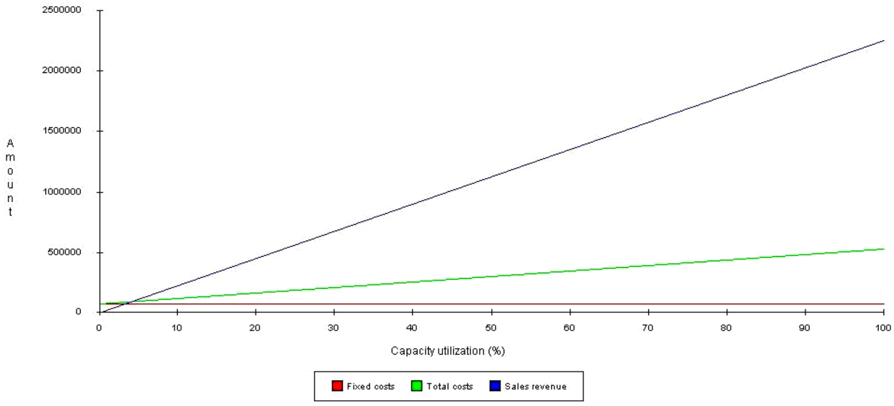

Fig. 4. *Analysis the critical point of project including costs of finance in 2013 (in euro)*

3.2. Evaluation the economic parameters of application the procedures of waste dumping of fly ash and slag from thermo power plants, heating plants and metallurgical plants with backfilling «at the place of origin», i.e. in the areas of abandoned mines

As it was already mentioned in the paper, at this place a complex techno-economical model of technological solution was considered for returning of the ash and slag from thermo power plants, heating plants and metallurgical plants and several other waste materials in different compounds in the opened caves of mines with the underground exploitation, as an example of underground mining system in the ore body «Borska reka» in RTB Bor.

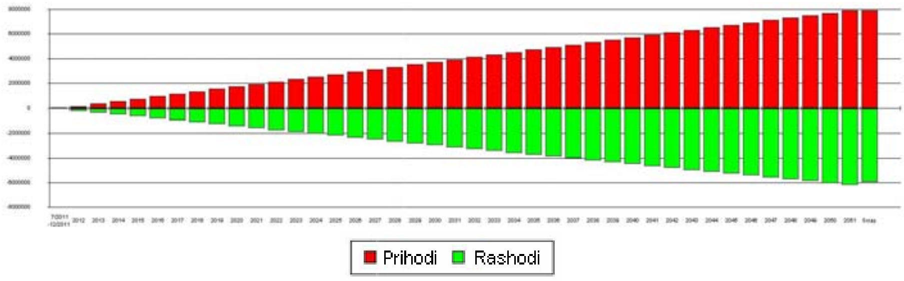

Fig. 5. *Accumulated «cash flow» for financial planning (in thousand euro)*

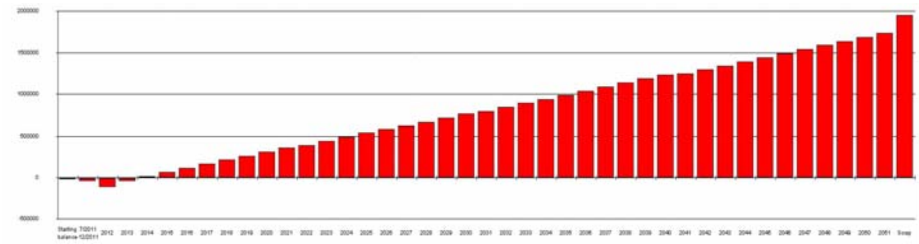

Fig. 6. *Cumulative discounted «cash flow» for normal return of investments (in thousand euro)*

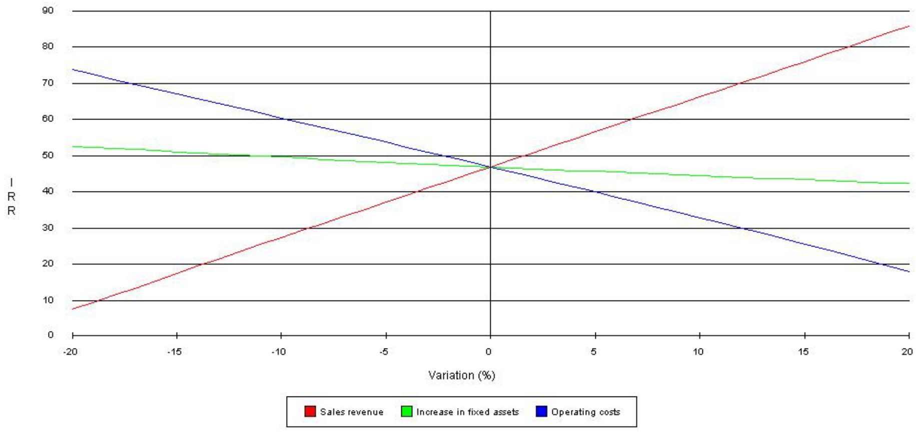

Fig. 7. *Diagram of sensitivity the internal rate of return (in thousand euro)*

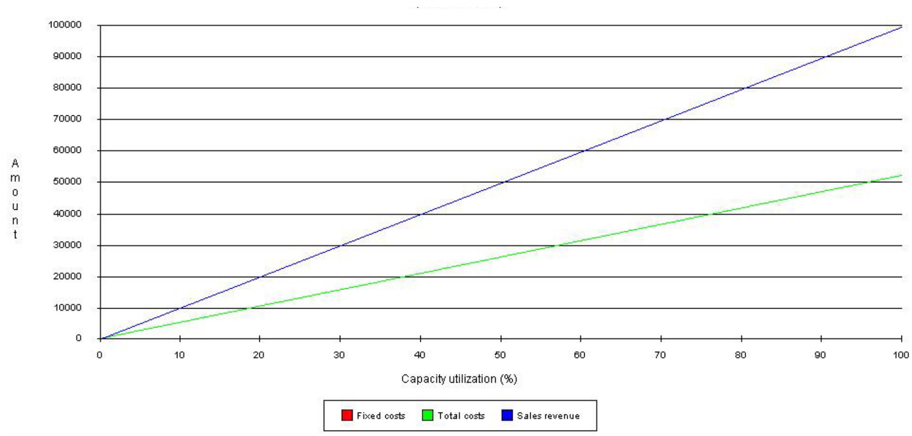

Fig. 8. *Analysis the critical point of project including costs of finance in 2013 (in thousand euro)*

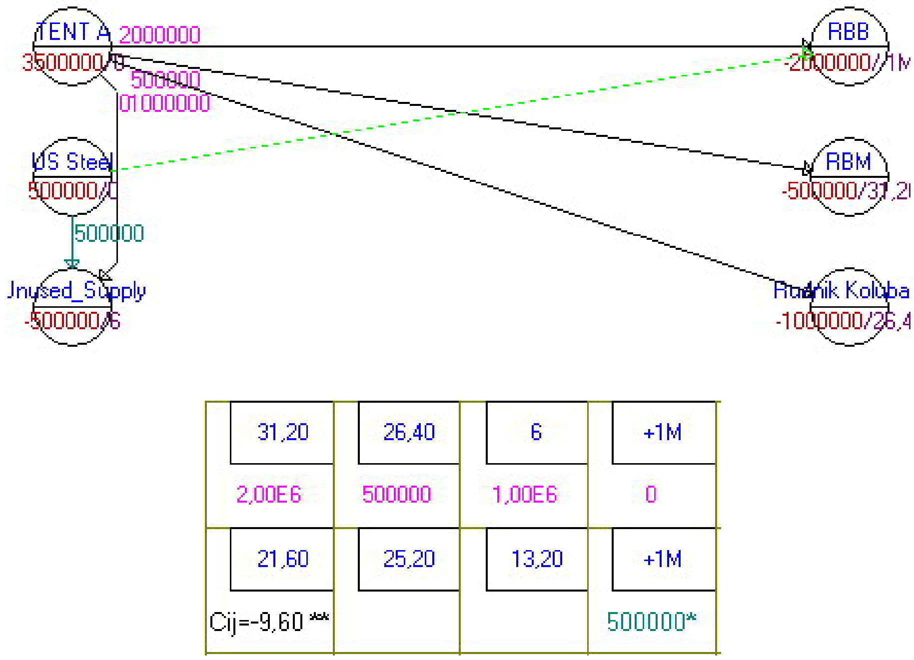

Fig. 9. *Minimization the transport costs – Network planning*

Table 1. *Solution of fly ash transport from TPP to the Mine:. Minimization (transport problem)*

01-17-2012	Od	Do	Količina pepela i šljake (t)	Jedinična cena €/t	Ukupni troškovi €	Smanjeni troškovi €
1	TENT A	RBB	1.50E+06	31.2	4.68E+07	0
2	TENT A	RBM	500000	26.4	1.32E+07	0
3	TENT A	Rudnik Kolubara	1.00E+06	6	6000000	0
4	TENT A	Unused_Supply	500000	0	0	0
5	US Steel	RBB	500000	21.6	1.08E+07	0
6	US Steel	RBM	0	25.2	0	8.4
7	US Steel	Rudnik Kolubara	0	13.2	0	16.8
8	US Steel	Unused_Supply	0	0	0	9.6
	Total	Objective	Function	Value =	7.68E+07	

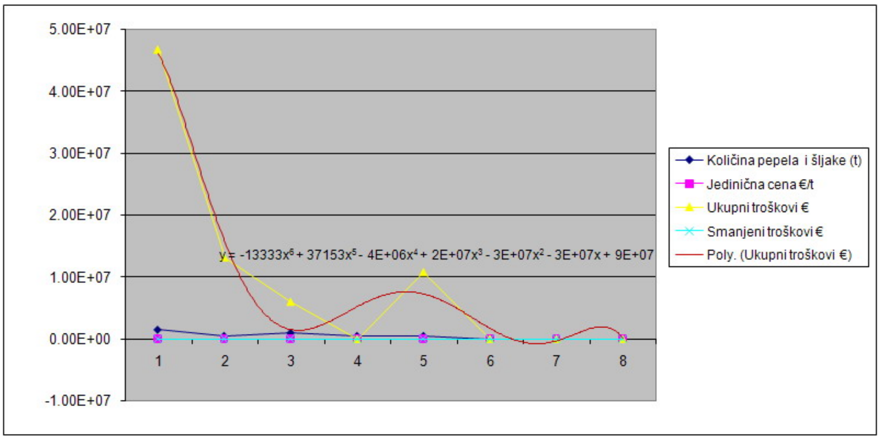

Fig. 10. *Minimization the transport costs –diagram*

Potential «producers» of fly ash and slag the TENT A, metallurgical complex US Steel from Smederevo were taken into consideration into analysis as well as the potential places of dumping the Copper Mines Bor, Copper Mine Majdanpek and Open pits of the mining Basin «Kolubara» near Lazarevac. From diagram (Figure 10), it could be noticed that minimum transport costs using the rail system of transport at distance of 50 km and transport of 1.000.000 t is in the Mining Basin «Kolubara», and that it is rational with projected distribution to transport with the same type of transporting, 2.000.000 t of ash and slag from TENT A, and 500.000 t of metallurgical slag from US Steel into the Copper Mine Bor.

4. DISCUSSION

Analyzing the results of techno-economical model, the critical parameters of model are chosen, which are treated in the multi criterion optimization. Method of network planning is used for optimization.

The results of optimization are shown in Table 1 and Figures 9 and 10. Previous explorations of this problem in former period, although voluminous and multi-discipline, where not, from some reasons universal. The approach to explorations was intended to some segments of problem, but never till now took in consideration the other aspects of problem. From one hand, probably caused by politics of management of thermo power plants and mining and metallurgical complexes, was not into the consideration amount of damage which appeared from non using agricultural land in adequate manner. In consideration of process of waste dumping from combustion process is considered only partial aspects of influence on living environment, without analyzing the new possibilities and technologies of protection, and economic interest did not also examine the influence of so called «agricultural damage», which is the first time considered in this paper, what is original approach, as the difference with previous applied.

On the other hand, never till today was not seriously examined possibility, to replace completely the waste dumps from the surface of the terrain and to be dumped in open scopes of underground (or open pit) mines, and whether the profit of **«agricultural damage»,** covers the costs of this process.

As the top of all in the paper is used the techno-economical model in which so called «**mining damages» is taken into consideration** from unexploitated available mineral resources, by which quantification and complex analysis the knowledge was gained about applicability the examined approach with all its positive effects.

5. CONCLUSION

From economic viewpoint, real costs of application of such system of dumping, costs of economic damage from application of this technology and the effects of ecological damage are treated in following analysis. Direct economic damage - **«agricultural damage»** from non application of intensive agricultural production at the place which is otherwise used as waste dump, which accidentally or with some purpose was not took into consideration and analysed in such manner, is app. 73 million euro, in the considered period. This damage is much larger if the other aspects of agricultural industrial superstructure will be considered, which inevitably follows the agricultural production.

Described technological solution considered from technological aspect and the interest of the thermo power plant itself (this statement is relate also for metallurgical facilities and heating plants) is less desirable, because it is less examined in the previous period.

On the other hand application of this technology has a long history in mining industry of Republic of Serbia and great number of papers and explorations is realized in this area. But, all of these explorations are related strictly on techno-economical aspect of application without detailed examination of ecological and especially economical aspect of their application. It wouldn´t be exaggerate the statement, that such complex techno-economical and ecological approach is pioneer in this scientific area, caused by irreconcilable differences between «producers» and «consumers» of this waste materials and absence of regulatory bodies which task would be mutual coordination between main «stakeholders».

Application of this technological solution demands the active role of state as the owner of these industrial entities as the key «stakeholders». When the problem is studied in detail then it could be found out that with this all are in profit. From viewpoint of power plants (metallurgical facilities and heating plants) they release themselves of surplus the waste materials, except the part which have market value (in cement industry, civil construction industry and the industries of several other civil construction materials), and mines obtain «free of charge» qualitative puzzolanic material which in appropriate mixture with crushed mining waste rocks and hydro flotation sand gave qualitative solid backfilling. From viewpoint of mines application of such system demands investments in surface complex for collection and preparation of backfilling mixture at the surface of the terrain, underground complex for backfilling and the system of circulating water. Benefits for mines are, beside elimination of direct «**mining damages»** from unexploitated available mineral resources, and with this higher rate of amortization of technological equipment, also elimination of damages the surface of the terrain and the objects built on it. Investments costs of the state relates on investments in rail transporting system and rail infrastructure. Costs of such investment would be covered through the elimination of direct economic damage - **«agricultural damage»** and through the elimination or reduction of «**mining damages».** From ecological aspect it is based on presented analyse most suitable solution because, usage of this solution most of influences on environment is completely eliminated.

As it is mentioned above, since it is dealing with significant investments, if the application of such systems of environmental protection would be ultimate measure defined with the certain legal regulations and rules (as they are in EU), and if they will be supported from the state and funds of Republic of Serbia, then will be created conditions for the whole territory of Republic of Serbia, to be released of this materials. In pure economical manner, if the whole problem is observed cumulatively, total profit for the Republic of Serbia would be app. **2 billion euro in period of 40 years, i.e. app. 50 million euro per year**, without taking into account the indirect effects from improvement living environment, better usage of available mineral resources, new working places, investments in infrastructure, etc.

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TRETMAN INDUSTRIJSKIH OTPADNIH VODA IZ PROCESA PROIZVODNJE BAKRA U RTB BOR**

Izvod

Najveći zagađivači vodenih resursa su industrijske otpadne vode koje nastaju nakon različitih proizvodnih tehnoloških procesa. U okviru industrijskog kompleksa RTB Bor u toku procesa proizvodnje bakra nastaju otpadne vode čiji se negativan uticaj na okolinu ogleda u dugoročnoj kontaminaciji zemljišta sa kojim dolaze u dodir i akumuliranju jona teških metala u njemu, u ulivanju u površinske vode i mešanju sa podzemnim vodama i njihovom zagađenju. Direktno najugroženije su Borska i Kriveljska reka koje pripadaju slivnom području reke Timok koji se dalje uliva u Dunav pa samim tim predstavlja širi ekološki problem međunarodnog karaktera. Cilj rada je karakterizacija otpadnih industrijskih voda nastalih u Rudarsko-topioničarskom basenu Bor i njihov uticaj na zagađenje okolnih vodotokova. Analizirani su uzorci otpadnih voda iz procesa proizvodnje sumporne kiseline, iz proizvodnje bakar-sulfata, elektrolitičke rafinacije bakra i pogona za preradu anodnog mulja. Urađena je detaljna kvalitativno-kvantitativna analiza uzoraka otpadne vode iz navedenih proizvodnih procesa i utvrđen povišen sadržaj jona teških metala (Cu, Fe, Mn, Zn, Pb, Ni, Bi, Cd, i dr.) koji višestruko premašuje MDK vrednosti definisane u zakonskoj regulativi Republike Srbije. Izvršena je neutralizacija otpadnih industrijskih voda i nakon hemijske karakterizacije prečišćenih voda utvrđeno je da pripadaju IV kategoriji voda po zakonskoj regulativi Republike Srbije. Na osnovu hemijskog sastava dat je predlog za tretman prečišćavanja uz valorizaciju prisutnog bakra.

Ključne reči: *otpadne vode, hemijska karakterizacija, neutralizacija*

1. UVOD

Zagađenje životne sredine predstavlja jedan od osnovnih ograničavajućih faktora daljeg razvoja čovečanstva. Poremećaji ekosistema izazvani ispuštanjem neprečišćenih otpadnih voda vremenom su narasli do takvih razmera da se prečišćavanje nametnulo kao nužnost. Rudarstvo i proizvodnja bakra u Boru, tokom proteklih sto godina, imalo je ogroman uticaj na životnu okolinu samog grada, ali i šireg regiona. Na području Bora je u zoni delovanja RTB-a degradirano preko 29.000 ha zemljišta pod

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šumama i oranicama dok površina degradiranog poljoprivrednog zemljišta u borskoj opštini iznosi preko 60% od ukupnog poljoprivrednog zemljišta [1]. Borska reka u koju se ulivaju sve otpadne vode sa jalovišta, flotacija i ostalih pogona za proizvodnju i preradu bakra, je jedna od najzagađenijih reka u svetu.

Najveći uticaj na zagađenje Borske reke imaju industrijske otpadne vode koje nastaju u procesima elektrolitičke rafinacije bakra, proizvodnji bakar-sulfata i proizvodnji plemenitrih metala. Analizom rečnog sedimenata Borske reke na sadržaj teških metala utvrđene su koncentracije bakra i do 30 puta veće od maksimalno dozvoljenih koncentracija propisanih zakonskim regulativama Republike Srbije [2].

Na osnovu kategorizacija reka i lokalnih vodotokova mogu se sagledati dimenzije zagađenja koja nastaju usled rastvaranja jona teških metala iz odloženih rudarskih otpadnih materijala i jona teških metala koji potiču iz otpadnih industrijskih voda nastalih pri proizvodnji i preradi bakra. Nesumnjivo je da na taj način, zagađenje slivnog područja reke Timok i dalje Dunava predstavlja širi ekološki problem međunarodnog karaktera. U ovom radu je prikazana karakterizacija otpadnih industrijskih voda nastalih tokom procesa dobijanja bakra i njihov uticaj na zagađenje okolnih vodotokova. Analizirani su uzorci otpadnih voda iz procesa proizvodnje sumporne kiseline, iz proizvodnje bakar-sulfata, elektrolitičke rafinacije bakra i pogona za preradu anodnog mulja. Urađena je detaljna kvalitativno-kvantitativna analiza uzoraka otpadne vode iz navedenih proizvodnih procesa. Pripremljen je kompozitni uzorak svih industrijskih otpadnih voda i izvršeno je prečišćavanje voda procesom neutralizacije. Na osnovu kvalitativnog i kvantitativnog sastava industrijskih otpadnih voda dat je predlog za njihov tretman pre ispuštanja u Borsku reku.

EKSPERIMENTI

Hemijska karakterizacija industrijskih otpadnih voda

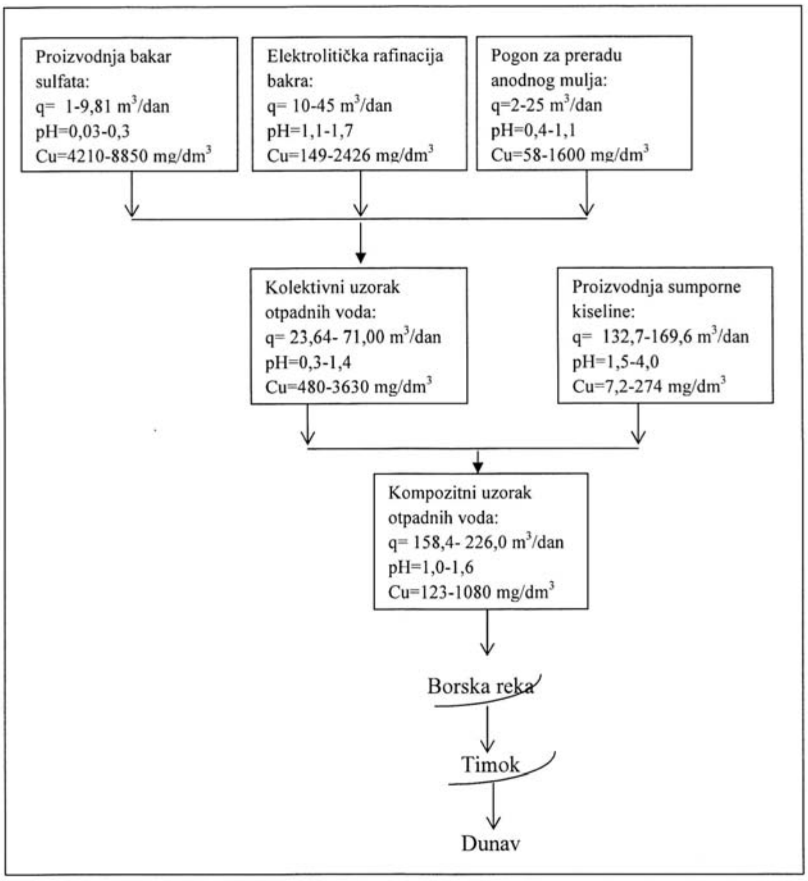
Ukupna zapremina industrijskih otpadnih voda procenjena je na osnovu planirane maksimalne proizvodnje bakra od 50.000 t/god [3]. Uzorkovanje otpadnih voda vršeno je jednom dnevno iz sledećih pogona: za proizvodnju sumporne kiseline, za proizvodnju bakar-sulfata, za elektrolitičku rafinaciju bakra i pogona za preradu anodnog mulja. Uzorkovanje je vršeno u kontinuitetu od dve nedelje. Sumirani su podaci po danima i mestu uzorkovanja. Merene su količine otpadne vode, temperatura uzorka u momentu uzorkovanja i pH vrednosti. Na osnovu dobijenih podataka formiran je jedan dnevni kompozitni uzorak iz svih analiziranih otpadnih industrijskih voda i izvršena njegova fizičko-hemijska karakterizacija:

- elementi: Ca, Cu, Fe, Bi, Na, Mg su analizirani primenom AAS - Atomski apsorpcioni spektrofotometar (Perkin-Elmer – 100),
- elementi: Sb, Al, As, Pb, Cd, Co, Cr primenom Atomsko emisionog spektrometra sa indukovano kuplovanom plazmom-AES-ICP (SPECTRO CIROS VISION),
- H_2SO_4 primenom V - Volumetrijska metoda
- Cl- primenom T - Turbidimetrijska metoda,
- SO_4^{2-} primenom G - Gravimetrijska metoda,
- Hg primenom CV-AAS - Bez plamena atomsko apsorpcioni Spektrofotometar (Perkin-Elmer FIMS - 100) i
- SiO_2, CaO, Fe_2O_3 primenom XRFA - X-ray fluoroscentna analiza na aparatu NITON XL3t-900 u skladu sa programom Mining mode - AutoCat file.

Kompozitni uzorci su podvrgnuti procesu neutralizacije i urađena je analiza eluata nakon neutralizacije.

REZULTATI I DISKUSIJA

Mesto nastajanja, količine i sadržaj bakra u industrijskim otpadnim vodama prikazani su na sl 1.



Sl. 1. *Blok-dijagram industrijskih otpadnih voda nastalih u RTB Bor*

Otpadne vode sa najnižom pH vrednošću i najvišom koncentracijom bakra su iz pogona za proizvodnju bakar-sulfata. Koncentracija bakra više hiljada puta prevazilazi MDK vrednost za kategoriju voda koje se mogu ispuštati u vodene recipijente. Takođe, i otpadne vode iz elektrolitičke rafinacije bakra i pogona za preradu anodnog mulja su jako kisele sa visokim koncentracijuma jona bakra. Kolektivni uzorak otpadnih voda tri pogona i otpadnih voda iz pogona za proizvodnju sumporne kiseline daje sliku sastava otpadnih industrijskih voda iz pogona proizvodnje bakra. Količina bakra u tim otpadnim vodama na godišnjem nivou iznosi približno 40.000 kg i u sadašnjim uslovima proizvodnje bakra predstavlja ekološki problem i ekonomski gubitak. Prosečna koncentracija bakra u analiziranih 14 kompozitnih uzoraka otpadnih voda iznosila je oko 500 mg/l, a pH vrednost: 1.0-1.6.

Otpadne vode su tretirane krečnim mlekom u cilju uklanjanja prisutnih jona teških metala. Urađene su serije opita procesa neutralizacije. Hemijska karakterizacija otpadnih voda pre i nakon neutralizacije je prikazana u tabeli 1.

***Tabela 1**. Hemijski sastav kompozitnih uzoraka otpadnih voda*

Parametar	**Jedinica**	**Kompozitni uzorak otpadne vode**		**III, IV klasa vode mg/dm^3**	**Analitička metoda**
		Pre neutralizacije	**Posle neutralizacije**		
Čvrsti ostatak sušen na 105°C	g/l	23,58 - 238,24			G
Suspendovane čestice	g/l	2,42 – 80,16			G
Sadržaj H_2SO_4	g/l	2,25 – 10,47			V
Aluminijum (Al)	mg/dm^3	66 - 243	<1		AES-ICP
Antimon (Sb)	mg/dm^3	<1	<1	0,05	AES-ICP
Arsen (As)	mg/dm^3	45 - 172	<1	0,05	AES-ICP
Kadmijum (Cd)	mg/dm^3	1 - 11	<1	0,01	AES-ICP
Kalcijum (Ca)	mg/dm^3	310 - 670			AAS
Hrom (Cr)	mg/dm^3	<1	<1	0.5	AES-ICP
Kobalt (Co)	mg/dm^3	1-2	<1	2,0	AES-ICP
Bakar (Cu)	mg/dm^3	123 - 1080	<1 – 2,3	0,1	AAS
Gvožđe (Fe)	mg/dm^3	3360 - 11690	<1 – 4,1	1,0	AAS
Olovo (Pb)	mg/dm^3	2,8 – 5,9	<1	0,1	AES-ICP
Magnezijum (Mg)	mg/dm^3	73 - 250	<1 -0,2		AAS
Mangan (Mn)	mg/dm^3	2,9 – 9,0	<1		ICP
Nikl (Ni)	mg/dm^3	4,3 - 62	<1	0,1	ICP
Selen (Se), rastvorni	mg/dm^3	1 - 121	<1	0,01	ICP
Natrijum (Na)	mg/dm^3	10 - 270	11- 211		AAS
Vanadijum (V)	mg/dm^3	1,3 - 6	<1	0,5	ICP
Cink (Zn)	mg/dm^3	51 - 2197	<1 – 11,7	1	ICP
Srebro (Ag)	mg/dm^3	<1	<1	0,02	ICP
Bizmut (Bi)	mg/dm^3	1 – 2,2	<1		AAS
Živa (Hg)	mg/dm^3	0,001 – 0,014	<0,001	0,001	CV-AAS
Hloridi (Cl^-)	mg/dm^3	17,47 – 131,72			T
Sulfati (SO_4^{2-})	mg/dm^3	16949 - 56013			G
Silikati (SiO_2)	%	2,72 – 27,93			XRFA
Fe_2O_3	%	17,07 – 28,64			XRFA
CaO	%	0.24 – 1,15			XRFA

Rezultati neutralizacije pokazuju da otpadna voda kompozitnog uzorka svih industrijskih voda iz proizvodnje bakra (koji obuhvata procese topljenja i rafinacije bakra) nakon procesa neutralizacije pripada IV klasi voda po zakonskoj regulativi Republike Srbije.

Visoka koncentracija bakra u ispitivanim otpadnim industrijskim vodama nameće potrebu izdvajanja bakra pre procesa neutralizacije. Koristeći ranije stečena iskustva na integralnom tretmanu rudarskog otpada sa industrijskim otpadnim vodama [4] predlaže se da se bakar iz otpadnih voda izdvaja procesom solventne ekstrakcije i elektrowininga (SX-EW) ili pak apsorpcijom na čvrstom katjonitu [5-7]. Nakon izdvajanja bakra vode bi se tretirale procesom neutralizacije.

ZAKLJUČAK

Izvršeno je uzorkovanje otpadnih industrijskih voda u kontinuitetu od dve nedelje. Analizirani su uzorci otpadnih voda iz procesa proizvodnje sumporne kiseline, proizvodnje bakar-sulfata, elektrolitičke rafinacije bakra i pogona za preradu anodnog mulja. Kompozitni uzorak je formiran na osnovu odnosa količina otpadnih voda iz navedenih procesa.

Urađena je detaljna kvalitativno-kvantitativna analiza uzoraka otpadne vode iz navedenih proizvodnih procesa kao i kompozitnih uzoraka. Utvrđen je povišen sadržaj jona teških metala (Cu, Fe, Mn, Zn, Pb, Ni, Bi, Cd, i dr.) koji višestruko premašuje MDK vrednosti definisane u zakonskoj regulativi Republike Srbije.

Sadržaj bakra u otpadnim vodama je visok (prosečna vrednost u ispitivanom periodu iznosila je oko 500 mg/l). Obzirom na visok sadržaj bakra u otpadnim vodama i uzimajući u obzir visoku cenu bakra na svetskoj berzi predloženo je da se pre neutralizacije otpadnih industrijskih voda bakar izdvojiti primenom SX-EW procesa ili apsorpcijom na čvrstom katjonitu. Na taj način postigo bi se značajan ekonomski efekat. Proces za izdvajanje bakra iz industrijskih otpadnih voda biće predmet daljeg istraživanja.

Rezultati neutralizacije industrijskih otpadnih voda potvrdili su da se primenom ovog tehnološkog procesa može prečistiti do kvaliteta koji odgovara IV kategoriji voda a koja po zakonskoj regulativi može da se ispusti u vodene recipijente.

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TREATMENT OF INDUSTRIAL WASTE WATER FROM COPPER PRODUCTION PROCESS IN RTB BOR**

Abstract

The biggest polluters of water resources are industrial waste water produced after various production technological processes. Within the industrial complex RTB Bor, the waste water are generated during the copper production process with negative impact on the environment, reflected in long-term contamination of soil with which they come into contact and accumulation of heavy metal ions in it, in inflow into surface water and mixing with ground water and their pollution. Directly, the most vulnerable are the Bor River and Krivelj River belonging to the catchment area of the River Timok that still flows into the Danube and therefore presents wider environmental problem of international character. The aim of this work is a characterization of industrial waste water generated in RTB Bor and their impact on the pollution of nearby water flows. The waste water samples were analyzed from the production process of sulfuric acid, production of copper sulfate, electrolytic copper refining and treatment plant of anode slime. Detailed qualitative and quantitative analysis of waste water samples was carried out from these production processes and high content of heavy metal ions (Cu, Fe, Mn, Zn, Pb, Ni, Bi, Cd, etc.) was established, that highly exceeds the limit values defined in the legal regulations of the Republic of Serbia. Neutralization of the waste industrial water was performed and after chemical characterization of purified water, it was found that they belong to the IV water category, according to the legislation of the Republic of Serbia. Based on chemical composition, a proposal for treatment with valorization of present copper was given.

Keywords: *waste water, chemical characterization, neutralization*

1. INTRODUCTION

Environmental pollution is one of the main basic limiting factors for further development of mankind. Ecosystem disturbances, caused by the discharge of untreated wastewater, have grown over time to such an extent that the treatment was

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imposed as a necessity. Mining and copper production in Bor, in the past hundred years, had a huge impact on the environment of town, but also in a wide region. In the area of Bor, in the zone of RTB activity, over 29,000 ha of land under forests and fields is degraded while the area of degraded agricultural land in the Bor municipality is over 60% of total agricultural land [1]. The Bor River, into which all waste water flows from the tailing dumps, flotation plants and other facilities for copper production and treatment, is one of the most polluted rivers in the world.

Industrial waste water, produced in the process of electrolytic copper refining, copper sulfate production and precious metals production, have the biggest impact on a pollution of the Bor River. Analyzing of river sediments from the Bor River on content of heavy metals has found higher copper concentrations up to 30 times than limit value concentration prescribed by the legal regulations of the Republic of Serbia [2].

Based on the classification of rivers and local streams, the dimensions of pollution, originating from dissolution of heavy metal ions from dumped mining waste and heavy metal ions, originating from industrial waste water generated during production and processing of copper, can be seen. There is no doubt that by this way, the pollution of the catchment area of the river Danube and further Timok presents a wider environmental problem of international character. This paper describes the characterization of industrial waste water generated during the process of copper production and their effect on pollution the nearby watercourses. The samples of wastewater were analyzed from the production process of sulfuric acid, copper sulfate production, electrolytic copper refining and plants for anode slime treatment. A detailed qualitative and quantitative analysis of wastewater samples was carried out from these production processes. A composite sample of all industrial wastewater was prepared and water treatment was done by the neutralization process. Based on qualitative and quantitative composition of industrial wastewater, a proposal was given for their treatment before discharging into the Bor River.

EXPERIMENTS

Chemical Characterization Industrial Wastewater

Total volume of this water is evaluated based on the planned copper production of maximum 50,000 t/year [3]. Sampling of wastewater was carried out once a day from the following plants: the production of sulfuric acid, copper sulfate production, electrolytic copper refining and plant for anode slime treatment. Sampling was done continuously for two weeks. Data were summarized by days and place of sampling. The quantities of waste water, temperature of sample at time of sampling and pH values were measured. Based on the obtained data, a daily composite sample was formed from all analyzed industrial wastewater and its physico-chemical characterization was made:

- elements: Ca, Cu, Fe, Bi, Na, Mg were analysed by the use of AAS - Atomic Apsorption Spectrophotometer (Perkin-Elmer – 100),
- elements: Sb, Al, As, Pb, Cd, Co,Cr by the use of Atomic Emission Spectrometer with Inductively Coupled Plasma - AES-ICP (SPECTRO CIROS VISION),
- H_2SO_4 by the use of V- Volumetric method
- Cl^- by the use of T- Turbidimetry method,
- SO_4^{2-} by the use of G –Gravimetric method,

- Hg by the use of CV-AAS – Cold vapour atomic apsorption Spectrophotometer (Perkin-Elmer FIMS - 100) and
- SiO_2, CaO ,Fe_2O_3 by the use of XRFA - X-ray fluorescent analysis on apparatus NITON XL3t-900 according to the program Mining mode - AutoCat file.

Composite samples were subjected to the neutralization process and the analysis of the eluate was analyzed after neutralization.

RESULTS AND DISCUSSION

Place of occurrence, quantity and content of copper in the industrial wastewater are shown in Figure 1.

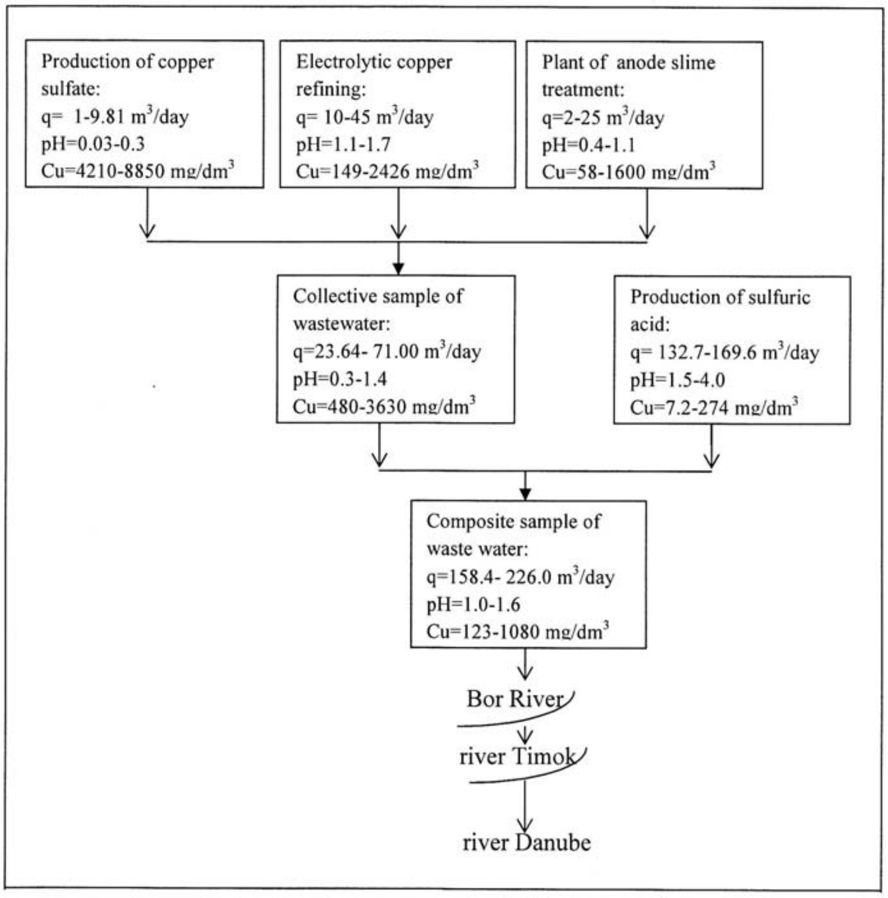

Fig. 1. *Flow-sheet of industrial waste water generated in RTB Bor*

Wastewater with the lowest pH and highest copper concentration are from the copper sulfate production plant. Copper concentrations exceeds several thousand times the limit value (LV) for the water category that can be discharged into the water recipients. Also, the waste water from electrolytic copper refining and plant for anode slime processing are highly acidic with high concentrations of copper ions.

A collective sample of wastewater from three plants and waste water from the plant for sulfuric acid production gives a picture of the industrial wastewater composition from the copper production plant. Copper quantity in these waste water at yearly level is approximately 40,000 kg and in the present conditions of copper production poresents an environmental problem and economic loss. The average concentration of copper in the analyzed 14 composite samples of wastewater was about 500 mg/L, and pH-value: 1.0-1.6.

Wastewater was treated with lime milk to remove the present heavy metal ions. Series of experiments of neutralization process were carried out. Chemical characterization of wastewater before and after neutralization is shown in Table 1.

Table 1. *Chemical composition of waste water composite samples*

Parameter	Unit	Composite sample of waste water		Analytical method
		Before neutralization	After neutralization	
Total solids dried at 105°C	g/L	23.58 - 238.24		G
Total suspended solids	g/L	2.42 – 80.16		G
Content of H_2SO_4	g/L	2.25 – 10.47		V
Aluminum (Al)	mg/dm^3	66 - 243	<1	AES-ICP
Antimony (Sb)	mg/dm^3	<1	<1	AES-ICP
Arsenic (As)	mg/dm^3	45 - 172	<1	AES-ICP
Cadmium (Cd)	mg/dm^3	1 - 11	<1	AES-ICP
Calcium (Ca)	mg/dm^3	310 - 670		AAS
Chromium (Cr)	mg/dm^3	<1	<1	AES-ICP
Cobalt (Co)	mg/dm^3	1-2	<1	AES-ICP
Copper (Cu)	mg/dm^3	123 - 1080	<1 – 2.3	AAS
Iron (Fe)	mg/dm^3	3360 - 11690	<1 – 4.1	AAS
Lead (Pb)	mg/dm^3	2.8 – 5.9	<1	AES-ICP
Magnesium (Mg)	mg/dm^3	73 - 250	<1 -0.2	AAS
Manganese (Mn)	mg/dm^3	2.9 – 9.0	<1	ICP
Nickel (Ni)	mg/dm^3	4.3 - 62	<1	ICP
Selenium (Se) dissolved	mg/dm^3	1 - 121	<1	ICP
Sodium (Na)	mg/dm^3	10 - 270	11- 211	AAS
Vanadium (V)	mg/dm^3	1.3 - 6	<1	ICP
Zinc (Zn)	mg/dm^3	51 - 2197	<1	ICP
Silver (Ag)	mg/dm^3	<1	<1	ICP
Bismuth (Bi)	mg/dm^3	1 – 2.2	<1	AAS
Mercury (Hg)	mg/dm^3	0.001 – 0.014	<0.001	CV-AAS
Chloride (Cl^-)	mg/dm^3	17.47 – 131.72		T
Sulphate (SO_4^{2-})	mg/dm^3	16949 - 56013		G
Silicate (SiO_2)	%	2.72 – 27.93		XRFA
Fe_2O_3	%	17.07 – 28.64		XRFA
CaO	%	0.24 – 1.15		XRFA

The results of neutralization show that the wastewater of composite sample of all industrial water from the copper production (which includes the process of copper smelting and refining process) after the neutralization process belongs to the IV class of water according to the legislation of the Republic of Serbia.

High copper concentration in the analyzed industrial wastewater imposes a need for copper extraction before the neutralization process. Using the previously gained experiences in the integrated treatment of mining waste with the industrial wastewater [4], it is proposed that copper from wastewater is separated by the solvent extraction process and electrowining (SX-EW) or by the absorption on a hard cationite [5-7]. After copper extraction, the water would be treated by the neutralization process.

CONCLUSIONS

Sampling of industrial wastewater was carried out continuously for two weeks. The samples of wastewater were analyzed from the production process of sulfuric acid, copper sulfate production, electrolytic copper refining and plant for anode slime treatment. A composite sample was formed based on the ratio of wastewater quantities from these processes. A detailed qualitative and quantitative analysis of wastewater samples was carried out from these production processes as well as the composite samples. The higher content of heavy metal ions was found (Cu, Fe, Mn, Zn, Pb, Ni, Bi, Cd, etc.), which highly exceeds the limit values defined in the legislation of the Republic of Serbia. Copper content in the wastewater is high (average value in tested period amounted to about 500 mg/L). Due to the high content of copper in waste water, and taking into account the high price of copper on the world stock exchanges, it has been proposed to extract copper before the neutralization of waste industrial water using the SX-EW process or absorption on a hard cationite. By this way, a significant economic effect would be achieved. The process for copper extraction from industrial waste water will be subjected to further research. The results of neutralization the industrial waste water have confirmed that the use of this technological process can purify up to the quality that fits the IV water class and that, according to the legislation, can be released into the water recipients.

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MOGUĆNOST PRIMENE MIKROORGANIZAMA U CILJU DOBIJANJA BAKRA IZ OTPADNIH MINERALNIH SIROVINA**

Izvod

Mikrobiološko luženje predstavlja u svetu priznat metod za izdvajanja korisnih komponenti iz siromašnih ruda i sekundarnih sirovina.

Prednost mikrobiološkog luženja mineralnih sirovina predstavlja malo ulaganje, odnosno ekonomska opravdanostog luženja, vrlo jednostavna primena i pogodnost ovakvog luženja sa aspekta zaštite životne sredine.

U ovom radu je ispitivanja mogućnost mikrobiološkog luženje bakra iz jalovine (raskrivke starog kopa u Boru) u laboratorijskim uslovima, korišćenjem kulture Acidithiobacillus ferrooxidans.

Izveden je eksperiment luženja u erlenmajerima uz mućkanje. Eksperiment je trajao tri nedelje, na prosečnoj temperaturi od 28^{0}C. Procenat izluženog bakra na kraju eksperimenta je iznosio 34%.

Dobijeni rezultati bi trebalo da posluže kao osnova za ponovno uvođenje ove, u svetu prihvaćene tehnologije u eksploataciji mineralnih sirovina, u cilju dobijanja korisnih komponenata iz siromašnih ruda kao i za remedijaciju kontaminiranog zemljišta.

Ključne reči: *bakar, luženje, Acidithiobacillus ferrooxidans*

UVOD

Intenzivna urbanizacija, brzi razvoj tehnologije u savremenom svetu, posebno u poslednjih trideset godina dovodi do sve većeg nagomilavanja otpadnog materijala različitog porekla i do sve većeg zagađivanja životne sredine. Mikroorganizmi imaju izuzetno važnu ulogu u prirodi i očuvanju životne sredine razgrađujući različite otpadne supstrate. Njihova heterogena metabolička aktivnost omogućava ne samo razgradnju većine organskih molekula i recikliranje biogenih elemenata, već i mnogobrojne transformacije neorganskih jedinjenja.

Transformacije, kruženje, migracije i koncentrovanje hemijskih elemenata u

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atmosferi, hidrosferi, litosferi i čitavoj biosferi mogu da se vrše istovremeno kako abiogenim, tako i biogenim putem. Među mikroorganizmima koji učestvuju u transformacijama i kruženju elemenata u prirodi poseban značaj se pridaje litotrofnim mikroorganizmima (mikroorganizmima koji se hrane kamenom). Uloga ovih mikroorganizama u prirodi upotrebljena je za njihovu primenu u dobijanju metala, zapravo prevođenje u rastvor (ili koncentrovanje) njihovih teško rastvornih jedinjenja (prvenstveno sulfida). Dakle, procesi koji u prirodi teku spontano, usmereni su i pojačani kako bi se dobili korisni metali, prvenstveno iz metalom siromašnih ruda i otpadnih materijala (vanbilansne rude, raskrivke, jalovine itd.) [1].

Mikrobiološko luženje mineralnih sirovina danas ima široku primenu u svetu, što ukazuje da je ova metoda teorijski i praktično dobro razrađena i da se ovim postupkom dobijaju značajne količine metala. Međutim, treba napomenuti da se parametri razlikuju za svaki slučaj posebno i da zavise od karakteristika podneblja i vrste mineralne sirovine. Za svaki konkretan slučaj primene bakterija u sistemu luženja potrebna su detaljna izučavanja sirovine koja se želi tretirati, ekoloških uslova pod kojima će se luženje izvoditi i same mikroflore koja će se upotrebiti. Preporučuje se korišćenje autohtone bakterioflore, kako bi se usmerili i intenzivirali već postojeći prirodni procesi [2].

Mikrobiološki postupci dobijanja metala značajni su iz sledećih razloga:

- Kao sirovina se upotrebljava otpadni materijal, a dobija se potrebni metal koji bi se nepovratno gubio;
- Postupci mikrobiološkog luženja su nekoliko puta jeftiniji od konvencionalnih, koji su u većini i neprimenljivi za siromašne sirovine;
- Zagađenje životne sredine je svedeno na najmanju moguću meru [1].

Cilj ovog rada je bio da se ispita mogućnost mikrobiološkog luženje bakra iz jalovine (raskrivke starog kopa u Boru) u laboratorijskim uslovima, korišćenjem kulture *Acidithiobacillus ferrooxidans*. Laboratorijskim istraživanjima su definisani sledeći parametri: fizičko-hemijske karakteristike jalovine, odnos tečne i čvrste faze, broj bakterija, vreme luženja, pad pH vrednosti tokom procesa, procenat utrošenog piritnog sumpora, kao i procenat izluženja bakra.

Mikrobiološki postupci luženja siromašnih ruda i jalovina, imaju značajnu ulogu kako za dobijanje "dopunskih" količina metala, tako i u konceptu zaštite okoline, jer se jednostavnom tehnologijom, stavljaju pod kontrolu i usmeravaju, a time i sprečavaju nekontrolisani odlivi metala u vodotokove i zemljište (koji u ovoj sredini predstavljaju polutante).

MATERIJAL I METODE

Hemijske analize

Hemijska karakterizacija jalovišta urađena je konvencionalnom metodom, alkalnim stapanjem sa $NaKCO_3$i rastvaranjem u HCl [3]. Iz filtrata su određivanji Fe, Al, Ti, Ca, Mg, a talog je dalje tretiran sa HF, u cilju dobijanja isparljivog SiF_4, tj. određivanja SiO_2 Ostatak taloga je ponovo tretiran kao silikatni materijal.

Za određivanje alkalnih metala i elemenata u tragovima uzorak je razlagan smesom $HClO_4$ i HF, a za određivanje fosfora uzorak je razlagan smesom carske vode i $HClO_4$.

Alkalni metali su određivani metodom atomske emisione plamene spektrofotometrije, Fe, Al, Ti, Ca, Mg i metali u tragu, metodom atomske apsorpcione plamene spektrofotometrije, a fosfor je određivam spektrofotometrijski u obliku žutog fosfomolibdatnog kompleksa.

Sulfidni sumpor iz jalovišta je određivan gravimetrijski, posle oksidacije sa $KClO_3$ i HNO_3 i taloženja u obliku $BaSO_4$. Korekcija na sulfatni sumpor iz jalovišta rađena je iz «sodnog ekstrakta» (ključali rastvor Na_2CO_3), u obliku $BaSO_4$ [3].

Rendgenska difrakciona analiza

Rendgenska difrakciona analiza (RDA) urađena je na difraktometru Philips PW -1710, sa bakarnom antikatodom, pri opterećenju cevi 40 kV i 20 mA.

Uzorci su snimani u području 2θ 5-60^0. Podaci su prikupljeni tako što je meren svaki 0,02^0 u trajanju od po 0,5 s. Prorezi ('slitovi') su bili fiksni 1,0 -0,10 mm [4].

Identifikacija minerala je urađena korišćenjem programa MPDS i baze podataka JCPDS.

Mikrobiologija

Čista kultura *Acidithiobacillus ferrooxidans* za eksperimente je pripremana trostrukim presejavanjem u erlenmajerima od 500 ml sa 100 ml sveže podloge 9K [5], pH vrednost podloge je podešena sumpornom kiselinom na 2.5. Treće presejavanje je izvedeno u erlenmajeru od 5 dm^3 sa 1 dm^3 9K podloge. Svi erlenmajeri su mućkani na horizontalnom šejkeru pri frekvenci od 200 tresaka u minuti na 28^{0}C. Nakon pet dana, bakterijska kultura je procеđena kroz membran filter (veličina pore 0.45 μm), oprana podlogom 9K bez gvožđa (0 K). Po završenom ceđenju, bimasa dobijena iz 1 dm^3 podloge, sa membrane je isprana sa 20 cm^3 podloge 0K.

Broj mikroorganizama je određivan metodom najverovatnijeg broja [6].

Opis eksperimenta luženja

Eksperiment je izveden sa bakterijskom kulturom *Acidithiobacillus ferrooxidans* i trajao je 21 dan, sa 100 ml rastvora za luženje 9K [5], sledećeg sastava (g/dm^3): $Fe_3(SO_4)_2$ (44.8) $(NH_4)_2SO_4$-3, K_2HPO_4-0.5, $MgSO_4 \cdot 7H_2O$-0.5, KCl-0.1, $Ca(NO_3)_2$-0.01, u erlenmajerima zapremine 500 ml pri početnoj vrednosti pH od 2,5 i gustini pulpe 5% (m/V) (5gr jalovišta u 100 ml rastvora). Kontrolna suspenzija je istog hemijskog sastava, istog pH kao i suspenzija sa *Acidithiobacillus ferrooxidans,* samo je u njoj sterilizacijom inaktivisana kultura *Acidithiobacillus ferrooxidans*.

Eksperiment je izveden na horizontalnoj tresilici firme New Brunswick Scientific. Temperatura inkubacije je bila 28^{0}C, a frekvenca rada tresilice 100 tresaka u minuti. Svakih sedam dana je analiziran pH, broj mikroorganizama i koncentracija bakra.

Sam postupak luženja se zasniva na oksidaciji Fe^{2+} u Fe^{3+}, koji zatim napada pirit, pri čemu je tiosulfat glavni intermedijer, a sulfat krajnji produkt. Oksidacija pirita se opisuje sledećim jednačinama:

$$FeS_2 + 6Fe^{3+} + 3H_2O \rightarrow S_2O_3^{2-} + 7Fe^{2+} + 6H^+ \quad (1)$$

$$S_2O_3^{2} + 8Fe^{3+} + 5H_2O \rightarrow 2SO_4^{2-} + 8Fe^{2+} + 10H^+ \quad (2)$$

Fe^{2+} (nastao u reakcijama 1 i 2) može biti reoksidovan do Fe^{3+}, zahvaljujući gvožđe - oksidujućem mikroorganizmu *Acidithiobacillus ferrooxidans*.

$$2Fe^{2+} + 0{,}5O_2 + 2\ H^+ \xrightarrow{\text{MIKROBI}} 2Fe^{3+} + H_2O$$

Ključna uloga *Acidithiobacillus ferrooxidans* je u regeneraciji Fe^{3+}, kao jakog oksidacionog sredstva i sumporne kiseline [7, 8], što sve zajedno dovodi do smanjenja pH vrednosti i prevođenja bakra iz čvrstog stanja u rastvor.

REZULTATI ISTRAŽIVANJA

Lužena je jalovina, tačkasto uzeta na 12 mesta sa raskrivke starog borskog kopa. Hemijski sastav jalovine prikazan je u Tabeli 1.

Tabela 1. Hemijski sastav jalovine

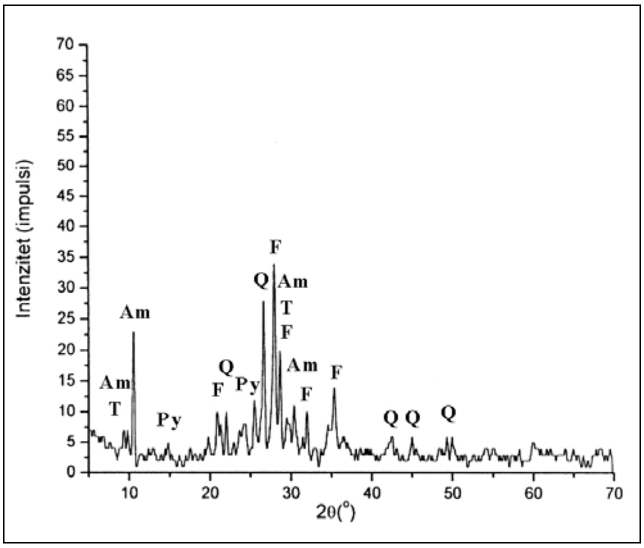
Komponenta	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	S	P_2O_5
%	58.92	15.12	2.98	0.91	0.90	1.12	2.96	0.071
Komponenta	Fe_{uk}	Fe^{2+}	Cu	Cu_{ox}	Zn	Pb	MnO	g.ž.
%	8.60	4.70	0.205	0.015	0.060	0.15	0.028	6.99

U Tabeli 2. je data distribucija jedinjenja sumpora. Sulfidni supstrati, dominantno pirit, prisutni su i u površinskom delu jalovišta borskog rudnika.

***Tabela 2.** Raspodela jedinjenja (i elementarnog) sumpora u uzorcima*

Uzorak	Elementarni S [%]	Sulfidni S [%]	Sulfatni S [%]	Ukupni S [%]
B_3	0,23	1,19	1,54	2,96

Rendgensko-difrakciona analiza je pokazala da se jalovina sastoji od kvarca (Q), feldspata (F), amfibola (Am), pirita (Py) i talka (T). Difraktogram praha uzorka jalovine je prikazan na Slici 1.



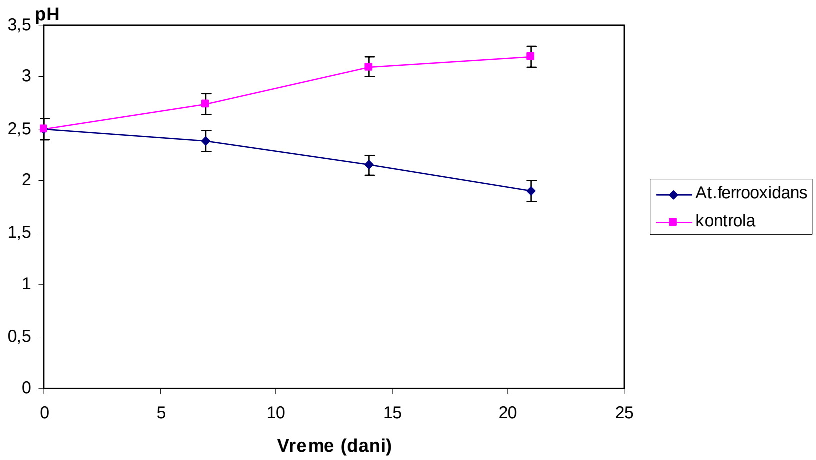
Sl. 1. *Difraktogram praha uzorka jalovine*

Eksperiment luženja bakra iz jalovišta izveden je sa bakterijskom kulturom *Acidithiobacillus. ferrooxidans*, koja kao izvor elektrona za svoj metabolizam koristi $FeSO_4$ iz podloge, pri čemu nastaje $Fe_2(SO_4)_3$, koji dalje oksiduje pirit. Hemijska oksidacija pirita kao rezultat daje redukovani oblik jona gvožđa, koji opet *Acidithiobacillus ferrooxidans* oksiduje do Fe(III) – jona. To znači da je proces cikličan i u prirodi poznat kao “fero-feri” ciklus.

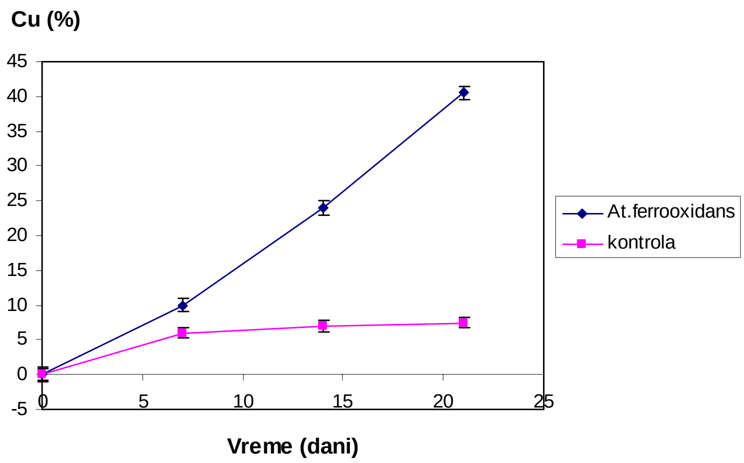
Početni broj *Acidithiobacillus ferrooxidans* je bio 2 x 10^5/ml. Vremenom se broj mikroorganizama povećavao tako da je sedmog dana eksperimenta iznosio 2,8 x 10^5/ml, četrnaestog 5,3 x 10^6/ml, a na kraju eksperimenta 7,5 x 10^6/ml.

Što se tiče sulfidnog sumpora, tokom procesa luženja, njegova količina je opala sa početnih 1,19 % na 0,4 %, u suspenziji sa *Acidithiobacillus ferrooxidans*, dok je u kontrolnoj suspenziji, pad iznosio sa 1,19 % na 1,05 %. Dobijeni rezultati potvrđuju ulogu mikroorganizma u oksidaciji pirita, a samim tim i u procesu izluženja bakra iz jalovišta.

Promena pH vrednosti i procenat izluženja bakra u suspenziji sa bakterijama kao i u kontrolnoj suspenziji, određivana su na početku i nakon 7., 14. i 21. dana eksperimenta. Dobijene vrednosti su prikazane na Slikama 2. i 3.



Sl. 2. *Promena pH vrednosti u kontrolnoj i u suspenziji sa Acidithiobacillus ferrooxidans tokom inkubacije na tresilici*



Sl. 3. *Izluženje bakra tokom inkubacije na tresilici*

Dobijeni rezultati pokazuju da je rastvaranje bakra povezano sa smanjenjem pH vrednosti, tj. povećanjem koncentracije bakterijski generisanog $Fe_2(SO_4)_3$ i sumporne kiseline u rastvoru za luženje.

Procenat izluženja bakra koji se može pripisati dejstvu *Acidithiobacillus ferrooxidans* (tj. efektivno izluženje) se dobija oduzimanjem procenta izluženja bakra iz kontrolne suspenzije od procenta izluženja metala iz suspenzije sa *Acidithiobacillus ferrooxidans* i iznosi 34%.

ZAKLJUČAK

Rezultati pokazuju da je mikrobiološki tretman jalovine bio efikasan, ali je ipak potrebno optimizovati proces u cilju dobijanja većeg stepena izluženja bakra, što se verovatno može postići povećanjem broja mikroorganizama u suspenziji, povećanjem gustine suspenzije, kao produžavanjem vremena luženja.

Mikrobiološko luženje predstavlja jeftin metod za tretman siromašnih i sekundarnih sulfidnih ruda bakra. Predviđa se da će razvoj ovog postupka ići u pravcu tretmana primarnih ruda bakra (halkopirit) i ruda drugih metala kao što je sfalerit.

Što se tiče naše zemlje, neophodno je da se naučni i tehnički napori usmere u pravcu izdvajanja korisnih komponenti iz siromašnih ruda i jalovišta mikrobiološkim luženjem. Pored toga, što se ovim putem dobijaju korisne komponente, sprečava se odliv štetnih elemenata u prirodnu sredinu, pri čemu se izbegava potencijalna opasnost od toksičnog delovanja nekog od metala na živi svet.

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Jelena Avdalović, Sonja Milićević*, Vladan Milošević**

INVESTIGATION THE POSSIBILITY OF APPLICATION THE MICROORGANISMS IN COPPER RECOVERY FROM WASTE MINERAL MATERIALS**

Abstract

Microbiological leaching is a widely accepted method for the extraction of useful components from low-grade ores and secondary mineral row materials.

The main advantages of this process are low investment, simple operation and its environmentally friendly property.

The object of this paper was to examine the possibility of microbiological leaching of copper from ore dump by Acidithiobacillus ferrooxidans.

Leaching experiments were performed by the shake flask testing technique at 28^0C, during three-week period. The percentage of the copper leached at the end of this experiment was 34 %.

The obtained results should serve as a basis for reuse this widely accepted technology for exploitation of mineral row materials in order to obtain useful components from poor ores, as well as for the remediation of contaminated soils.

Keywords: *copper, leaching, Acidithiobacillus ferrooxidans*

INTRODUCTION

In last decades, intensive population growth and industrial and technological development caused serious water, air and soil contamination and raised concern for the environmental protection. Microorganisms play an important role in preserving the environment by decomposing the waste materials. Their heterogenic metabolic activity provides decomposition of the organic molecules, recycling the biogenic elements and transformation of large numbers of inorganic compounds.

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Transformations, cyclic reactions, migrations and concentration of chemical elements in the atmosphere, hydrosphere, lithosphere and entire biosphere can be simultaneously preformed both, by abiogenic and biogenic way. One of the microorganisms that are especially involved in many transforming and cyclic reactions are the lithotrophs. These microorganisms have a main role in recovering metals, by leaching low soluble compounds (mainly sulphides). Naturally, spontaneous occurring processes are directed and enhanced in such a way to recover metals from the low-grade ores and waste materials [1].

Today, microbial leaching of raw minerals is a world-widely accepted, indicating that this method is theoretically and practically well-developed and is possible to obtain significant amounts of metals. However, it should be noted that those parameters are different in each case, and that they are dependant on the characteristics of region and type of mineral raw material. Each specific case of bacteria application in leaching system requires detailed study of mineral raw material that is to be treated, environmental conditions for leaching and the microflora that will be used. It is recommended to use native bacterioflora in order to intensify the already existing natural processes [2].

Microbial methods for recovering metals are important for following reasons:

- Waste materials is being used as a raw material giving the metal as that final product, that would be irretrievably lost;
- Microbial leaching methods are several times cheaper compared to the conventional one that are inapplicable for the low grade ores;
- Minimum threats to the environment [1].

In order to extract copper from the tailings, microbial leaching has been conducted in laboratory using the culture of *Acidithiobacillus ferrooxidans*. Parameters, like physical and chemical characteristics of tailings, solid-liquid ratio, number of bacteria, leaching time, pH decreasing, percentage of pyrite sulphur consumption as well as the percentage of the leached copper, were determined.

Microbial methods of leaching low-grade raw materials and tailings plays very important role for obtaining the additional amounts of metals and in the concept of environmental protection, because it allows use of relatively simple technology to control and redirect uncontrolled loss of metals into the soil and waterstreams.

MATERIALS AND METHODS

Chemical analysis of the ore dumps

Silicate analysis of the ore dumps was conducted using the conventional method, by alkaline fusion with $NaKCO_3$ and dissolution in HCl [3]. From the filtrate Fe, Al, Ti, Ca and Mg, were determined while the residue was further treated with HF in order to obtain volatile SiF_4, from which the SiO_2 content was determined. The remaining precipitate was treated again as silicate material.

For the determination of alkaline metals and trace elements, the sample was decomposed with a mixture of $HClO_4$ and HF, while for the determination of phosphorus, the sample was decomposed with a mixture of aqua regia and $HClO_4$.

The alkaline metals were determined by atomic emission flame spectrophotometry; Fe, Al, Ti, Ca, Mg and trace metals by atomic absorption flame spectrophotometry, while phosphorus was determined by spectrophotometry, as yellow phosphomolybdate complex.

Sulphide sulphur from the ore dumps was determined gravimetrically after oxidation with $KClO_3$ and HNO_3 followed by precipitation as $BaSO_4$. Correction on sulphate sulphur from the ore dumps was determined in the "soda-extract" (boiling solution of Na_2CO_3), as $BaSO_4$ [3].

X-ray diffraction (XRD) analysis

The XRD patterns were obtained on a Philips PW-1710 automated diffractometer using a Cu tube operated at 40 kV and 20 mA. The diffraction data were collected in the 2θ Bragg angle range from 5 to 60°, counting for 0.5 s at every 0.02° step. The divergence and receiving slits were fixed at 1 and 0.1 units, respectively [4]. The minerals were determined using MPDS software and JCPDS diffraction library.

Microbiology

Pure culture of *Acidithiobacillus ferrooxidans* was prepared for the experiments with three successive reseedings in 500 ml Erlenmeyer flasks containing 100 ml of 9K medium [5] adjusted to pH 2.5 with sulphuric acid. The third reseedings were carried out in 5 dm^3 flasks that contained 1 dm^3 of 9K medium. All flasks were shaken using a horizontal shaker with rotation and temperature set at 200 rpm and 28 ± 1°C, respectively. After five days, the bacterial culture was filtered through 0.45 μm membrane filters, washed with 9K iron-free medium (0K) and subsequently resuspended in 20 cm^3 of 0K medium.

The number of microogranisms was determined by the Most Probable Number Method [6].

Leaching experiments design

The leaching experiments were carried out with bacterium *Acidithiobacillus ferrooxidans*. Experimental conditions were: leaching period of 21 d, leaching solution (g/dm3): $Fe(SO_4)_2$ (44.8), $(NH_4)_2SO_4$ (3), K_2HPO_4 (0.5), $MgSO_4 \cdot 7H_2O$ (0.5), KCl (0.1), Ca(NO3)2 (0.01), (9K) at a pH of 2.5 in 500 mL Erlenmeyer flasks at a pulp density of 5% (m/V) (5 g leaching substrate in 100 ml solution). The control suspension had the same chemical content and pH value as the suspension with *Acidithiobacillus ferrooxidans,* but the *Acidithiobacillus ferrooxidans* culture had been inactivated by sterilization. Experiment was performed on a horizontal shaker New Brunswick Scientific. The incubation temperature was 28°C and the rotation speed 100 rpm. Number of microorganisms, concentration of copper and pH were analysed each seven days.

The process of leaching is based on Fe^{2+} oxidation to Fe^{3+}, which after that attacks pyrite, with thyosulphat as major intermedier, and sulphat as terminal product. Oxidation of pyrite can be described with following equations:

$$FeS_2 + 6Fe^{3+} + 3H_2O \rightarrow S_2O_3^{2-} + 7Fe^{2+} + 6H^+ \quad (1)$$

$$S_2O_3^{2-} + 8Fe^{3+} + 5H_2O \rightarrow 2SO_4^{2-} + 8Fe^{2+} + 10H^+ \quad (2)$$

Fe^{2+} (produced in reactions 1 and 2) can be reoxydized to Fe^{3+} by acting of iron-oxydizing microorganism *Acidithiobacillus ferrooxidans.*

$$2Fe^{2+} + 0{,}5O_2 + 2\,H^+ \xrightarrow{\text{MICROBES}} 2Fe^{3+} + H_2O$$

Key role of *Acidithiobacillus ferrooxidans* is to regenerate sulphur acid and Fe^{3+}, which is strong oxidizing agent [7, 8]. All these things lead to lower pH and leaching of copper from solid phase.

RESULTS AND DISCUSSION

Samples were taken from twelve different locations on Bor ore dumps. Chemical analyses of ore dumps are presented in Table 1.

Table 1. Chemical analyses of waste

Component	SiO_2 %	Al_2O_3 %	CaO %	MgO %	Na_2O %	K_2O %	S %	P_2O_5 %
%	58.92	15.12	2.98	0.91	0.90	1.12	2.96	0.071
Component	Fe_{total} %	Fe^{2+} %	Cu %	Cu_{ox} %	Zn %	Pb %	MnO %	LOI %
%	8.60	4.70	0.205	0.015	0.060	0.15	0.028	6.99

Table 2. explains a distribution of sulphur compounds. Sulphide substrates, and dominantly pyrite, are also present in surface parts of Bor mine ore dump.

Table 2. Distribution of compounds (end elemental) sulphur in samples

Sample	Pure element S[%]	Sulhide S [%]	Suljate S [%]	Total S [%]
B_3	0.23	1.19	1.54	2.96

The X-ray powder diffraction analyses show that ore dump contens quartz *(Q)*, feldspars *(F)*, amphibole *(Am)*, pyrite *(Py)*, talc *(T)*.

X-ray diffractogram of ore dumps is shown on Figure 1.

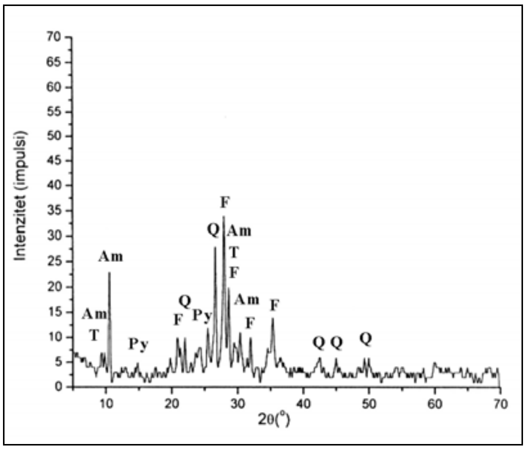

Fig. 1. *XRD diffractogram of ore dumps*

The experiment of copper leaching from ore dump was conducted with bacterial culture *Acidithiobacillus ferrooxidans*, which uses $FeSO_4$ from medium as a source for its own metabolism producing $Fe_2(SO_4)_3$, which later oxydises pyrite. Fe^{3+} ion is use as an oxidizing agent in pyrite leaching, leading to increase in Fe^{2+} levels, which is going to be again bacterially oxidized to Fe^{3+}.

Bioleaching of pyrite is continued, due to regeneration Fe^{3+} ion as oxidizing agent. This process is cyclic and well-known as “fero-feri” cycle.

The initial number of microgranisms was $2x10^5$ per ml. This number increased during experiment , and after seven days it was 2,8 $x10^5$/ml, after fourteen it was 5,3 $x10^6$/ml, and on the end of the experiment it was 7,5 $x10^6$/ml.

During the leaching process, sulphide sulphur content in suspension with *Acidithiobacillus ferrooxidans* decreased from 1.19% to 0.4%, while in the control suspension its content decreased from 1.19% to 1.05%. Obtained results confirm the role of microorganism in pyrite oxidation, as well as in process of copper leaching from ore dump.

Change of pH and percentage of copper leached in suspension with bacteria, as well as in control suspension, were determined on start and after 7, 14, and 21 days of experiment. The results obtained are presented on Figure 2. and Figure 3.

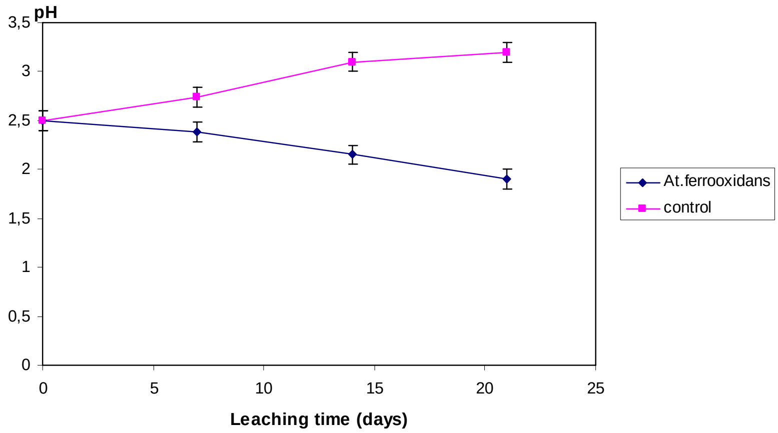

Fig. 2. *pH profiles during bioleaching of ore dumps in suspension with Acidithiobacillus ferrooxidans and control suspension, during the incubation process on shaker*

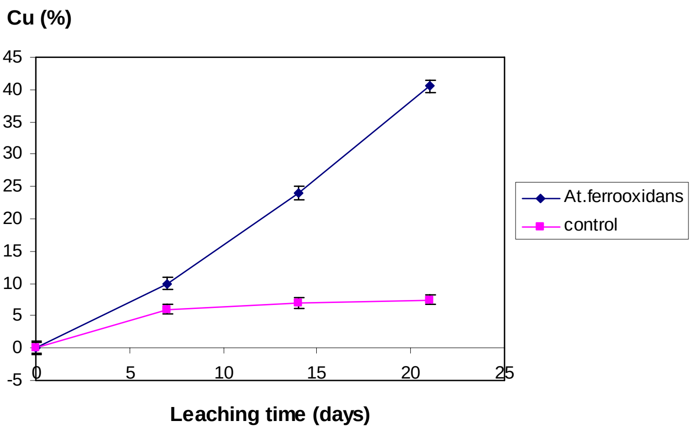

Fig. 3. *Amount of Cu leached during the incubation process on shaker*

Obtained results indicate that there is relationship between copper leaching and decrease of pH value, which is directly correlated with concentration of bacterially produced sulfuric acid and $Fe_2(SO_4)_3$ in leaching medium.

The percentage of leached copper, resulting from the activity of *Acidithiobacillus ferrooxidans, (i.e.*the effective metal leaching), was calculated by subtraction of percentage metal leaching in the control suspension from that in the *Acidithiobacillus. ferrooxidans* suspension, and it equals 34 %.

CONCLUSION

These results undoubtly proved that microbiological treatment of ore dump had been efficient, and the future task is to optimize this process in order to get larger amount of copper leached. It could be probably achieved by increasing the number of microorganisms in suspension, increasing the density of suspension, or increasing the time of leaching.

Microbial leaching is an inexpensive method for treatment of low-grade and secondary copper sulfide ores. Therefore, it would be significant and beneficial, for country like Serbia, to focus scientific and technical efforts toward separation of useful components from raw materials by this method. Furthermore, microbial leaching of low-grade ores and ore dumps also plays very important role in the concept of environmental protection, because it allows use of relatively simple technology to control and redirect uncontrolled loss of metals into the soil and water-streams.

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Predrag Dimovski, Zdravko Hojka**, Željko Dželetović****

UPOREDNA TEHNO-EKONOMSKA ANALIZA PRIMENE POSTUPKA ODLAGANJA PEPELA I ŠLJAKE IZ TERMOELEKTRANA, TOPLANA I METALURŠKIH POSTROJENJA KONVENCIONALNIM POSTUPCIMA I VRAĆANJEM ISTIH «NA MESTO NASTANKA» ODNOSNO U PROSTORE NAPUŠTENIH RUDNIKA UZ PRETHODNU PRIPREMU I UZ UPOTREBU SAVREMENIH TEHNOLOGIJA ODLAGANJA, REKULTIVACIJE I REMEDIJACIJE I NAJSAVREMENIJIH METODA ZAŠTITE

Izvod

Dosadašnja iskustva u proizvodnji i preradi metala, nemetala i ugljeva, ukazala su na ozbiljnost problema odlaganja otpadnih materija na površini terena, sa svim pratećim posledicama po poljoprivredno zemljište i ukupan ekosistem kao celinu. Obzirom da se radi o godišnjim količinama od nekoliko miliona m^3 *ovog materijala, koji je gotovo uvek u izvesnoj meri otrovan, a ne retko i kancerogen, pitanje njegovog odlaganja u prirodi (najčešće na poljoprivrednom zemljištu ili neposredno uz njega u blizini postrojenja u kojima se stvara) i samim tim narušavanje ukupnog ekosistema mora biti tretirano sa odgovarajućom pažnjom. Stoga, odlaganje ovih materija predstavlja ozbiljan problem, koji zahteva ekološki prihvatljiva i ekonomski održiva rešenja.*

Ključne reči: *Ekologija, ekonomija, održivi razvoj, rudarstvo, industrijske štete*

1. UVOD

Obzirom da je danas u svetu poznat veliki broj otrovnih jedinjenja, moguće ih je detaljno studijski ispitati da bi smo ih uspešno primenjivali (izbegavajući stvaranje, razlaganje, upotrebu i uništavanje) i stoga u krajnjoj instanci zaštitili životnu sredinu. Istovremeno velika grupa visoko toksičnih jedinjenja (VTJ), od kojih izdvajamo diokside i ostale, koji su relativno malo ispitani do sada zavređuju odgovarajuću pažnju tek od nedavno.

Na slici 1. data je uslovna šema ciklusa (VTJ) u prirodi kao refleksija stvarnih

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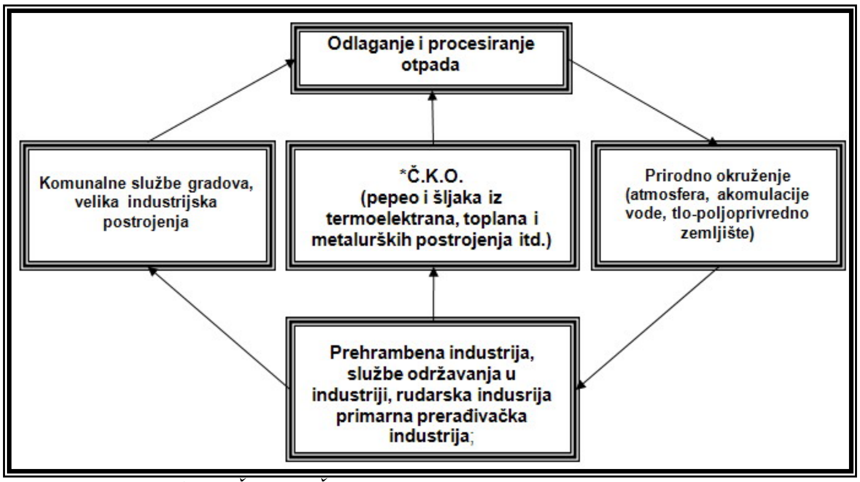
zbivanja u ovom trenutku. Kao što se uočava, emisija otrovnih materija učestvuje u tom lancu infiltrirajući se u okruženje, a potom u proces prerade, hranu, povrće i voće, razne proizvode životinjskog porekla (mleko, meso, jaja itd.) i tako se na ovaj ili onaj način vraćaju u ljudski organizam sa primerenim pripadajućim posledicama. Prirodno, najracionalniji pristup rešenju ovog problema nije eliminisan prihvatanjem i akumuliranjem (VTJ), već stremljenjem ka eliminisanju dobijenih toksičnih materija.Takođe, sasvim je prirodno, na taj način izbegavanje stvaranja (VTJ), odnosno razbijanje recirkulacionog ciklusa koji je šematski prikazan na slici 1. [Dimovski, 2003., Grechko, Denisov, 2001.], a rešenja za ovo nalaze se u procesiranju otpada primenom metoda korišćenja koje iz otpada istovremeno likvidiraju diokside (VTJ).



➢ *Č.K.O.- Čvrst komunalni otpad*

Sl. 1. *Šema postojećeg ciklusa kretanja toksičnih materija u prirodi*

Poseban problem predstavljaju tzv. «neovlašćena» odlaganja koja su najčešći slučaj. Tako dolazi do odlaganja materija sa visokom temperaturom u trenutku odlaganja (600-900°C) koja pri tome i dalje sagoreva i stvara emisiju otrovnih dioksidnih gasova direkto u atmosferu, što predstvlja između 25-30% najvećih zagađivača. Analize referentnih informacija naučnih i tehnoloških istraživanja omogućuju definisanje glavnih uslova koji omogućuju rešenje razmatranih problema tokom tretmana odgovarajućih materijala (otpada). Ovi uslovi su:

- ❖ Prilično visoka temperatura procesa ($t > 1250°C$);
- ❖ Oksidirajuća atmosfera (oksidacioni faktor sagorevanja $a > 1.05$);
- ❖ Konačno trajanje procesiranja proizvoda u ovim uslovima ($D > 2sec.$);
- ❖ Termalna trenutnost procesa (TIP)[****]

Iz prethodne analize nameće se zaključak da rešavanje problema odlaganja otpadnih materijala u prirodi predstavlja složen i zahtevan zadatak. Pri rešavanju ove vrste problema mogući su razni pristupi. Za eksperimentalna testiranja i tehno-ekonomska modeliranja, namenjena rešavanju ovog problema u radu su izabrani sledeći postupci:

[****] *Thermal instantaneity of process*

1. Odlaganje pepela i šljake iz termoelektrana, toplana i metalurških postrojenja, na postojeći (konvencionalni) način, tj. na poljoprivrednom i drugom zemljištu postupcima i na način kojim se, bez prethodne pripreme, maksimalno degradira površina terena, i potom ista privodi prvobitnoj nameni, sa više ili manje uspeha.
2. Odlaganje pepela i šljake iz termoelektrana, toplana i metalurških postrojenja na postojeći (konvencionalni) način, uz prethodnu pripremu i uz upotrebu savremenijih tehnologija odlaganja, i rekultivacije i remedijacije.
3. Tretman pepela i šljake iz termoelektrana, toplana i metalurških postrojenja vraćanjem istih «na mesto nastanka» odnosno u prostore napuštenih rudnika uz prethodnu pripremu i uz upotrebu savremenijih tehnologija odlaganja, rekultivacije i remedijacije i najsavremenijih metoda zaštite.

Ovakav pristup izabran je iz razloga što je potrebno do detalja rasvetliti stvarno stanje u ovoj oblasti, uzimajući u obzir zahteve održivog razvoja i ekonomsku dimenziju rešavanja svakog problem, sa ciljem da se uprednom ekološko-ekonomskom analizom dođe do najprihvatljivijeg rešenja ovog problema.

2. EKSPERIMENTALNI DEO

Kao objekti eksperimentalnih testiranja izabrani su pepeilište termoelektrane Nikola Tesla u obrenovcu tzv. TENT A, i otvoreni otkopani prostori površinskih kopova rudarskog basena «Kolubara», otvoreni otkopani prostori površinskih kopova rudarsko-topioničarskog basena Bor i otvoreni otkopani prostori u Jami rudnika bakra Bor. Da bi se stekao uvid u stepen uticaja odloženih otpadnih materija (pepela i šljake iz termoelektrana, toplana i metalurških postrojenja), bez prethodne pripreme na obradivom i dugom poljoprivrednom zemljištu, odnosno u prirodi u opšte, u radu su prezentirani određeni rezultati istraživanja, iz kojih je moguće utvrditi uticaj odloženih materija na pedološki sastav zemljišta posle odlaganja. Rovni lignit iz rudarskog basena "Kolubara", koji se sagoreva u termoelektrani «TENT» A, ima vrlo neujednačen kvalitet. [Dželetović i sar., 2001.] Učešće mineralnih materija koje prate ugljenu supstancu varira, te se sadržaj pepela u rovnom (sirovom) lignitu iz rudarskog basena "Kolubara" kreće od 22 do 40%, dok se u očišćenom lignitu on kreće od 9,5 do 20 %. Očišćen lignit ima izmenjen hemijski sastav pepela u odnosu na sastav pepela rovnog uglja. Hemijski elementi koji se nalaze u ugljevima imaju uglavnom dvojako poreklo. Većina elemenata koje danas nalazimo u ugljevima potiče uglavnom iz ostataka biljnih i drugih živih organizama, od kojih su postali ugljevi. Pojedini mikroelementi koje danas nalazimo u ugljevima su, osim toga, mogli dospeti u ugljene slojeve i iz okoline, iz okolnih stena ili preko cirkulišućih podzemnih voda, koje nose niz rastvorenih mineralnih supstanci. Pepeo koji nastaje sagorevanjem lignitskog uglja rudarskog basena "Kolubara" poseduje, u poređenju sa fizičkim osobinama prirodnih zemljišta, malu specifičnu masu i izrazito nisku zapreminsku masu i u zbijenom i u rastresitom stanju, čime se objašnjava njegova visoka podložnost raznim erozionim uticajima, (tabela 1.).

__Tabela 1.__ Fizičke osobine letećeg pepela iz TE "Kolubara"

Specifična masa (g/cm^3)	1,93	1,93	1,86-2,06	2,5-2,6
Specifična površina (cm^2/g)	4020	4020		
Ostatak na situ od 0,0063mm (%)	27,6	36,1		
Zapreminska masa u rastresitom stanju (kg/m^3)	600	550	462-539	1000
Zapreminska masa u zbijenom stanju (kg/m^3)	760	760	-	1700

Sadržaji pojedinih teških metala u pepelu (Tabela 2) su povišeni za pojedine biljne vrste i mogu biti toksičnih koncentracija. Relativno su visoke koncentracije: Va, V, Cd i Al; i one mogu uticati ne samo na rast biljaka, nego i na kvalitet semena.

__Tabela 2.__ Hemijska analiza pepela koji nastaje sagorevanjem lignitskog uglja iz rudarskog basena "Kolubara" u termoelektranama.

	TENT - A	**TENT - B**	**TEK - A**
Sastav	**(%)**		
SiO_2	55,40	56,20	50,35
Fe_2O_3	24,87	24,47	24,39
Al_2O_3	8,87	9,04	9,57
CaO	4,55	5,22	8,56
MgO	2,07	1,95	4,20
SO_3	1,38	1,14	1,13
$P2O_5$	0,07	0,08	0,22
TiO_2	0,17	0,16	0,22
Na_2O	1,49	0,90	0,45
K_2O	1,06	0,75	0,87

3. PRIKAZ REZULTATA

3.1. Tehnološki opis mogućih varijanti rešavanja problema

3.1.1. Odlaganje pepela i šljake iz termoelektrana, toplana i metalurških postrojenja, na postojeći (konvencionalni) način, tj. na poljoprivrednom i drugom zemljištu postupcima i na način kojim se, bez prethodne pripreme terena

Ovakvo rešenje problema odlaganje pepela i šljake je trenutno u aktivnoj primeni u većini aktivnih postrojenja koje u svom tehnološkom postupku stvaraju značajne količine ovih nusproizvoda. Ono se u osnovi sastoji u odlaganju ovog industrijskog otpada na obradivo i drugo poljoprivreno zemljište bez (ili samo delimično) prethodne pripreme terena namenjenog ovoj svrsi, uz maksimalno degradiranje površina terena, koji se potom privodi prvobitnoj nameni, sa više ili manje uspeha. Rešenje se u osnovi sastoji u iskopu i uklanjanju produktovnog površinskog sloja poljoprivrednog zemljišta, iskopu niže ležećih slojeva do određene dubine, nasipanja sloja gline (ili bez toga), izradi drenažnih bunara i kanala oko iskopane kasete, i odlaganje pepela i šljake u iskopani prostor do projektom određene visine. Sa ekonomskog stanovišta, stvarni troškovi primene ovakvog sistema odlaganja, troškovi ekonomske štete od primene ove tehnologije i efekti ekoloških oštećenja su obrađeni u narednoj analizi. Direktni troškovi* održavanja i eksploatacije postojećeg sistema za prikupljanje, pripremu, transport i odlaganje pepela i šljake TE "Nikola Tesla A" iznose 11,70 Eur/t, odloženog pepla i šljake [Dražović i sar., 2010.].

3.1.2. Odlaganje pepela i šljake iz termoelektrana, toplana i metalurških postrojenja na postojeći (konvencionalni) način, uz prethodnu pripremu terena i uz upotrebu savremenijih tehnologija odlaganja, rekultivacije i remedijacije

Rešenje problema odlaganje pepela i šljake iz termoelektrana, toplana i metalurških postrojenja na ovaj način podrazumeva kompleks mera i postupaka kojima bi se postojeći sistem odlaganja otpadnih materija tehnološki unapredio, tako da se uticaji na životnu sredinu svedu u prihvatljive okvire i da se postupak rekultivacije i remedijacije učini održivim. Predloženo rešenje u osnovi se sastoji od primene savremenih mera zaštite okolnog zemljišta, voda i vazduha od uticaja odloženih materija. Takođe, tehnološko rešenje predviđa primenu gustih hidromešavina u postupku transporta i ugradnje pepela i šljake na deponiji.

Sa ekološkog aspekta on je povoljnije rešenje jer se najveći broj uticaja na životnu sredinu svodi u propisane granice, a pojedini uticaji se u potpunosti eliminišu. Zbog gotovo «hermetičke izolacije» prostora deponije uticaj odloženih materija na okolno poljoprivredno zemljište se svodi na minimum. Takođe primena guste hidromešavine smanjuje količinu vode u deponiji i njen uticaj na podzemne i površinske vode, a solidifikacija deponije u dužem vremenskom periodu potpuno eliminiše nastajanje uvala i depresija u prostoru deponije. Ugradnja geotekstilnih pokrivača i biorazgradivih materijala sa ugrađenim biljnim kulturama poboljšava remedijaciju zauzetog prostora. Ojačavanje visokih kosina «zelenim terasmeš sistemom i biorogozama», uz prethodnu solidifikaciju i nanošenje humusnog pokrivača, dopunski osigurava prostor od uticaja eolske erozije i spiranja čestica odloženog materijala.

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* *Ovaj podatak dobijen je iz «Studije opravdanosti i rekonstrukcije sistema za prikupljanje, pripremu, transport i odlaganje pepela i šljake TE"Nikola Tesla A" sa idejnim projektom i studijom o proceni uticaja na životnu sredinu», Rudarski institut d.o.o.- Energoprojekt – entel a.d, 2010.*

Sl. 2. *Izgled i konstruktivni elementi zelenog terasmeh sistema*

3.1.3. Tretman pepela i šljake iz termoelektrana, toplana i metalurških postrojenja vraćanjem istih «na mesto nastanka» odnosno u prostore napuštenih rudnika uz prethodnu pripremu i uz upotrebu savremenijih tehnologija odlaganja, rekultivacije i remedijacije i najsavremenijih metoda zaštite.

Jedan deo nastalih količina šljake i pepela iz metalurških postrojenja i termoelektrana nalazi primenu, zbog svojih pucolanskih svojstava u industriji cementa i hemijskoj industriji. Nažalost, potrebe za ovim materijalima u pomenutim granama privrede kreću se od 10-30% u odnosu na ukupnu količinu ovih materija. [Dimovski, 2012.]

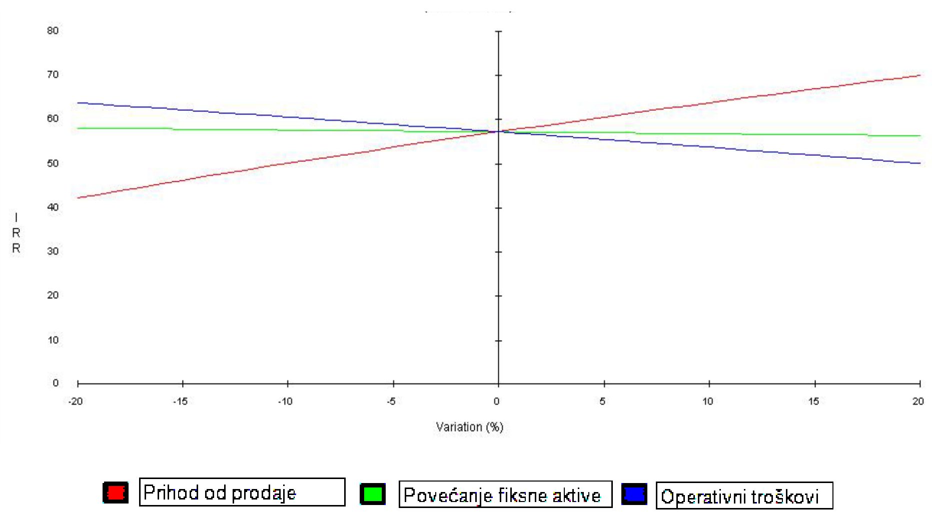
Na ovom mestu obrađena je, kao jedna od alternativa, tehnologija rešavanja ovog problema kroz njegovo vraćanje u utrobu zemlje, u stare otkopa.

3.2. Ekonomska analiza predloženih rešenja

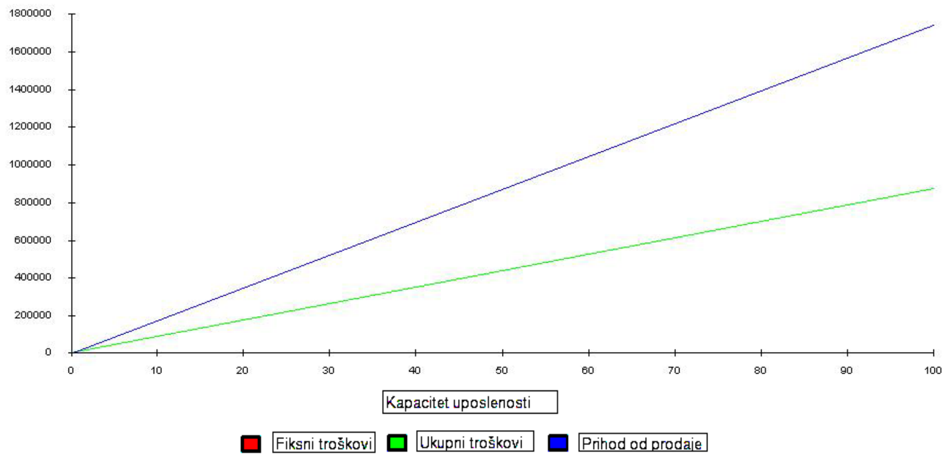
Za ekonomsko finansijsku ocenu primenjen je postupak ekonomske ocene projekata po UNIDO standardima i standardima svetske banke. [Hauarnek i sar., 2001.]. Primenjeni model kao konstantu u svakoj od razmatranih mogućih rešenja uzima procenjenu visinu štete nastale od neprimenjivanja intenzivne poljoprivredene proizvodnje određenih kultura na prostoriji namenjenoj za deponiju pepela i šljake, u period ekploatacije prostora deponije i ostale relevantne troškove izgradnje i eksploatacije deponija po opisanom tehnološkom postupku. Kao osnovni proizvod, za ekonomsku ocenu u ekonomskom modelu figurira proizvedena električna energija, i eventualno kao dopunski program cena pepela i šljake na komercijalnom tržištu, u slučaju termoelektrana, odnosno količine proizvedenih obojenih metala i ostalih proizvoda u slučaju rudnika u koje se odlažu ove materije. Rezultati modelovanja dati su u narednim tabelama i dijagramima.

3.2.1. Procena ekonomskih parametara primene postupka odlaganja pepela i šljake iz termoelektrana, toplana i metalurških postrojenja na postojeći (konvencionalni) način, uz prethodnu pripremu terena i uz upotrebu savremenijih tehnologija odlaganja, i rekultivacije i remedijacije

Kako je već navedeno, površina poljoprivrednog zemljišta, koja će se u narednom periodu zauzeti, za potrebe izgradnje deponije pepela, a sve u cilju nastavka normalne proizvodnje električne energije u TENT-A, procenjena je na oko 500 ha, u okviru ovog dela istraživanja razmotreni su neophodni dodatni troškovi za primenu savremenijih tehnologija odlaganja, i rekultivacije i remedijacije zemljišta. Kako je već navedeno osnovni proizvod, za ekonomsku ocenu u ekonomskom modelu figurira proizvedena električna energija, i eventualno kao dopunski program cena pepela i šljake na komercijalnom tržištu. Kao vremenski horizont uzeto je vreme od danas pa za 40 godina za koje se vreme očekuje rad normalan elektrane sa postojećim kapacitetima i sa postojećom ili neznatno modernizovanom tehnologijom.



Sl. 3. *Dijagram osetljivosti interne stope povraćaja uloženih sredstava (u hiljadama evra)*

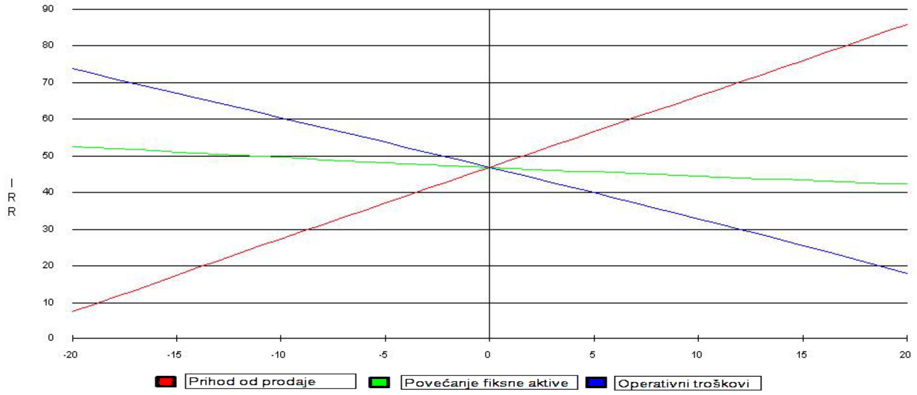


Sl. 4. *Analiza kritične tačke projekta sa uključenim troškovima finansiranja 2013 (u hiljadama evra)*

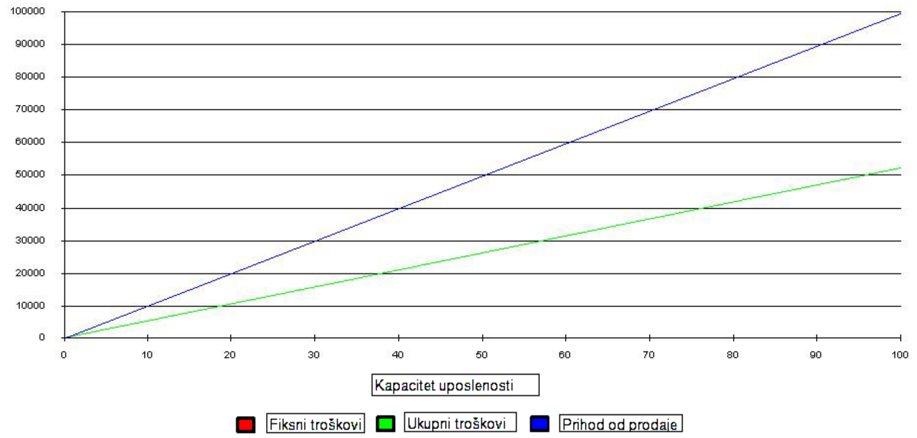
3.2.2. Procena ekonomskih parametara primene postupka odlaganja pepela i šljake iz termoelektrana, toplana i metalurških postrojenja vraćanjem istih «na mesto nastanka» odnosno u prostore napuštenih rudnika uz prethodnu pripremu i uz upotrebu savremenijih tehnologija odlaganja, rekultivacije i remedijacije i najsavremenijih metoda zaštite

U cilju trajnog rešavanja problema odlaganja pepela i šljake iz termoelektrana, toplana i metalurških postrojenja, kao logična mogućnost sa stanovišta zaštite životne sredine, nameće se tehničko rešenje koje piodrazumeva vraćanje i odlaganje ovih materija na mesto nastanka, odnosno u otvorene prostore rudnika sa površinskom ili podzemnom eksploatacijom.

Ako se ima u vidu da su ovi prostori već degradirani samom tehnologijom otkopavanja, koja nema, na sadašnjem nivou tehnološkog razvoja, tehnoekonomski opravdanu alternativu, i da je za odlaganje ovih materija na površini terena potrebna degradacija značajne površine zemljišta, onda je sa stanovišta održivog razvoja ovo jedno od prihvatljivih rešenja, ukoliko se dokaže ekonomska opravdanost. Na ovom mestu razmotren je kompleksni tehnoekonomski model, tehnološkog rešenja vraćanja pepela i šljake iz termoelektrana, toplana i metalurških postrojenja i raznih drugih otpadnih materija u različitim vrstama mešavina u prazne prostore rudnika sa podzemnom eksploatacijom, na primeru podzemnog proizvodnog sistema u rudnom telu RT «Borska reka» u RTB Bor. [Dimovski, 1992.].



Sl. 5. *Dijagram osetljivosti interne stope povraćaja uloženih sredstava (u hiljadama evra)*



Sl. 6. *Analiza kritične tačke projekta sa uključenim troškovima finansiranja 2013 (u hiljadama evra)*

4. DISKUSIJA

Kako je navedeno u tački 3.1.1., posmatrano sa tehnološkog aspekta i interesa same termoelektrane (ova konstatacija se odnosi i na metalurška postrojenja i toplane) postojeći postupak odlaganja pepela i šljake je uhodan i za primenu najjednostavniji.

Sa ekološkog aspekta on je na osnovu iznetih analiza najnepovoljniji i predstavlja trajno oštećivanje kompletnog ekosistema, posebno u delu promene pedološkog sasatav zemljišta, koji je njegovom primenom trajno oštećen i onesposobljen za osnovnu namenu.

Sa ekonomskog stanovišta, stvarni troškovi primene ovakvog sistema odlaganja, troškovi ekonomske štete od primene ove tehnologije i efekti ekoloških oštećenja su obrađeni u prethodnoj analizi. Direktna ekonomska šteta - **«poljoprivredna šteta»** od ne primenjivanja intenzivne poljoprivredne proizvodnje na prostoru koji je inače upotrebljen kao deponija, koja u do sadašnjem periodu slučajno ili namerno nije uzeta u razmatranje i analizirana na ovakav način, iznosi približno 73 miliona evra, u razmatranom periodu. Ova šteta je mnogo veća ako bi se razmotrili ostali aspekti privredne nadgradnje koji neminovno prate poljoprivrednu proizvodnju..

Ako se uzmu u obzir svi analizirani parametri može se zaključiti da je dalja primena ovakvog sistema, bez obzira na izvesna poboljšanja dugoročno neodrživa kako sa stanovišta zaštite životne sredine tako ni iz ugla dugoročne strategije održivog razvoja. Upornom primenom ovakve tehnologije državi se nanosi nenadoknadiva šteta.

Predloženo tehnološko rešenje opisano u tačkiu 3.1.2. posmatrano sa tehnološkog aspekta i interesa same termoelektrane (ova konstatacija se odnosi i na metalurška postrojenja i toplane) je nešto složenija, jer predpostavlja kompleksniji način pripreme terena za odlaganje, veće investiciono opterećenje, i veće troškove održavanja i primene predloženog sistema. Međutim i sa ovim investicionim i tehnološkim opterećenjima projekat proizvodnje električne energije nudi vrlo visoku stopu akumulativnosti projekta, što se vidi iz ekonomske analize, date u tački 3.1.4.1. ovog rada. Sa ekološkog aspekta on je na osnovu iznetih analiza povoljnije rešenje jer se najveći broj uticaja na životnu sredinu svodi u propisane granice, a pojedini uticaji se u potpunosti eliminišu. Zbog gotovo «hermetičke izolacije» prostora deponije uticaj odloženih materija na okolno poljoprivredno zemljište se svodi na minimum. Takođe primena guste hidromešavine smanjuje količinu vode u deponiji i njen uticaj na podzemne i površinske vode, a solidifikacija deponije u dužem vremenskom periodu potpuno eliminiše nastajanje uvala i depresija u prostoru deponije. Međutim, i pored svih pomenutih ekoloških benefita od primene predloženog rešenja ostaje navedena direktna ekonomska šteta - **«poljoprivredna šteta»** koja iznosi približno 73 miliona evra, sa svim analiziranim indirektnim efektima. Ukoliko bi primena ovakvih sistema zaštite bila ultimativna mera definisana određenim zakonskim propisima i pravilima (kakva važe u EU), i bila podržana od strane državnih organa i fondova Republike Srbije, onda bi efekti njihove primene došli do punog izražaja.Sa stanovišta rudnika primena ovog sistema zahteva investicije u površinski kompleks za prihvat i pripremu zasipne mešavine na površini terena, podzemnog kompleksa za zasipavanje i sistema za povratne vode. Benefiti rudnika su pored eliminisanja direktne rudarske štete od ne otkopane raspoložive korisne mineralne sirovine, i samim time viših stopa amortizacije tehnološke opreme, takođe i eliminisanje oštećenja površine terena i objekata na njoj. Investicioni trošak države odnosi se na investicije u železnički transportni sistem i železničku infrastrukturu. Troškovi ovih investicija pokrili bi se kroz eliminisanje direktne – poljoprivredne štete i kroz eliminisanje ili smanjivanje **rudarskih šteta**. Sa ekološkog aspekta on je na osnovu iznetih analiza najpovoljnije rešenje jer se najveći broj uticaja na životnu sredinu u potpunosti eliminiše. Kako je napred pomenuto, pošto se radi o značajnim investicionim ulaganjima, ukoliko bi primena ovakvih sistema zaštite bila ultimativna mera definisana određenim zakonskim propisima i pravilima (kakva važe u EU), i bila podržana od strane državnih organa i fondova Republike Srbije, stvorili bi se uslovi da se prostor Republike Srbije u potpunosti oslobodi ovih materija. U čisto ekoonomskom smislu, ukoliko bi se posmatralo kumulativno, ukupni profit Republike Srbije iznosio bi oko **2 milijarde evra u periodu od oko 40 godina, odnosno oko 50 miliona evra godišnje**, ne računajući indirektne efekte od popravljanja stanja životne sredine, boljeg iskorišćenja raspoloživih resursa, novih radnih mesta, investicija u infrastrukturu itd.

5. ZAKLJUČAK

U radu je data kompleksna, uporedna tehno-ekonomska analiza primene postupka odlaganja pepela i šljake iz termoelektrana, toplana i metalurških postrojenja. Radi se o veoma dobro poznatom problemu kome se do sada iz raznih razloga nije pristupalo na celovit i sve obuhvatan način. Parcijalnim rešenjima popravljani su izdvojeni slučajevi, a pri razmatranju predloženih tehnoloških rešenja, nije uziman u obzir efekat industrijskih šteta u potrebnoj meri tako da su mnoga rešenja doneta bez prave argumantacije. Politika održivog tehnološkog razvoja Republike Srbije mora da integriše sve raspoložive resurse i mogućnosti i da zakonodavstvom i pratećim propisima obaveže glavne aktere na primenu tehnoloških rešenja koja minimalno oštećuju životnu sredinu i poboljšavaju održivo korišćenje raspoloživih prirodnih i privrednih resursa.

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COMPARATIVE TECHNICAL-ECONOMIC ANALYSIS OF APPLICATION THE DUMPING PROCESS OF FLY ASH AND SLAG FROM THERMO POWER PLANTS, HEATING PLANTS AND METALLURGICAL PLANTS BY CONVENTIONAL PROCEDURES AND BACKFILLING TO THE « PLACE OF ORIGIN» I.E. IN THE ABANDONED MINED AREAS OF MINES WITH PREVIOUS PREPARATION AND APPLICATION OF MODERN DUMPING TECHNOLOGIES, RECLAMATION AND REMEDIATION AND MODERN METHODS OF PROTECTION

Abstract

Previous experiences in production and processing of metals, nonmetals and coals, have shown the significance of problem of dumping the waste materials on the surface of e terrain, with all following consequences on the agricultural land and eco system as whole. Since, in this case is delaing with the material in annual amount of several millions m^3, which is almost certainly in some measure poisoned, and not rarely cancerous, the question of its dumping in nature (mostly on the agricultrural land ore in the close neighbourhood, closed to the facilities which produce it), and with it interruption of whole eco system must be treated with appropriate care. Therefore, the process of dumping such materials presents significant problem, which demands ecologically acceptable and economicly sustainable solutions.

Keywords: *ecology, economy, sustainable development, mining, industrial damages*

1. INTRODUCTION

Since in the modern world exists a great number of poison chemical compounds, it is possible to make detail exploration of them in purpose of their success full application (avoiding production, disintegration, application and destruction) and therefore in final to protect living environment. Simultaneously big group of highly toxic compounds (HTC), where dioxides and other are separated, which

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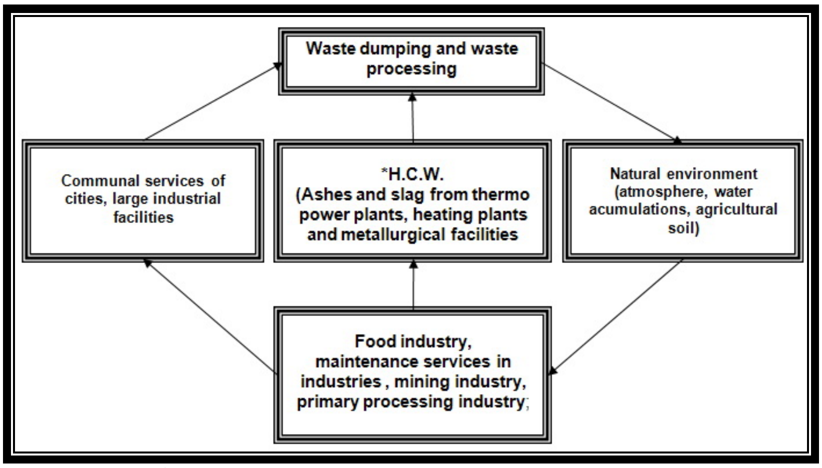
are relatively small explored till now, recently earn appropriate attention.

Figure 1 gives a condition scheme of natural cycle as the reflection of real happenings in present time. As it is espied, the emission of poisonous substances participate in thic chain by its infiltration in environment, and then on process of manufacturing, food, vegetables and fruits, various products of animal orgin (milk, meat, eggs, etc.), and in one or oth-erwise is returning in human organism with adequate joint conseqences.

Naturally, the most rational approach to this problem was not eliminated with the acceptance and accumation of (HTC), but with the aspiration to eliminate obtained toxic materials. Also, it is quite natural, avoiding the production of (HTC), i.e. cutting the recirculating cycles, which is schematicly shown in fig.1. [Dimovski, 2003, Grechko, Denisov, 2001.], and the solutions for this is in processing of waste by application the methods which simultaneously eliminate dioxides (HTC).



➢ *H.C.W.- Hard comunal waste*

Fig. 1. *Scheme of existing cycle of toxic materials in nature*

Special problem reperesents so-called «unauthorized» dumping which are the most frequent case. There is waste dumping of materials with high temperature in the moment of dumping (600-900°C), which at the same time still burn and make the emission of toxic dioxide gases direct into atmosphere, which is app. 25 - 30 % of greatest polluters. Analyses of adequate information of scientific and technologic explorations enable defining main conditions which make possible solving mentioned problems during the treatment of some materials (waste). These are:

- ❖ Extrimely high temperature of process (t > 1250°C);
- ❖ Oxidizing atmosphere (oxidizing factor of combustion a > 1.05);
- ❖ Final time of processing the products in such conditions (D>2 sec.);
- ❖ Thermal instantaneous of process (TIP) ****

From the mentioned analyse a conclusion can be made that solving of waste dumping the waste materials in nature represents a complex and demanding task. In solving such type of problems exists different approaches.For the experimental testings and techno-economic modeling

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**** *Thermal instantaneity of process*

aimed to solve this problem in the paper, the following processes are chosen:

1. Dumping fly ash and slag from thermo power plants, heating plants and metallyrgic facilities by conventional procedures on arable and the other agricultural land by using the procedures and in manner which make, without previous preparation, maximal degradation of surface of the terrain, and then reclamation to the previous purpose, with more or less success.
2. Dumping fly ash and slag from thermo power plants, heating plants and metallyrgic facilities by conventional procedures, with previous preparation, and using modern technologies of dumping, reclamation and restoration.
3. Treatment of fly ash and slag from thermo power plants, heating plants and metallyrgic facilities with backfilling it «at the place of origin» i.e. In the abandoned mined out areas of mines with previous preparation and with application of modern technologies of dumping, reclamation and restoration and modern protection methods

Such approach is choosen from the reason because it is necessary to enlite to the single detail real state in this area, taking into consideration demands of sustainable development and economic dimension of solving any problem, with purpose to, by comparation ecological-economical analyse, reach the most acceptable solution of the problem.

2. EXPERIMENTAL PART

As the objects of experimental testings are choosen waste dump of thermo power plant Nikola Tesla in Obrenovac, so-called «TENT»A, and the mined out areas of open pit mines of mining basin «Kolubara», mined areas of the open pit mines of RTB Bor and mined out caves in the underground copper mine «Jama» of Bor copper mine. To find out what is the degree of influence of dumped waste materials (fly ash and slag from thermo power plants, heating plants and metallyrgic facilities), without previous preparation on arable and other agricultural land i.e. in nature at all, the certain results of explorations are present in this paper, from which is enable to establish influence of waste materials on the pedologic content of soil after the process of waste dumping. Raw lignite from the coal basin «Kolubara», what burning in the thermo power plant «TENT» A, has very variable quality. [Dželetović et al., 2001]. Content of mineral meterials which follows coal substance vary, so the content of fly ashes in raw lignite from mining basin «Kolubara», it is from 22 to 40%, and in the cleaned lignite it is from 9.5 to 20%. Clean lignite has different chemical content of ash, in comparation with raw lignite. Chemical elements contained in coals has dual origin. Most of the chemical elements content into the coals come from the remains of plants and other living organisms, from which became coal seams. Some of micro elements which exists in coals, could be brought, into the coal seams from the surrounding, from the surrounding rocks, or by circulating underground waters, which is bringing several dissoluted mineral substances. Ashes made by combustion of lignite of mining basin «Kolubara» have, in comparation with physical characteristics natural soils, small specific mass, extremely low density, either in intact coal massive, or in disinegrated mass, which explain their high erosion disposal (Table 1).

Table 1. *Physical characteristics of fly ashfrom «TENT»A*

Specific mass (g/cm^3)	1.93	1.93	1.86-2.06	2.5-2.6
Specific area (cm^2/g)	4020	4020		
Remains on screen from 0,0063mm (%)	27.6	36.1		
Volume mass in disintegrated state (kg/m^3)	600	550	462-539	1000
Volume mass in compacted state (kg/m^3)	760	760	-	1700

Content of some heavy metals in ash (Table 2) are raised for the some plant sorts and they could have toxic concentrations. Relatively are high concentrations of: Va, V, Cd and Al; and they could have influence not only to the grow of plants, but also on the quality of seeds.

Table 2. *Chemical analysis of ash made in combustion of lignite from the Mining Basin «Kolubara» in thermo power plants*

	TENT - A	**TENT - B**	**TEK - A**
Content	**(%)**		
SiO_2	55.40	56.20	50.35
Fe_2O_3	24.87	24.47	24.39
Al_2O_3	8.87	9.04	9.57
CaO	4.55	5.22	8.56
MgO	2.07	1.95	4.20
SO_3	1.38	1.14	1.13
$P2O_5$	0.07	0.08	0.22
TiO_2	0.17	0.16	0.22
Na_2O	1.49	0.90	0.45
K_2O	1.06	0.75	0.87

3. PRESENTATION OF THE RESULTS

3.1. Technological description of possible variants of solving the problems

3.1.1. Dumping fly ash and slag from thermo power plants, heating plants and metallurgical plants by conventional procedures on arable and the other agricultural land by using the procedures and in manner which make, without previous preparation

Such solution of problem of waste dumping the fly ashes and slag is in the moment in active application im most of the electric power plants which in their technological procedure produce significant amount of waste products. It is basicly consists of waste dumping of this industrial waste on arable and the other agricultural land without (or partly) previous preparation of terrain aimed for such purpose, with maximal degradation surface of the terrain, and then reclamation to the previous purpose, with more or less success. Solution is basicly consists of digging and removal productive surface seam of agricultural land, digging lower seams to some depth, dam the seam of clay (or without it), making vertical drains and channels around the dug cassette, waste dumping the fly ashes and slag into the cave to the project defined height. From the economy viewpoint, the real costs of this system application of waste dumping, costs of economic damage from application of this technology and the effects of ecological damges are presented in following analysis. Direct costs* of maintenance and exploitation of existing system for collecting, preparation, transport and dumping fly ashes and slag in TENT A is 11,70 Eur/t, measured on dumped fly ashes and slag [Dražović i sar., 2010.].

3.1.2. Dumping fly ash and slag from thermo power plants, heating plants and metallurgical plants by conventional procedures, with previous preparation, and using modern technologies of dumping, reclamation and restoration

Solution of problem of waste dumping the fly ashes and slag from thermo power plants, heating plants and metallyrgic facilities in this way means complex of measures and procedures by which, existing system of dumping of waste materials, is going to be improved, so the influences on living environment will be reduced into the acceptable frames, and the procedure of reclamation and restoration make sustainable. Proposed solution basicly consists of application of modern measures of protection the surrounding land, water and atmosphere from influence of dumped materials. Also, technological solutions foresee application of dense hydro mixtures in procedure of transport and building in fly ashes and slag into the slag dump. From the ecological aspect, it is more favorable solution, because the most of influences on living environment is reduced into the acceptable level, and some of them are completely eliminated. Because of almost «hermetic isolation» of the slag dump area influence of dumped materials on the surrounding agricultural land is reduced on minimum. Also, the application of dense hydro mixtures reduce amount of free water in dump and their influence on underground and surface water, and solidification of dump in longer period completely eliminate appearance of caves and depressions in the area of dump. Building in geotextiles covers and biodissintegrated materials with integrated plant cultures improve restoration of occupied area. Reinforce of high slopes by «green terasmesh system and biocattail», with previous solidification and humus covering, additionaly protect the area from influences of eolian erosion and flood the particles of dumped materials.

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* *This fact is obtained from the source «Feasibility Study and Reconstruction the System for Collection, Preparation, Transport and Dumping of Ash and Slag from the TPP"Nikola Tesla A" with Conceptual Design and Study on Impact Assesment on Environment», Mining Institute Ltd.- Energoprojekt – entel a.d, 2010.*

Fig. 2. *View and constructive elements of green terasmesh system*

3.1.3. Treatment of fly ash and slag from thermo power plants, heating plants and metallurgical plant with backfilling on the « place of origin» i.e. in the abandoned mined areas of mines with previous preparation and with application of modern technologies of dumping, reclamation and restoration and modern protection methods

The part of amount of slag and fly ash from metallurgical plantsand thermo power plants, have the application, because of its puzzuolanic characteristics, in cement and chemical industry. Unfortunately, demands for these materials in mentioned branches of economy vary from 10-30 % in comparation with total amount of these materials. [Dimovski, 2012.] In this place is treated, as one alternative, technology of solving of theses problems by its backfilling into the underground mined out caves.

3.2. Economic analyses of proposed solutions

For the economic and financial evaluation, a procedure of economical estimate of investment projects is applied in accordance to the UNIDO standards and standards of WORLDBANK. [Hauarnek et al., 2001.] Applied models as a constant in any of considerd possible solutions take estimated amount of damage appeared from non application intensive agricultural production of some plants on the area aimed for the waste dump, in period of exploitation of the area of the dump and the other relevant costs of building and the exploitation of dump in accordance to described technological procedure. As a basic product, for the economical appraisal in economical model is produced electric energy, and eventally as additional program price of fly ashes and slag on commercial market, in case of thermo power plants, i.e. amount of produced non-ferrous metals and other products in case of mines in which are dumping these materials. The results of modeling are shown in fthe ollowing tables and diagrams.

3.2.1. Estimate of economical parameters of application the procedure of waste dumping of fly ash and slag from thermo power plants, heating plants and metallurgical plants by conventional procedures, with previous preparation, and using modern technologies of dumping, reclamation and restoration

As it is already mentioned, surface of agricultural land, which is going to becaptured in future period, in purpose of building the waste dump, with final aim of continuity the normal production of electric energy in TENT A, is estimated on 500 ha, in this part of explorations is considered necessary additional costs for the application modern technologies of waste dumping, and reclamation and restoration of captured land. Since, as it is mentioned, that the basic product, for the economical appraisal in economic model exists produced electric energy, and eventally as additional program price of fly ashes and slag on commercial market. As a time horizon is taken period from today and next 40 years for which is expected normal work of thermo power plant with existing capacities, and with existing or insignificantly improved technology.

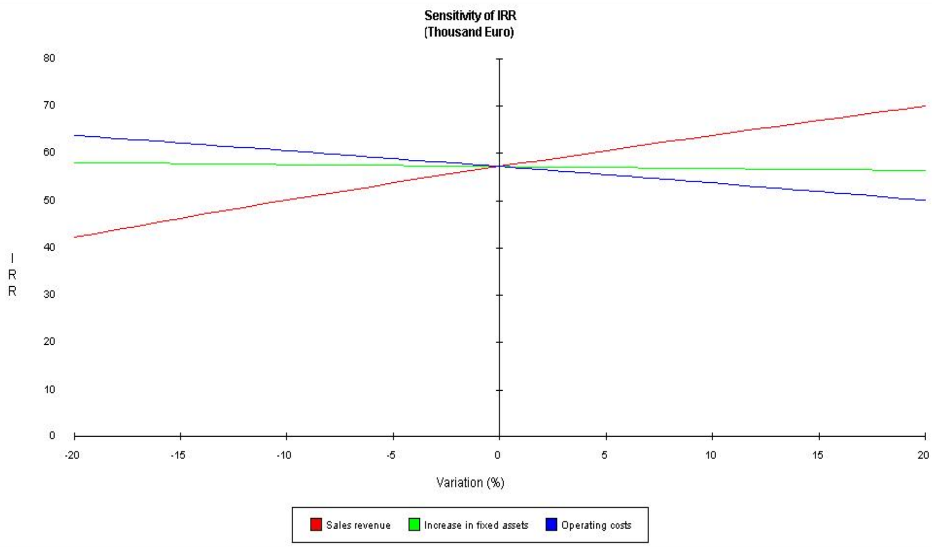

Fig. 3. *Diagram of sensitivity of internal rate of return (in thousand euro)*

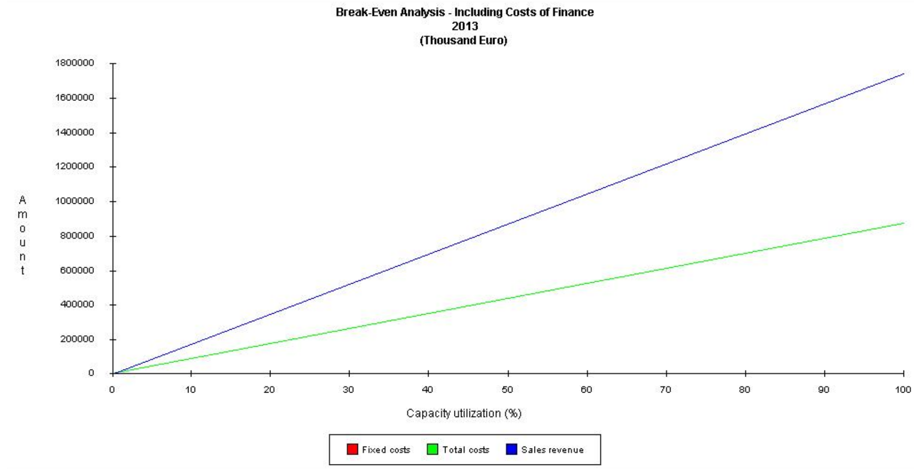

Fig. 4. *Analysis of critical point of the project including costs of finance in 2013 (in thousand euro)*

3.2.2. Estimate of economical parameters of application the procedure of waste dumping of fly ash and slag from thermo power plants, heating plants and metallurgical plants with backfilling to the « place of origin» i.e. in the abandoned mined out areas of mines with previous preparation and with application of modern technologies of dumping, reclamation and restoration and modern protection method

In purpose of permanent solving the problem of dumping the fly ash and slag from thermo power plants, heating plants and metallyrgic facilities, as a logical possibility from viewpoint of environ-mental protection, is imposing technical solution which undertake backfilling and dumping this materials at the place of origin i.e. in the abandoned mined out areas of mines with open pit or underground exploitation. Having on mind, that these areas are already degradated with the minig technology itself, which has not, at the present level of technological development, techno-economically feasible alternative, and the dumping these materials demand degradation of significant area, then from viewpoint of sustainable development, such solution is one of most acceptable, if could be justified economical feasibility. At this place a complex techno-economic model is considered of technological solution of returning of fly ash and slag from thermo power plants, heating plants and metallyrgic facilities and several other waste materials in different compounds in opened caves of mines with underground exploitation, as an example of underground minig system in ore body «Borska reka» in RTB Bor. [Dimovski, 1992].

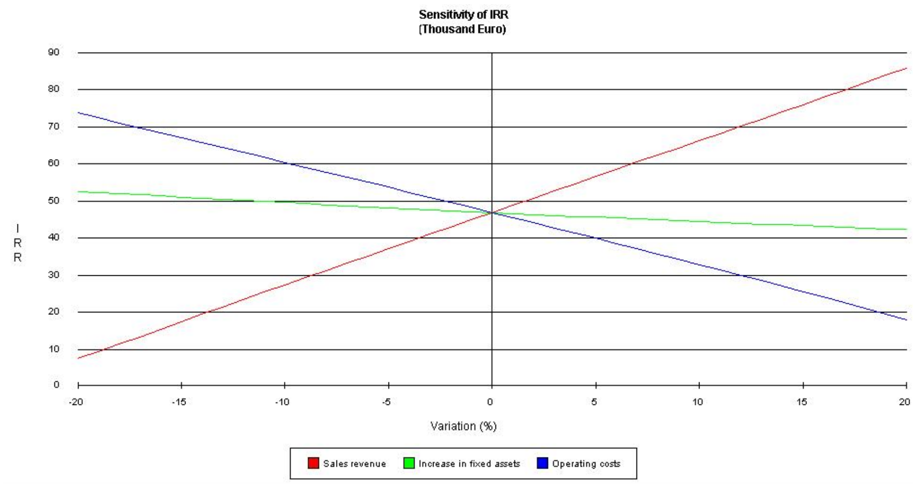

Fig. 5. *Diagram of sensitivity of internal rate of return (in thousand euro)*

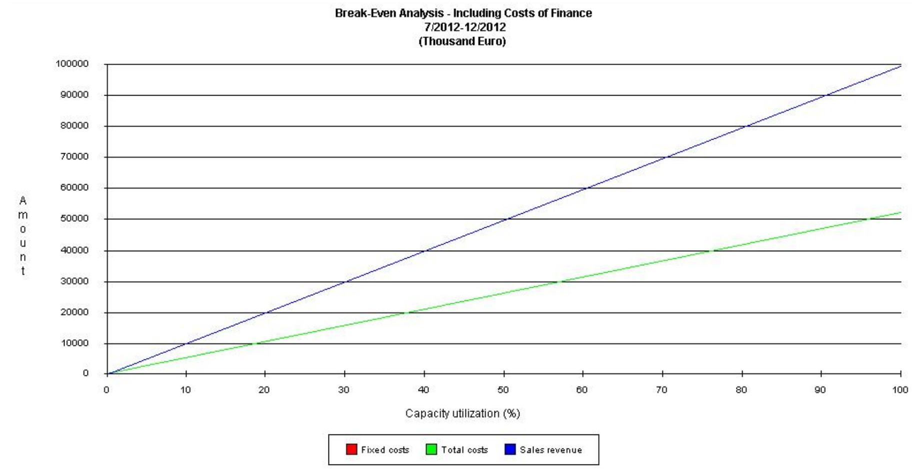

Fig. 6. *Analysis of critical point of project including costs of finance in 2013.(in thousand euro)*

4. DISCUSSION

As it is mentioned in chapter 3.1.1., from technological aspect and interest of thermo power plant itself (this statement is relate also for metallyrgic facilities and heating plants) existing procedure of dumping the fly ash and slag is operating smoothly and most simpliest in application. From ecological aspect, it is based on presented analyses most unpleasant and represents permanent damaging of comlete eco system, especially in part of change the pedological content of soil, which is whit it application permanently damaged and incapacitated for it basic purpose. From economic viewpoint, real costs of application of such system of dumping, costs of economic damage from application of this technology and the effects of ecological damage are treated in following analyse. Direct economic damage - **«agricultural damage»** from non application of intensive agricultural production at the place which is otherwise used as waste dump, which accidentally or with some purpose was not took into consideration and analysed in such manner, is app. 73 milion euro, in considered period. This damage is much bigger if are considered other aspects of agricultural industrial superstructure which inevitably follows agricultural production. Taking into consideration all analysed parameters, it could be concluded that further application of that system, beside to certain improvement long term unsustainable neither from the aspect of environmental protection, nor from vievpoint of long term strategy of sustainable development. Stubborn application of such technology making irreparable damage to the state. Technological solution described in chapter 3.1.2. considered from technological aspect and the interest of the thermo power plant itself (this statement is relate also for metallyrgic facilities and heating plants) have bigger complexity, because it presents more complex way of preparation the captured terrain, bigger investments, and bigger costs of maintenance and application proposed system. Meanwhile, with this investment and technological burden also, project of production of electrical energy offers very high rate of accumulation of project, which could be seen from economical analyse, shown in chapter 3.2.2. of this paper. From ecological aspect, it is based on presented analyses, more suitable solution because the most of influences on environment is reduced to acceptable frame, and some of them is completely eliminated. Because of almost «hermetic isolation» of the slag dump area influence of dumped materials on the surrounding agricultural land is reduced on minimum. Also the application of dense hydro mixtures reduce amount of free water in dump and their influence on underground and surface water, and solidification of dump in longer period completely eliminate appearance of caves and depressions in the area of dump. Meanwhile, beside all mentioned ecological benefits of application of prposed solution remains mentioned direct economic damage - **«agricultural damage»**, which is app. 73 milion euro, with all considered indirect effects. If the application of such systems of environmental protection would be ultimate measure defined with certain legal regulations and rules (as they are in EU), and if they will be supported from the state and funds of Republic of Serbia, then the effects of their application will have full expression. From viewpoint of mines application of this system demands investments in surface facilities for collecting, preparation of backfilling mixture at the surface of the terrain, underground complex for bacfilling and the sytem for reversible water. Benefits for mines are, beside the elimination of direct economic damage - «**mining damages»** from unexploitated available mineral resources, and with this higher rate of amortization of technological equipment, also elimination of damages the surface of the terrain and the objects built on it. Investments costs of the state relates on investments in rail transporting system and rail infrastructure. Costs of such investment would be covered through the elimination of direct economic damage - **«agricultural damage»** and through the elimination or reduction of «**mining damages».** From ecological aspect it is based on presented analyse most suitable solution because, usage of this solution most of influences on environment is completely eliminated. As it is mentioned above, since it is dealing with significant investments, if the application of such systems of environmental protection would be ultimate measure defined with certain legal regulations and rules (as they are in EU), and if they will be supported from the state and funds of the Republic of Serbia, then will be created conditions for the whole territory of the Republic of Serbia, to be released of this materials. In pure economical manner, if the whole problem is observed cumulatively, total profit for Republic of Serbia would be app. **2 billion euro in period of 40 years, i.e. app. 50 milion euro per year**, without taking into account the indirect effects from improvement the living environment, better usage of available mineral resources, new workih places, investments in infrastructure etc.

5. CONCLUSION

This paper presents a complex comparative techno-economic analysis of applied procedures of waste dumping ashes and slag from thermo power plants, heating plants and metallurgical facilities. In the matter is considered well known problem which was not appropriately treated as whole from different reasons. By partial solutions was only repared singular cases, and in considerations of proposed solutions were not taken effect of industrial damages at appropriate level, and therefore the technical solutions where adopted without real argumentation. Policy of sustainable technological development of Republic of Serbia must integrate any reliable resources and possibilities, and by legislation and following legal regulations and standards, and to obligate main actors on application the technological solutions which minimally damaging living environment and improve sustainable using of reliable natural and economy resources.

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OPTIMIZACIJA RADA POSTROJENJA ZA PRANJE (HIDROCIKLONA) PRI TRETMANU ERUPTIVNOG AGREGATA 0/2 mm SA ASPEKTA POTREBNOG SADRŽAJA FILERA (FRAKCIJA -0,063 mm)

Izvod

U predmetnom radu analiziran je rad postrojenja za pranje kamenog agregata 0/2 mm. Istraživanja su sprovedena na polustabilnom postrojenju za pranje kamenih agregata površinskog kopa „Drenik“ u Srebreniku. Pozicije istražnih radova su se nalazile na dozatoru prijemnog koša, hidrociklonu, razvodnom sisitemu za napajanje vodom, gumenim transporterima itd). U radu su korištene metode mjerenja protoka materijala, obračuna kapaciteta transportera, laboratorijske metode utrđivanja granulometrijskog sastava dobijenog materijala itd.

Rezultati istraživanja su iskazani u obliku tabelarnih podataka i dijagrama zavisnosti sadržaja filera (frakcije agregata tehničkog kamena granulacije -0,063 mm) od kapaciteta doziranog materijala.

Ključne riječi: *hidrociklon, sadržaj filera, granulometrijska struktura opranog materijala.*

1. UVOD

Strogi zahtjevi standarda za izradu asfalt betona i cement betona sačinjenih od agregata eruptivnog karaktera kao punila nalažu, pored povoljnih fizičko hemijskih karakteristika agregata, i povoljan granulometrijski sastav frakcija kamenih agregata. Naročito izražen problem kod traženog granulometrijskog sastava javlja se kod kamenog agregata 0/2 mm i to kod traženog okvira procentualnog sastava sitnih čestica – filera (-0,063 mm). Najefikasniji način odstranjivanja suvišne količine sitnih čestica - filera (-0,063 mm) pokazao se pored aerociklona, odstranjivanje hidrociklonima, obzirom da omogućuju lakše izdvajanje u većem procentualnom okviru. Samo instalisanje postrojenja bez usklađivanja tehničko-tehnoloških parametara ne obezbjeđuje obavezno tražene karakteristike tretiranog materijala.

1.1. Cilj naučnog rada i definisanje problema

Cilj ovog rada je da dokaže uticaj ulaznih parametara (kapacitet ulaznog materijala) pri radu postrojenja za pranje agregata (hidrociklona) na sadržaj filera (frakcije agregata tehničkog kamena granulacije -0,063 mm) u opranom materijalu, a u

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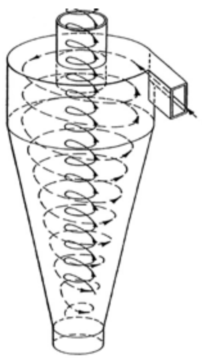
odnosu na standarde za pojedine vrste asfalt betona i cement betona [3] [4].

2. TEHNIČKO - TEHNOLOŠKI PRINCIP RADA

Hidrocikloni rade na principu delovanju gravitacijske i centrifugalne sile koja se javlja nakon tangencijalnog uvođenja vode u gonji dio hidrociklona. Zbog specifične konstrukcije, hidrociklonima se postiže vrtložno strujanje suspenzije u kojem se pod djelovanjem centrifugalne sile izdvajaju čestice s većom specifičnom težinom od tekuće komponente prema stijenci hidrociklona i naknadno djelovanjem gravitacije bivaju izbačene kroz donji dio hidrociklona. Obrađena voda napušta hidrociklon u vrtložnom strujanju usmjerenom suprotno od smjera djelovanja gravitacijske sile.



Sl. 1. *Prikaz vrtložnih struja u hidrociklonu*

Do klasiranja dolazi na kontaktu dva vrtloga unutar hidrociklona (vanjski i unutrašnji), pri čemu krupne cestice koje klize prema dnu uz plašt hidrociklona izlaze u formi otoka (apeks-proizvod), a sitne cestice s najvećim dijelom vode izlaze na vrhu hidrociklona u formi preliva (vorteks-proizvod).

Za razliku od klasifikatora s vertikalnim i horizontalnim strujanjem vode kod kojih se klasiranje događa u polju sile teže (g = 9,81 m/s), u hidrociklonu je to centrifugalno polje u kojem ubrzanja mogu iznositi i do 1000 g. Zbog toga je proces klasiranja znatno ubrzan što omogućava manje dimenzije uređaja, te klasiranje zrna veličine u rasponu od 0,005 do 5 mm, dok kod mehaničkih klasifikatora donja granica veličine zrna iznosi približno 0,04 mm (40 μm).

Režim kretanja čestica se odvija od ravnotežnog stanja do formiranja granice razdvajanja i kretanja čestica u vrtložnoj vanjskoj i unutrašnjoj struji suspenzije. Pošto se kod zahtjeva klasiranja i odvodnja-vanja na hidrociklonima radi o finodisperznim i grubodisperznim česticama, pulpa se kreće u unutrašnjem prstenastom vrtlogu i to laminarno.

3. METODOLOGIJA RADA

Istraživanja su se bazirala na: definisanju metodologije istraživanja, analizi rada postrojenja za pranje kamenih agregata, provođenje eksperimenata pri različitim ulaznim parametrima i iskazivanju dijagrama granulometrijskog sastava dobijenog materijala pri datom kapacitetu doziranog materijala i stalnom kapacitetu dozirane vode.

Istraživanja su se sprovodila na lokalitetu PK „Drenik“ tj. na polustabilnom postrojenju za pranje kamenih agregata na predmetnoj lokaciji.

Rezultati istraživanja su iskazani tabelarno (brojčane vrijednosti strukture granulometrijskog sastava dobijenog materijala pri određenim vrijednostima ulaznih parametara); grafički (grafikoni sa krivim granulometrijskog sastava dobijenog agregata pri određenoj vrednosti ulaznih parametara).

Model istraživanja struktuiran je vrstom istraživanja kao i postavljenim ciljem istraživanja.

Strukturno model istraživanja se mogao podijeliti u sljedeće faze:

a) Terenska „in situ“ merenja ulaznih i izlaznih parametara,
b) Laboratorijska ispitivanja sadržaja sitnih čestica
c) Obrada dobijenih rezultata.

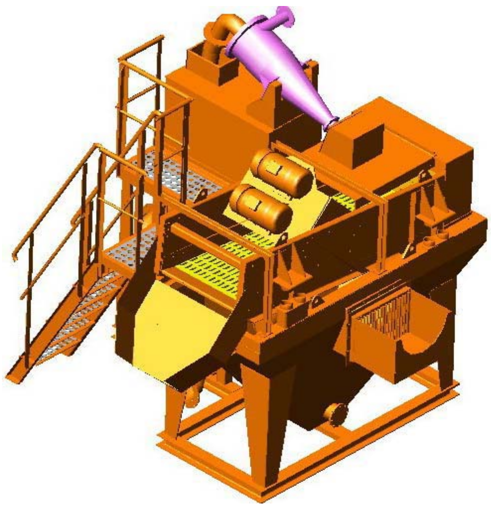
3.1. Terenska „in-situ“ ispitivanja

Terenska ispitivanja su obavljena na postrojenju hidrociklona za koje se može dati sljedeći opis rada [2]:

Hidrociklon-mašina za pranje i kompletnu preradu granulata je posebno dizajnirana i proizvedena za preradu, pranje, prosijavanje i sušenje granulata. Hidrociklon se sastoji se iz sljedećih dijelova:

- Postolja na kojem se nalazi rezervoar za nečistu vodu opremljen sa plovkom koji održava nivo nečiste vode istim;
- Centrifugalne pumpe koju pokreće električni motor;
- Hidrociklona sa rezervoarom za povratnu vodu, mulj, prašinu u koji ponovo utiče voda za vrijeme centrifuge;
- Vibrirajućeg sita kojeg pokreće par motora pogonjenih vibratorom;
- Kompletnog radnog postolja sa pristupnim penjalicama koja šalje mješavinu pod pritiskom u hidrociklon koji procesom centrifuge razdvaja mulj i nečistoće koje se ponovno vraćaju u rezervoar sa nečistoćama od koncentrisanog pijeska koji izlazi iz hidrociklona.

Granulat izlazi van sa vrha ciklona, pada i raspoređuje se po vibracionom situ gde se vrši prosijavanje. Mješavina unutar bazena je stabilizirana plovkom koji otvara i zatvara ventil za obnavljanje (ponovno dobijanje) mješavine i drži je uvijek na istom nivou kako pumpa ne bi radila „na suho" odnosno presušila. Centrifugalna pumpa sa zatvorenim radnim kolom obložena je veoma tankim slojem gume. Radno kolo sa dva nosača i promjenjivim oblogama gume je veoma otporno na trošenje i pri upotrebi mješavine sačinjene od drobljenih materijala. Ciklon - razdjelnik je namjenski dizajniran tako da je otporan na vlagu, ne uzimajući u obzir variranja pri dolasku materijala da obezbijedi veoma visoku gustinu prilikom izlaza materijala iz njega. Sposoban je da podnese neočekivan pritisak većih materija bez blokiranja sposobnosti promjene gustine pri izlazu. Osim visoke otpornost na habanje odlikuje se i sa jednostavnim održavanjem i malim vremenom zastoja. Ciklon je obložen posebnom gumom, koja ih štiti protiv abrazije i korozije. Navedena guma je prirodna guma sa veoma velikim otporom na abraziju (trošenje). Iz ovoga razloga, sve unutrašnje površine razdjelnika koje su u dodiru sa emulzijama za brušenje su obložene gumom. Razdelnik je zasnovan na iste dvije sile i to: centrifugalnoj i gravitacionoj sili. Ove sile obično nastaju centrifugalnom pumpom koja proizvodi silu mnogo veću od sile gravitacije. Materijal dolazi u razdjelnik kroz tangencijalni ulaz koji daje rotacijski efekt emulziji, rezultirajući centrifugalnom silom koja uzrokuje da čestice veće gustoće budu uz unutrašnje površine razdjelnika. Kao rezultat nastavljanja dodavanja materijala i okrenutog konusnog oblika razdjelnika, ove teže već razdijeljene čestice usled gravitacije tonu na dno ka izlazu (ispustu). Voda, cementne čestice, mulj i ilovača idu naviše kroz kovitlac formirajući srednju spiralu u odlivnik i bivaju ispušteni kroz cev odlivnika. Ključ uspjeha razdjelnika jeste otpusni regulator koji je postavljen ispod ispusta u donjem protoku. Produžena cijev donjeg protoka uzrokuje efekat sifona koji u povratku proizvodi vakum u donjem protoku razdjelnika. Ovaj vakuum je efikasan u zadržavanju otpusnog regulatora zatvorenim, zadržavajući većinu vode, mulja i ilovače koji se otpuštaju preko odlivnika. Kada je težina čvrstih materijala u razdjelniku tolika da efikasno može nadvladati vakuum, otpusni regulator je prinudno otvoren što dozvoljava otpuštanje materijala [2]. Tehnološki postupak pranja agregata obavlja se korištenjem vode iz usjeka površinskog kopa koji se nalazi ispod nivoa osnovnog platoa. Prilikom rada hidrocilona dolazi samo do kruženja vode unutar usjeka kroz niz filtracionih pregrada bez ispuštanja vode u okolne vodotoke.



Sl. 2. *Aksonometrijski prikaz uređaja hidrociklona*

Sl. 3. *Postrojenje hidrociklona*

Pomenutim ispitivanjima obavljena su sljedeća mjerenja, odnosno radni postupci:

1. Mjerenja kapaciteta ulaznog materijala u hidrociklon i kapacitetu izlaznog materijala iz hidrociklona na izlaznom gumenom transporteru. Mjerenja su vršena na način da se sa gumenog transportera dužine jedan metar uzimao cjelokupan uzorak te pomoću obrazca (2.2) dobijao promatrani kapacitet:

$$Q = q * v, \text{ (t/h)} \quad (2.2.)$$

gdje je:

Q - kapacitet (t/h),

q - masa materijala po dužnom metru. transportera (t/m),

v - brzina tračnog transportera (m/h).

2. Rad hidrocilona pri različitim vrijednostima kapaciteta dozirnog materijala i pri stalnom kapacitetu dozirane vode (Q_v= 150 m^3/h)

Vrijednosti kapaciteta doziranog materijala:

Q_1= 27,2 t/h

Q_2= 38,5 t/h

Q_3= 51 t/h

Q_4= 65,4 t/h

3.2. Laboratorijska ispitivanja

Kada je riječ o laboratorijskom ispitivanju granulometrijskog sastava ispitivanja su vršena u okviru certificirane labaratorije pri čemu su prosijavanja vršena na standardnim sitima.

Sastav serije sita diktiraju građevinski standardi pa su se primjenjivala sita sljedećih vrijednosti otvora (mm): 0,063; 0,09; 0,25;0,5; 0,71; 1,00; 2,00; [1]

3.3. Obrada dobijenih podataka

Obrada dobijenih podataka vršena je numeričkom analizom korištenjem softwerskog alata Microsoft Office Excell 2007. Rezultati ispitivanja su prikazani pomoću tabela i dijagrama.

4. REZULTATI ISTRAŽIVANJA

Rezultati sprovedenih istraživanja dati su u vidu granulometrijskog sastava dobijenog materijala brojčano u tabelama, i to pri pet različitih vrijednosti kapaciteta doziranog materijala u postrojenje hidrociklona.

4.1. Granulometrijski sastav ulaznog materijala u postrojenje hidrociklona

Rezultati sprovedenih istraživanja dati su tabelarno kao aritmetička sredina niza od po devet nezavisnih merenja i kao takvi su iskazani brojčano prema sljedećem obrascu :

$$X = (x_1 + x_2 + \ldots + x_n) / n \quad (4.1.)$$

X - aritmetička sredina mjerenja;

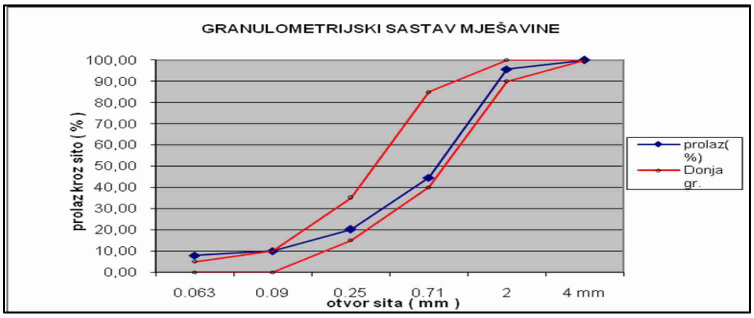
$x_1, x_2, x_3 \ldots x_n$ – *pojedinačna mjerenja*

n - broj mjerenja.

U tabeli 1. dat je granulometrijski sastav ulaznog materijala u postrojenje hidrociklona sa procentima prosjeva na otvorima sita kako su dati u tabeli.

Tabela 1. *Struktura granulometrijskog sastava dozirnog-ulaznog materijala*

Otvor sita	Prolaz (%)	Donja gr.	Gornja gr.
0.063	7.90	0	5
0.09	10.00	0	10
0.25	20.20	15	35
0.71	*44.60*	*40*	*85*
2	95.70	90	100
4 mm	100	100	100

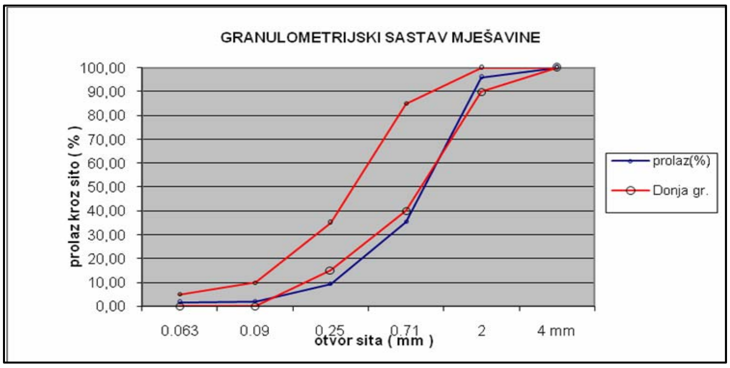


Sl. 4. *Dijagram granulometrijskog sastava ulaznog, doziranog, materijala*

4.2. Granulometrijski sastav opranog kamenog materijala nakon tretmana u postrojenju hidrociklona

Tabela 2. *Vrijednosti prolaza tretiranog materijala na hidrociklonu (%), pri datim vrijednostima otvora sita, kapacitet Q_1=27,2 t/h.*

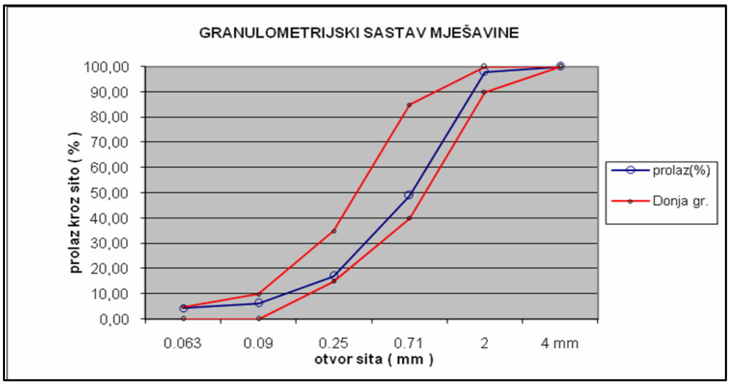
Otvor sita	Prolaz (%)	Donja gr.	Gornja gr.
0.063	1.66	0	5
0.09	2.03	0	10
0.25	9.43	15	35
0.71	35.49	40	85
2	95.93	90	100
4 mm	100	100	100



Sl. 5. *Dijagram granulometrijskog sastava tretiranog materijala pri kapacitetu dozirnog materijala Q_1=27,2 t/h*

Tabela 3 .*Vrijednosti prolaza tretiranog materijala na hidrociklonu (%), pri datim vrijednostima otvora sita, kapacitet Q_2=38,5 t/h*

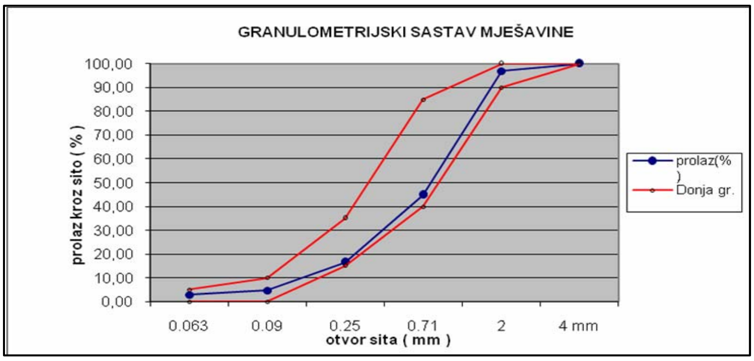
Otvor sita	Prolaz (%)	Donja gr.	Gornja gr.
0.063	4.47	0	5
0.09	6.27	0	10
0.25	17.00	15	35
0.71	49.00	40	85
2	98.00	90	100
4 mm	100	100	100



Sl. 6. *Dijagram granulometrijskog sastava opranog materijala pri kapacitetu dozirnog materijala Q_2=38,5 t/h*

Tabela 4. *Vrijednosti prolaza tretiranog materijala na hidrociklonu (%), pri datim vrijednostima otvora sita, kapacitet Q_3=51 t/h*

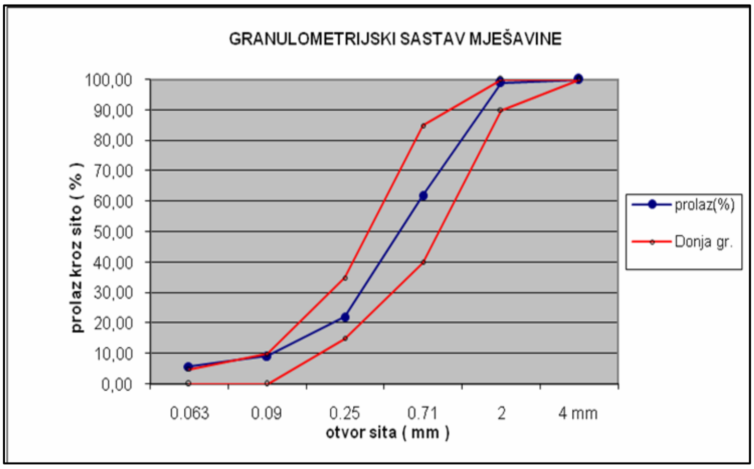
Otvor sita	Prolaz (%)	Donja gr.	Gornja gr.
0.063	2.88	0	5
0.09	4.73	0	10
0.25	16.46	15	35
0.71	44.86	40	85
2	96.91	90	100
4 mm	100	100	100



Sl. 7. *Dijagram granulometrijskog sastava opranog materijala pri kapacitetu dozirnog materijala Q_3=51 t/h*

Tabela 5. Vrijednosti prolaza tretiranog materijala na hidrociklonu (%), pri datim vrijednostima otvora sita, kapacitet Q_4=65,4 t/h

Otvor sita	Prolaz (%)	Donja gr.	Gornja gr.
0.063	5.76	0	5
0.09	9.23	0	10
0.25	22.19	15	35
0.71	62.01	40	85
2	99.00	90	100
4 mm	100	100	100



Sl. 8. *Dijagram granulometrijskog sastava opranog materijala pri kapacitetu dozirnog materijala Q_4=65,4 t/h*

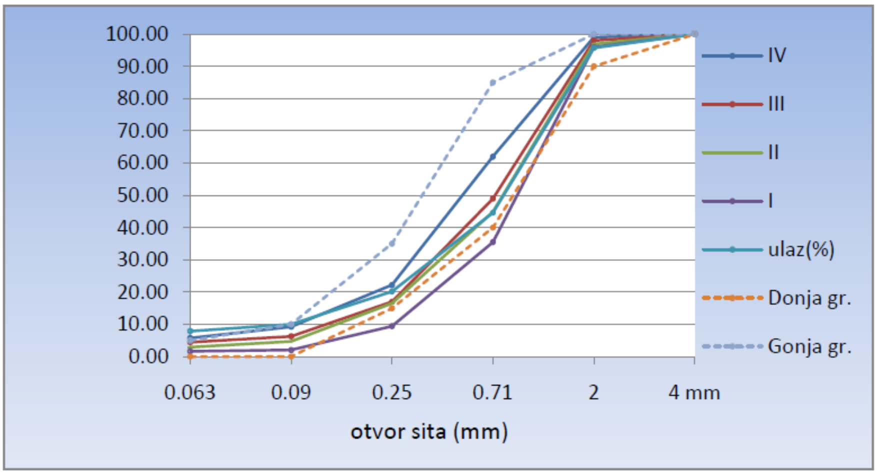
5. DISKUSIJA REZULTATA. IZBOR POVOLJNIH VARIJANTI RADA

Na osnovu dobijenih podataka pri obavljenim istraživanjima može se konstatovati da za zahtjeve standarda BAS EN 1304 [3], koji zahtijevaju sadržaj filera od 5 % najpovoljnija varijanta rada je pri kapacietu ulaznog doziranog materijala od Q_x=51 t/h, dok je za zahtjeve standarda HRN EN 933-1:2003+A_1:2007 [4], koji zahtijevaju sadržaj filera od 10 % najpovoljnija varijanta rada pri kapacietu ulaznog doziranog materijala od Q_x=65,4 t/h.

Analizirajući sliku 9. može se zaključiti da sa povećanjem kapaciteta doziranog materijala u hidrociklon sadržaj sitnih čestica u izlaznom tretiranom materijalu u ispitivanom okviru raste. Imajući u vidu konstrukcione karatkeristike hidrociklona, tehnološki postupak rada, dolazi se do zaključka da povećanjem kapaciteta doziranog materijala pri konstantnoj vrijednosti vode koja stvara pulpu unutar hidrociklona, stvara se unutar hidrociklona gušća smješa te se smanjuje količina sitnih čestica koje izlaze na preliv hidrociklona kao nusproizvod.

Tabela 6. *Zbirne vrijednosti prolaza opranog- tretiranog materijala na hidrociklonu*

otvor sita	IV	III	II	I	ulaz(%)	Donja gr.	Gonja gr.
0.063	5.76	4.47	2.88	1.66	7.90	0	5
0.09	9.23	6.27	4.73	2.03	10.00	0	10
0.25	22.19	17.00	16.46	9.43	20.20	15	35
0.71	62.01	49.00	44.86	35.49	44.60	40	85
2	99.00	98.00	96.91	95.93	95.70	90	100
4 mm	100.00	100.00	100.00	100.00	100	100	100



Sl. 9. *Zbirni dijagram sa usporednim krivim granulometrijskog sastava tretiranog materijala*

6. ZAKLJUČCI

Na osnovu sprovedenih istraživanja koja su prezentovana u ovom radu i koja su data tekstualno, brojčano, tabelarno i grafički pomoću dijagrama, može se zaključiti sljedeće:

- Hidrociklone se mogu efikasno koristiti u procesu odstranjivanja sitnih čestica i nečistoća pri tretiranju sitnijih frakcija kamenih agregata (0/2 mm, 2/4 mm, 0/4 mm)
- Pri promjeni ulaznih parametara (kapaciteta doziranog materijala) dolazi do promjene strukture granulometrijskog sastava dobijenog - opranog materijala.
- Povećanjem kapaciteta doziranog materijala na maksilmalnu vrijednost od 65,4 t/h, sadržaj filera (frakcije agregata tehničkog kamena granulacije -0,063 mm) se povećava do prosječne vrijednsti od 5,76 %.
- Smanjenjem kapaciteta doziranog materijala na minimalnu vrijednost od 27,2 t/h, sadržaj filera (frakcije agregata tehbničkog kamena granulacije -0,063 mm) se smanjuje do prosječne vrednosti od 1,66%.
- Promjena varijante rada tj. promjena kapaciteta dozirnog materijal je relativno jednostavan i brz proces, te kompletno rukovanje i upravljanje postrojenjem hidrociklona u automatskom režimu rada omogućava visoku efikasnost i produktivnost.

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OPTIMIZATION OF OPERATION THE PLANT FOR WASHING (HYDROCYCLONE) IN TREATMENT THE ERUPTIVE AGGREGATE 0/2 mm FROM THE ASPECT OF REQUIRED FILLER CONTENT (FRACTION -0.063 mm)

Abstract

The present paper analyzes the operation of the plant for washing stone aggregate 0/2 mm. Researches were conducted on a semi fixed plant for washing aggregates at the open pit "Drenik" in Srebrenik. Positions of exploration works were on dispenser entrance points, hydrocyclones, distribution system for water supply rubber belt conveyors, etc.). The methods for measuring material flow, calculation the capacity of conveyors, laboratory methods for grain-size distribution of the obtained material were used in this work. The research results are present in the form of tabular data and dependence diagrams of filler content (fractions of technical stone aggregate, granulation -0.063 mm) on capacity of dosed material.

Keywords: *hydrocyclone, filler content, granulometric structure of washed material*

1. INTRODUCTION

Strict requirements of the standards for making the asphalt concrete and cement concrete, made of aggregate of igneous character as filler need, besides their favorable physical-chemical properties of aggregates, also the favorable grain-size distribution of stone aggregate fractions. Especially significant problem with the required grain-size distribution occurs in mineral aggregate 0/2mm and the required percentage composition of fines - filler (-0.063 mm). The most effective way to remove the excess amounts of fine particles - filler (-0.063 mm) was, besides the aerocyclone, removal by hydrocyclones, as it makes easier the separation in higher percentage. The plant installation, without harmonizing the technical-technological parameters, does not necessarily provide the required characteristics of treated material.

1.1. Purpose of scientific research and definition the problem

The aim of this paper is to prove the effect of input parameters (capacity of input material) in the plant operation for washing aggregates (hydrocyclone) on the

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content of filler (fractions of technicals stone aggregate, granulation -0.063 mm) in washed material in relation to the standards for certain types of asphalt concrete and cement concrete [3] [4].

2. TECHNICAL AND TECHNOLOGICAL PRINCIPLE

Hydrocyclones operate on the principle of action the gravity and centrifugal force that occur after tangential introduction of water into the upper part of hydrocyclone. Due to the specific structure, hydrocyclone achieved turbulent flow of suspension in which, under the effect of centrifugal force, removes the particles with higher specific gravity than the liquid component on the hydrocyclone wall and subsequently being ejected by gravity through the lower part of hydrocyclone. The processed water leaving the hydrocyclone (vortex flow) is directed opposite to the direction of gravitational force action.

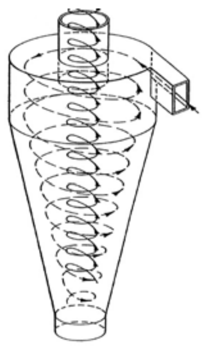

Fig. 1. *View of vortex flow in hydrocyclone*

Grading occurs at the contact of two vortexes inside the hydrocyclone (external and internal), where large particles that glide down the mantle hydrocyclone come in the form of underflow (apex-product), and fine particles with most of the water comes out on top in the form of hydrocyclone overflow (vortex-product).

Unlike the classifier with vertical and horizontal flow of water in which grading is in the field of gravity (g=9.81 m/s), the hydrocyclone is a field in which the centrifugal acceleration can reach up to 1000 g. Therefore, the grading process is significantly accelerated what is allowed by smaller size of plant and grading of grain-size in the range of 0.005 to 5 mm, since in mechanical classifiers, the lower limit of grain-size is about 0.04 mm (40 μm).

Regime of particle movements takes place from equilibrium to the formation of separation limit and particle movement in the outer and inner vortex flow of suspension. Since in the grading and drainage requirements in hydrocyclone, the fine dispersive and rough dispersive particles are present, the pulp moves laminar into the inner ring vortex.

3. METHODOLOGY

Research was based on: defining the research methodology, analysis of operation the plant for stone aggregate washing, conducting experiments with various input parameters and expression the grain-size distribution diagrams of the obtained material at given capacity of dosed material and permanent capacity of dosed water.

Research was carried out at the locality of the open pit "Drenik", i.e. on a semi-stable plant for rock aggregate washing at this location.

The research results are present in tables (numerical values of a grain-size distribution structure, obtained at certain values of input parameters) graphically (graphs with curves of grain-size distribution of the obtained aggregate at the obtained value of input parameters).

Research model is determined by a type of research as well as the set goal of research.

Structural model of research could be divided into the following phases:

a) Field "in situ" measurements of input and output parameters,
b) Laboratory tests of content the fine particles,
c) Processing of the obtained results

3.1. Field "in-situ" tests

Field tests were conducted at the plant of hydrocyclone for which the following description of operation can be given [2]:

Hydrocyclone – machine for washing and complete processing the granules is specifically designed and manufactured for processing, washing, sieving and drying the granules. The hydrocyclone consists of the following parts:

- Base on which the sewage tank equipped with a float that maintains the same level of impure water;
- Centrifugal pumps driven by an electric motor;
- Hydrocyclone with a reservoir for the return water, mud, dust, which again affects the water during the spin;
- Vibrating screens driven by a pair of engines powered vibrator;
- Full access to the base of access climbers, which sends the mixture under pressure in hydrocyclone, centrifuge process that separates the mud and dirt, and water that comes back into the tank with impurities from concentrated sand out of the hydrocyclone.

Granulate comes out from the top of cyclone, falls and it is distributed by vibrating sieve for sieving. Mixture inside the pool is a stabilized float which opens and closes the valve for regeneration (recovery of) mixture and keeps it always at the same level as pump would not operate "dry" or dry up. Centrifugal pump with closed impeller was coated with a very thin layer of rubber. Impeller with two carriers and floating rubber linings is very resistant to wear and when using a mixture made of crushed material. cyclone - a dedicated hub designed so that it is resistant to moisture, without taking into account the variation in the arrival of materials to provide very high density while leaving material from it. It is able to withstand the pressure of an unexpected major matter without blocking the ability to change the density of output. In addition to its high resistance to abrasion, it is also characterized with simple maintenance and little downtime. Cyclone is coated with a special rubber, which protects it against abrasion and corrosion. Specified rubber is natural rubber with very high resistance to abrasion (wear). For this reason, the inner surface of manifolds which are in contact with the slurry are coated with rubber. Separator is based on the same two forces, namely: centrifugal and gravitational force. These forces are typically caused by centrifugal pump which produces a much greater force than the force of gravity. Material comes in a dispenser through a tangential port that provides rotary effect emulsion; the resulting centrifugal force causes the particles to be higher density inner surface manifolds. As the result of continuous adding the material and focused tapered hub, these heavier particles are already separated by gravity to sink to the bottom of outlet. Water, cement particles, silt and clay flow up through the vortex forming a spiral in the middle and are discharged through a pipe separator. Key to success is the relief controller that is set below the drain in the bottom flow. Extended barrel lower flow causes the siphon effect which in return produces a vacuum in the lower flow dividers. This vacuum is effective in keeping the discharge regulator closed, keeping most of the water, silt and clay that are released. When weight of solid materials such that the distributor can effectively overcome the vacuum relief regulator is forced open allowing the release of the material [2]. Technological aggregate washing process is carried out using water from the cut open pit which is located below the main plateau of hydrocyclone. In operation of hydrocyclone, water circulates only inside the groove through a series of filtering partitions without water drainage in the surrounding water flows.

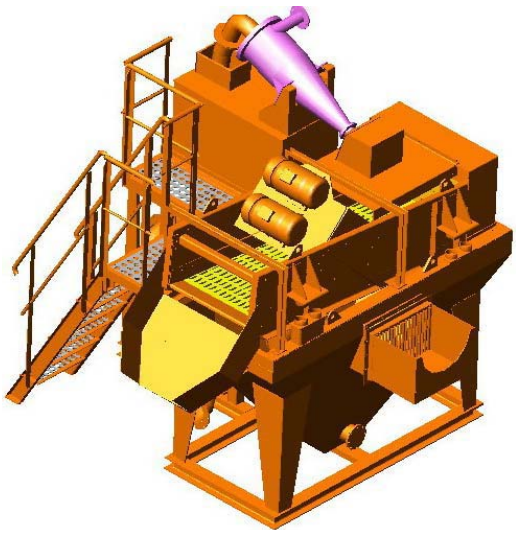

Fig. 2. *Axonometric view of hydrocyclone*

Fig. 3. *Hydrocyclone plant*

By the afore mentioned testing, the following measurements or operating procedures were carried out:

1. For measuring the input materials in hydrocyclone capacity and output material from the hydrocyclone outlet rubber conveyor. Measurements were carried out in a way that the rubber conveyor length one meter sample are taken and, using Form (2.2) received the observed capacity:

$$Q = q * v \quad (t/h) \tag{2.2.}$$

Where:

Q - capacity (t/h),
q - weight material per meter of conveyor (t/m),
v - belt conveyor speed (m/h)

2. Hydrocyclone work at various capacity dosing material and permanent capacity dosed water ($Qv = 150\ m^3/h$)

Capacity values of dosed material:

Q_1=27.2 t/h

Q_2=38.5 t/h

Q_3=51 t/h

Q_4=65.4 t/h

3.2. Laboratory tests

Laboratory testing of grain-size distribution was carried out within the certified laboratory where screenings were performed on standard sieves.

Composition of sieve series is dictated by the construction standards so the following values of sieve openings (mm) were used: 0.063, 0.09, 0.25, 0.5, 0.71, 1.00, 2.00; [1].

3.3. Data processing

Data processing was performed by numerical analysis using the software package Microsoft Office Excel 2007. Test results are shown in tables and diagrams.

4. RESULTS

The results of research are given in the form of grain-size distribution of the obtained material numerically in tables, and at five different capacity values of dosed material in the hydrocyclone plant.

4.1. Grain-size distribution of feed material in the hydrocyclone plant

The results of realized research are given in the form of tables as the arithmetic mean of a series of nine independent measurements and as such are present numerically in the following form:

$$X = (x_1 + x_2 + ... + x_n) / n \tag{4.1.}$$

X - arithmetic mean of measurement;
x_1 - x_2, x_3 ...... x_n-individual measurements
n - number of measurements.

Table 1 gives the grain-size distribution of feed material in the hydrocyclone plant with percentages of the average sieve openings that are given in Table.

Table 1. *Structure of grain-size distribution of feeding-input materials*

Mesh size	Passages (%)	Lower limit	Upper limit
0.063	7.90	0	5
0.09	10.00	0	10
0.25	20.20	15	35
0.71	*44.60*	*40*	*85*
2	95.70	90	100
4 mm	100	100	100

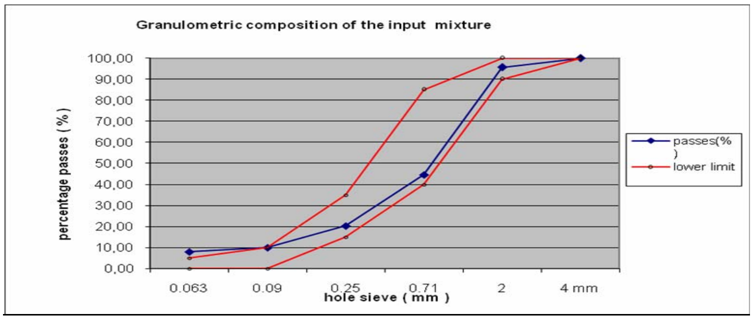

Fig. 4. *Diagram of input grain-size distribution, dosage, materials*

4.2 Grain-size distribution of washed stone material after treatment in the hydrocyclone plant

Table 2. Values of passages the treated material on hydrocyclone (%) for the given values of sieve mesh size, capacity $Q_1 = 27.2$ *t/h*

Mesh size	Passages(%)	Lower limit	Upper limit
0.063	1.66	0	5
0.09	2.03	0	10
0.25	9.43	15	35
0.71	35.49	40	85
2	95.93	90	100
4 mm	100	100	100

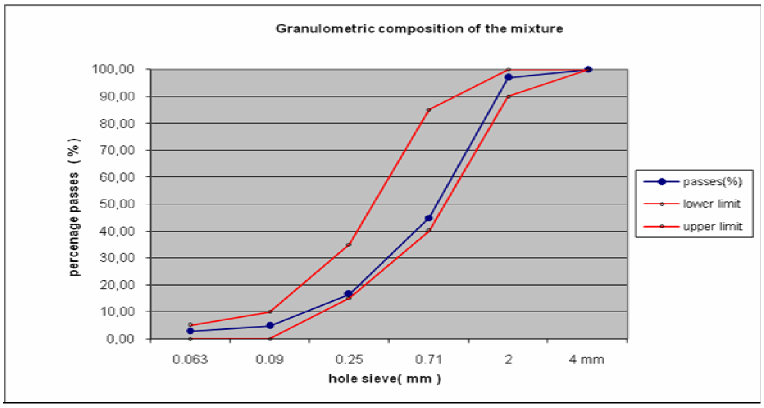

Fig. 5. *Diagram of grain- size distribution of treated material with capacity of dosing material* $Q_1 = 27.2$ *t/h*

Table 3. *Values of passages the treated material on hydrocyclone (%), for the given values of sieve mesh size, capacity* $Q_2 = 38.5$ *t/h*

Mesh size	Passages(%)	Lower limit	Upper limit
0.063	1.66	0	5
0.09	2.03	0	10
0.25	9.43	15	35
0.71	35.49	40	85
2	95.93	90	100
4 mm	100	100	100

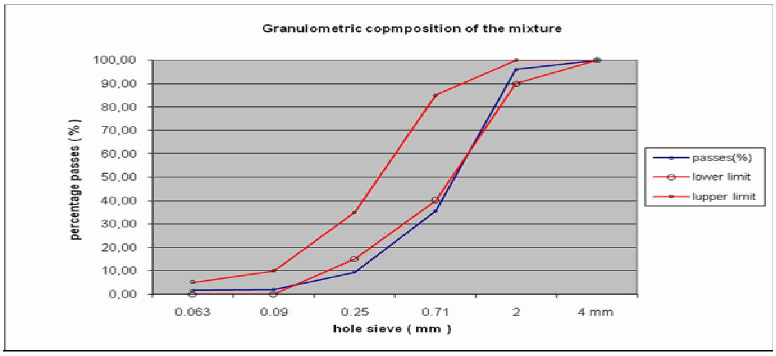

Fig. 6. *Diagram of grain- size distribution of washed material with capacity of dosing material* $Q_2 = 38.5$ *t/h*

Table 4. *Values of passages the treated material on hydrocyclone (%), for the given values of sieve mesh size, capacity* $Q_3 = 51$ *t/h*

Mesh size	Passages(%)	Lower limit	Upper limit
0.063	4.47	0	5
0.09	6.27	0	10
0.25	17.00	15	35
0.71	49.00	40	85
2	98.00	90	100
4 mm	100	100	100

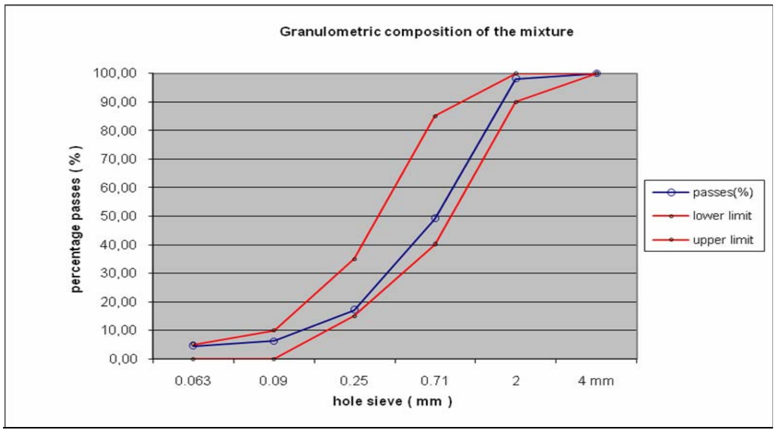

Fig. 7. *Diagram of grain- size distribution of washed material with capacity of dosing material* $Q_3 = 51$ *t/h*

Table 5. *Values of passages the treated material on hydrocyclone (%), for the given values of sieve mesh size, capacity Q_4 = 65.4 t/h*

Mesh size	Passages(%)	Lower limit	Upper limit
0.063	5.76	0	5
0.09	9.23	0	10
0.25	22.19	15	35
0.71	62.01	40	85
2	99.00	90	100
4 mm	100	100	100

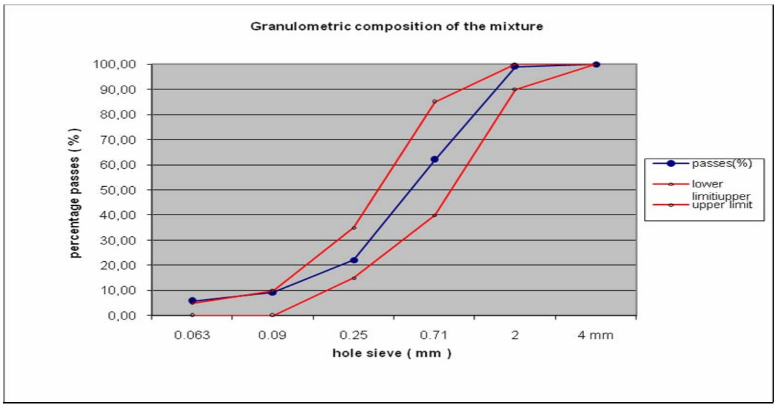

Fig. 8. *Diagram of grain- size distribution of washed material with capacity of dosing material Q_4 = 65.4 t/h*

5. DISCUSSION THE RESULTS, SELECTION OF FAVORABLE OPERATION VARIANT

Based on the obtained data of the research, it can be stated that the most favorable variant of operation, with capacity of input dosed material of Q_x = 51 t/h, is suitable for requirements of the standard EN 1304 [3], which require filler content of 5%, while the most favorable variant of operation, with capacity of input dosed material of Q_x = 65.4 t/h, is suitable for requirements of the standard BS EN 933-1:2003 + A1: 2007 [4], which require a filler content of 10%.

Analyzing Figure 9, it can be concluded that the increase in capacity of dosed material in hydrocyclone, the content of fine particles in the discharged treated material, in tested framework, increases. Considering the structural characteristics of hydrocyclone, the technological procedure of operation, it is concluded that increasing the capacity of dosedf at constant value of water producing pulp inside the hydrocyclone, denser mixture is created and reduces the amount of fine particles entering the hydrocyclone overflow as a byproduct.

Table 6. *Summary aggregate values of passage the washed-treated material on hydrocyclone*

Mesh size	IV	III	II	I	Input(%)	Lower limit	Upper limit
0.063	5.76	4.47	2.88	1.66	7.90	0	5
0.09	9.23	6.27	4.73	2.03	10.00	0	10
0.25	22.19	17.00	16.46	9.43	20.20	15	35
0.71	62.01	49.00	44.86	35.49	44.60	40	85
2	99.00	98.00	96.91	95.93	95.70	90	100
4 mm	100.00	100.00	100.00	100.00	100	100	100

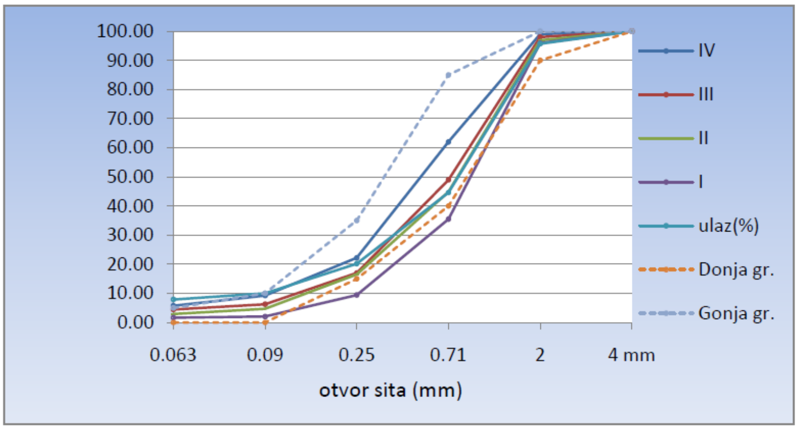

Fig. 9. *Summary diagrams with comparative curves of grain-size distribution of treated material*

6. CONCLUSIONS

Based on the conducted research, present in this paper and that are given textually, numerically, tabular and graphically using diagrams, the following can be concluded;

- Hydrocyclones can be effectively used in the process of removal the particles and impurities small to treat finer fraction aggregates (0/2 mm, 2/4 mm, 0/4 mm.)
- Changing the input parameters (capacity dosed material) leads to the change of grain-size distribution of the obtained washed material.
- Increasing the capacity of dosed material to maximum value of 65.4 t/h, the content of filler (fractions of technical stone aggregate, granulation of - 0.063 mm) increases to the average value of 5.76%.
- Reduction the capacity of dosed material to minimum of 27.2 t/h, the content of filler (fractions of technical stone aggregate, granulation of -0.063 mm) reduces to the average value of 1.66%
- Changing the operation variant, i.e. changing the capacity of dosed material is relatively simple and quick process, and complete handling and control of hydrocyclone plant in the automatic mode enables high efficiency and productivity.

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ISPITIVANJE UTICAJA DISPERGATORA NATRIJUM-POLIAKRILATA I NATRIJUM-SILIKATA NA POVEĆANJE STABILINOSTI SUSPENZIJE TOPIONIČKE ŠLJAKE***

Izvod

Laboratorijska ispitivanja sprovedena u radu, usmerena su ka utvrđivanju stabilnosti suspenzije topioničke šljake ispitivanjem jednog od uticajnih faktora-koncentracije dispergatora na njenu stabilnost.

U radu je ispitivana stabilnost suspenzije topioničke šljake na dva načina:

1. *Utvrđivanje stabilnosti suspenzije brzinom sedimentacije preko visine formiranja taloga na dnu menzure u određenim vremenskim intervalima;*
2. *Utvrđivanje stabilnosti suspenzije, odredjivanjem elektrokinetičkog ili zeta potencijala topioničke šljake, merenjem elktroforetske pokretljivosti na Riddick-ovom zetametru sa elektroforetskom ćelijom.*

U eksperimentima su korišćeni neorganski dispergator natrijum-silikat (vodeno staklo) i organski dispergator natrijum poliakrilat.

Analizom eksperimentalnih rezultata, utvrđeno je da primena navedenih dispergatora u odgovarajućim koncentracijama povećava stabilnost suspenzije formirane od topioničke šljake.

Natrijum-poliakrilat prisutan u koncentraciji od 50 g/t i natijum-silikat u koncentraciji od 5 g/t, pozitivno utiču na povećanje stabilnosti suspenzije, što potvrđuju jednačine pravih.

Natrijum-poliakrilat i natrijum-silikat u koncentraciji od 100 g/t, smanjuju stabilnost suspenzije formirane od topioničke šljake.

Sa natrijum-poliakrilatom u koncentraciji od 50 mg/l, su izmerene veće vrednosti zeta potencijala (od -21 do -29) mV, u rasponu pH skale od 3 do 11, sa natrijum-silikatom u koncentraciji od 5 mg/l izmerene vrednosti su niže (od -17 do -28) mV, dok se izmerene vrednosti na čistoj šljaci bez dodataka dispergatora kreću u intervalu (od -13 do -18) mV, čime je potvrđen pozitivan efekat istih na povećanje stabilnosti. U koncentracijama od 100 mg/l, dispergatori izazivaju pad potencijala, a samim tim i smanjuju stabilnost.

Natrijum-poliakrilat se pokazao kao bolji dispergator u odnosu na natrijum-silikat.

Ključne reči: *topionička šljaka, stabilnost suspenzije, zeta potencijal*

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1. UVOD

Jedan od glavnih problema u industrijskom procesu flotiranja topioničke šljake je održavanje pulpe u stabilnom stanju. Suspenzija formirana od topioničke šljake, veštačke tvorevine karakterističnog fizičko-hemijskog sastava, razlikuje se od suspenzija formiranih od prirodnih materijala u vodi. Polazeći od navedenog problema u flotaciji topioničke šljake, da se brzim taloženjem krupnih čestica šljake na dno flotacione ćelije, u prvim minutima flotiranja, narušava njena stabilnost, ispitivan je uticaj koncentracije dispergatora na povećanje stabilnosti suspenzije.

Jedna od fizičkih osobina suspenzije je i stabilnost suspenzije. S tim u vezi, ispitivanja su se odnosila na brzinu sedimentacije (formiranje taloga), čestica šljake na dno menzure. Za suspenziju se kaže da je stabilna ukoliko je postignuta njena potpuna postojanost. U suprotnom stabilnost suspenzije je narušena [1].

Eksperimentalni deo merenja zeta potencijala, bazira se na osnovnoj teoriji i modelima DES-a, (dvojnog električnog sloja), kao i pojma elektrokinetičkog (zeta potencijala) [2]. Poznavanje naelektrisanja površine čestica je od značaja za vođenje nekog procesa, tačnije za kontrolu stabilnosti suspenzija. Da bi se postigla stabilnost suspenzije, potrebno je stvaranje uslova koji će izmeniti površinsko naelektrisanje suspendovanih čestica i izazvati jako elektro-statičko odbijanje između samih čestica, a samim tim i povećati stabilnost suspenzije [2,3]. Disperznost koloidnog sistema u vode-noj i nevodenoj sredini prati se kontrolom naelektrisanja/zeta potencijala i to pomoću: pH vrednosti, dodavanjem polielektrolita i uvodjenjem potencijal određujućih jona. Preko vrednosti zeta potencijala na površini čestica može se kontrolisati osnovno svoj-stvo suspenzije. Stabilnost vodenih koloi-dnih suspenzija može biti postignuta sa povećanjem površinskih naelektrisanja čestica [2,3].

Uopšte za postizanje stabilnosti disperzionog sistema koriste se dispergatori. Najčešće korišćeni dispergatori su polielektroliti koji se adsorbuju na površini čestica menjajući njeno površinsko naelektrisanje. Primarna karakteristika dispergatora je njihova sposobnost obrazovanja koloidnih formi, usled čega dolazi do povećanja viskoziteta, t.j. postizanja disperznosti finih čestica i stabilnosti tako nastalog disperzionog sistema. Elektrostatičke sile odbijanja su najznačajniji faktor za postizanje stabilnosti suspenzije [3].

Naime brzina sedimentacije i merenje zeta potencijala su metode koje se koriste za utvrđivanje stabilnosti neke suspenzije .

U industrijskim uslovima flotiranja topioničke šljake, zbog karakterističnog hemijskog i mineraloškog sastava , dolazi do narušavanja stabilnosti pulpe formirane od topioničke šljake, što dalje ima direktnog uticaja na niska tehnološka iskorišćenja korisne komponente, bakra, iz topioničke šljake.

Uzimajući u obzir prethodno iznete konstatacije, osnovni cilj rada je bio, u laboratorijskim uslovima, ispitati stabilnost suspenzije formirane od topioničke šljake kao i mogućnost uspostavljanja i održavanja stabilnosti iste dodatkom dispergatora u različitim koncentracijama.

2. EKSPERIMENTALNI DEO

2.1. Materijali

Za eksperimentalna ispitivanja korišćena je topionička šljaka koja se kao nus produkat topljenja koncentrata bakra u plamenim pećima [4]. Šljake plamenih peći, hlađenjem, očvršćavaju u staklastu masu, fajalit, u kome je uprskan bakar, i magnetit u dovoljno krupnim kristalima [5].

Na uzorku topioničke šljake izvršena je kompleksna hemijska i mineraloška analiza.

Rendgenskom difrakcionom analizom uzorka topioničke šljake, ustnovljeno je prisustvo minerala: fajalita (Fe_2SiO_4), magnetita (Fe_3O_4), i kvarca (SiO_2). Fajalit predstavlja gvoždjem bogat mineral koji se u prirodi javlja u mineralu olivina, (($Mg, Fe)_2SiO_4$). Olivin je izomorfna smeša forsterita (Mg_2SiO_4) i fajalita (Fe_2SiO_4) [5,6].

Hemijskom analizom utvrđen je sadržaj osnovnih elemenata u topioničkoj šljaci koji je dat u tabeli 1.

Tabela 1.

Element	Sadržaj %	Jedinjenje	Sadržaj %	Element	Sadržaj g/t
Cu-uk	0,84	SiO_2	32,77	Au	0,5
Cu-ox	0,16	Al_2O_3	4,86	Ag	3,3
Cu-sulf	0,30	Fe_3O_4	9,68		
Cu elem	0,38				
Fe-uk	37,05				
S	0,81				
Ca	3,21				
Mg	0,62				

Reagensi

Rodamin B i Rodamin D - indikatori za vidljivo praćenje sedimentacije suspenzije u sedimentacionom cilindru. Svrha primene navedenih indikatora je bojenje suspenzije topioničke šljake u jarko ljubičastu boju, koja se dobija njihovom mešavinom, bez ikakvog uticaja i promene na hemijski sastav iste i odigravanja bilo kakvih hemijskih reakcija u formiranoj suspenziji uz njihovu primenu, radi lakšeg praćenje formiranja taloga na dno menzure.

Natrijum poliakrilat - [-CH2-CH(COONa)-]n, predstavlja natrijumovu so akrilne kiseline, pri čemu se njegovom polimerizujom stvaraju molekuli sa velikom molekulskom masom. Ovaj reagens adsorbuje veliku količinu vode i to 200-300 puta veću od sopstvene mase. Povezuje se u lanac polimera u čijem sastavu ulazi karboksilna grupa (-COOH). U vodenom rastvoru ova grupa ima negativno naelektrisanje, tj. formira se COO^- anjon. Ovi anjoni se međusobno odbijaju pri čemu se snažno "uvijaju i stupaju", u sve veći kontakt sa prisutnim karboksilnim grupama. Kako se ova polimerizacija nastavlja, dolazi do bujanja pri čemu hidrofilne koloidne čestice obrazuju micele. Prisutnost pomenutih anjona i nastanak micela su značajni za uspostavljanje stabilnosti disperzionog sistema [7].

Vodeno staklo- Na_2SiO_3

Vodeno staklo, natrijumova so silicijumove kiseline, je so jake baze i slabe kiseline.

Silicijumova kiselina H_2SiO_3, se javlja u rastvoru u koloidnom obliku, čiji stepen disperznosti zavisi od pH i koncentracije rastvora. Što znači, da ako se koristi kao dispergator u vodenim suspenzijama menja svoj sastav od nižih pH vrednosti ka višim. Na primer: na nižim pH vrednostima dobijaju se rastvori koji sadrže polijone, koloidne čestice silicijumove kiseline, dok se pri višim pH vrednostima dobijaju pravi rastvori koji sadrže proste jone SiO^{3-}[8].

2.2. Metode

2.2.1. Određivanje stabilnosti suspenzije formirane od topioničke šljake taloženjem u menzuri

Dispergatori natrijum poliakrilat [$-CH_2-CH(COONa)-$]n i natrijum silikat Na_2SiO_3 (vodeno staklo), su dodavani u formiranu suspenziju od topioničke šljake, u koncentracijama od 5, 10, 50 i 100 g/t. Sadržaj čvrstog u menzuri iznosio je 30% maseno, sa stepenom usitnjavanja sirovine od 80% (-0,075) mm. Uticaj dispergatora na stabilnost, predstavljen je funkcionalnom zavisnošću brzine formiranja takoga od vremena taloženja. Aproksimacijom dobijnih eksperimentalnih krivih, za posmatrani vremenski interval od 0-1,4 min, (predpostavljeni vremenski interval taloženja krupnih čestica na dno flotacijske ćelije u indutrijskim uslovima), utvrđena je zavisnost ispitivanih faktora-koncentracije dispergatora na stabilnost suspenzije topioničke šljake.

Analizirane su eksperimentalne krive sa i bez dodatka dispergatora.

2.2.2. Određivanje stabilnosti suspenzije formirane od topioničke šljake merenjem zeta potencijala

Vrednosti elektrokinetičkog potencijala odredjivane su merenjem elektroforetske pokretljivosti u elektroforetskoj ćeliji na Ridick-ovom zetametru, na prethodno pripremljenim rastvorima odgovarajućih koncentracija, proračunatih u odnosu na zapreminu ćelije zetametra i to: natrijum poliakrilat u koncentracijama od 50 i 100 mg/l i natrijum silikat u koncentracijama od 5 i 10 mg/l, usvojenih po osnovu najveće i najmanje postignute stabilnosti u seriji eksperimenata taloženja. Koncentracije dispergatora u eksperimentima taloženja (5, 10, 50 i 100 g/t) identične su koncentracijama (5, 10, 50 i 100 mg/l) u eksperimentima određivanja zeta potencijala.

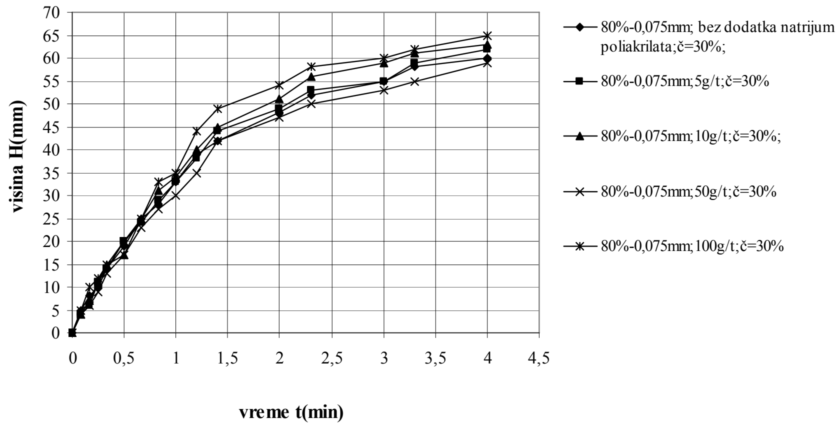
Kao regulatori pH vrednosti sredine u svim eksperimentima korišćeni su: H_2SO_4 i Ca $(OH)_2$.

Paralelno su analizirane vrednosti zeta potencijala na čistoj šljaci bez dodatka dispergatora, i uz dodatak navedenih disperaora u odgovarajućim koncentracijama. Za bolju stabilnost suspenzije, zeta potencijal mora imati veće vrednosti (pozitivne ili negativne) od IEP (izoelektrična tačka potencijala) [6].

3. REZULTATI

3.1 Eksperimenti taloženja

Slika 1 prezentuje eksperimentalne krive dobijene kao rezultat izvođenja laboratorijskih eksperimenata utvrđivanja stabilnosti suspenzije, očitavanjem visine formiranog taloga u menzuri, sa natrijum poliakrilatom u funkciji vremena taloženja.



Sl. 1. *Uporedni prikaz visine formiranja taloga u funkciji vremena uz dodatak natrijum poliakrilata i bez njegovog dodatka*

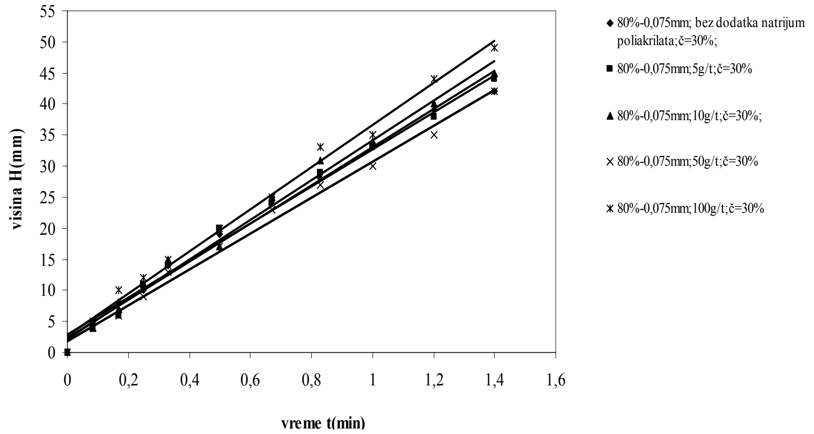
U cilju definisanja, zavisnosti koeficijenta pravca pravih k od koncentracije natrijum poliakrilata (slika 3), na dobijenim eksperimentalnim krivama, aproksimacijom je utvrdjena linearna zavisnost (y= kx + n), visine formiranog taloga od vremena talonja, u intervalu od 0 do 1,4 min (tabela 1, slika 2).

- ♦ Uslovi izvođenja eksperimenata dati su tabelarno (tabela 2).

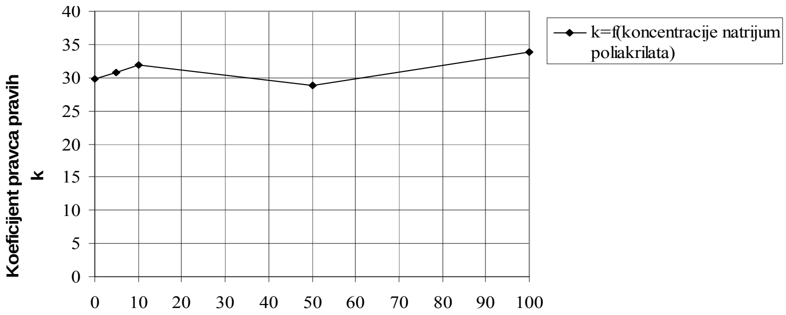
Tabela 2. *Uslovi izvođenja eksperimenata sa natrijum poliakrilatom*

Sadr. čvr. (%)	Količina Natrijum poliakrilata g/t	Step.otv. sir. (sadržaj klase - 0,075 mm) %	pH	Jednačina prave	Step. korelacije
30	/	80	Prirodna 7,14	Y=29,814x+2,8369	R^2=0,9883
30	5	80		Y=30,749x+2,2903	R^2=0,9892
30	10	80		Y=31,923x+2,1492	R^2=0,9895
30	50	80		Y=28,904x+1,8234	R^2=0,9922
30	100	80		Y=33,845x+2,7525	R^2=0,9918

Aproksimacija eksperimentalnih krivih u intervalu od 0 do 1,4 min prikazana je na slici 2.



Sl. 2. *Visina formiranja taloga u funkciji vremena uz dodatak natrijum poliakrilata i bez njegovog dodatka (prikaz linearizovanih krivih)*



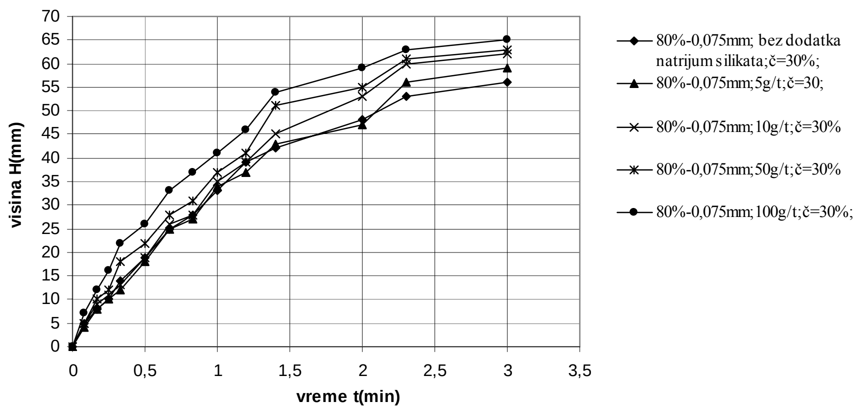
Sl. 3. *Funkcionalna zavisnost koeficijenta pravca pravih k od koncentracije natrijum poliakrilata*

Matematičkom analizom podataka iz tabele 2 i slika 2 i 3, izvodi se zaključak uticaja natrijum poliakrilata, u koncentraciji od 50 g/t čvrstog, na povećanje stabilnosti suspenzije topioničke šljake. Prisutan natrijum poliakrilat u koncentracijama od 5 i 10 g/t čvrstog u suspenziji topioničke šljake, nije imao uticaja na povećanje stabilnosti suspenzije. Povećana koncentracija od 100 g/t čvrstog, narušava njenu stabilnost.

Izvedene konstatacije potvrđuju koeficijenti pravca pravih k, dobijeni matematičkom aproksimacijom eksperimentalnih krivih (tabela 2). Matematički analizirano, najmanja vrednost koeficijenta pravca pravih k, znači najmanju brzinu formiranja taloga za određeni vremenski interval, tj ukazuje na postignuti efekat dispergatora na povećanje stabilnosti suspenzije i obrnuto.

Po osnovu gore navedenog, najveća stabilnost postignuta je sa natrijum poliakrilatom u koncentraciji od 50 g/t čvrstog (najmanja vrednost koeficijenta k), dok je najmanja u koncentraciji od 100 g/t čvrstog (najveća vrednost koeficijenta k).

Slika 4 prezentuje krive dobijene kao rezultat izvođenja laboratorijskih eksperimenata sa natrijum silikatom.



Sl. 4. *Uporedni prikaz visine formiranja taloga u funkciji vremena uz dodatak natrijum silikata i bez njegovog dodatka*

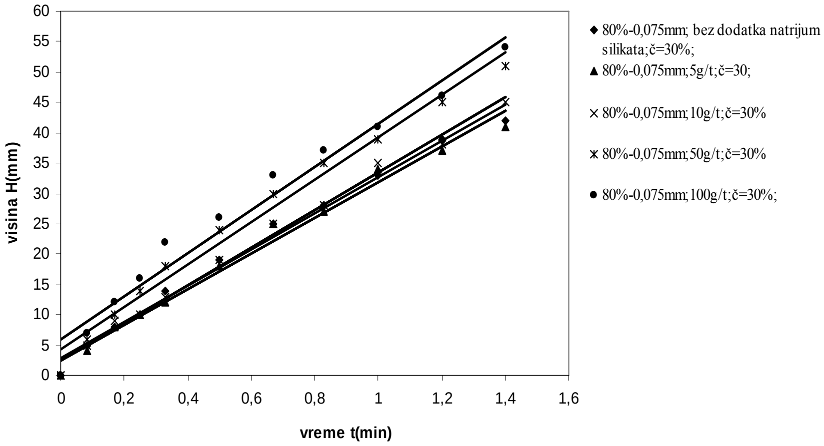
U cilju definisanja, zavisnosti koeficijenta pravca pravih k od koncentracije natrijum silikata (slika 6), na dobijenim eksperimentalnim krivama, aproksimacijom je dobijena linearna zavisnost (y= kx + n), visine formiranog taloga od vremena taloženja, u intervalu od 0 do 1,4 min (tabela 3, slika 5).

♦ Uslovi izvođenja eksperimenata dati su tabelarno (tabela 3).

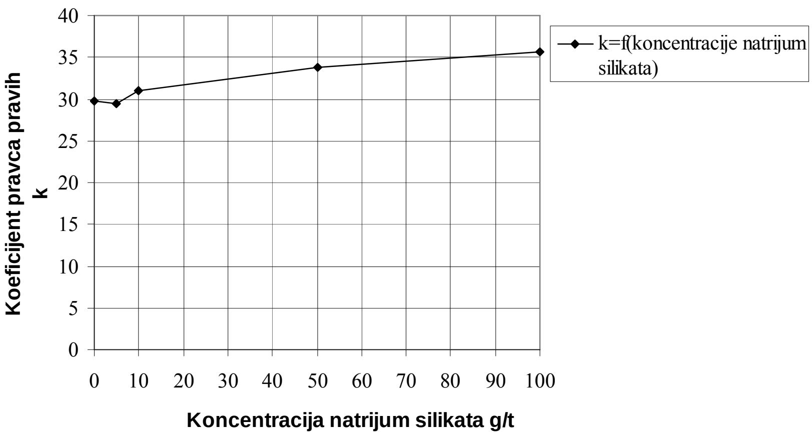
Tabela 3. *Uslovi izvođenja eksperimenata sa natrijum silikatom*

Sadr. čvr. (%)	Količina natrijum-silikata g/t	Step.otv. sir. (sadržaj klase - 0,075 mm) %	pH	Jednačina prave	Step. korelacije
30	/	80	Prirodna 7,14	Y=29,814x+2,8369	R^2=0,9883
30	5	80		Y=29,465x+2,4046	R^2=0,9858
30	10	80		Y=30,934x+2,5456	R^2=0,9917
30	50	80		Y=33,872x+3,4637	R^2=0,986
30	100	80		Y=35,634x+5,8881	R^2=0,9702

Aproksimacija eksperimentalnih krivih u intervalu od 0 do 1,4 min prikazana je na slici 5.



Sl. 5. *Visina formiranja taloga u funkciji vremena uz dodatak natrijum silikata i bez njegovog dodatka (prikaz linearizovanih krivih)*



Sl. 6. *Funkcionalna zavisnost koeficijenta pravca pravih k od koncentracije natrijum silikata*

Uporednom analizom ostvarenih eksperimentalnih rezultata, (slika 5 i 6), mogu se sagledati postignuti efekat stabilnosti suspenzije sa natrijum silikatom.

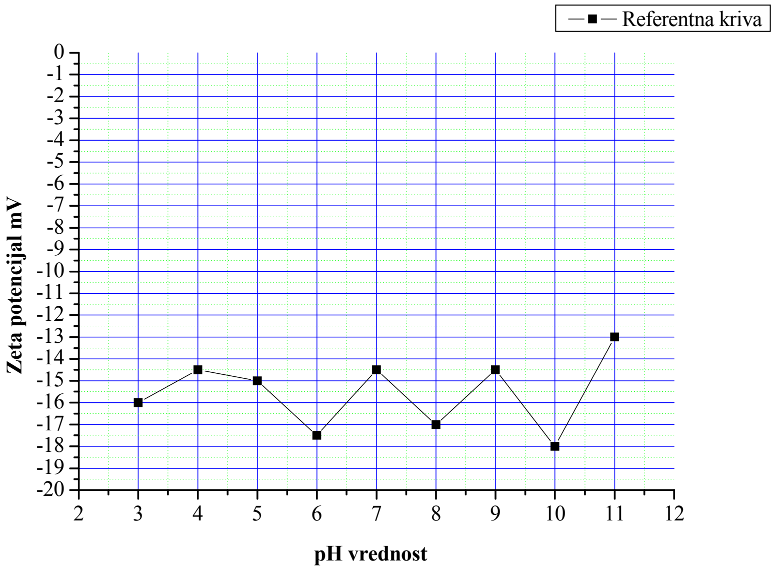
Neznatan efekat povećanja stabilnpsti suspenzije topioničke šljake, postignut je sa natrijum-silikatom u koncentraciji od 5 g/t čvrstog (najmanja vrednost koeficijenta k). Povećana koncentracija natrijum silikata u suspenziji topioničke šljake od 10, 50 i 100 g/t čvrstog, ne utiče na povećanje stabilnosti suspenzije, već se negativno odražava na istu, što je potrvrđeno jednačinama pravih (tabela 3).

Uporednom analizom ostvarenih eksperimentalnih rezultata (slike 3 i 6), uočava se bolji efekat natrijum poliakrilata na stabilnost suspenzije u poredjenju sa natrijum silikatom.

4.2. Ispitivanje stabilnosti suspenzije preko zeta potencijala

Imajući u vidu da je ispitivana sirovina topionička šljaka, “mešavina” više mineralnih formi, koristi se pojam “srednja” vrednost elektrokinetičkog–zeta potencijala (srednji zeta potencijal).

Odredjene srednje vrednosti zeta potencijala na topioničkoj šljaci u f-ji pH vrednosti sredine, bez dodatih dispergatora prikazane su na slici 7 (referentna kriva) i u tabeli 4.



Sl. 7. *Srednji zeta potencijal topioničke šljake bez dodatih dispergatora (referentna kriva)*

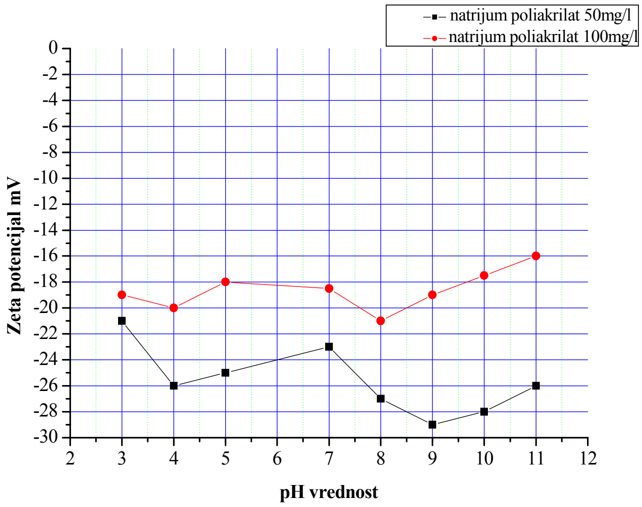
Tabela 4. *Srednji zeta potencijal šljake bez dodatih dispergatora*

pH vrednost sredine	2	3	4	5	6	7	8	9	10	11	12
Napon; V	200	200	200	200	200	200	200	200	200	200	200
Uvećanje; x	6	6	6	6	6	6	6	6	6	6	6
Elektroforetska pokretljivost; μ/s/V/cm	/	1,2	1,1	1,14	1,30	1,1	1,28	1,1	1,35	1	/
Elektrokinetički potencijal; mV	/	-16	-14,5	-15	-17,5	-14,5	-17	-14,5	-8	-13	/

Dobijeni rezultati daju povezanost između stabilnosti pulpe i pH sredine.

Sa slike 7 se uočavaju izmerene negativne vrednosti zeta potencijala na čistoj šljaci u celom rasponu pH skale merenja. Po osnovu izmerenih vrednosti zeta potencijala, suspenzija topioničke šljake, uz regulatore pH vrednosti sredine, sumporne kiseline i kalcijum hidroksida, je na gornjoj granici slabe disperznosti [6,9].

Odredjene vrednosti zeta potencijala sa natrijum poliakrilatom u koncentracijama od 50 i 100 mg/l i bez dodatka istog, prikazane su na slici 8.



Sl. 8. *Uporedni grafički prikazi srednjeg zeta potencijala topioničke šljake uz dodatak dispergatora natrijum poliakrilata u koncentracijama od 50 mg/l i 100mg/l*

Prisutan natrijum poliakrilat [-CH2-CH(COONa)-]n, u koncentraciji od 50 mg/l daje veće srednje negativne vrednosti izmerenog zeta potencijala u odnosu na koncentraciju istog u rastvoru od 100 mg/l, u rasponu pH vrednosti sredine od 3 do 11, (slika 8). Uporednom analizom sa odredjenim vrednostima zeta potencijala na čistoj šljaci bez prisustva dispergatora (slika 7), izvodi se zaključak povećane stabilnosti sa natrijum poliakrilatom u koncentraciji od 50 mg/l. Po osnovu odredjenih većih negativnih vrednosti zeta potencijala u celom rasponu pH vrednosti sredine, sa prisutnim dispergatorom u koncentraciji od 50 mg/l, može se reći da je postignuta srednja stabilnost suspenzije topioničke šljake [6,9]. Rezultati odredjenih vrednosti zeta potencijala dati su u tabelama 5 i 6.

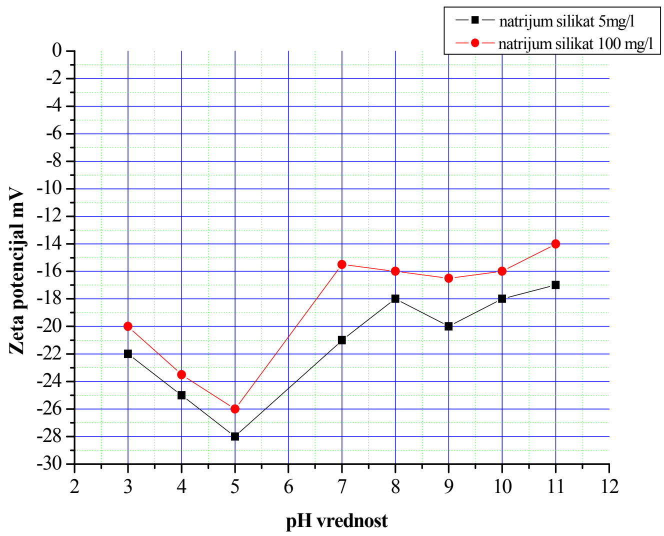
Tabela 5. *Srednji zeta potencijal topioničke šljake sa dodatim dispergatorom natrijum poliakrilatom u koncentraciji od 50 mg/l*

pH sredine	2	3	4	5	6	7	8	9	10	11	12
Napon; V	200	200	200	200	200	200	200	200	200	200	200
Uvećanje; x	6	6	6	6	/	6	6	6	6	6	6
Elektroforetska pokretljivost; μ/s/V/cm	/	1,60	1,95	1,85	/	1,75	2,0	2,2	2,1	1,95	/
Elektrokinetički potencijal; mV	/	-21	-26	-25	/	-23	-27	-29	-28	-26	/

Tabela 6. *Srednji zeta potencijal topioničke šljake sa dodatim dispergatorom natrijum poliakrilatom u koncentraciji od 100 mg/l*

pH sredine	2	3	4	5	6	7	8	9	10	11	12
Napon; V	200	200	200	200	200	200	200	200	200	200	200
Uvećanje; x	6	6	6	6	/	6	6	6	6	6	6
Elektroforetska pokretljivost; μ/s/V/cm	/	1,4	1,5	1,35	/	1,4	1,6	1,4	1,30	1,2	/
Elektrokinetički potencijal; mV	/	-19	-20	-18	/	-18.5	-21	-19	-17.5	-16	/

Odredjene vrednosti zeta potencijala sa natrijum silikatom kao dispergatorom u koncentracijama od 5 i 100 mg/l, prikazane su na slici 9.



Sl. 9. *Uporedni grafički prikazi srednjeg zeta potencijala topioničke šljake uz dodatak dispergatora natrijum silikata u koncentracijama od 5 mg/l i 100mg/l*

Efekat postignute stabilnosti suspenzije dodatkom natrijum silikata u koncentraciji od 5 mg/l potvrđuju negativnije vrednosti potencijala, u poređenju sa vrednostima potencijala u prisustvu natrijum silikata u rastvoru u koncentraciji od 100 mg/l, (slika 9). Uporednom analizom vrednosti zeta potencijala na čistoj šljaci bez prisustva dispergatora (slika 7), izvodi se zaključak povećane stabilnosti sa natrijum silikatom u koncentraciji od 5 mg/l. Po osnovu većih negativnih vrednosti zeta potencijala u rasponu pH vrednosti sredine od 3 do 11, sa prisutnim natrijum silikatom u koncentraciji od 5 mg/l, može se reći da suspenzija topioničke šljake, ima umerenu do srednju stabilnost [6,9]. Rezultati odredjenih vrednosti zeta potencijala dati su u tabelama 7 i 8.

Tabela 7. *Srednji zeta potencijal topioničke šljake sa dodatim dispergatorom natrijum silikatom u koncentraciji od 5 mg/l*

pH sredine	2	3	4	5	6	7	8	9	10	11	12
Napon; V	200	200	200	200	/	200	200	200	200	200	200
Uvećanje; x	6	6	6	6	/	6	6	6	6	6	6
Elektroforetska pokretljivost; μ/s/V/cm	/	1,65	1,85	2,1	/	1,6	1,35	1,5	1,35	1,25	/
Elektrokinetički potencijal; mV	/	-22	-25	-28	/	-21	-18	-20	-18	-17	/

Tabela 8. *Srednji zeta potencijal topioničke šljake sa dodatim dispergatorom natrijum silikatom u koncentraciji od 100 mg/l*

pH sredine	2	3	4	5	6	7	8	9	10	11	12
Napon; V	200	200	200	200	/	200	200	200	200	200	200
Uvećanje; x	6	6	6	6	/	6	6	6	6	6	6
Elektroforetska pokretljivost; μ/s/V/cm	/	1,5	1,75	1,95	/	1,15	1,2	1,25	1,2	1,05	/
Elektrokinetički potencijal; mV	/	-20	-23,5	-26	/	-15,5	-16	-16,5	-16	-14	/

Natrijum poliakrilat se pokazao kao bolji dispergator u odnosu na natrijum silikat, po osnovu izmerenih većih vrednosti potencijala u rasponu pH vrednosti od 3 do 11.

5. ZAKLJUČAK

Stabilnost suspenzije topioničke šljake se može u odgovarajućoj meri modifikovati primenom odgovarajućih dispergatora, natrijum poliakrilata i natrijum silikata.

Efekat povećanja stabilnosti suspenzije topioničke šljake ostvaren je sa natrijum silikatom u koncentraciji od 5 g/t čvrstog. Povećana koncentracija natrijum silikata u suspenziji topioničke šljake, ne utiče na povećanje stabilnosti suspenzije, već se negativno odražava na istu.

Pozitivan efekat na povećanje stabilnosti suspenzije ostvaren je sa natrijum poliakrilatom u koncentraciji od 50 g/t čvrstog, dok koncentracija istog od 100 g/t čvrstog, ima negativan uticaj na stabilnost suspenzije.

Prema srednjim vrednostima zeta potencijala na čistoj šljaci (-13 do -18 mV), u rasponu pH vrednosti sredine od 3 do 11, suspenzija topioničke šljake je na gornjoj granici slabe disperznosti. Znak naelektrisanja površine koloidnih čestica šljake, kao sto se vidi iz vrednosti zeta potencijala, je negativan.

Sa prisutnim natrijum poliakrilatom [-CH2-CH(COONa)-]n, u koncentraciji od 50 mg/l dobijene su veće negativnije vrednosti zeta potencijala (-21 do -29 mV) u poređenju sa vrednostima pri koncentraciji od 100 mg/l (-16 do -21 mV) i vrednostima zeta potencijala čiste šljake (-13 do -18 mV). Suspenzija je srednje stabilna.

Postignuta stabilnost suspenzije sa navedenim dispergatorom može se objasniti hemijskim karakteristikama ovog organkog jedinjenja. Anjoni dispergatora sa funkcionalnim grupama $-COO^-$ obrazuju lanac polimera i micele, odnosno gelastu stukturu i tako doprinose stabilizaciji suspenzije.

Sa natrijum-silikatom u koncentraciji od 5 g/t (odnosno 5 mg/l), dobijene su veće negativne vrednosti zeta potencijala (-17 do -28 mV) u poređenju sa vrednostima zeta potencijala sa natrijum silikatom u koncentraciji od 100 mg/l (-14 do -26) i vrednostima zeta potencijala na čistoj šljaci bez prisustva dispergatora, ukazuju na postignutu veću stabilnost suspenzije. Takođe, primetne su i veće vrednosti potencijala u kiseloj sredini u intervalu pH od 3 do 5, što se može objasniti prisutnim polijonima u rastvoru na nižim pH vrednostima sredine, tj. prisutnim koloidnim česticama silicijumove kiseline (H_2SiO_3). Suspenzija je umerena do srednje stabilna.

Organski dispergator natrijum poliakrilat se pokazao kao efikasniji, u poređenju sa natrijum silikatom u koncentraciji od 5 mg/l, po osnovu postizanja veće stabilnosti, u znatno većoj koncentraciji od 50 mg/l.

Prethodno iznete konstatacije izvedene po osnovu ostvarenih eksperimentalnih rezultata, potvrđene su odgovarajućom grafičkom interpretacijom i matematičkom analizom koeficijenata pravca pravih k.

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TESTING THE EFFECTS OF SODIUM POLYACRYLATE AND SODIUM SILICATE DISPERSING AGENTS TO INCREASE THE SUSPENSION STABILITY OF SMELTER SLAG***

Abstract

Laboratory testing, carried out in this paper, are focused on a stability determination of smelting slag suspension by investigation one of the influence factors - concentration of dispersing agents on its stability.

Testing the suspension stability of smelter slag was carried out in this work by two ways:

1. *Determining the suspension stability by sedimentation rate through the height of deposit formation on the bottom of measuring beaker at the certain time intervals;*
2. *Determining the suspension stability by determination the electrokinetic or zeta potential of smelter slag measuring the electrophoretic mobility on the Riddick zetameter with electrophoretic cell.*

Inorganic and organic dispersing agents of sodium silicate (water glass) and sodium polyacrylate were used in the experiments.

Analyzing the experimental results has determined that the usage of those dispersants in the adequate concentrations increases the stability of formed suspension of smelter slag.

Sodium polyacrylate, present in concentration of 50 g/t and sodium silicate in concentration of 5 g/t have positive effect on the increase of suspension stability, what is confirmed by the kune equations.

Sodium polyacrylate and sodium silicate in concentration of 100 g/t sodium polyacrylate and sodium silicate decrease the stability of formed suspension of smelter slag.

Higher values of zeta potential (-21÷ -29 mV) were measured during work with sodium polyacrylate of 50 mg/l concentration in the interval of pH range from 3 to 11. During work with sodium silicate in concentration of 5mg/l, the measured values of zeta potential were lower (-17 ÷ -28 mV), while in the experiments without addition of any dispersing agent, the interval of meas-

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ured values was -13 ÷ -18 mV. Those results show a positive effect of dispersing to the increase of smelter slag stability for the mentioned conditions. Concentrations of 100 mg/l of dispersing agents caused a potential decrease and thereby a decrease of stability. Sodium polyacrylate has been showed as better dispersing agent than sodium silicate.

Keywords: *smelting slag, suspension stability, dispersing agent, zeta potential*

1. INTRODUCTION

One of the main problems in the industrial process of smelting slag flotation is to maintain a pulp in a stable condition. The formed suspension from smelting slag, an artificial creation of the characteristic physical-chemical composition differs from the formed suspension from natural materials in water. Starting from the above problem in the smelting slag flotation that rapid deposition of large particles of slag on the bottom of flotation cell, in the first minutes of flotation, disturbs its stability, the effect of dispersant concentration on increasing the suspension stability was studied.

One of the physical properties of suspension is the suspension stability. In this respect, testing related to the sedimentation rate (deposit formation), slag particles on the bottom of measuring beaker. It is said for suspension that is stable if its total stability is achieved. Otherwise, suspension stability is disturbed [1].

Experimental part of measurement the zeta potential is based on the basic theory and models of DES, (double electrical layer), and the concept of electrokinetic (zeta potential) [2]. Knowledge of the surface charge of particles is of great importance for some process control, namely to control the suspension stability. In order to achieve the suspension stability, it is necessary to create the conditions that will change the surface charge of suspended particles and cause heavy electrostatic repulsion between the particles and thus increase the stability of suspension [2,3]. Dispersion of colloidal systems in aqueous and non-aqueous environment is monitored by the control of a charge/zeta potential using: pH value, addition of polyelectrolyte and introduction of potential determining ions. By the zeta potential values on the surface of particles, the basic feature of suspension can be controlled. Stability of aqueous colloidal suspensions can be achieved increasing the surface charge of particles [2,3].

General, the dispersing agents are used to achieve the stability of dispersion system. The most commonly used dispersants are polyelectrolytes that are adsorbed on the surface of particles changing its surface charge. The primary characteristic of dispersants is their ability to create the colloidal forms, which lead to an increase in viscosity, i.e. achieving the dispersion of fine particles and stability of such formed dispersion system. Electrostatic forces are the most important factor in achieving the suspension stability [3].

Namely, the sedimentation rate and zeta potential measurement are methods that are used to determine the stability of some suspension.

In the industrial conditions of smelting slag flotation, due to the characteristic chemical and mineralogical composition, the degradation of pulp stability, formed from the smelting slag, occurs which further has a direct impact on low technological recoveries of useful component, copper, from the smelting slag.

Taking into account the previously stated conclusions, the main aim of this work to test in the laboratory conditions the suspension stability, formed from the smelting slag, as well as the ability to establish and maintain the stability of the same adding a dispersant at different concentrations.

2. EXPERIMENTAL PART

2.1. Materials

Smelter slag was used for experimental tests as a by-product of copper concentrate smelting smelting in reverberatory furnaces [4]. Slags of rever-beratory are cooled in a glassy mass, fayalite, in which copper and magnetite are splashed in a sufficiently large crystals [5].

A complex chemical and mineralogical analysis was carried out on a sample of smelter slag.

X-ray diffraction analysis of smelter slag samples showed the presence of minerals: fayalite (Fe_2SiO_4) magnetite (Fe_3O_4) and quartz (SiO_2). Fayalite presents an iron-rich mineral that occurs in the nature in the mineral olivine (($(Mg, Fe)_2$ SiO_4). Olivine is an somorphic mixture of forsterite (Mg_2SiO_4) and fayalite (Fe_2SiO_4) [5,6].

Content of basic elements in the smelter slag was determined by chemical analysis and given in Table 1.

Table 1.

Element	Content %	Compound	Content %	Element	Content g/t
Cu-total	0.84	SiO_2	32.77	Au	0.5
Cu-ox	0.16	Al_2O_3	4.86	Ag	3.3
Cu-sulf	0.30	Fe_3O_4	9.68		
Cu elem	0.38				
Fe-total	37.05				
S	0.81				
Ca	3.21				
Mg	0.62				

Reagents

Rhodamine B and **Rhodamine D** – indicators for visible monitoring the sedimentation of suspension in the sedimentation cylinder. The purpose of application of these indicators is to paint a suspension smelting slag in a bright purple color, which is obtained by their mixture without any effect and change in the chemical composition of the same and development any kind of chemical reactions in the formed suspension with their application for easy monitoring the formed deposit on the bottom of measuring beaker.

Sodium polyacrylate - [-CH_2-CH (COONa)-]n, is a sodium salt of acrylic acid, where its polymerization forms molecules with large molecular mass. This rea-gent absorbs large amounts of water 200-300 times greater than its own mass. It is connected into a polymer chain, consisting of carboxyl group (-COOH).

In aqueous solution, this group has a negative charge, i.e. it forms COO-anion. These anions repel each other with a strong "writhe and come" in increasing contact with the present of carboxylic groups. As this polymerization continues, there are flourishing where the hydrophilic colloid particles form micelle. The presence of these anions and formation of micelles are important for establishing the stability of dispersion systems [7].

Water glass - Na_2SiO_3

Water glass, sodium salt of silica acid, is a salt of strong base and weak acid.

Silicium acid H_2SiO_3 occurs in a solution in a colloidal form, with degree of dispersion that depends on pH and solution concentration. This means, if it is used as dispersant in aqueous suspensions, it changes its composition from lower to higher pH values. For example, at lower pH values, the solutions are obtained containing poly ions, colloidal particles of silicium acid, whereas at higher pH values, the solutions are obtained containing simple ions SiO^{3-}[8].

2.2. Methods

2.2.1. Determining the stability of suspension formed from the smelting slag by deposition in a measuring beaker

Sodium polyacrylate dispersant $[-CH_2-CH(COONa)-]_n$ and sodium silicate Na_2SiO_3 (water glass), were added to the suspension formed from smelting slag, at concentrations of 5, 10, 50 and 100 g/t. Solid content in a measuring beaker was 30% mass with fragmentation degree of resources of 80% (-0.075) mm. The effect of dispersant on stability is represented by the functional dependence of formation rate of deposit on deposition time. By approximation the obtained experimental curves for observed time interval of 0 to 1.4 min, (the assumed time interval of deposition the large particles on the bottom of flotation cell in the industrial conditions), the dependence of tested factors of dispersant concentration on the suspension stability of smelting slag was established.

The experimental curves were analyzed with and without the addition of dispersant.

2.2.2. Determining the stability of suspension formed from the smelter slag by measuring the zeta potential

Electrokinetic potential values were determined measuring the electrophoretic mobilities in the electrophoretic cell on the Ridick zetameter, in previously prepared solutions of appropriate concentrations, calculated in relation to the cell volume of zetameter, as follows: sodium polyacrylate in concentrations of 50 and 100 mg/l and sodium silicate in concentrations of 5 and 10 mg/l, adopted on the basis of minimum and maximum achieved stability in a series of deposition experiments. Dispersant concentration in the deposition experiments (5, 10, 50 and 100 g/t) are identical to the concentrations (5, 10, 50 and 100 mg/l) in the experiments of determining the zeta potential.

As regulators of pH value, the followings were used in all experiments: H_2SO_4 and Ca $(OH)_2$.

The values of zeta potential were analyzed in parallel on pure slag without the addition of dispersant, and with the addition of mentioned dispersants in appropriate concentrations. For better suspension stability, zeta potential must have higher values (positive or negative) than IEP (isoelectric potential point) [6].

3. RESULTS

3.1. Deposition experiments

Figure 1 presents the experimental curves obtained as the result of performing the laboratory experiments for determining the stability of suspension reading the height of formed deposit in a measuring beaker with sodium polyacrylate in a function of deposition time.

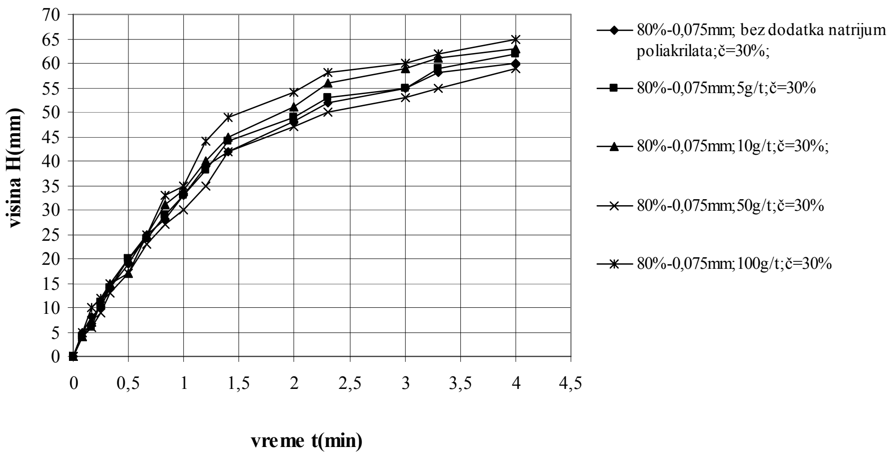

Fig. 1. *Comparative view the height of deposit formation as a function of time with addition of sodium polyacrylate and without its addition*

In order to define a dependence of direction coefficient of lines k on concentration of sodium polyacrylate (Figure 3), on the obtained experimental curves, a linear dependence (y = kx + n) was determined of the formed deposit height on deposition time in the range of 0 to 1.4 min (Table 1, Figure 2).

♦ Conditions of performing the experiment are given in tables (Table 2).

Table 2. *Experimental conditions in work with sodium polyacrilate*

Solid cont. (%)	Amount of sodium polyacrylate g/t	Degree of raw material openess (class content - 0.075 mm) %	pH	Line equations	Correlation degree
30	/	80	Natural 7.14	Y=29.814x+2.8369	R^2=0.9883
30	5	80		Y=30.749x+2.2903	R^2=0.9892
30	10	80		Y=31.923x+2.1492	R^2=0.9895
30	50	80		Y=28.904x+1.8234	R^2=0.9922
30	100	80		Y=33.845x+2.7525	R^2=0.9918

Approximation of the experimental curves in the range of 0 to 1.4 min is presented in Figure 2.

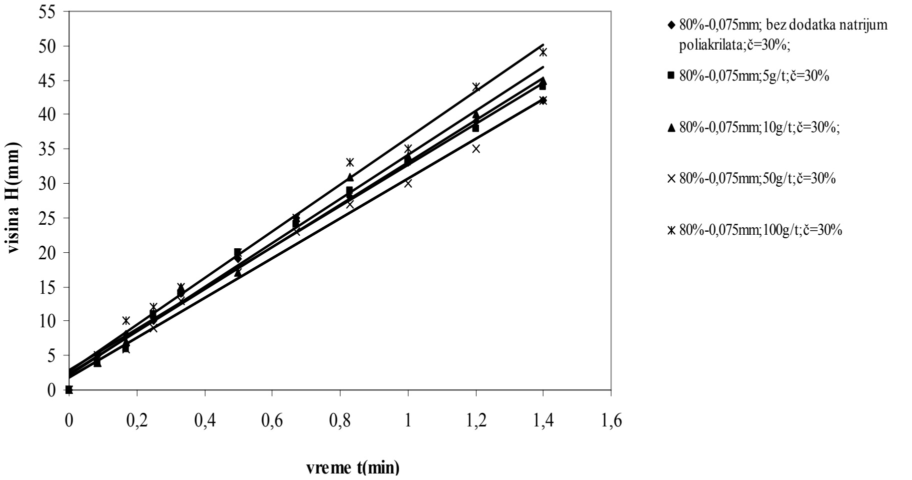

Fig. 2. *Height of deposit formation as a function of time with addition of sodium polyacrylate and without its addition (view of linearized curves)*

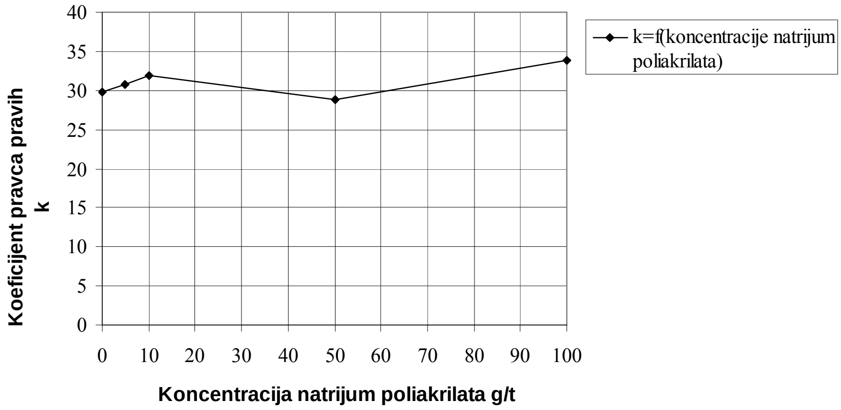

Fig. 3. *Functional dependence the coefficient k of line directions on concentration of sodium polyacrylate*

By mathematical analysis of the data from Table 2 and Figures 2 and 3, a conclusion is made of sodium polyacrylate effect, in concentration of 50 g/t of solid, on increasing the suspension stability of smelter slag. The present sodium polyacrylate in concentrations of 5 and 10 g/t of solid in suspension of smelter slag had no effect on increasing the stability of suspension. The increased concentration of 100 g/t of solid undermines its stability.

Derived findings confirm that the coefficients of line direction k, obtained by mathematical approximation of the experimental curves (Table 2). Mathematically analyzed, the lowest value of the coefficient of line direction k, means minimum rate of deposit formation for the specified time interval, i.e. it indicates a dispersant effect on increasing the suspension stability and vice versa.

Based on the above, the highest stability was achieved with sodium polyacrylate in concentration of 50 g/t solid (the lowest value of the coefficient k), while the lowest stability was achieved in concentration of 100 g/t of solid (the highest value of the coefficient k).

Figure 4 presents the curves obtained as the result of performing the laboratory experiments with sodium silicate.

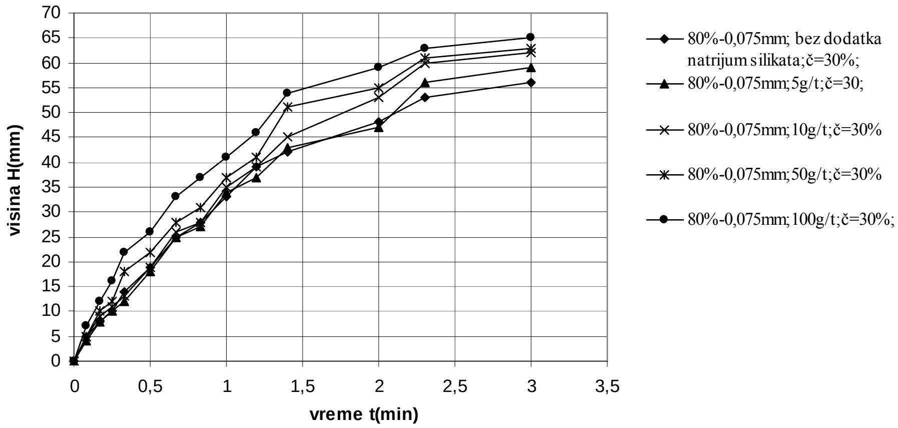

Fig. 4. *Comparative view the height of deposit formation as a function of time with addition of sodium silicate and without its addition*

In order to define a coefficient dependence of line direction k on concentration of sodium silicate (Figure 6) on the obtained experimental curves, a linear dependence (y= kx + n) of the formed deposit height on deposition tine in the time interval of 0 to 1.4 min was obtained by approximation (Table 3, Figure 5).

- Conditions of performing the experiments are given in tables (Table 3).

Table 3. *Experimental conditions in work with sodium silicate*

Solid cont. (%)	Amount of sodium silicate g/t	Degree of raw material openess (class content - 0.075 mm) %	pH	Line equations	Correlation degree
30	/	80	Natura 7,14	Y=29.814x+2.8369	R^2=0.9883
30	5	80		Y=29.465x+2.4046	R^2=0.9858
30	10	80		Y=30.934x+2.5456	R^2=0.9917
30	50	80		Y=33.872x+3.4637	R^2=0.986
30	100	80		Y=35.634x+5.8881	R^2=0.9702

Approximation of experimental curves in the time interval of 0 to 1.4 min is present in Figure 5.

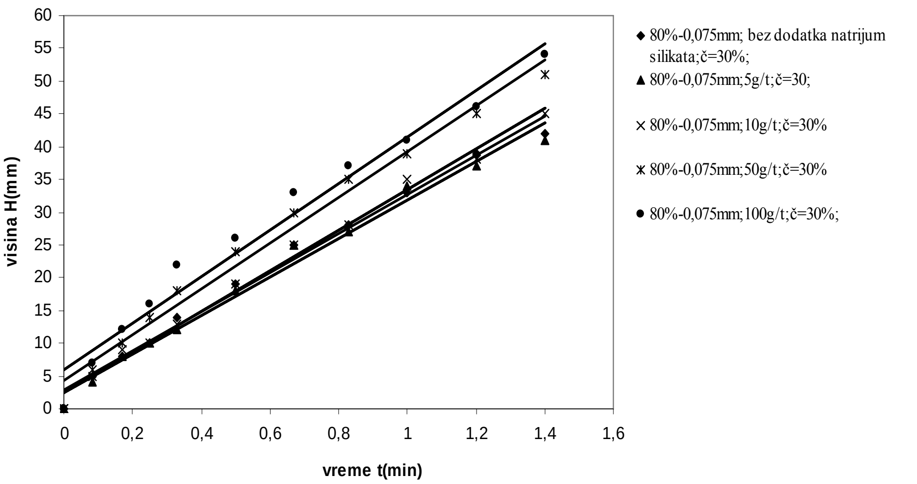

Fig. 5. *Height of deposit formation as a function of time with addition of sodium silicate and without its addition (view of linearized curves)*

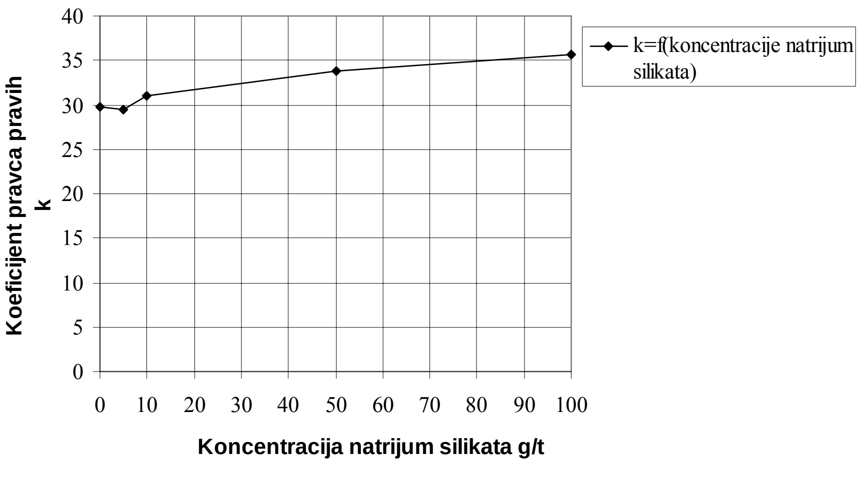

Fig. 6. *Functional dependence the coefficient k of line directions on concentration of sodium silicate*

The achieved stability effect of suspension with sodium silicate can be seen by comparative analysis of experimental results (Figures 5 and 6).

A negligible effect of increasing the suspension stability of smelting slag, was realized with sodium silicate in concentration of 5 g/t of solid (the lowest value of the coefficient k). The increased concentration of sodium silicate in a suspension of smelting slag of 10, 50 and 100 g/t of solid, does not increase the suspension stability, but it has a negative effect on it, what was confirmed the equations of lines (Table 3).

By comparative analysis of experimental results (Figures 3 and 6), there is better effect on sodium polyacrylate on the suspension stability compared with sodium silicate.

3.2. Testing the stability of suspension through zeta potential

Having in mind that tested raw material smelting slag is a "mixture" of several mineral forms, the term "average" value of electrokinetic – zeta potential (the average zeta potential) is used. Certain average values of zeta potential from the smelting slag in a function of pH value, without added dispersants are shown in Figure 7 (reference curve) and Table 4.

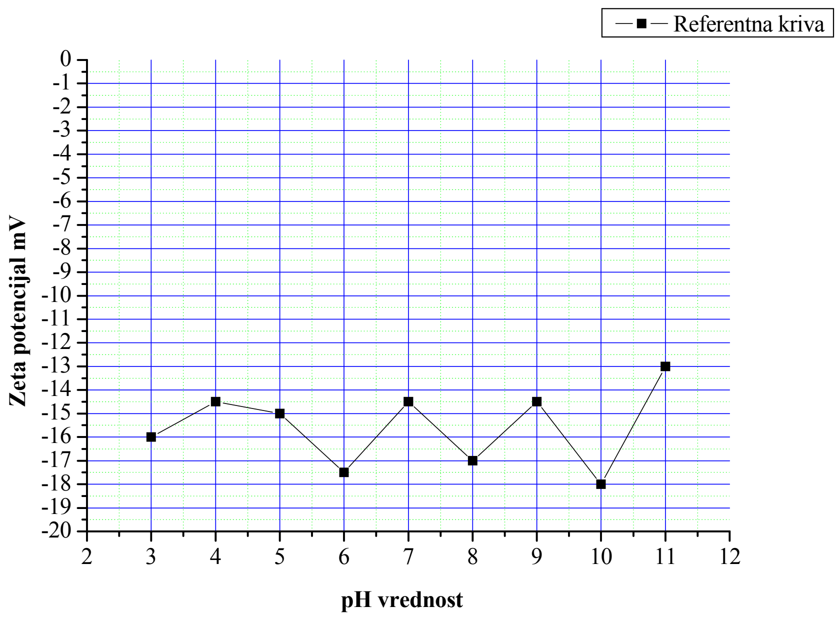

Fig. 7. *Average zeta potential of smelter slag without addition of dispersing agents (reference curve)*

Table 4. *Average zeta potential of smelter slag without added dispersing agents*

pH value	2	3	4	5	6	7	8	9	10	11	12
Voltage, V	200	200	200	200	200	200	200	200	200	200	200
Increase, x	6	6	6	6	6	6	6	6	6	6	6
Electrophoretic mobility, μ/s/V/cm	/	1.2	1.1	1.14	1.30	1.1	1.28	1.1	1.35	1	/
Electrokinetic potential, mV	/	-16	-14.5	-15	-17.5	-14.5	-17	-14.5	-8	-13	/

The obtained results give a correlation between the pulp stability and pH.

In Figure 7, the negative measured values of zeta potential are observed on pure slag in the whole range of pH measurement scales. Based on the measured values of zeta potential, the suspension of smelting slag, with regulators of pH value, sulfuric acid and calcium hydroxide, is at the upper limit of weak dispersion [6.9].

Certain values of zeta potential with sodium polyacrylate in concentrations of 50 and 100 mg/l and without addition of the same, are shown in Figure 8.

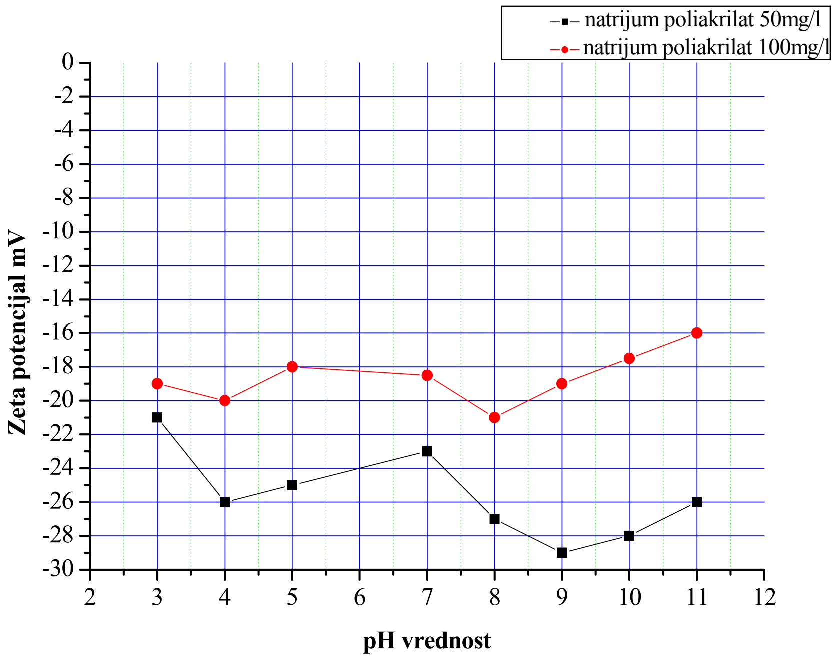

Fig. 8. *Comparative graphics the average zeta potential of smelter slag with addition of sodium polyacrilate dispersant in concentrations of 50 mg/l and 100mg/l*

Present sodium polyacrylate [-CH_2-CH(COONa)-]n, in concentration of 50 mg/l gives higher average negative values of measured zeta potential as compared with the concentration of the same in solution of 100 mg/l, in the range of pH value of 3 to 11, (Figure 8). By comparative analysis with the certain values of zeta potential on pure slag without presence of dispersants (Figure 7), a conclusion is made on increased stability with sodium polyacrylate in concentration of 50 mg/l. Based on the certain higher negative values for zeta potential in the whole range of pH value, with the present dispersant in concentration of 50 mg/l, it can be said that the average suspension stability of smelting slag was attained [6,9]. Results of certain values of zeta potential are given in Tables 5 and 6.

Table 5. Average zeta potential of smelter slag with added sodium polyacrylate as dispersing agent in concentration of 50 mg/l

pH value	2	3	4	5	6	7	8	9	10	11	12
Voltage, V	200	200	200	200	200	200	200	200	200	200	200
Increase, x	6	6	6	6	/	6	6	6	6	6	6
Electrophoretic mobility, μ/s/V/cm	/	1.60	1.95	1.85	/	1.75	2.0	2.2	2.1	1.95	/
Electrokinetic potential, mV	/	-21	-26	-25	/	-23	-27	-29	-28	-26	/

Table 6. Average zeta potential of smelter slag with added sodium polyacrylate as dispersing agent in concentration of 100 mg/l

pH value	2	3	4	5	6	7	8	9	10	11	12
Voltage, V	200	200	200	200	200	200	200	200	200	200	200
Increase, x	6	6	6	6	/	6	6	6	6	6	6
Electrophoretic mobility, μ/s/V/cm	/	1.4	1.5	1.35	/	1.4	1.6	1.4	1.30	1.2	/
Electrokinetic potential, mV	/	-19	-20	-18	/	-18.5	-21	-19	-17.5	-16	/

Certain value of zeta potential with sodium silicate as dispersing agent in concentrations of 5 and 100 mg / l, are shown in Figure 9.

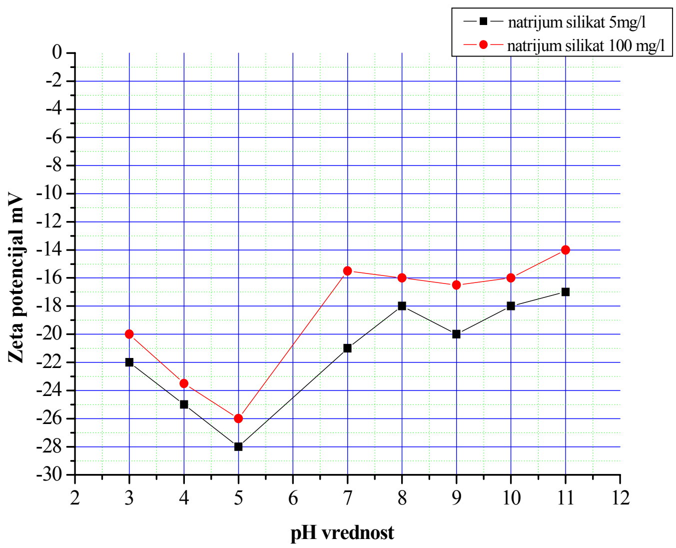

Fig. 9. *Comparative graphics the average zeta potential of smelter slag with addition of sodium silicate dispersant in concentrations of 5 mg/l and 100mg/l*

The effect of achieved suspension stability with addition of sodium silicate in concentration of 5 mg/l confirms more negative values of potential, compared with the potential values in the presence of sodium silicate in a solution in concentration of 100 mg/l (Figure 9). By comparative analysis of the zeta potential value on pure slag without the presence of dispersant (Figure 7), a conclusion can be made in increased stability with sodium silicate in concentration of 5 mg/l. Based on higher negative values of zeta potential in the range of pH value of 3 to 11, with the present sodium silicate in concentration of 5 mg/l, it can be said that the suspension of smelting slag has a moderate to average stability [6.9]. The results of certain zeta potential values are given in Tables 7 and 8.

Table 7. *Average zeta potential of smelter slag (with added sodium silicate as dispersing agent in concentration of 5 mg/l)*

pH value	2	3	4	5	6	7	8	9	10	11	12
Voltage, V	200	200	200	200	/	200	200	200	200	200	200
Increase, x	6	6	6	6	/	6	6	6	6	6	6
Electrophoretic mobility, μ/s/V/cm	/	1.65	1.85	2.1	/	1.6	1.35	1.5	1.35	1.25	/
Electrokinetic potential, mV	/	-22	-25	-28	/	-21	-18	-20	-18	-17	/

Table 8. *Average zeta potential of smelter slag (with added sodium silicate as dispersing agent in concentration of 100 mg/l)*

pH value	2	3	4	5	6	7	8	9	10	11	12
Voltage, V	200	200	200	200	/	200	200	200	200	200	200
Increase, x	6	6	6	6	/	6	6	6	6	6	6
Electrophoretic mobility, μ/s/V/cm	/	1.5	1.75	1.95	/	1.15	1.2	1.25	1.2	1.05	/
Electrokinetic potential, mV	/	-20	-23.5	-26	/	-15.5	-16	-16.5	-16	-14	/

Sodium polyacrylate has proven to be better dispersing agent compared to sodium silicate, based on the measured values of potential in the range of pH values from 3 to 11.

5. CONCLUSION

Stability of smelting slag suspension can be suitably modified using the appropriate dispersants, sodium polyacrylate and sodium silicate

The effect of increasing the suspension stability of smelting slag was obtained with sodium silicate in concentration of 5 g/t of solid. The increased concentration of sodium silicate in the smelting slag suspension does not increase the suspension stability, but it has a negative effect on it.

Positive effect on increasing the stability of suspensions was achieved with sodium polyacrylate in concentration of 50 g/t of solid, while the same concentration of 100 g/t of solid has a negative effect on suspension stability.

According to the average values zeta of potential on pure slag (-13 to-18mV), in the range of pH values from 3 to 11, the suspension of smelting slag is at the upper limit of weak dispersion. Sign of charge the colloidal particles of slag, as it is seen from the value of zeta potential, is negative.

With the present sodium polyacrylate [-CH_2-CH(COONa)-]n , in concentration of 50 mg/l, higher negative values of zeta potential were obtained (-21 do -29 mV) compared with the values in concentration of 100 mg/l (-16 do -21 mV) and values of zeta potential of pure slag (-13 do -18 mV). The suspension was medium stable.

The achieved suspension stability with this dispersant can be explained by the chemical properties of this organic compound. Dispersant anions with the functional groups $-COO^-$ form a chain of polymers and micelles, i.e. gelatinous structure and thus contribute to the stabilization of suspension.

With sodium silicate in concentration of 5 g/t (that is 5 mg/l), higher negative values of zeta potential (-17 do -28 mV) were obtained in comparison with zeta potential values with sodium silicate in concentration of 100 mg/l (-14 do -26) and zeta potential values on pure slag without presence of dispersant, what points out higher realized suspensions stability.

Also, higher values of potential are notable in the acidic media in the range of pH value of 3 to 5, what can be explained by the present polyions in a solution at lower pH values, i.e. present colloidal particles of silicium acid (H_2SiO_3). The suspension is moderately to medium stable.

Organic sodium polyacrylate dispenser has proved to be more efficient in comparison with sodium silicate in concentration of 5 mg/l, based on achieving a higher stability in much more higher concentration of 50 mg/l.

Previously stated conclusions, derived on the basis of realized experimental results are confirmed by corresponding graphical interpretation and mathematical analysis of the coefficients of line direction k.

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MEHANIČKE KARAKTERISTIKE MALTERA KOJI SADRŽI LETEĆI PEPEO TRETIRAN RAZLIČITIM FIZIČKIM POSTUPCIMA**

Izvod

U ovom radu su prikazani rezultati laboratorijskih ispitivanja čiji je cilj bio da se utvrdi uticaj letećeg pepela koji je tretiran različitim fizičkim postupcima (mehanička aktivacija, mlevenje i prosejavanje) na mehaničke karakteristike maltera, odnosno njegovu čvrstoću na pritisak i savijanje. Leteći pepeo je u ovim ispitivanjima korišćen kao supstituent za cement u hidrauličnim vezivima. Supstitucija portland cementa letećim pepelom kretala se od 10 do 70% maseno. Najpovoljniji rezultati su dobijeni prilikom zamene portland cementa letećim pepelom koji je prethodno mehanički aktiviran u laboratorijskom vibro mlinu sa prstenovima.

Ključne reči: *pepeo, cement, malter, čvrstoća*

1. UVOD

Pucolanski materijali (pucolani) su silikatni ili alumosilikatni materijali koji sami po sebi poseduju vrlo malo ili nimalo cementacionih svojstava. Međutim, veoma važna karakteristika pucolanskih materijala je njihova sposobnost da reaguju sa krečom ili portland cementom u prisustvu vode. Naime, SiO_2 i Al_2O_3 koji ulaze u sastav pucolanskih materijala reaguju sa kalcijum hidroksidom, $Ca(OH)_2$, pri čemu nastaju hidratisana kalcijum silikatna kao i hidratisana kalcijum aluminatna jedinjenja. Ova jedinjenja nisu rastvorna u vodi.

Pucolanski materijali se dele na prirodne (vulkanski pepeo, plovućac, dijatomejska zemlja) i veštačke (leteći pepeo, mikrosilika, metakaolin i sl.). Svojstvima pucolanskih materijala, kao i njihovom uticaju na karakteristike različitih građevinskih materijala posvećena je velika pažnja u svetskoj literaturi [1-6].

Leteći pepeo predstavlja fino dispergovani produkt sagorevanja uglja iz ter-

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moelektrana, izdvojen iz dimnih gasova, čija se veličina zrna kreće od 0 do 1 mm. To je heterogeni materijal sastavljen iz čestica različitih fizičkih, hemijskih, mineraloških i morfoloških svojstava, što je uslovljeno kvlitetom uglja, kao i uslovima i tehnologijom sagorevanja. Prema literaturnim podacima, godišnja proizvodnja letećeg pepela u Srbiji iznosi više od 5 000 000 tona [7].

Zahvaljujući pucolanskim svojstvima letećeg pepela, ovaj materijal se može primeniti u proizvodnji hidrauličnih veziva i betona (posebno u proizvodnji portland-cementnog klinkera, kao aktivna komponenta koja delimično može zameniti cement, ili kao agregat u betonu).

Da bi leteći pepeo mogao delimično da zameni cement mora da zadovolji određene zahteve standarda u pogledu hemijskih i fizičko-mehaničkih osobina.

Leteći pepeli koji se proizvode na teritoriji Republike Srbije su takvog kvaliteta da se mogu uspešno primeniti kao građevinski materijali (ne samo u industriji cementa i betona već i za izgradnju puteva, solidifikaciju tla i slično). Uprkos tome, najveće količine letećeg pepela još uvek nisu našle svoju primenu i locirane su u okviru deponija pepela. Uzimajući u obzir ovu činjenicu, neophodno je preduzeti određene mere kako bi se razmotrila i obezbedila svaka mogućnost njegove upotrebe.

Pored toga što se primenom letećeg pepela u komercijalne svrhe smanjuje njegov negativan uticaj na životnu sredinu, posredno se doprinosi očuvanju prirodnih mineralnih sirovina, snižavaju se troškovi potrebni za njihovu eksploataciju i odlaganje, kao i troškovi vezani za deponovanje pepela. U skladu s tim, treba imati u vidu da se prilikom izgradnje deponije letećeg pepela moraju ispoštovati sve predviđene zakonske odredbe [8] što, takođe može imati uticaja na troškove deponovanja.

2. KARAKTERIZACIJA I PRIPREMA POLAZNIH UZORAKA

2.1. Karakterizacija polaznih uzoraka

Polazni uzorak letećeg pepela koji je korišćen u ovim ispitivanjima uzet je iz termoelektrane "Nikola Tesla" – Obrenovac. Prema svom hemijskom sastavu (koji je prikazan u tabeli 1) ovaj pepeo se odlikuje visokim sadržajem hemijski aktivnog SiO_2 i visokim sadržajem kiselih oksida (SiO_2 + Al_2O_3 + Fe_2O_3) kao i niskim sadržajem baznih oksida (CaO, MgO). Na osnovu toga, a prema standardu SRPS B.C1.018, ovaj pepeo se može svrstati u veštačke pucolane – silikatne leteće pepele. Granulometrijski i mineraloški sastav ovog uzorka prikazani su na slikama (1 i 2).

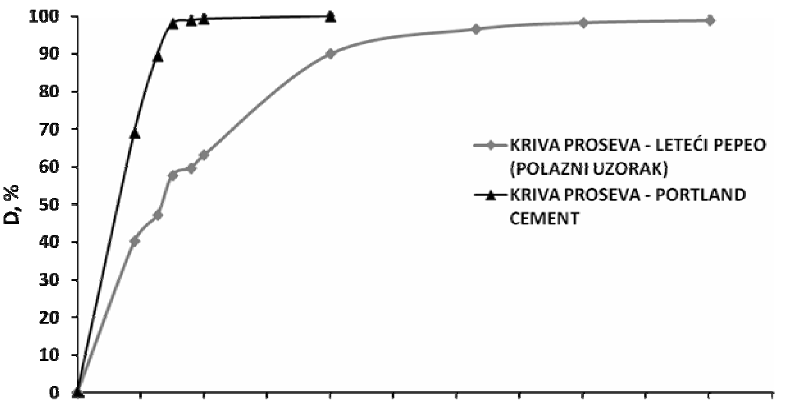
Uzorak portland cementa uzet je iz fabrike cementa "Titan Cementara Kosjerić" za potrebe ovih ispitivanja. Cement je visokog je kvaliteta, oznake PC 52,5 N (SRPS B.C1.011), a dobijen je mlevenjem portland cementnog klinkera uz dodatak kalcijum sulfata do 5%. U pogledu hemijskih, fizičkih i mehaničkih osobina ovaj cement je u potpunosti ispunjavao sve zahteve propisane standardom. U tabelama 1 i 2 prikazani su njegov hemijski sastav i fizičko-mehaničke karakteristike, a na slikama 1 i 3 njegov granulometrijski i mineraloški sastav.

Tabela 1. *Hemijski sastav uzoraka letećeg pepela i portland cementa*

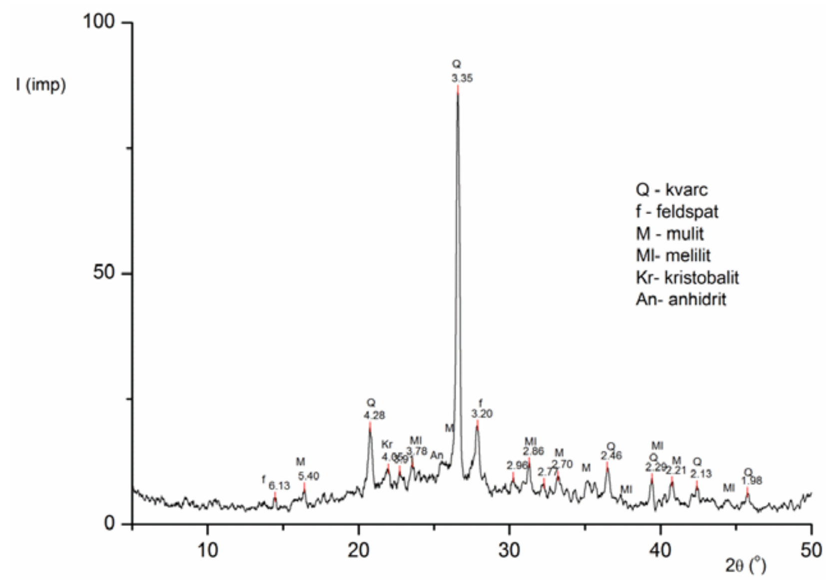
Komponenta	Sadržaj, %	
	Leteći pepeo	Portland cement
SiO_2	56,19	20.92
Al_2O_3	23,61	5.81
Fe_2O_3	5,37	3.55
CaO	6,42	63.07
MgO	2,11	1.86
SO_3	2,05	1,89
TiO_2	0,68	/
Na_2O	0,48	0,20
K_2O	0,87	0,74
MnO	/	0.09
Cl	/	0.003
CaO aktivni	0,29	/
SiO_2 aktivni	31,22	/
Gubitak žarenjem	2,04	0,96

Tabela 2. *Fizičko-mehaničke karakteristike portland cementa*

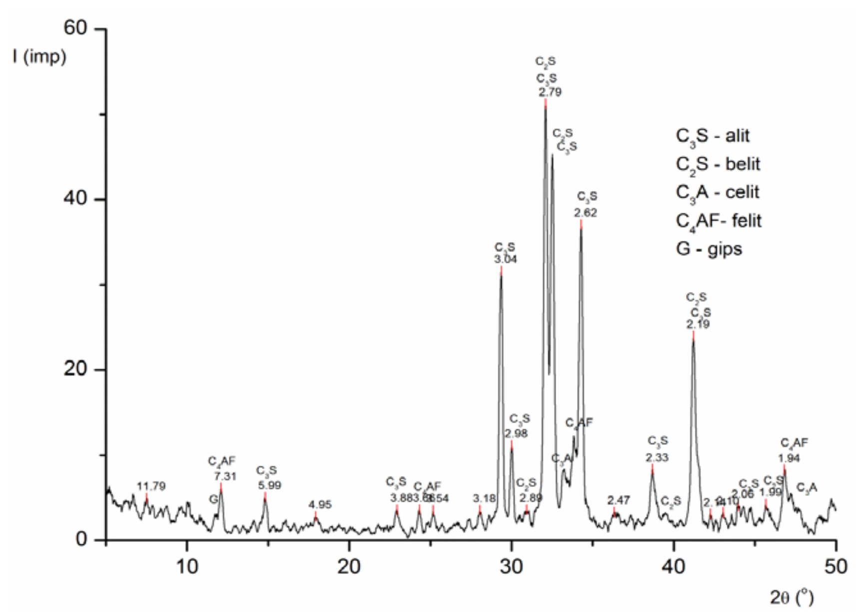
Čvrstoća na savijanje, MPa	2 dana		5,7
	7 dana		7,7
	28 dana		9,5
Čvrstoća na pritisak, MPa	2 dana		24,9
	7 dana		38,3
	28 dana		58,1
Vezivanje	Voda za standardnu konzistenciju, ml		25,8
	Početak, h : min		2:35
	Kraj, h : min		3:30
Stalnost zapremine	Kolačići	U vodi	Nema deformacija
		Na vazduhu	Nema deformacija
		Kuvano	Nema deformacija
	Prsten		Nema deformacija
Ostatak na situ otvora 90 µm, %			1,20
Gustina, g/cm^3			3,15
Specifična površina, cm^2/g			3850
Sadržaj vlage, %			0,43



Sl. 1. *Granulometrijski sastav letećeg pepela i portland cementa*



Sl. 2. *Mineraloški sastav letećeg pepela*



Sl. 3. *Mineraloški sastav portland cementa*

2.2. Priprema uzoraka letećeg pepela za potrebe ispitivanja

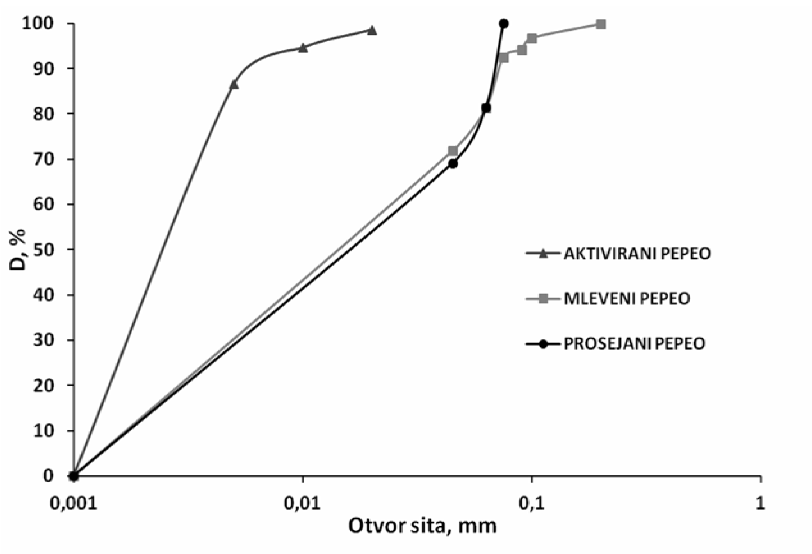
Za potrebe formiranja hidrauličnih veziva koja sadrže portland cement i leteći pepeo u različitim masenim odnosima, polazni uzorak letećeg pepela tretiran je različitim fizičkim postupcima. Na jednom delu uzorka izvršena je mehanička aktivacija u vibracionom mlinu sa prstenovima u trajanju od 35 minuta.

Drugi deo uzorka je mleven u laboratorijskom mlinu sa kuglama u trajanju od 22 minuta, kako bi se postigla odgovarajuća finoća pepela u skladu sa standardom ASTM C618 (minimum 66% klase -45 + 0 μm).

Analizom granulometrijskog sastava polaznog uzorka (slika 1) utvrđeno je da se prosejavanjem na situ otvora 75 μm postiže zadovoljavajuća finoća letećeg pepela (prema standardu), tako da je treći deo uzorka tretiran postupkom suvog sejanja na pomenutom situ. Granulometrijski sastavi svakog od uzoraka, dobijenih nakon odgovarajućeg tretmana prikazani su na slici 4, a njihova pucolanska aktivnost i specifična površina u tabeli 3.

Tabela 3. *Fizičke karakteristike letećeg pepela tretiranog različitim postupcima*

Vrsta pepela	Pucolanska aktivnost		Specifična površina po Blaine-u, cm^2/g
	Čvrstoća na savijanje, MPa	Čvrstoća na pritisak, MPa	
aktivirani	5,3	17,2	11770
mleveni	4,2	12,5	6940
prosejani	4,0	9,5	3810



Sl.4. *Granulometrijski sastav aktiviranog, mlevenog i prosejanog letećeg pepela*

3. EKSPERIMENTALNA ISPITIVANJA

Dalji eksperimentalni postupak odvijao se kroz tri serije opita. U prvoj seriji opita, portland cementu su dodavane različite količine aktiviranog letećeg pepela (10, 20, 30, 40, 50, 60 i 70%), a zatim su tako dobijene smeše homogenizirane radi ujednačavanja hemijskog sastava. U drugoj seriji opita portland cementu su dodavane analogne količine mlevenog letećeg pepela i nakon toga je takođe izvršena homogenizacija smeša. Isti postupak je ponovljen i u trećoj seriji opita, gde je kao supstituent za cement upotrebljen prosejani leteći pepeo. Od ovako dobijenih vezivnih materijala formiran je malter prema standardnom postupku. Na epruvetama od maltera je posle 2, 7, i 28 dana odležavanja u vodenoj sredini izvršeno ispitivanje čvrstoće na pritisak i savijanje (standardni postupak na presi marke "Toni Technik"). Ispitivanja su izvršena u fabrici cementa "Titan Cementara Kosjerić".

4. REZULTATI I DISKUSIJA

Rezultati eksperimentalnih ispitivanja su prikazani u tabelama 4 – 6 i na slikama 5 – 10.

Tabela 4. *Čvrstoće na pritisak i savijanje maltera koji sadrži aktivirani leteći pepeo*

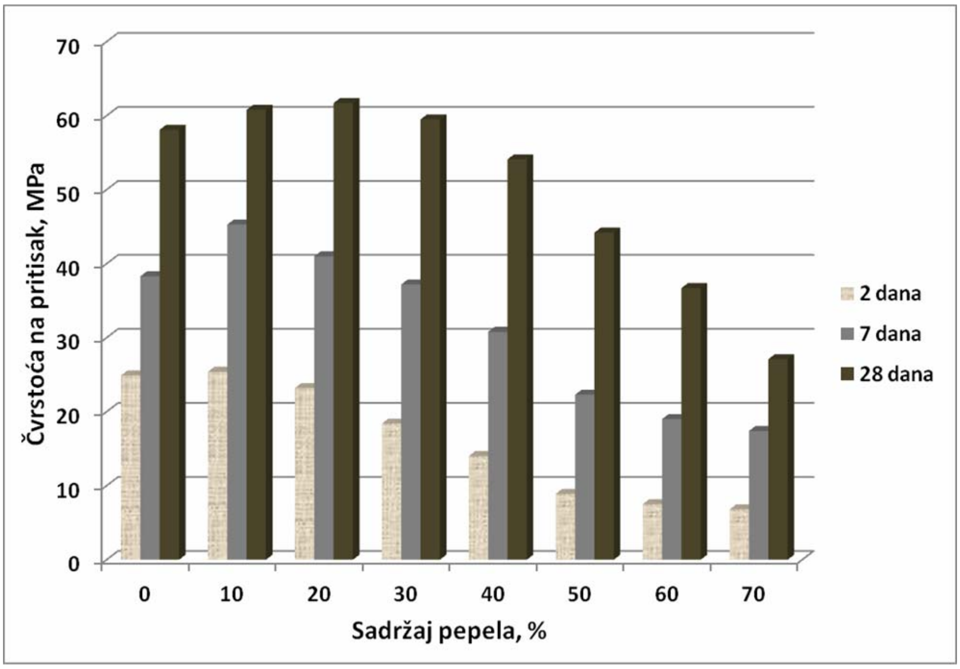
Količina pepela u uzorku, %	Čvrstoća na savijanje, MPa			Čvrstoća na pritisak, MPa		
	2 dana	7 dana	28 dana	2 dana	7 dana	28 dana
0	5,7	7,7	9,5	24,9	38,3	58,1
10	6,1	8,1	9,8	25,4	45,3	60,8
20	5,4	7,2	9,0	23,2	41	61,7
30	4,1	6,9	9,0	18,4	37,2	59,5
40	3,2	6,2	8,5	14,0	30,8	54,1
50	2,5	4,9	7,7	8,9	22,3	44,2
60	2,5	4,1	6,4	7,5	19	36,7
70	1,9	3,2	5,4	6,8	17,4	27,1

Tabela 5. *Čvrstoće na pritisak i savijanje maltera koji sadrže mleveni leteći pepeo*

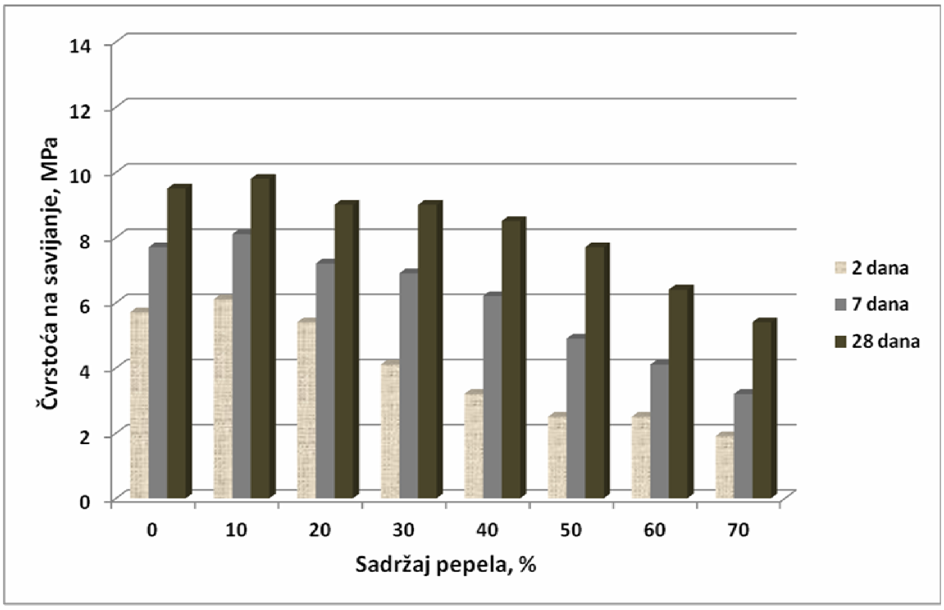
Količina pepela u uzorku, %	Čvrstoća na savijanje, MPa			Čvrstoća na pritisak, MPa		
	2 dana	7 dana	28 dana	2 dana	7 dana	28 dana
0	5,7	7,7	9,5	24,9	38,3	58,1
10	4,4	7,8	9,1	19,6	41,8	59,6
20	3,9	6,5	8,5	18,1	36,9	53,1
30	3,5	6	7,8	15,8	31,1	49,4
40	2,7	4,7	7,3	11,9	24,9	47,3
50	2,5	3,9	6,2	10,6	19,5	36,3
60	1,8	3	4,9	8,2	13,2	26,7
70	1,3	2,2	3,9	5,1	12,3	21,5

Tabela 6. Čvrstoće na pritisak i savijanje maltera koji sadrže prosejani leteći pepeo

Količina pepela u uzorku, %	Čvrstoća na savijanje, MPa			Čvrstoća na pritisak, MPa		
	2 dana	7 dana	28 dana	2 dana	7 dana	28 dana
0	5,7	7,7	9,5	24,9	38,3	58,1
10	4,3	6,8	8,8	19,3	37,9	56,6
20	3,8	6,6	8,5	16,9	35,2	53,2
30	3,3	5,6	7,6	15,6	29,1	45,8
40	2,9	5	7,1	13,7	24,8	39,1
50	2,4	3,8	5,9	9,8	18,1	33,3
60	1,5	3,1	5,2	7,3	11,4	24,2
70	1,2	1,8	3,3	4,9	9	19,4



Sl. 5. *Čvrstoća na pritisak maltera koji sadrže aktivirani leteći pepeo*



Sl. 6. *Čvrstoća na savijanje maltera koji sadrže aktivirani leteći pepeo*

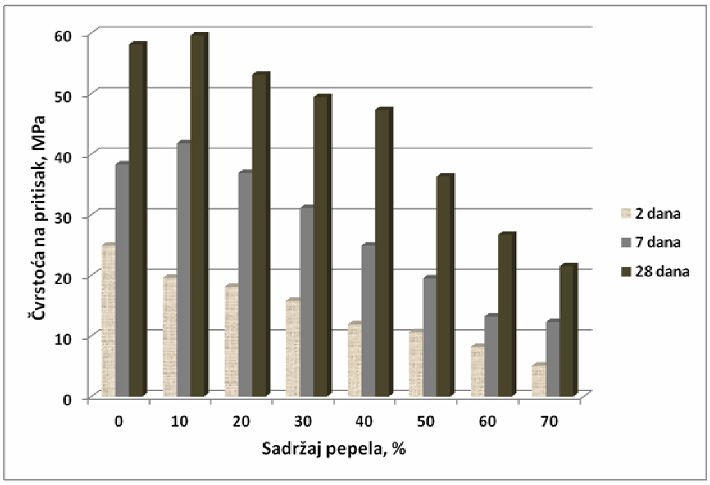
Iz tabele 4 i sa slika 5 i 6 se može uočiti da supstitucija cementa aktiviranim letećim pepelom do određene količine može uticati na povećanje čvrstoće maltera. Tako malteri koji sadrže hidraulična veziva sa 10, 20 i 30% aktiviranog letećeg pepela postižu čak veću čvrstoću na pritisak nakon 28 dana nego malter koji kao vezivo sadrži samo portland cement. Pri tome, u zavisnosti od sadržaja pepela, čvrstoće maltera na pritisak posle 2 dana (početna čvrstoća) i čvrstoće na pritisak posle 28 dana (tzv. marka cementa), ove smeše se mogu svrstati u određeni tip cementa (SRPS B.C1.011) i to:

- smeše sa 10 i 20% aktiviranog pepela pripadaju tipu portland cemenata sa dodatkom silikatnog letećeg pepela u količini do 20%, daju normalnu početnu čvrstoću, a nakon 28 dana postižu čvrstoću na pritisak veću od 50 MPa. Ovi cementi prema standardu nose oznaku PC 20V 52,5N
- smeša koja sadrži 30% mlevenog pepela pripada tipu portland cementa sa dodatkom slilikatnog letećeg pepela u količini 20 – 35%, daje normalnu početnu čvrstoću, a nakon 28 dana takođe postiže čvrstoću na pritisak veću od 50 MPa. Ovaj cement nosi oznaku PC 35V 52,5N.

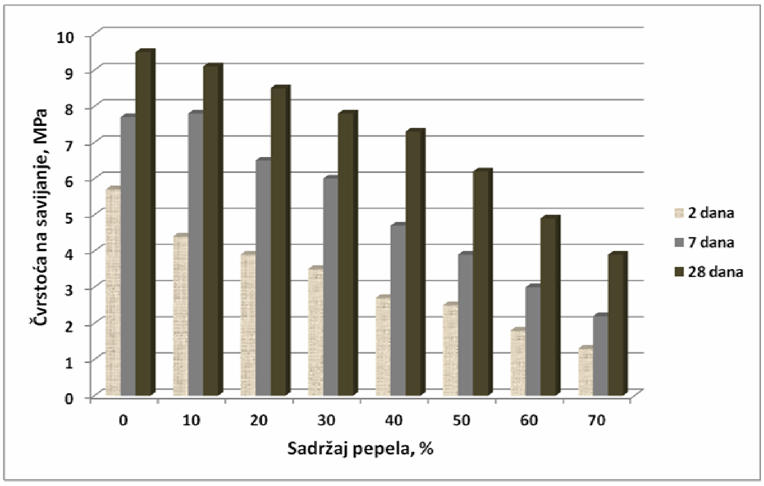
Neke od smeša koje sadrže veći procenat aktiviranog letećeg pepela (preko 35%) mogu se svrstati u pucolanske cemente:

- smeše koje sadrže 40 i 50% aktiviranog letećeg pepela pripadaju tipu pucolanskih cemenata sa dodatkom aditiva u količini 11 – 55%, nakon 28 dana dostižu čvrstoću na pritisak veću od 40 MPa i nose oznaku P55 42,5N. Treba istaći da bi se smeša koja sadrži 40% aktiviranog pepela, prema čvrstoći na pritisak koju dostiže nakon 28 dana, mogla svrstati u višu klasu cemenata, među tim, to nije moguće zbog relativno niske početne čvrstoće od 14,0 MPa.

- smeše koje sadrže više od 55% aktiviranog letećeg pepela ne mogu se svrstati u cemente bilo kog tipa prema pomenutom standardu.
- Na osnovu podataka iz tabele 5 i sa slika 7 i 8 može se konstatovati da sa povećanjem sadržaja mlevenog letećeg pepela u smešama, čvrstoća na savijanje i pritisak maltera generalno opada. Ipak, treba naglasiti da malter koji sadrži smešu sa 10% pepela postiže veću čvrstoću na pritisak nakon 7 i 28 dana od maltera sa čistim portland cementom. Analogno prvoj seriji opita, pojedine smeše pripadaju određenim tipovima cementa (SRPS B.C1.011):

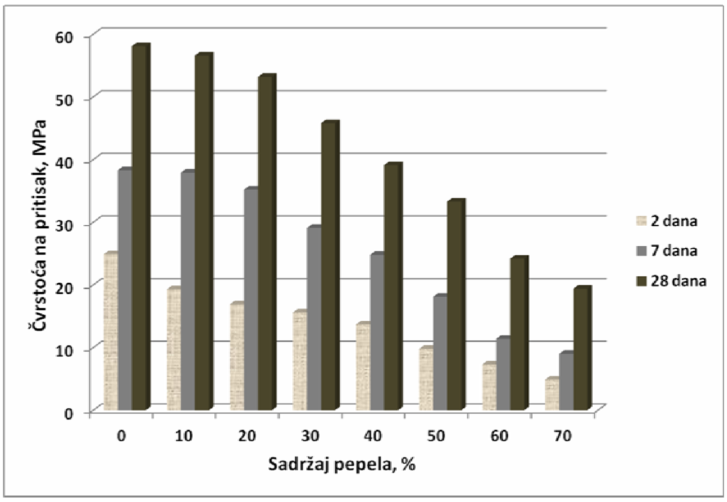


Sl. 7. *Čvrstoća na pritisak maltera koji sadrže mleveni leteći pepeo*

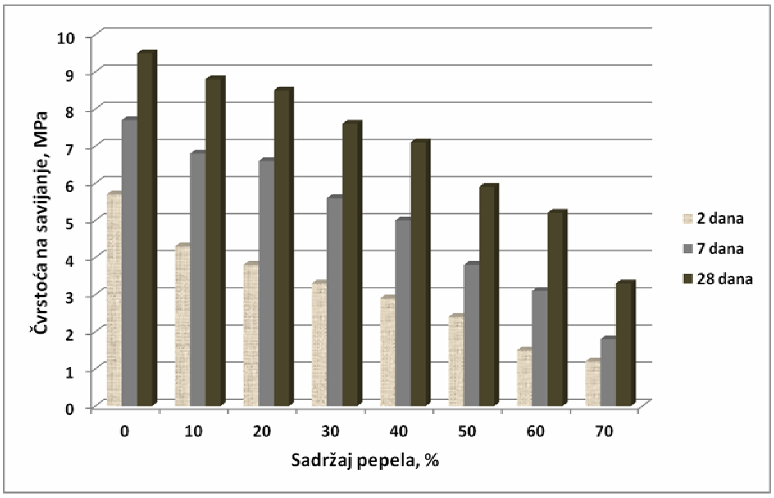


Sl. 8. *Čvrstoća na savijanje maltera koji sadrže mleveni leteći pepeo*

- smeše sa 10 i 20% mlevenog pepela pripadaju tipu portland cemenata sa dodatkom slilikatnog letećeg pepela u količini do 20% i prema standardu nose oznaku PC 20V 52,5N
- smeša koja sadrži 30% mlevenog pepela pripada tipu portland cementa sa dodatkom slilikatnog letećeg pepela u količini 20 – 35%. Ovaj cement nosi oznaku PC 35V 42,5N
- smeše koje sadrže 40 i 50% mlevenog letećeg pepela pripadaju tipu pucolanskih cemenata sa dodatkom aditiva u količini 11 – 55%, sa oznakama P55 42,5N i P55 32,5N, redom.



Sl. 9. *Čvrstoća na pritisak maltera koji sadrže prosejani leteći pepeo*



Sl. 10. *Čvrstoća na savijanje maltera koji sadrže prosejani leteći pepeo*

Kao što se može videti iz tabele 6 i sa slika 9 i 10, u trećoj seriji opita, sa povećanjem količine prosejanog letećeg pepela u smešama, ravnomerno opadaju njihova čvrstoća na savijanje i pritisak. Pored toga, analogno prvoj i drugoj seriji opita, cementi sa 10, 20 i 30% pepela mogu se svrstati u portland cemente sa dodatkom silikatnog letećeg pepela u količini do 20%, odnosno do 35% i prema čvrstoći na pritisak koju daju nakon 2 i 28 dana od spravljanja epruveta, nose oznake PC 20V 52,5N, PC 20V 42,5 N i PC 35V 42,5N. Smeše koje sadrže 40 i 50% prosejanog pepela pripadaju pucolanskim cementima iste oznake, tj. P55 32,5N.

5. ZAKLJUČAK

Mehaničke karakteristike maltera koji kao hidraulična veziva sadrže smeše portland cementa i letećeg pepela u velikoj meri zavise od količine pepela u smeši, kako je i očekivano. Međutim, supstitucija cementa aktiviranim letećim pepelom (prva serija opita) dala je znatno bolje rezultate u pogledu fizičko-mehaničkih karakteristika maltera, nego što je to postignuto u druge dve serije opita, kada je kao supstituent korišćen mleveni, odnosno prosejani leteći pepeo. Očigledno je da se mehaničkom aktivacijom može u znatnoj meri uticati na pucolanska svojstva letećeg pepela, a samim tim i na karakteristike mešavina portland cement – leteći pepeo. Kada se uporede prva i druga serija opita, zaključak je da nema velike razlike u tome da li je leteći pepeo samleven ili prosejan do adekvatne klase krupnoće (u ovom slučaju -75 +0 μm). Ipak, nešto bolji rezultati su postignuti prilikom upotrebe mlevenog letećeg pepela, posebno kod smeša koje sadrže 20 i 40% pepela. Tako, smeše iz druge serije opita koje sadrže 20 i 40% mlevenog letećeg pepela pripadaju višoj klasi cemenata u odnosu na pandane iz treće serije opita.

Prema srpskim standardima, maksimalna količina pucolana koja se može dodati cementu iznosi 55%, tako da se smeše sa 60 i 70% letećeg pepela ne mogu svrstati ni u jedan tip cemenata, bilo da se radi o aktiviranom, mlevenom ili pro-sejanom letećem pepelu. Ipak, ovakvi materijali svakako mogu naći primenu (u putogradnji, solidifikaciji zemljišta, itd.) jer je čvrstoća na pritisak koju oni daju nakon 28 dana odležavanja epruveta u vodi relativno visoka, posebno ako se uzme u obzir količina pepela koja zamenjuje cement u ovim hidrauličnim vezivima.

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MECHANICAL CHARACTERISTICS OF MORTAR CONTAINING FLY ASH TREATED BY DIFFERENT PHYSICAL METHODS**

Abstract

This paper presents the results of laboratory tests with the aim to determine the effect of fly ash treated with various physical methods (mechanical activation, grinding and sieving) to the mechanical characteristics of mortar and its compressive and bending strength. Fly ash is used in this testing as a substituent for cement in hydraulic binders. Substitution of Portland cement with fly ash ranged from 10 to 70 % mass. The most favorable results were obtained in replacement the Portland cement with fly ash that was previously mechanically activated in a laboratory vibrating ring mill.
Keywords: *ash, cement, mortar, strength*

1. INTRODUCTION

Pozzolanic materials (pozzolana) are silicate or aluminosilicate materials which by themselves possess very little or no cementation properties. However, a very important characteristic of pozzolanic materials is their ability to react with lime or Portland cement in the presence of water. Namely, SiO_2 and Al_2O_3 that form a part of pozzolanic materials react with calcium hydroxide, $Ca(OH)_2$, to form the hydrated calcium silicate as well as hydrated calcium aluminate compounds. These compounds are not soluble in water.

Pozzolanic materials are divided into natural (volcanic ash, pumice, diatomaceous earth) and artificial (fly ash, microsilica, metakaolin, etc.). A great attention is paid in the world literature to the properties of pozzolanic materials and their impact on characteristics of different building materials [1-6].

Fly ash is a finely dispersed product of coal combustion from thermal power plants, separated from flue gases, whose grain size ranges from 0 to 1 mm. It is a heterogeneous material composed of particles of different

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physical, chemical, mineralogical and morphological properties, which depends coal quality and combustion conditions and technology. According to the literature, the annual production of fly ash in Serbia amounts to more than 5 000 000 tons [7].

Thanks to the pozzolanic properties of fly ash, the material can be applied in the production of hydraulic binders and concrete (especially in the production of Portland cement clinker, as an active component that can partially replace the cement, or as an aggregate in concrete).

In order to replace partially cement, the fly ash has to meet the certain requirements of the standard in terms of chemical and physico-mechanical properties.

Fly ash that are produced in the territory of the Republic of Serbia are of such quality that they can be successfully applied as building materials (not only in the cement and concrete industry, but also for the construction of roads, soil solidification, etc.). Despite this, the largest amounts of fly ash are still not found their application and they are located within the ash dump. Taking into account this fact, it is necessary to take the certain measures in order to discuss and provide any possibility of its use.

In addition to using the fly ash for commercial purposes reduces its negative impact on the environment; this directly contributes to the conservation of natural mineral resources, reducing the costs to their exploitation and disposal, as well as the costs related to the disposal of ash. Accordingly, it should be noted that during construction of the fly ash dump, the all required statutory provisions have to be complied [8], what may also have an impact on the costs of disposal.

2. CHARACTERIZATION AND PREPARATION OF STARTING SAMPLES

2.1. Characterization of starting samples

The starting sample of fly ash, used in this testing, was taken from the thermal power plant "Nikola Tesla" - Obrenovac. According to its chemical composition (as shown in Table 1), this ash has high content of chemically active SiO_2 and high content of acidic oxides (SiO_2 + Al_2O_3 + Fe_2O_3) and low content of base oxides (CaO, MgO). Based on this, and according to the Standard SRPS B.C1.018, this ash can be placed in the artificial pozzolana - siliceous fly ash. Grain size distribution and mineralogical composition of this sample are shown in Figures 1 and 2.

A sample of Portland cement was taken from a cement factory "Titan Cement Plant Kosjerić" for the purposes of these tests. Cement is a high quality, mark PC 52.5 N (SRPS B.C1.011), and it was obtained by grinding the Portland cement clinker with addition of calcium sulfate up to 5%. In terms of chemical, physical and mechanical properties, this cement has fully complied the requirements prescribed by the Standard. Tables 1 and 2 show its chemical composition, physic-mechanical properties, and Figures 1 and 3 show its grain size distribution and mineralogical composition.

Table 1. *Chemical composition of fly ash and Portland cement samples*

Component	Content, %	
	Fly ash	Portland cement
SiO_2	56.19	20.92
Al_2O_3	23.61	5.81
Fe_2O_3	5.37	3.55
CaO	6.42	63.07
MgO	2.11	1.86
SO_3	2.05	1.89
TiO_2	0.68	/
Na_2O	0.48	0.20
K_2O	0.87	0.74
MnO	/	0.09
Cl	/	0.003
CaO active	0.29	/
SiO_2 active	31.22	/
Loss of ignition	2.04	0.96

Table 2. Physico-mechanical characteristics of the Portland cement sample

Flexural strength, MPa	2 days		4.9
	7 days		7.6
	28 days		8.7
Compressive strength, MPa	2 days		20.7
	7 days		44.5
	28 days		61.4
Binding	Water requirement for standard consistency, ml		25.8
	Initial, h : min		2:35
	Final, h : min		3:30
Volume constancy	Cement specimens	In water	Without deformations
		In the air	Without deformations
		Boiled	Without deformations
	Ring		Without deformations
Residue on sieve opening size 90 µm, %			1.20
Density, g/cm^3			3.15
Specific surface area, cm^2/g			3850
Wet, %			0.43

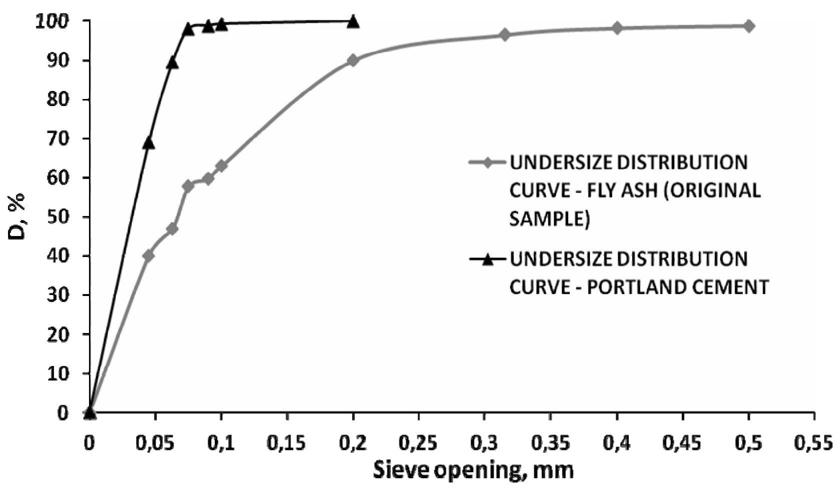

Fig. 1. *Grain size distribution of fly ash and Portland cement*

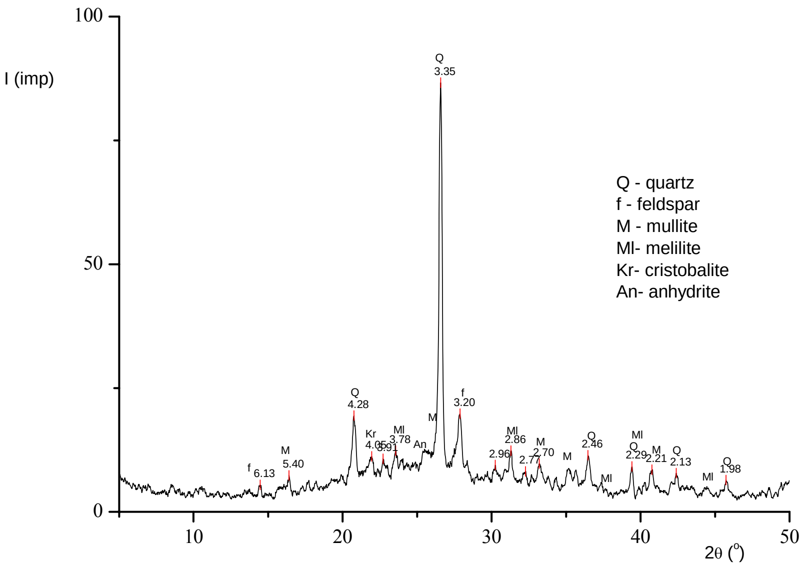

Fig. 2. *Mineralogical composition of fly ash*

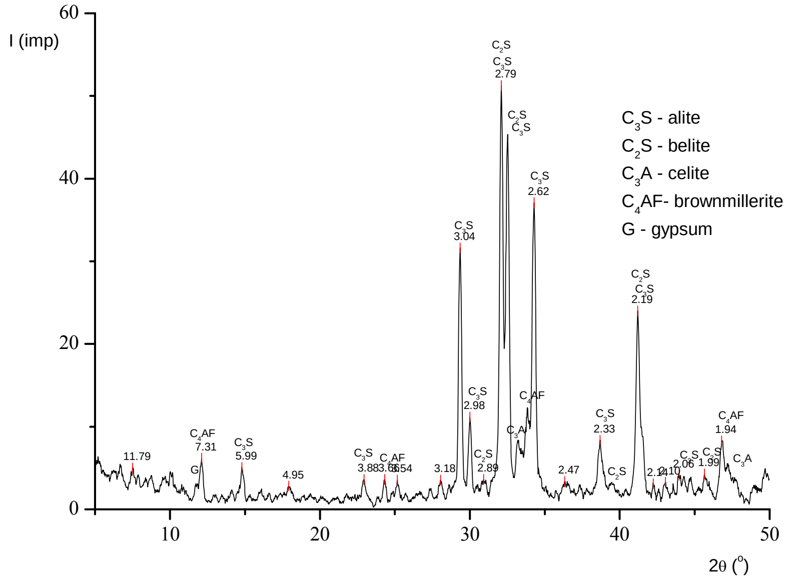

Fig. 3. *Mineralogical composition of Portland cement*

2.2. Preparation the samples of fly ash for the needs of testing

For the needs of formation the hydraulic binders containing the Portland cement and fly ash in different mass ratios, the starting sample of fly ash was treated by different physical methods. A mechanical activation in a vibrating ring mill for the period of 35 minutes was performed on one part of sample.

The second part of sample was ground in a laboratory ball mill for the period of 22 minutes, in order to achieve the appropriate fineness of ash in accordance with the Standard ASTM C618 (minimum 66%, class -45 + 0 μm).

The analysis of grain size distribution of the starting sample (Figure 1) has showed that screening on a sieve of 75 μm resulted into satisfactory fineness of fly ash (according to the Standard), so that the third part of sample was treated by the method of dry screening on the given sieve. Grain size distributions of each sample, obtained after appropriate treatment, are shown in Figure 4, and their pozzolanic activity and specific surface area in Table 3.

Table 3. *Physical characteristics of fly ash treated by different methods*

Type of fly ash	Pozzolanic activity		Specific area per Blaine, cm^2/g
	Flexular strength, MPa	Compressive strength, MPa	
activated	5.3	17.2	11770
ground	4.2	12.5	6940
sieved	4.0	9.5	3810

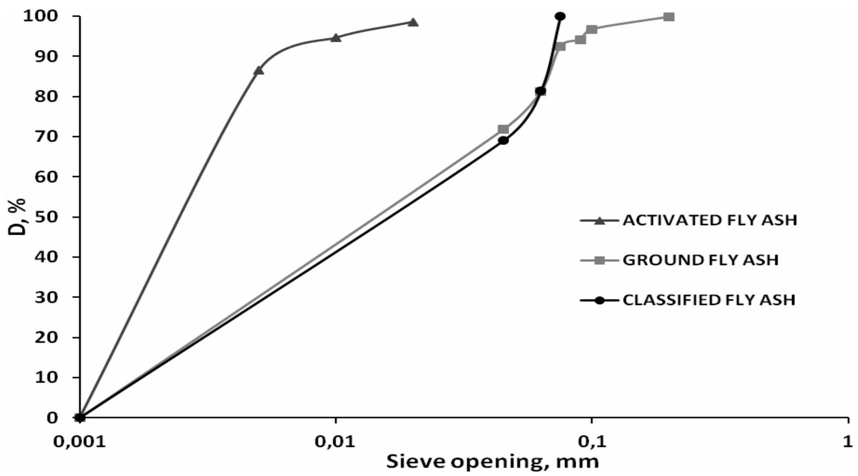

Fig. 4. *Grain size distribution of activated, ground and sieved fly ash*

3. EXPERIMENTAL TESTING

Further experimental procedure was carried out through three series of experiments. In the first series of experiments, varying amounts of activated fly ash (10, 20, 30, 40, 50, 60 and 70%) were added to the Portland cement, and then the resulting mixtures were homogenized for equalization the chemical composition. In the second series of experiments, the analogue ground amounts of fly ash were added to the Portland cement and then a homogenization of mixtures was also made. The same procedure was repeated in the third series of experiments, where the sieved fly ash was used as a substituent for cement. From such obtained binding materials, a mortar was formed according to the Standard method. On specimens of mortar, after 2, 7, and 28 days of aging in aqueous media, the compressive strength and bending strength (standard method on the press "Toni Technik") were tested. The tests were performed in the cement plant "Titan Cement Plant Kosjerić".

4. RESULST AND DISCUSSION

The results of experimental testing are present in Tables 4 – 6 and Figures 5 – 10.

Table 4. *Flexural and compressive strengths of mortar containing the activated fly ash*

Amount of ash in sample, %	Flexural strength, MPa			Compressive strength, MPa		
	2 days	7 days	28 days	2 days	7 days	28 days
0	5.7	7.7	9.5	24.9	38.3	58.1
10	6.1	8.1	9.8	25.4	45.3	60.8
20	5.4	7.2	9.0	23.2	41	61.7
30	4.1	6.9	9.0	18.4	37.2	59.5
40	3.2	6.2	8.5	14.0	30.8	54.1
50	2.5	4.9	7.7	8.9	22.3	44.2
60	2.5	4.1	6.4	7.5	19	36.7
70	1.9	3.2	5.4	6.8	17.4	27.1

Table 5. *Flexural and compressive strengths of mortar containing the ground fly ash*

Amount of ash in sample, %	Flexural strength, MPa			Compressive strength, MPa		
	2 days	7 days	28 days	2 days	7 days	28 days
0	5.7	7.7	9.5	24.9	38.3	58.1
10	4.4	7.8	9.1	19.6	41.8	59.6
20	3.9	6.5	8.5	18.1	36.9	53.1
30	3.5	6	7.8	15.8	31.1	49.4
40	2.7	4.7	7.3	11.9	24.9	47.3
50	2.5	3.9	6.2	10.6	19.5	36.3
60	1.8	3	4.9	8.2	13.2	26.7
70	1.3	2.2	3.9	5.1	12.3	21.5

Table 6. *Flexural and compressive strengths of mortar containing the sieved fly ash*

Amount of ash in sample, %	Flexural strength, MPa			Compressive strength, MPa		
	2 days	**7 days**	**2 days**	**7 days**	**2 days**	**7 days**
0	5.7	7.7	9.5	24.9	38.3	58.1
10	4.3	6.8	8.8	19.3	37.9	56.6
20	3.8	6.6	8.5	16.9	35.2	53.2
30	3.3	5.6	7.6	15.6	29.1	45.8
40	2.9	5	7.1	13.7	24.8	39.1
50	2.4	3.8	5.9	9.8	18.1	33.3
60	1.5	3.1	5.2	7.3	11.4	24.2
70	1.2	1.8	3.3	4.9	9	19.4

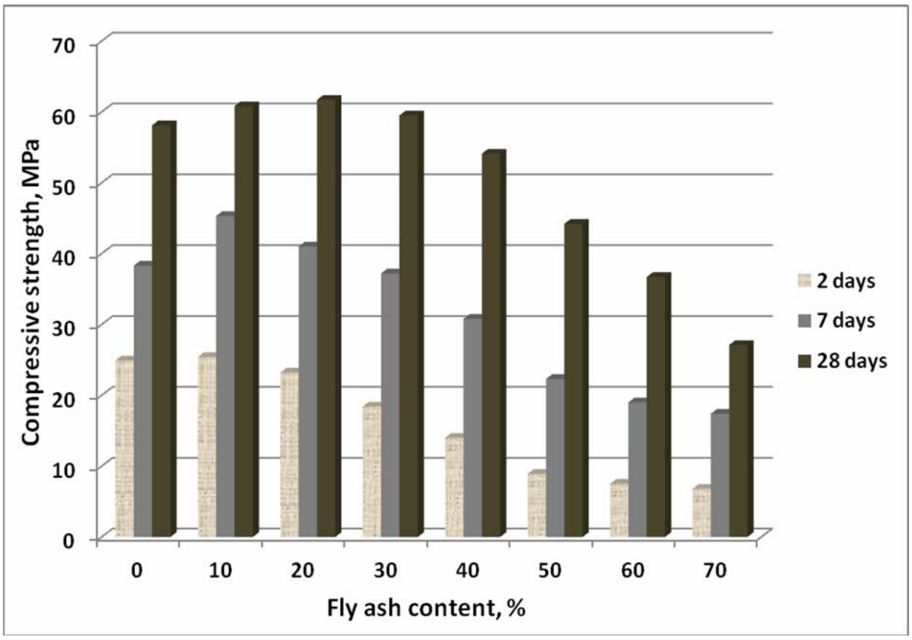

Fig. 5. *Compressive strength of mortar containing the activated fly ash*

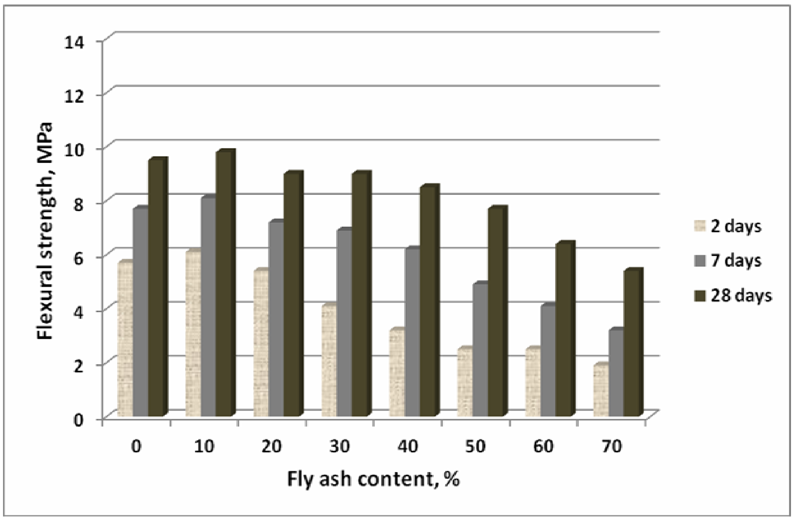

Fig. 6. *Flexural strength of mortar containing the activated fly ash*

It can be seen from Table 4 and Figures 5 and 6 that the substitution of cement with activated fly ash to the certain amounts can cause an increase in strength of mortar. So mortars containing hydraulic binders with 10, 20 and 30% activated fly ash achieve even higher compressive strength after 28 days than mortar as a binder containing only the Portland cement. In addition, depending on the ash content, the strength of mortar on pressure after 2 days (the initial strength) and compressive strength after 28 days (so called the brand of cement), these mixtures can be classified into a specific type of cement (SRPS B.C1.011) as follows:

- mixtures with 10 and 20% of activated ash, belonging to the type of Portland cement with addition of silica fly ash to the amount up to 20%, give normal early strength, and after 28 days achieve a compressive strengths higher than 50 MPa. These cements are marked according to the Standard PC 20V 52.5 N,
- mixture that contains 30% of the ground ash belong to the type of Portland cement with addition of silica fly ash to the amount 20 - 35%, giving a normal early strength, and after 28 days also achieves a compressive strength higher than 50 MPa. This cement is marked PC 35V 52.5 N.

Some of the mixtures containing higher percentage of activated fly ash (over 35%) can be classified in the pozzolanic cements:

- mixtures containing 40 and 50% of activated fly ash belong to the type of pozzolanic with additives in the amount of 11-55%; after 28 days they reach the compressive strength higher than 40 MPa and they are marked with P55 42.5 N. It should be noted that a mixture, containing 40% activated ash, regarding to the compressive strength that is reached after 28 days, could be classified into higher class of cements, however, this is not possible due to the relatively low initial strength of 14.0 MPa,
- mixtures, containing more than 55% of activated fly ash, cannot be classified into any type of cement according to this Standard,

- based on data from Table 5 and Figures 7 and 8, it can be concluded that with the increase of ground fly ash content in mixtures, the bending and compressive strength of mortar generally decreases. However, it should be noted that the mortar, containing a mixture with 10% fly ash, achieves higher compressive strength after 7 and 28 days than the mortar with pure Portland cement. Analogous to the first series of experiments, some of the mixtures belong to the certain types of cement (SRPS B.C1.011):

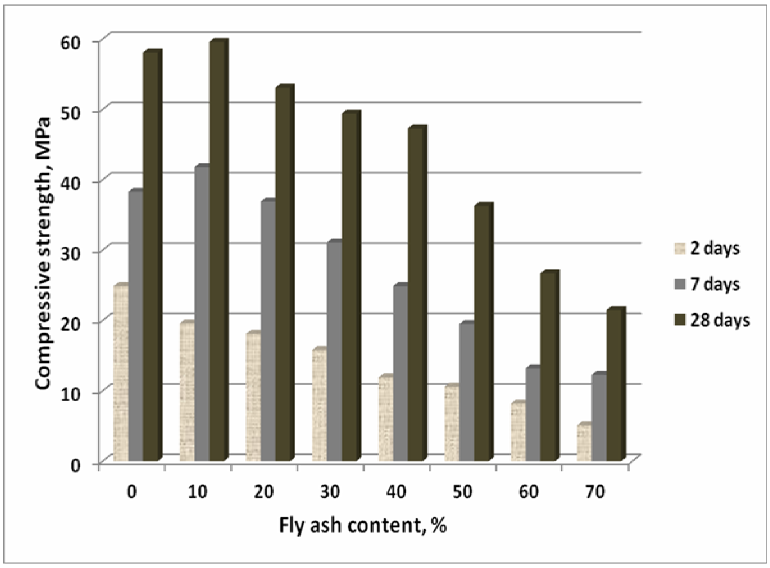

Fig. 7. *Compressive strength of mortar containing the ground fly ash*

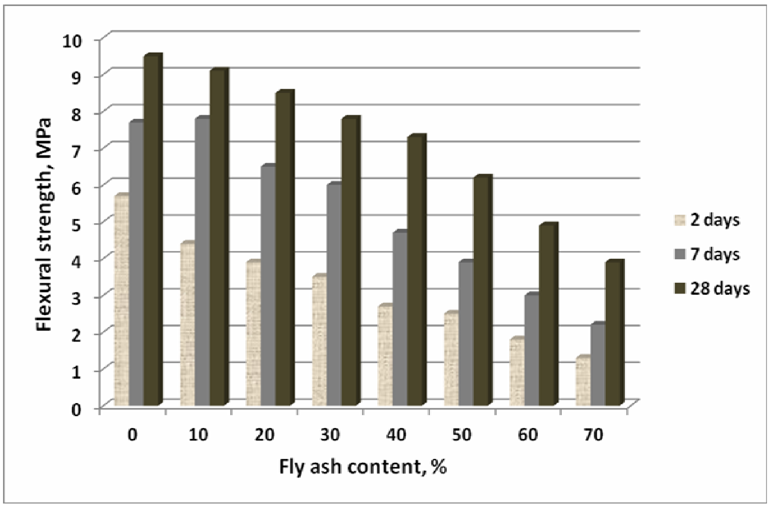

Fig. 8. *Flexural strength of mortar containing the ground fly ash*

- mixtures with 10 and 20% of ground ash belong to the type of Portland cement with silicate fly ash addition in the amount up to 20%, and according to the Standard they are marked with PC 20V 52.5 N,
- mixture, containing 30% of ground ash, belong to the type of Portland cement with addition of silicate fly ash in the amount of 20 - 35%. This cement is marked with PC 35V 42.5 N,
- mixtures, containing 40 and 50% of ground fly ash, belong to the type of pozzolanic cements with additive in the amount of 11-55%, with marks P55 and P55 42.5 N 32.5 N, respectively.

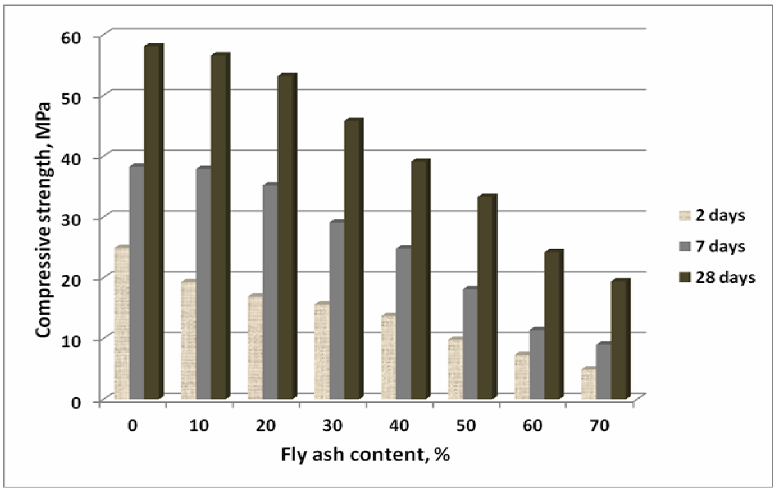

Fig. 9. *Compressive strength of mortar containing the sieved fly ash*

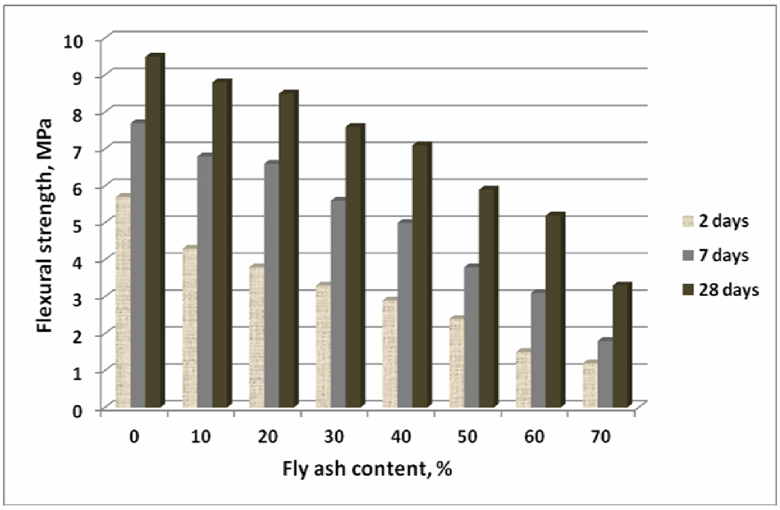

Fig. 10. *Flexural strength of mortar containing the sieved fly ash*

As it can be seen from Table 6 and Figure 9 and 10, in the third series of experiments, with increasing amount of sieved fly ash in mixtures, their banding and compressive strengths decrease uniformly. Furthermore, analogue to the first and second series of experiments, the cements with 10, 20 and 30% of fly ash can be classified into the Portland cements with silica fly ash addition in the amount up to 20%, i.e. up to 35% and according to their the compressive strength after 2 and 28 days of preparing the specimens, marked as PC 20V 52.5N, PC 20V 42.5 N and PC 35V 42.5N. Mixtures, containing 40 and 50% of sieved ash, belong to the pozzolanic cements of the same mark, P55 32.5 N.

5. CONCLUSION

Mechanical characteristics of mortar as a hydraulic binder containing the mixtures of Portland cement and fly ash are highly dependent on the amount of ash in the mixture, as it is expected. However, substitution of cement with activated fly ash (first series of experiments) gave significantly better results in terms of physico-mechanical characteristics of mortar than it is achieved in the other two series of experiments, when the ground and sieved fly ash was used as a substitute. It is obvious that the mechanical activation can significantly affect the pozzolanic properties of fly ash, and therefore the characteristics of mixtures of Portland cement - fly ash. When comparing the first and second series of experiments, the conclusion is that there is no a great difference in whether the fly ash is ground or sieved to the appropriate size class (in this case -75 +0 μm). However, slightly better results were achieved in using the ground fly ash, especially in mixtures containing 20 and 40% of ash. Thus, the mixtures from the second series of experiments, containing 20 and 40% of fly ash ground, belong to higher class of cements compared to the counterparts from the third series of experiments.

According to the Serbian Standards, maximum amount of pozzolan that can be added to cement is 55%, so that the mixtures of 60 and 70% fly ash cannot be classified into any type of cements, whether it is activated, ground or sieved fly ash. Nevertheless, such materials can certainly find application (in the road construction, soil solidification, etc.). because their compressive strength after 28 days of aging the specimens in water is relatively high, especially if it is taken into account the amount of ash that replaces cement in these hydraulic binders.

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UTICAJ RUDNIČKIH OBJEKATA RTB BOR NA ZAGAĐENJE OKOLNIH POVRŠINSKIH VODOTOKOVA**

Izvod

Otpadne vode koje se generišu u pogonima RTB-a Bor, bilo direktno tokom tekuće proizvodnje ili indirektno usled razlaganja odložene rudničke raskrivke i flotacijske jalovine formiranjem kiselih drenažnih voda, zagađuju Borsku i Kriveljsku reku, koja se dalje uliva u reku Timok, odnosno reku Dunav.

Ključne reči: *kisele rudničke vode, teški metali, RTB Bor, zagađenje reka*

UVOD

Procenjuje se da iz deponija u Republici Srbiji nastane oko 890.000 m^3 procednih voda dnevno, koje sadrže 41.590 tona raznog organskog i neorganskog zagađenja, 389 tona azota i 426 tona fosfora, kao i teške metale kao što su bakar, cink, nikl i hrom. Značajno mesto u zagađenju voda zauzimaju prostori deponovane flotacijske i rudničke jalovine nastale u procesu rudarsko-prerađivačke industrije (flotacijska jalovišta i odlagališta Bora i Majdanpeka, Rudnika, Velikog Majdana, Zajače, Raške, Vranja, i dr.), deponije nastale pri metalurškoj preradi mineralnih sirovina i deponije pepela i šljake nastale pri energetsko-toplotnoj proizvodnji (termoelektrane i toplane).

STANJE POVRŠINSKIH VODOTOKOVA U ZONI UTICAJA RTB BORA

Otpadne vode koje se generišu u pogonima RTB-a Bor slika 1, (bilo direktno tokom tekuće proizvodnje ili indirektno usled razlaganja odložene rudničke raskrivke i flotacijske jalovine formiranjem kiselih drenažnih voda) zagađuju Borsku i Kriveljsku reku, koja se dalje uliva u reku Timok, odnosno reku Dunav.

* *Institut za rudarstvo i metalurgiju Bor*

** *Ovaj rad je proistekao iz Projekta broj TR: 37001 „Uticaj rudarskog otpada iz RTB-a Bor na zagađenje vodotokova sa predlogom mera i postupka za smanjenje štetnog dejstva na životnu sredinu“ koji je finansiran sredstvima Ministarstva prosvete, nauke i tehnološkog razvoja Republike Srbije.*

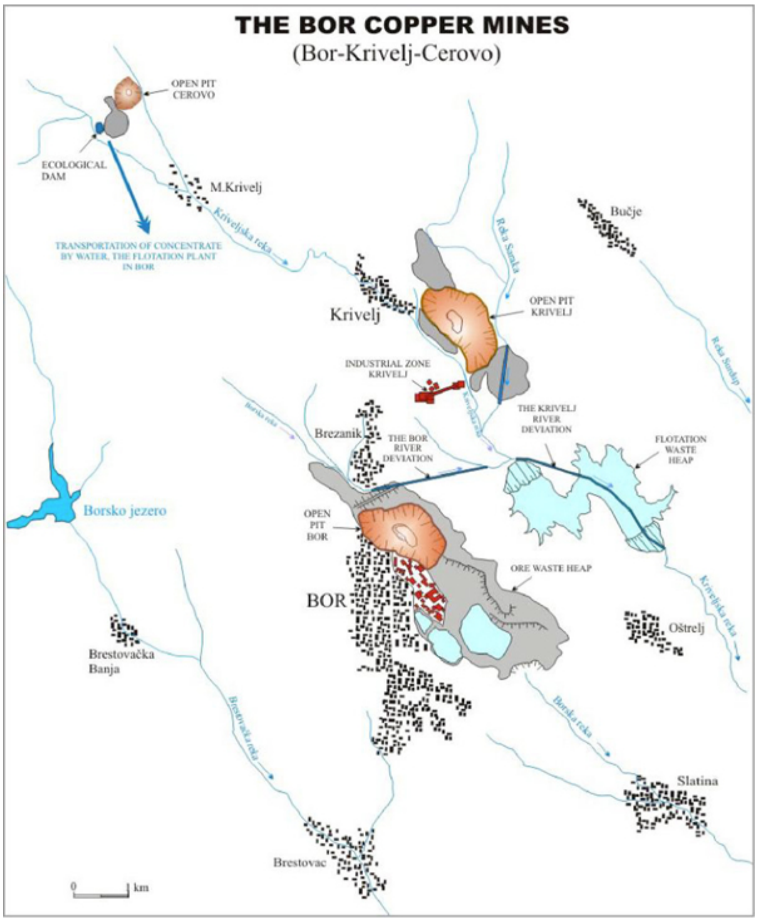
Ova zagađenja su najčešće predstavljena niskom pH vrednošću, povećanim sadržajem jona teških metala, suspendovanim česticama i finim česticama flotacijske jalovine koja je deponovana u dolinama navedenih reka na površini od preko 2000 hektara. Osim što drenažne vode sa aktivnih i neaktivnih jališta i kopovskih odlagališta pogona RTB-a direktno zagađuju površinske vodotokove, pod direktnim štetnim uticajem površinskih voda su i aluvijalne izdani u rečnim dolinama kroz koje navedene reke protiču.

Vodotokovi na prostoru Mali Krivelj – Zagrađe pripadaju slivu Bela reka, Timočkom slivu, odnosno slivu Dunava.

Slivu Bele reke pripadaju:

1. Kriveljska reka sa svojim pritokama;
2. Cerova reka sa svojim pritokama;
3. Borska reka sa svojim pritokama;
4. Ravna reka sa svojim pritokama.

Izvore zagađenja ovih vodotokova 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, slika 1.



Sl. 1. *Hidrološka mreža u domenu rudnika Bakra Bor*

Kriveljska reka je ugrožena od izvorišta prema ušću: od strane površinskog kopa Cerovo, od strane odlagališta kopovske jalovine površinskog kopa Cerovo, od strane površinskog kopa Veliki Krivelj, od strane odlagališta kopovske jalovine površinskog kopa Veliki Krivelj (odlagalište Saraka) i od strane flotacijskog jalovišta Veliki Krivelj (polje I i II).

Cerova reka je ugrožena od izvorišta prema ušću: od strane površinskog kopa Cerovo i od strane odlagališta kopovske jalovine površinskog kopa Cerovo.

Borska reka je ugrožena od izvorišta prema ušću: od strane grada Bora (komunalne odpadne vode), od strane pogona za preradu rude bakra (odpadne vode TIR-a), od strane odlagališta kopovske jalovine starog Borskog kopa (severo-istočno odlagalište) i od strane flotacijskog aktivnog jalovišta Borske flotacije (jalovište RTH) kao i starog flotacijskog jalovišta u Boru.

Ravna Reka je u prethodnom periodu bila ugrožena otpadnim vodama pogona za preradu kvarcnog peska „Belorečki Peščar“. Sa sanacijom pogona za preradu, Bela reka više nije ugrožena.

Pored gore pobrojanih reka, na ovom prostoru postoji i niz potoka koji su takođe ugroženi, a pripadaju slivovima gore navedenih reka, a samim tim i slivu Bele reke.

Potok Valja Lutarica, koji sa potocima Bigar i Deljboka formira Cerovu reku ugrožen je od strane: površinskog kopa Cerovo i od strane odlagališta kopovske jalovine površinskog kopa Cerovo.

Saraka potok koji pripada slivu Kriveljske reke ugrožen je od strane: površinskog kopa Veliki Krivelj i od strane odlagališta kopovske jalovine površinskog kopa Veliki Krivelj (odlagalište Saraka).

Borski potok koji posle izvršenog izmeštanja iz prirodnog korita takođe pripada slivu Kriveljske reke ugrožen je vodama koje se ispumpavaju iz pogona za podzemnu eksploataciju bakra „Jama Bor“ kao i odložene kopovske jalovine, ispod kojih jednim delom potok protiče.

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 Socijalističke Republike Srbije br. 31/82 (parametri hemijskog kvaliteta). U vezi sa parametrima hemijskog kvaliteta, izbor najreprezentativnijih – karakterističnih elemenata je prikazan u tabeli 1.

***Tabela 1**. Maksimalne količine opasnih materija u vodama u mg/l vode po klasama određenim propisima o klasifikaciji voda*

Br.	**Opasne materije i rN**	**Količina mg/l**	
		Klase	
		I / II	**III / IV**
1.	Kadmijum	0.005	0.01
2.	Olovo	0.05	0.1
3.	Živa	0.001	0.001
4.	Arsen	0.05	0.05
5.	Hrom	0.1	0.5
6.	Nikl	0.05	0.1
7.	Fluor	1.0	1.5
8.	Bakar	0.03	1.0
9.	Cink	0.2	1.0

10.	Bor	0.3	1.0
11.	Gvožđe	0.3	1.0
12.	Selen	0.01	0.01
13.	rN	6.8-8.5	6-9

Ovim Pravilnikom propisuju se opasne materije koje se ne smeju direktno ili indirektno unositi u vode. Navedene klase sụ: Klasa I: voda koja u prirodnom stanju ili posle dezinfekcije može da se koristi za piće, prehrambenu industriju; Klasa II: voda koja je odgovarajuća za kupanje, rekreaciju, sportove na vodi, uključujući vodu koja posle osnovnog prečišćavanja (koagulacija, filtracija i dezinfekcija) može da se upotrebi za piće i prehrambenu industriju; Klasa III: voda koja može da se koristi za navodnjavanje i industrije izuzev prehrambene industrije;̣ Klasa IV: voda koja može da se koristi samo posle posebne obrade.

Pravilnik koji propisuje maksimalno dozvoljenu količinu opasnih i štetnih materija u zemljištu i vodi koje mogu da oštete ili promene proizvodnu sposobnost zemljišta i koje dolaze ispuštanjem iz fabrika i izlivanjem iz deponija, dat je u Službenom listu Socijalističke Republike Srbije br. 23/94. U tabeli 2 prikazani su podaci o maksimalno dozvoljenim količinama opasnih i štetnih materija u vodi.

Tabela 2. *Maksimalno dozvoljena količina opasnih i štetnih materija*

Br.	Parametar	MDK u vodi (mg/L)
1.	Kadmijum	Do 0.01
2.	Olovo	Do 0. 1
3.	Živa	Do 0.001
4.	Arsen	Do 0.05
5.	Hrom	Do 0.5
6.	Nikl	Do 0. 1
7.	Fluor	Do 1.5
8.	Bakar	Do 0.1
9.	Cink	Do 1.0
10.	Bor	Do 1.0

Opasne materije, u smislu ovog pravilnika su: kadmijum, olovo, živa, arsen, hrom, nikl i fluor, a štetne materije su: bakar, cink i bor.

Površinski vodotokovi u borskom kompleksu se karakterišu malim protokom i kolebljivim nivoima vode.

Najvažnije reke su Zlotska reka, Borski potok koji posle uliva u RTB Bor industrijske otpadne vode postaje Borska reka, Kriveljska reka, Ravna reka i Timok. U oblasti rudnika Cerovo prisutne su dve reke: Valja Mare, jugoistočno od površinskog kopa i reka Cerovo zapadno od njega. Ova dva toka se spajaju kod Malog Krivelja da bi oformila Kriveljsku reku koja teče u svom prirodnom basenu do površinskog kopa Veliki Krivelj. Rudarske aktivnosti su proteklih godina veoma uticale na prirodne tokove reka, posebno na Borsku reku. Borska reka je prvobitno tekla sa severozapada na jugoistok i dalje do Bora, koja je pre oko 30 godina skrenuta tunelom sagrađenim severno od starog borskog kopa, tako da ona sada utiče u Kriveljsku reku ispred tunela za devijaciju

Kriveljske reke ispod polja 1 flotacijskog jalovišta Veliki krivelj. Tok Kriveljske reke je takođe izmenjen u odnosu na prvobitni tok i to kod površinskog kopa Veliki Krivelj gde sada oivičava kop, i kod jalovišta Veliki Krivelj gde je skrenut u podzemni kolektor koji prolazi ispod flotacijskog jalovišta.

Kriveljska reka sa Borskom i Ravnom rekom čini Belu reku, koja utiče u reku Timok i dalje odlazi u Dunav.

REZULTATI I DISKUSIJA

U tabelama 3 i 3a su prikazani rezultati fizičko hemijskih ispitivanja uzoraka sa lokacije ušća Borske i Kriveljske reke, koje se ulivaju u Belu reku. Uzorci voda su prikupljeni 18. 05. 2012. godine.

Tabele 3 i 3a. *Rezultati fizičko hemijskih ispitivanja uzoraka sa lokacije ušća Borske i Kriveljske reke koji su uzorkovani 18.05.2012.god*

Parametar	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	19	19.3	tamno siva/da	1813	5.40	8.7	0.32	2.8
Kriveljska reka	19	14.6	Svetlo braon/ bez	1307	5.01	12.5	<0.1	0.4
Borska i Kriveljska reka nakon ušća	19	15.7	Svetlo braon/ bez	1598	4.99	12.2	<0.1	1.7

Parametar	Cr (mg/dm^3)	Ni (mg/dm^3)	Cr (mg/dm^3)	Se (mg/dm^3)	As (mg/dm^3)	Fe-uk (mg/dm^3)	Sus.mater. (mg/dm^3)	SO_4^{-2} (mg/dm^3)
Borska reka	<0.1	0.2	<0.1	0.25	0.27	11.8	194.0	1268.5
Kriveljska reka	<0.1	<0.1	<0.1	<0.2	<0.1	2.4	294.0	779.2
Borska i Kriveljska reka nakon ušća	<0.1	0.15	<0.1	<0.2	<0.1	4.9	199.0	1103.1

Za analizu kvaliteta površinskih voda, u borskom regionu, uzeti su kao hemijski parametri prvenstveno teški metali. Sadržaj olova do 1.5 mg/l pojavio se jedino u Borskoj reci i metaluškim otpadnim vodama, kadmijum u drenažnom jezeru Cerova (do 0.35 mg/l), hroma nema, arsena u Jamskim vodama, Borskoj reci i TIR-ovim vodama (od 0.19-6.6 mg/l). Selena ima takođe u TIR-ovim vodama 18.6 mg/l, u Borskoj reci 0.25 mg/l i drenažnim vodama RTH 0.23 mg/l. Koncentracija bakra, cinka, gvožđa je skoro kod svih voda višestruko povećana u odnosu na vrednosti koje su propisane zakonom (maksimalno dozvoljena koncentracija elemenata - MDK, data je u Tabeli 1 i Tabeli 2). Površinske vode u okviru borskog regiona Borska reka, Kriveljska reka i Bela reka po svom sastavu ne mogu da se svrstaju ni u IV klasu i spadaju u vode sa visokim sadržajem potencijalno toksičnih elemenata (teški metali) prema nivou maksimalno dozvoljene koncentracije.

ZAKLJUČAK

Kontinuirano sprovođenje rudarskih i metalurških aktivnosti u trajanju od preko jednog veka na teritoriji opštine Bor, dovelo je do ozbiljnog zagađenja okolnih vodotokova, pre svega borske i kriveljske reke. Kriveljska reka uzvodno od rudnika na Cerovu ima kvalitet vode koji odgovara klasi I/II, koja ima široku upotrebu u poljoprivredi za navodnjavanje, direktno za piće kada su u pitanju domaće životinje i dr. Nizvodno od rudnika na Cerovu menja se drastično kvalitet vode kriveljske reke, kao posledica uliva kontaminiranih otpadnih rudničkih voda sa Cerova, voda sa površinskog kopa Veliki Krivelj, Saraka potoka, jamske vode, drenažnih voda jalovišta Veliki Krivelj. Nizvodno od flotacijskog jalovišta Veliki Krivelj do mesta gde se spajaju borska i kriveljska reka, voda kriveljske reke zbog prisutnog zagađenja, se ne možemo svrstati ni u jednu klasu, odnosno van kategorija je. Obzirom na njen kvalitet ona nema svoju primenu, čak ni u industrijskim objektima. Vodotok borske reke nastaje spajanjem komunalnih voda nakon izlaska iz komunalnog kolektora, drenažnih voda iz TIR-ovog kolektora, vode iz jezera Robule i metalurških voda. Kako su sve navedene vode koje čine vodotok borske reke veoma zagađene, borska reka je čitavim svojim tokom do spajanja sa kriveljskom rekom van kategorije, odnosno van bilo kakve upotrebe. Proces remedijacije zagađenih voda borske i kriveljske reke je dugotrajan proces koji mora započeti odmah, pre svega prečišćavanjem svih industrijskih voda koje nastaju tokom redovne eksploatacije i prerade rude bakra a koje se ispuštaju bez ikakvog prečišćavanja u vodotokove, i tu spadaju pre svega jamske vode, metalurške vode, vode sa aktivnih površinskih kopova. Nakon toga kvalitet voda u borskoj i kriveljskoj reci će se za kratko vreme znatno poboljšati, što predstavlja prvi uslov za prestanak daljeg kontinuiranog zagađenja površinskih vodo-tokova u zoni uticaja industrijskih objekata RTB-a Bor.

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Ljubiša Obradović, Mile Bugarin*, Vladan Marinković**

THE EFFECT OF MINE FACILITIES ON POLLUTION THE SURROUNDING SURFACE WATERWAYS**

Abstract

Wastewater, generated in the sites of RTB Bor, either directly in the current production, or indirectly due to the decomposition of deposited mine overburden material and flotation tailings by formation of acid drainage water, pollute the Bor and Krivelj River, which still flow into the Timok and Danube River.
Keywords: *acid mine water, heavy metals, RTB Bor, pollution of rivers*

INTRODUCTION

It is estimated that the landfills in the Republic of Serbia settle around 890,000 m^3 of seepage water per day, containing 41,590 tons of various organic and inorganic pollution, 389 tons of nitrogen and 426 tons of phosphorus, as well as heavy metals such as copper, zinc, nickel and chromium. The important place in water pollution is occupied by the areas deposited flotation tailings and mine waste, formed in the process of mine and processing industry (flotation tailing dumps and landfills of Bor and Majdanpek, Mine, Veliki Majdan, Zajača, Raška, Vranje, etc.), the landfills incurred in the metallurgical treatment of mineral raw materials and landfills of ash and slag formed during thermal-energy production (power plants and heating plants).

CONDITION OF SURFACE WATER FLOWS IN THE IMPACT ZONE OF RTB BOR

Wastewater, generated in the sites of RTB Bor, Figure 1(either directly in the current production, or indirectly due to the decomposition of deposited mine overburden material and flotation tailings by formation of acid drainage water) pollute

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the Bor and Krivelj River, which still flow into the Timok and Danube River. These pollutions are often presented by low pH value, increased content of heavy metal ions, suspended particles and fine particles of flotation tailings, which is deposited in the valleys of these rivers on the area of over 2000 hectares. Except that drainage water from active and inactive tailing dumps and open pit dumps from the sites of RTB directly contaminate the surface water flows, under the direct harmful effect of surface water are also the alluvial aquifers in the river valleys through which these rivers flow.

Water flows in the area of Mali Krivelj - Zagradje belong to the basin of the Bela River, Timok basin, and the basin of the Danube.

The basin of Bela River includes:

1. Krivelj River with its tributaries;
2. Cerova River with its tributaries;
3. Bor River with its tributaries;
4. Ravna River with its tributaries;

Sources of pollution of these waterways are presented by active and inactive mining operations (surface and underground), flotation tailings dumps, waste rock dumps from open pits, wastewater formed in the process of copper ore processing municipal wastewater, Figure 1.

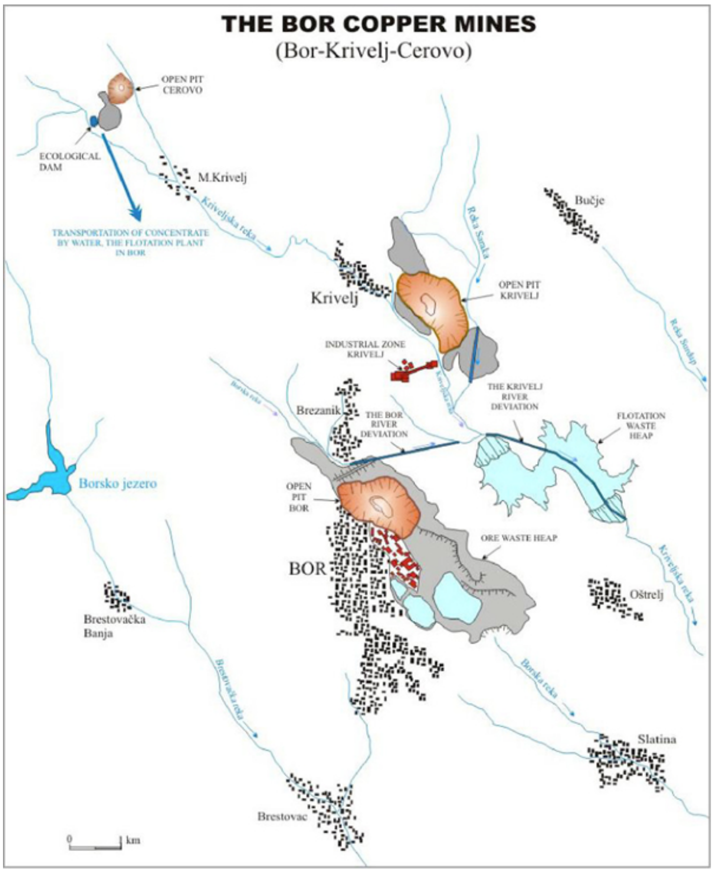

Fig. 1. *Hydrological network in the domain of the Copper Mine Bor*

The Krivelj River is threatened from the source to the mouth: by the open pit Cerovo, waste rock dump of the open pit Cerovo pit, open pit Veliki Krivelj , waste rock dump of the open pit Veliki Krivelj (landfill Saraka) and flotation tailing dump Veliki Krivelj (fields I and II).

Cerova River is threatened from the source to the mouth: by the open pit Cerovo and waste rock dump of the open pit Cerovo.

The Bor River is threatened from the source to the mouth: by the town of Bor (municipal waste water), copper ore processing plant (waste water from TIR), waste rock dump of the old open pit (north-east landfill) and the active flotation tailing dump Bor flotation (tailing dump RTH) as well as the old flotation tailing dump in Bor.

The Ravna River was previously threatened by wastewater from the plant for quartz sand processing "Belorečki Peščar". With the rehabilitation of processing plant, the Bela River is no longer endangered.

In addition to the above listed rivers, there are a number of streams in this area which are also threatened, and belong to the basins of the above rivers, and thus to the basin of the Bela River.

The Valja Lutarica stream, which with the streams with Bigar and Deljboka forms the Cerova River, is threatened: by the open pit Cerovo and waste rock dump of the open pit Cerovo.

The Saraka strem that belongs to the basin of the Krivelj River is threatened: by the open pit Veliki Krivelj and waste rock dump of the open pit Veliki Krivelj (landfill Saraka).

The Bor stream, which after the completion of relocation from the natural riverbed, also belongs to the basin of the Krivelj River is threatened by water pumped from the site for underground mining of copper, "Jama" Bor, as well as dumped open pit waste rock, below which the stream flows in part.

In the Republic of Serbia, the protection of surface water is regulated by the law, which is based on classification of water into four classes according to the level of pollution and use. The limit values of elements are given in the Official Gazette of the Socialist Republic of Serbia No. 31/82 (chemical quality parameters). Regarding to the chemical quality parameters, the selection of the most representative - characteristic elements is shown in Table 1.

Table 1. *Maximum quantities of hazardous substances in water in mg/l of water per classes, determined by regulations on water classification*

No.	Hazardous substances and rN	Quantity mg/L	
		Classes	
		I /II	III/IV
1.	Cadmium	0.005	0.01
2.	Lead	0.05	0.1
3.	Mercury	0.001	0.001
4.	Arsenic	0.05	0.05
5.	Chrome	0.1	0.5
6.	Nickel	0.05	0.1
7.	Fluorine	1.0	1.5
8.	Copper	0.03	1.0
9.	Zinc	0.2	1.0
10.	Boron	0.3	1.0
11.	Iron	0.3	1.0
12.	Selenium	0.01	0.01
13.	rN	6.8-8.5	6-9

This Regulation prescribes that hazardous substances must not be directly or indirectly put into water. The above classes are: Class I: water in its natural state or after disinfection can be used for drinking and food industry; Class II: water appropriate for bathing, recreation, water sports, including water after primary treatment (coagulation, filtration and disinfection) can be used for drinking and food industry; Class III: water that can be used for irrigation and industries except food industries; Class IV: water that can be used only after special treatment.

The Regulation which prescribes maximum allowable quantity of hazardous and harmful substances in soil and water that might damage or change the production capacity of soil and which come from factory discharges and seepages from landfills is given in the Official Gazette of the Socialist Republic of Serbia No. 23/94. Table 2 shows data on maximum allowable quantities of hazardous and harmful substances in water.

Table 2. *Maximum allowable quantities of hazardous and harmful substances*

No.	Parameter	MDK in water (mg/L)
1.	Cadmium	Up to 0.01
2.	Lead	Up to 0. 1
3.	Mercury	Up to 0.001
4.	Arsenic	Up to 0.05
5.	Chrome	Up to 0.5
6.	Nickel	Up to 0. 1
7.	Fluorine	Up to 1.5
8.	Copper	Up to 0.1
9.	Zinc	Up to 1.0
10.	Boron	Up to 1.0

Hazardous materials, in terms of this regulation are: cadmium, lead, mercury, arsenic, chromium, nickel and fluoride, and harmful substances are: copper, zinc and boron.

Surface water flows in the Bor complex are characterized by low flow and fluctuating water levels.

The most important rivers are: Zlot River, Bor stream that after flows into the RTB Bor industrial wastewater becomes the Bor River, Krivelj River, Ravna River and Timok. In the area of the mine Cerovo, there are two rivers, Valja Mare, south-east of the open pit and Cerova in the west of it. These two flows are merged near Mali Krivelj to form the Krivelj River that flows in its natural basin to the open pit Veliki Krivelj. Mining activities over the past year have impacted on the natural flows of rivers, particularly the Bor River. The Bor River originally flowed from the northwest to the southeast and further to Bor, which was, about 30 years ago, diverted by a tunnel, built in the north of the old open pit Bor, so that it now flows into the Krivelj River in front of the tunnel for deviation the Krivelj River below the Field 1 of the flotation tailing dump Veliki Krivelj. The flow of the Krivelj River was also modified from the original flow near the open pit Veliki Krivelj, where it now borders the open pit, and near the tailing dump Veliki Krivelj, where the river flow was diverted into the underground collector that runs under the flotation tailing dump.

The Krivelj River with the Bor and Ravna River makes the Bela River, which flows into the river Timok and further flows into the river Danube.

RESULTS AND DISCUSSION

Tables 3 and 3a show the results of physical and chemical testing of samples from the site of mouth the Bor and Krivelj River, which flow into the Bela River. Water samples were taken on May 18, 2012.

Tables 3 and 3a. *Results of physical and chemical testing of samples from the site of mouth the Bor and Krivelj River, taken on May 18, 2012*

Parameter	**T (°C) air**	**T (°C) water**	**Colour / smell**	**El.conduct. μS/cm**	**pH**	**Cu mg/dm^3**	**Pb mg/dm^3**	**Zn mg/dm^3**
Bor River	19	19.3	Dark gray/yes	1813	5.40	8.7	0.32	2.8
Krivelj River	19	14.6	Light brown/ without	1307	5.01	12.5	<0.1	0.4
Bor and Krivelj River after mouth	19	15.7	Light brown/ without	1598	4.99	12.2	<0.1	1.7

Parameter	**Cr (mg/dm^3)**	**Ni (mg/dm^3)**	**Cr (mg/dm^3)**	**Se (mg/dm^3)**	**As (mg/dm^3)**	**Fe-total (mg/dm^3)**	**Suspended matters (mg/dm^3)**	**SO_4^{-2} (mg/dm^3)**
Bor River	<0.1	0.2	<0.1	0.25	0.27	11.8	194.0	1268.5
Krivelj River	<0.1	<0.1	<0.1	<0.2	<0.1	2.4	294.0	779.2
Bor and Krivelj River after mouth	<0.1	0.15	<0.1	<0.2	<0.1	4.9	199.0	1103.1

For analysis the surface water in the Bor region, heavy metals were primarily taken as the chemical parameters. Lead content to 1.5 mg/L appeared only in the Bor River and metallurgical waste water; cadmium in the drainage lake Cerova (up to 0.35 mg/L), no chromium; arsenic in the pit water, Bor River and the water of TIR (of 0.19-6.6 mg/L). Selenium is also present in this water of TIR, 18.6 mg/L, in the Bor River, 0.25 mg/L and drainage water of RTH, 0.23 mg/ L.

Concentration of copper, zinc and iron is several times higher in nearly all water than the level specified by law (maximum allowable concentration of elements - MDK, is given in Table 1 and Table 2). Surface water within the Bor region, the Bor River, Krivelj River and Bela River, by its composition, cannot be classified into the class IV, and they belong into the water with high content of potentially toxic elements (heavy metals) according to the level of maximum allowable concentration.

CONCLUSION

Continuous implementation the mining and metallurgical activities for a period of over a century in the municipality of Bor, has led to serious pollution of the nearby waterways, especially the Bor River and Krivelj River. The Krivelj River, upstream from the mine Cerovo, has water quality that belongs to the class I/II, which is widely used in the agriculture for irrigation, directly for drinking when it comes to domestic animals and others. Downstream of the mine Cerovo, the Krivelj River water quality is changed drastically as the result of contaminated mine wastewater inflows from Cerovo, water from the open pit Veliki Krivelj, Saraka stream, pit water, drainage water from the tailing dump Veliki Krivelj.Downstream from the flotation tailing dump Veliki Krivelj to the place where the Bor River and Krivelj River are joined, water from the Krivelj River cannot be classified into any class due to the present pollution, i.e. the water is out of the category. Considering its quality, it has no use, even in the industrial facilities. The Bor River watercourse is created by merging the municipal water after leaving the municipal sewer, drainage water from the TIR collector, water from the Robule Lake and metallurgical water. As all of this water that makes the watercourse is much polluted; the Bor River in its entire course to the junction with the Krivelj River is outside the category or out of any use. The remediation process of polluted water of the Bor and Krivelj River is a long process that must begin immediately, first of all by treatment the all industrial water, generated during regular mining and processing of copper ore and which are discharged without any treatment into watercourses, and these include primarily the pit water, metallurgical water, water from the active open pits. After that, the water quality in the Bor and Krivelj River will be greatly improved in a short period of time, which is the first condition for termination of further continuous pollution the surface watercourses in the area of impact the industrial facilities of RTB Bor.

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ISTRAŽIVANJA MOGUĆNOSTI TRETIRANJA POLIMETALIČNE BARITSKE RUDE GRAVITACIJSKOM METODOM KONCENTRACIJE[**]

Izvod

Najčešće primenjivani postupak u pripremi polimetalične rude i rude barita je gravitacijska koncentracija, kao predtretman flotacijskoj metodi koncentracije. Ona se zasniva na razlici u gustinama korisnih i ostalih prisutnih mineralnih komponenata i na različitim putanjama kojima se kreću zrna različitih gustiina u gravitacionim mašinama i uređajima.

Sprovedena istraživanja mogućnosti primene gravitacijske koncentracije na dostavljenoj polimetaličnoj masivno sulfidnoj baritskoj rudi, između ostalog, obuhvataju oglede koncentracije na klatnom stolu na određenim užim klasama krupnoće. Prethodno je izveden, na reprezentativnom uzorku rude, preliminarni ogled pliva-tone u teškoj tečnosti-bromoformu.

Nakon procesuiranja na klatnom stolu, dobijeni rezultati su laboratorijski obrađeni i dati na hemijsku analizu.

Ključne reči: *gravitacijska koncentracija, pliva tone analiza, klatni sto*

UVOD

Na klatnom stolu se gravitacijska koncentracija obavlja u fluidu voda, gde za uspešnu koncentraciju veliki značaj imaju posledična segregacija zrna po krupnoći i gustini, izazvana istovremenim velikim značajem sila trenja i inercijalnih sila različitog ubrzanja zrna prisutnih na površini ploče stola. Zrna su različita i po geometrijskom obliku i nivou srastanja sa drugim, u rudi prisutnim mineralnim formama[1].

Kako barit ima veliku gustinu (oko 4,4-4,5 x 10^3 кg/m^3), realno je očekivati da će njegovo odvajanje od uobičajeno prisutnih jalovih minerala (kvarc, kalcit, škriljci ... čija se prosečne gustine kreću od 2,5-3,1 x 10^3 кg/m^3) biti uspešno. Međutim, imajući u vidu da se radi o masivno sulfidno baritnoj rudi, pretpostavlja se, da će se sulfidni minerali (čija se prosečna gustina kreće u granicama od 6,0-5-4,8-4,6-4,2 x 10^3 кg/m^3) koncentrisati zajedno

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sa baritom, a što će biti utvrđeno nakon izvođenja serije ogleda, metodom gravitacijske koncentracije na klatnom stolu [2].

P-T analiza, je jedan vid sagledavanja karakteristike mineralne sirovine u pogledu raslojavanja tretiranog materijala po gustini kojim je omogućeno odvajanje lakših, u našem slučaju jalovih minerala, od dela težih, u našem slučaju korisnih minerala, na predmetnoj gustini delenja, bromoformu $\rho = 2.820$ кg/m^3. P-T analiza, se u principu izvodi na seriji različitih gustina ali zbog trenutno ograničenih mogućnosti laboratorije ista je izvedena samo na gustini bromoforma [3].

Pri izvođenju preliminarnog ogleda P-T analize, pošli smo sa predpostavkom da će na gustini raslojavanja od 2.820 кg/m^3 doći do masene raspodele. Tako će u plivajuću frakciju otići jalovi minerali, gustine manje od gustine bromoforma. U konkretnom slučaju, a po osnovu sagledavanja rezultata mineraloške analize (silikati, kvarciti, podređeno karbonati, itd.), dok će se u tonuću frakciju skoncentrisati sulfidni minerali i barit, imajući u vidu njihove gustine, znatno veće od gustine bromoforma.

UZORCI

Tretirani su uzorci polimetalične baritske rude sa oznakama "KOP" i "DEPO" Uzorci su pripremljeni u skladu sa standardima laboratorije za uzorkovanje i pripremu uzoraka - akreditovane Laboratorije za PMS i ispitivanja Instituta za rudarstvo i metalurgiju u Boru.

PROCEDURA

Gravitacijska koncentracija na klatnom stolu

Za oglede gravitacijske koncentracije na klatnom stolu u fluidu voda, prosejavanjem su, iz svedene klase krupnoće, do 100% -3,35 mm, uzorci razvrstani na dve uže klase krupnoće : -3,35 + 1,18 mm i -1,18 + 0 mm, što dalje znači da su na klatnom stolu, u prvoj seriji ogleda, tretirane sledeće klase krupnoće:

Skupna klasa: -3,35 + 0 mm;

Izdvojena klasa: -3,35 + 1,18 mm;

Izdvojena klasa: -1,18 + 0 mm.

Pošto, rezultati tretiranja ovih klasa krupnoće na klatnom stolu nisu bili zadovoljavajući,u drugoj seriji ogleda, klasa krupnoće -3,35 + 0 mm, je naknadno drobljenjem i prosejavanjem svedena do krupnoće ***100% -1,18 mm***, radi postizanja većeg stepena otvorenosti sirovine i ista je zatim tretirana na klatnom stolu.

Sa završetkom tretiranja uzorka, na odgovarajućim mestima klatnog stola (Slika 1) izdvajaju se u odvojenim posudama sledeći proizvodi (prva serija ogleda):

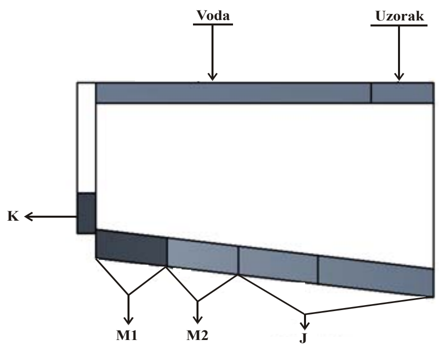
K-koncentrat;

M_1-međuproizvod;

M_2-međuproizvod;

J_{def}-definitivna jalovina.

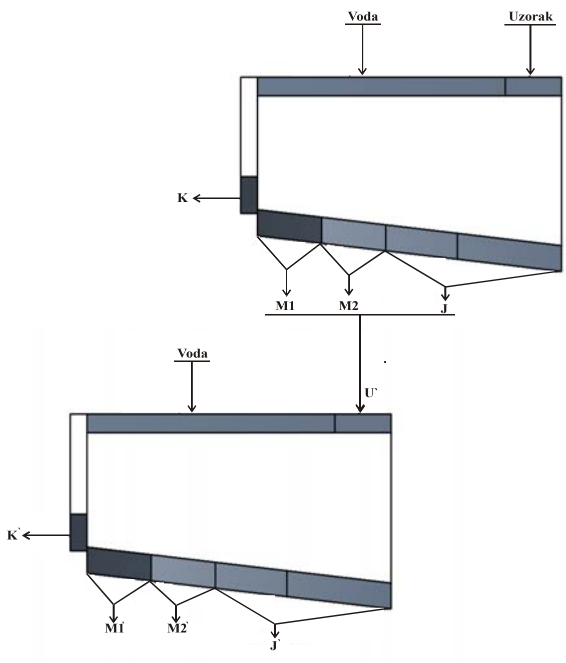
Napomena: Zbog malog masenog učešća međuproizvoda M_2, u prvoj seriji ogleda koncentracije izvršeno je spajanje ovog međuproizvoda i jalovine, koja je označena kao definitivna jalovina i kao takva analizirana na navedene elemente.



Sl. 1. *Izdvajanje proizvoda ogleda koncentracije na klatnom stolu u prvoj seriji ogled*

Iz izdvojenih proizvoda nakon odvodnjavanja i sušenja, su izuzeti uzorci za hemijsku analizu i analizirani na sledeće elemente: Cu, Pb, Zn, Fe, S_{uk}, $S_{sulfidni}$, $S_{sulfatni}$ i $BaSO_4$.

Šema toka druge serije ogleda gravitacijske koncentracije na klatnom stolu, sa mestima doziranja uzoraka i mestima izdvajanja proizvoda koncentracije data je na slici 2.



Sl. 2. *Šema toka druge serije ogleda gravitacijske koncentracije*

Šema obuhvata dva stepena koncentracije.

U prvom stepenu koncentracije na klatnom stolu,dolazi do razdvajanja na sledeće proizvode:

- Koncentrat K;
- Međuproizvod M_1;
- Međuproizvod M_2;
- Jalovina .

Ulaz u drugi stepen koncentracije, uslovno nazvanom "prečišćavanje", predstavljaju spojeni proizvodi iz prvog stepena koncentracije: međuproizvod M_1, međuproizvod M_2 i jalovina, kako je i prikazano na Slici 2. Razdvajanjem na klatnom stolu u drugom stepenu koncentracije dobijaju se sledeći proizvodi:

- Koncentrat K';
- Međuproizvod M_1';
- Međuproizvod M_2';
- Jalovina' .

Spajanjem koncentrata iz prvog i drugog stepena koncentracije, dobijamo konačni bilans proizvoda druge serije ogleda koncentracije, tj. proizvode:

- Koncentrat K;
- Koncentrat K';
- ($K + K' = K_{def}$)
- Međuproizvod M_1';
- Međuproizvod M_2';
- Jalovina'.

Preliminarni ogled P-T je izveden na sledeći način: suvi uzorak je potapan u konusni sud u kome se nalazi teška tečnost-bromoform, sa gustinom (2.820 kg/m^3), slika 3. Nakon mešanja i smirivanja tečnosti dolazi do prirodnog raslojavanja u bromoformu na laku (LF, -2820 kg/m^3) i tešku frakciju (TF, +2820 kg/m^3) gustina. Iste se zatim izdvajaju iz posude. Frakcije gustina odlaze na dalju obradu koja se sastoji od postupka centrifugiranja (radi odstranjivanja zaostale teške tečnosti), pa potom sušenja. Konačno, izvršeno je merenje uzoraka izdvojene teške i lake frakcije.

Imajući u vidu gustine prisutnih minerala u ispitivanoj sirovini, koja je vrlo kompleksnog mineraloškog sastava, a koje su kako je već napomenuto znatno veće od gustine bromoforma, došlo je do koncentrisanja celokupne mase tretiranog uzorka u teškoj frakciji, odnosno maseno učešće TF iznosi praktično 100%, kod oba tretirana uzorka "KOP" i "DEPO". Do očekivanog izdvajanja jalovih minerala u plivajućoj frakciji nije došlo, što se dalje može prokomentarisati njihovim srastanjem sa ostalim teškim mineralnim formama, kao i nedovoljnom otvorenošću sirovine, posebno ako se ima u vidu mineraloški izveštaj koji upućuje da su predmetni uzorci tipa masivno sulfidno baritne rude sa znatnim masenim udelom sulfida i barita 60-70% i shodno tome manjim učešćem petrogenih komponenata.

Sl. 3. *Ogled P-T*

EKSPERIMENTALNI DEO

Prva serija ogleda

Prikaz rezultata prve serije ogleda gravitacijske koncentracije tretiranih uzoraka, "KOP" i "DEPO", na klatnom stolu, prikazan je respektivno u Tabelama (1-6) i na slikama (4-6).

Tabela 1. *Uzorak "KOP" 100% -3,35+0 mm*

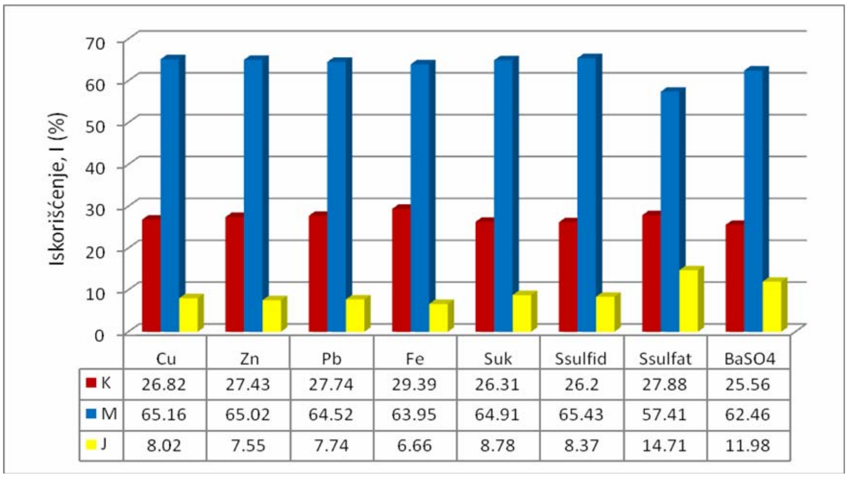
Proizvod	m (%)	Cu (%)	ItCu (%)	Zn (%)	ItZn (%)	Pb (%)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	Itsuk (%)	Ssulfidni (%)	ItSsulfid. (%)	Ssulfatni (%)	ItSsulfatni (%)	$BaSO_4$ (%)	$ItBaSO_4$ (%)
Koncentrat	25,17	1,47	26,82	5,15	27,43	3,27	27,74	23,62	29,39	38,36	26,31	35,69	26,20	2,67	27,88	15,08	25,56
Med.Proiz	64,67	1,39	65,16	4,75	65,02	2,96	64,52	20,00	63,95	36,83	64,91	34,69	65,43	2,14	57,41	14,34	62,46
Jalovina	10,16	1,09	8,02	3,51	7,55	2,26	7,74	13,26	6,66	31,71	8,78	28,22	8,37	3,49	14,71	17,50	11,98
Ulaz	100	1,38	100,00	4,72	100,00	2,97	100,00	20,23	100,00	36,69	100,00	34,28	100,00	2,41	100,00	14,85	100,00

Tabela 2. *Uzorak "KOP" : Tretirana klasa krupnoće -3,35+1,18 mm.*

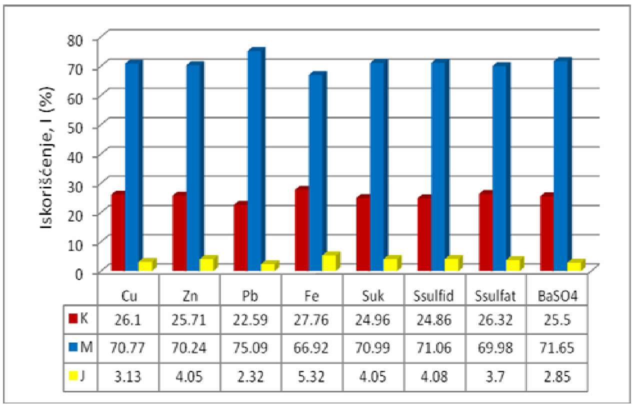
Proizvod	m (%)	Cu (%)	ItCu (%)	Zn (%)	ItZn (%)	Pb (%)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	Itsuk (%)	Ssulfidni (%)	ItSsulfidni (%)	Ssulfatni (%)	ItSsulfatni (%)	$BaSO_4$ (%)	$ItBaSO_4$ (%)
Koncentrat	20,27	1,55	26,10	4,88	25,71	3,12	22,59	21,45	27,76	39,17	24,96	36,35	24,86	2,82	26,32	15,32	25,50
Med,Proiz	70,36	1,39	70,77	4,41	70,24	3,43	75,09	17,10	66,92	36,86	70,99	34,36	71,06	2,48	69,98	14,24	71,65
Jalovina	6,37	0,68	3,13	2,81	4,05	1,17	2,32	15,00	5,32	23,20	4,05	21,75	4,08	1,45	3,70	6,26	2,85
Ulaz	100	1,38	100,00	4,42	100,00	3,21	100,00	17,98	100,00	36,51	100,00	34,02	100,00	2,49	100,00	13,98	100,00

Tabela 3. *Uzorak "KOP": Tretirana klasa krupnoće -1,18 + 0 mm.*

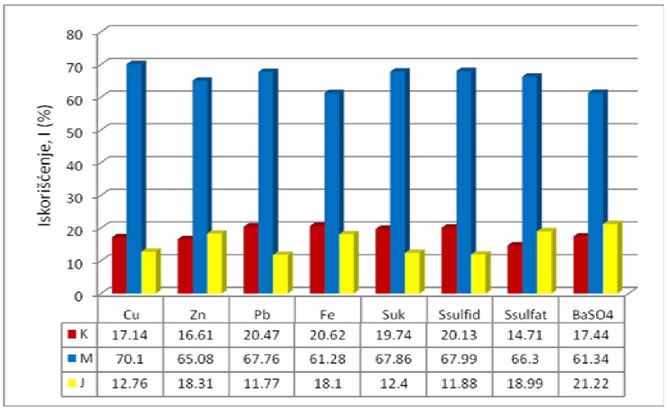
Proizvod	m (%)	Cu (%)	ItCu (%)	Zn (%)	ItZn (%)	Pb (%)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	Itsuk (%)	Ssulfidni (%)	ItSsulfid, (%)	Ssulfatni (%)	ItSsulfatni (%)	$BaSO_4$ (%)	$ItBaSO_4$ (%)
Koncentrat	17,78	1,30	17,14	4,08	16,61	3,58	20,47	20,00	20,62	38,05	19,74	36,02	20,13	2,03	14,71	15,44	17,44
Med,Proiz	67,52	1,40	70,10	4,21	65,08	3,12	67,76	15,65	61,28	34,45	67,86	32,04	67,99	2,41	66,30	14,30	61,34
Jalovina	14,70	1,17	12,76	5,44	18,31	2,49	11,77	21,23	18,10	28,90	12,40	25,73	11,88	3,17	18,99	22,72	21,22
Ulaz	100	1,35	100,00	4,37	100,00	3,11	100,00	17,24	100,00	34,27	100,00	31,82	100,00	2,45	100,00	15,74	100,00



Sl. 4. *Grafički prikaz tehnoloških iskorišćenja u proizvodima koncentracije na uzorku "Kop", 100% -3,35+0 mm*



Sl. 5. *Grafički prikaz tehnoloških iskorišćenja u proizvodima koncentracije na uzorku "Kop", tretirana klasa krupnoće -3,35+1,18 mm*



Sl. 6. *Grafički prikaz tehnoloških iskorišćenja u proizvodima koncentracije na uzorku "Kop", tretirana klasa krupnoće -1,18 + 0 mm*

Tabela 4. *Uzorak "DEPO" 100% -3,35+0 mm*

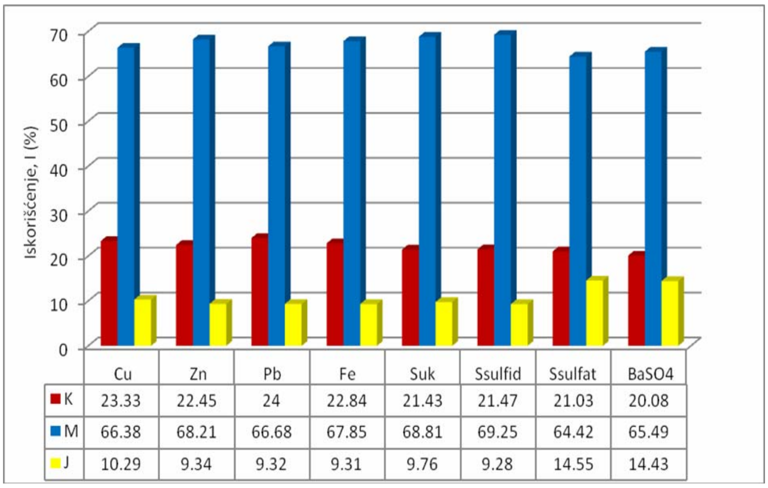
Proizvod	m (%)	Cu (%)	ItCu (%)	Zn (%)	ItZn (%)	Pb (%)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	Itsuk (%)	Ssulfidni (%)	ItSsulfid. (%)	Ssulfatni (%)	ItSsulfatni (%)	$BaSO_4$ (%)	It$BaSO_4$ (%)
Koncentrat	21,41	0,86	23,33	4,55	22,45	3,74	24,00	22,17	22,84	37,00	21,43	33,70	21,47	3,30	21,03	19,76	20,08
Međ.Proiz	68,04	0,77	66,38	4,35	68,21	3,27	66,68	20,72,	67,85	37,38	68,81	34,20	69,25	3,18	64,42	20,28	65,49
Jalovina	10,55	0,77	10,29	3,84	9,34	2,95	9,32	18,33	9,31	34,18	9,76	29,55	9,28	4,63	14,55	28,82	14,43
Ulaz	100	0,79	100,00	4,34	100,00	3,34	100,00	20,78	100,00	36,96	100,00	33,60	100,00	3,36	100,00	21,07	100,00

Tabela 5. *Uzorak "DEPO": Tretirana klasa krupnoće -3,35+1,18 mm*

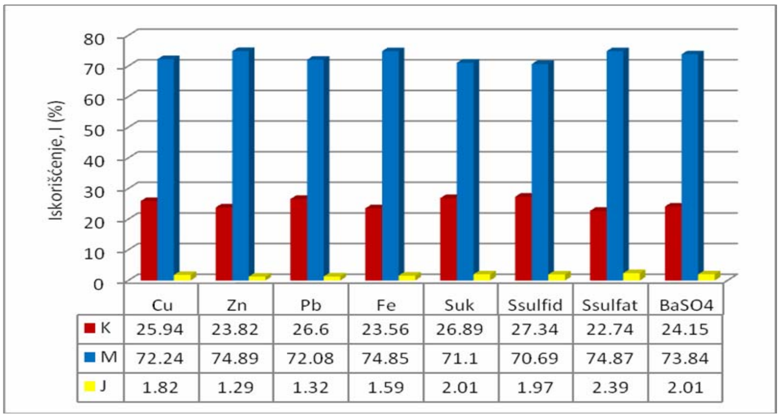
Proizvod	m (%)	Cu (%)	ItCu (%)	Zn (%)	ItZn (%)	Pb (%)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	Itsuk (%)	Ssulfidni (%)	ItSsulfid. (%)	Ssulfatni (%)	ItSsulfatni (%)	$BaSO_4$ (%)	It$BaSO_4$ (%)
Koncentrat	24,80	0,87	25,94	4,21	23,82	3,74	26,60	19,28	23,56	36,18	26,89	33,20	27,34	2,98	22,74	20,12	24,15
Međ.Proiz	73,29	0,82	72,24	4,48	74,89	3,43	72,08	20,72	74,85	32,37	71,10	29,05	70,69	3,32	74,87	20,82	73,84
Jalovina	1,91	0,79	1,82	2,97	1,29	2,41	1,32	16,88	1,59	35,10	2,01	31,04	1,97	4,06	2,39	21,80	2,01
Ulaz	100	0,83	100,00	4,38	100,00	3,49	100,00	20,29	100,00	33,37	100,00	30,12	100,00	3,25	100,00	20,66	100,00

Tabela 6. *Uzorak "DEPO": Tretirana klasa krupnoće -1,18 + 0 mm*

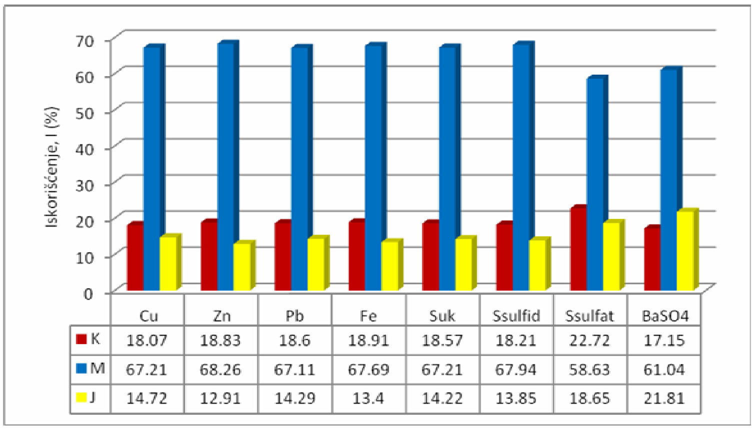
Proizvod	m (%)	Cu (%)	ItCu (%)	Zn (%)	ItZn (%)	Pb (%)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	ItSuk (%)	Ssulfidni (%)	ItSsulfid. (%)	Ssulfatni (%)	ItSsulfatni (%)	$BaSO_4$ (%)	$ItBaSO_4$ (%)
Koncentrat	18,77	0,79	18,07	4,15	18,83	3,43	18,60	20,72	18,91	34,89	18,57	31,54	18,21	3,35	22,72	20,24	17,15
Med.Proiz	64,90	0,85	67,21	4,35	68,26	3,58	67,11	21,45	67,69	36,53	67,21	34,03	67,94	2,50	58,63	20,84	61,04
Jalovina	16,33	0,74	14,72	3,27	12,91	3,03	14,29	16,88	13,40	30,72	14,22	27,56	13,85	3,16	18,65	29,60	21,81
Ulaz	100	0,82	100,00	4,14	100,00	3,46	100,00	20,57	100,00	35,27	100,00	32,51	100,00	2,77	100,00	22,16	100,00



Sl. 7. *Grafički prikaz tehnoloških iskorišćenja u proizvodima koncentracije na uzorku "Depo", 100% -3,35+0 mm*



Sl. 8. *Grafički prikaz tehnoloških iskorišćenja u proizvodima koncentracije na uzorku "Depo", tretirana klasa krupnoće. -3,35+1,18 mm*

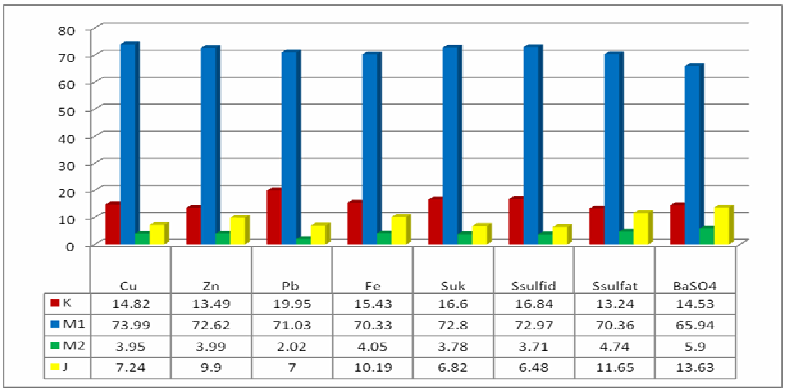


Sl. 9. *Grafički prikaz tehnoloških iskorišćenja u proizvodima koncentracije na uzorku "Depo", tretirana klasa krupnoće -1,18+0 mm*

Prikaz ostvarenih rezultata druge serije ogleda gravitacijske koncentracije tretiranih uzoraka, "KOP" i "DEPO", na klatnom stolu, prikazan je respektivno u Tabelama (7-13) i na Slikama (10-17).

Tabela 7. *Uzorak "KOP": Tretirana klasa krupnoće 100%-1,18+ 0 mm (prvi stepen koncentracije)*

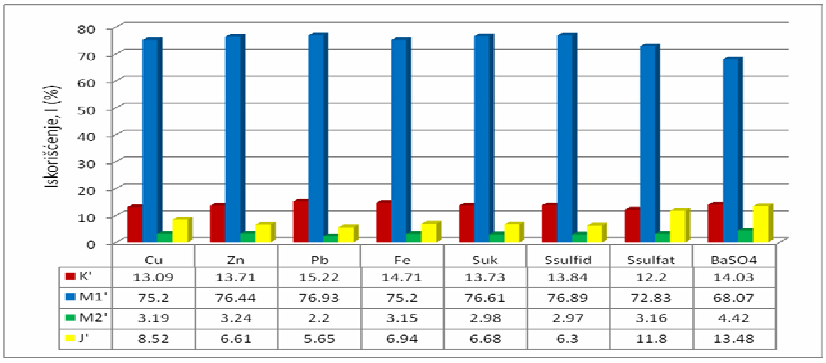
Proizvod	m (%)	Cu (%)	ItCu (%)	Zn (%)	ItZn (%)	Pb (%)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	It Suk (%)	Ssulfidni (%)	ItSsulfid, (%)	Ssulfatni (%)	ItSsulfatni (%)	$BaSO_4$ (%)	$ItBaSO_4$ (%)
Koncentrat K	14,98	1,33	14,82	6,31	13,49	3,81	19,95	27,19	15,43	39,75	16,60	37,68	16,84	2,07	13,24	13,94	14,53
Med,M_1	72,58	1,37	73,99	7,01	72,62	2,80	71,03	25,57	70,33	35,97	72,80	33,70	72,97	2,27	70,36	13,06	65,94
Med,M_2	4,46	1,19	3,95	6,28	3,99	1,30	2,02	23,95	4,05	30,38	3,78	27,89	3,71	2,49	4,74	19,02	5,90
Jalovina	7,98	1,22	7,24	8,69	9,90	2,51	7	33,68	10,19	30,64	6,82	27,22	6,48	3,42	11,65	24,56	13,63
Ulaz	**100**	**1,34**	**100**	**7**	**100**	**2,86**	**100**	**26,39**	**100**	**35,86**	**100**	**33,52**	**100**	**2,34**	**100**	**14,37**	**100**



Sl. 10. *Grafički prikaz tehnoloških iskorišćenja u proizvodima koncentracije na uzorku "KOP", klasa 100% -1,18 + 0 mm (prvi stepen koncentracije)*

Tabela 8. *Uzorak "KOP": Tretirana klasa krupnoće 100% -1,18+ 0 mm (drugi stepen koncentracije)*

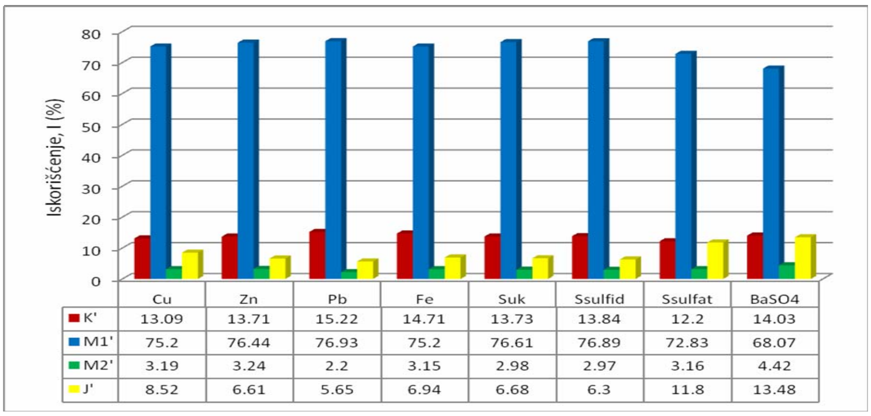
Proizvod	m (%)	Cu (%)	ItCu (%)	Zn (%)	ItZn (%)	Pb (%)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	Itsuk (%)	Ssulfidni (%)	ItSsulfid, (%)	Ssulfatni (%)	ItSsulfatni (%)	$BaSO_4$ (%)	$ItBaSO_4$ (%)
KoncentratK'	13,13	1,33	13,09	7,15	13,71	3,67	15,22	29,35	14,71	37,51	13,73	35,19	13,84	2,32	12,20	14,66	14,03
Med,M_1'	75,43	1,33	75,20	6,94	76,44	3,23	76,93	26,11	75,20	36,44	76,61	34,03	76,89	2,41	72,83	12,38	68,07
Med,M_2'	3,37	1,26	3,19	6,59	3,24	2,07	2,20	24,49	3,15	31,72	2,98	29,38	2,97	2,34	3,16	17,98	4,42
Jalovina'	8,07	1,41	8,52	5,61	6,61	2,22	5,65	22,52	6,94	29,71	6,68	26,06	6,30	3,65	11,80	22,92	13,48
Ulaz'	100	1,33	100	6,84	100	3,17	100	26,19	100	35,88	100	33,38	100	2,49	100	13,69	100



Sl. 11. *Grafički prikaz tehnoloških iskorišćenja u proizvodima koncentracije na uzorku "KOP", klasa 100% -1,18 + 0 mm (drugi stepen koncentracije)*

Tabela 9. *Uzorak "KOP": Tretirana klasa krupnoće 100% -1,18+ 0 mm (drugi stepen koncentracije) - U odnosu na ulaz 85,02%*

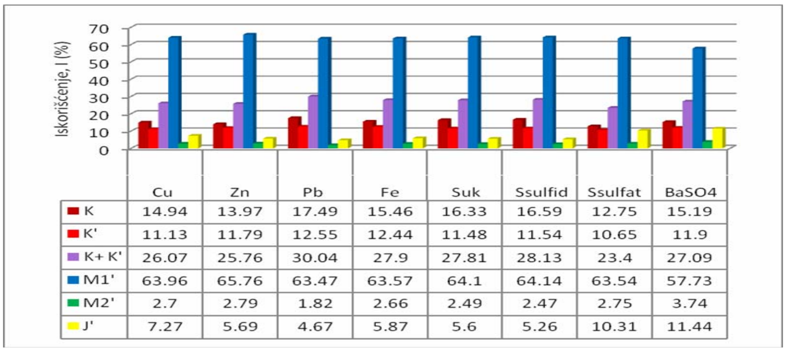
Proizvod	m (%)	Cu (%)	ItCu (%)	Zn (%)	ItZn (%)	Pb (%)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	Itsuk (%)	Ssulfidni (%)	ItSsulfid, (%)	Ssulfatni (%)	ItSsulfatni (%)	$BaSO_4$ (%)	$ItBaSO_4$ (%)
Koncentrat K'	11,16	1,33	13,09	7,15	13,71	3,67	15,22	29,35	14,71	37,51	13,73	35,19	13,84	2,32	12,20	14,66	14,03
Med,M_1'	64,13	1,33	75,20	6,94	76,44	3,23	76,93	26,11	75,20	36,44	76,61	34,03	76,89	2,41	72,83	12,38	68,07
Med,M_2'	2,86	1,26	3,19	6,59	3,24	2,07	2,20	24,49	3,15	31,72	2,98	29,38	2,97	2,34	3,16	17,98	4,42
Jalovina'	6,87	1,41	8,52	5,61	6,61	2,22	5,65	22,52	6,94	29,71	6,68	26,06	6,30	3,65	11,80	22,92	13,48
Ulaz'	85,02	1,33	100	6,84	100	3,17	100	26,19	100	35,88	100	33,38	100	2,49	100	13,69	100



Sl. 12. *Grafički prikaz tehnoloških iskorišćenja u proizvodima koncentracije na uzorku "KOP", klasa 100% -1,18 + 0 mm (drugi stepen koncentracije). U odnosu na ulaz 85,02%*

Tabela 10. *Uzorak "KOP": Konačni bilans proizvoda koncentracije tretirane klase krupnoće 100% -1,18+0 mm*

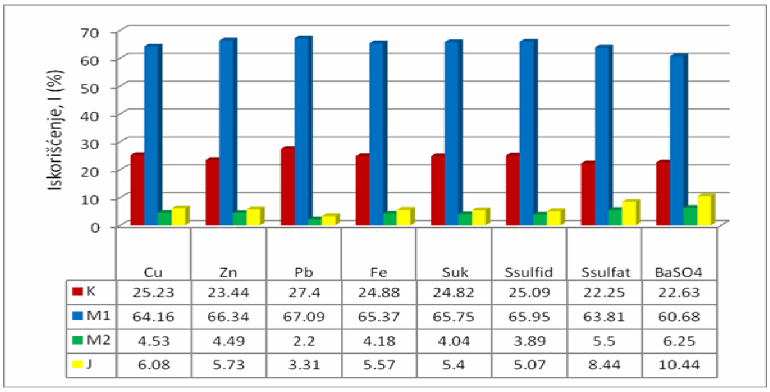
Proizvod	m (%)	Cu (%)	ItCu (%)	Zn (%)	It Zn (%)	Pb (%)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	It Suk (%)	Ssulfidni (%)	It Ssulfid, (%)	Ssulfatni (%)	ItSsulfatni (%)	$BaSO_4$ (%)	$ItBaSO_4$ (%)
Koncentrat K	14,98	1,33	14,94	6,31	13,97	3,81	17,49	27,19	15,46	39,75	16,33	37,68	16,59	2,07	12,75	13,94	15,19
Koncentrat K'	11,16	1,33	11,13	7,15	11,79	3,67	12,55	29,35	12,44	37,51	11,48	35,19	11,54	2,32	10,65	14,66	11,90
K_{def}(K+K')	26,14	1,33	26,07	6,67	25,76	3,75	30,04	28,11	27,90	38,79	27,81	36,62	28,13	2,18	23,40	14,25	27,09
Med,M_1'	64,13	1,33	63,96	6,94	65,76	3,23	63,47	26,11	63,57	36,44	64,10	34,03	64,14	2,41	63,54	12,38	57,73
Med,M_2'	2,86	1,26	2,70	6,59	2,79	2,07	1,82	24,49	2,66	31,72	2,49	29,38	2,47	2,34	2,75	17,98	3,74
Jalovina'	6,87	1,41	7,27	5,61	5,69	2,22	4,67	22,52	5,87	29,71	5,60	26,06	5,26	3,65	10,31	22,92	11,44
Ulaz	**100**	**1,33**	**100**	**6,77**	**100**	**3,26**	**100**	**26,34**	**100**	**36,46**	**100**	**34,03**	**100**	**2,43**	**100**	**13,75**	**100**



Sl. 13. *Grafički prikaz tehnoloških iskorišćenja u proizvodima koncentracije na uzorku "KOP", klasa 100% -1,18 + 0 mm - Konačni bilans proizvoda koncentracije*

Tabela 11. *Uzorak "DEPO" : Tretirana klasa krupnoće 100% -1,18 + 0 mm (prvi stepen koncentracije)*

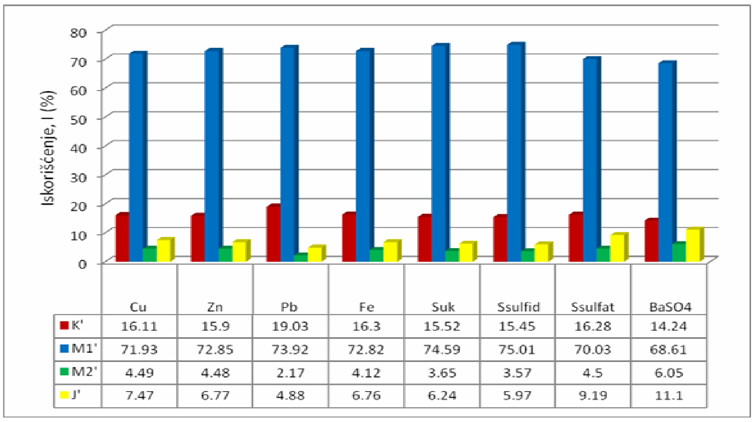
Proizvod	m (%)	Cu (%)	ItCu (%)	Zn (%)	ItZn (%)	Pb (%)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	Itsuk (%)	Ssulfidni (%)	ItSsulfid (%)	Ssulfatni (%)	ItSsulfatni (%)	$BaSO_4$ (%)	$ItBaSO_4$ (%)
Koncentrat K	24,79	0,85	25,23	4,91	23,44	3,09	27,40	25,57	24,88	33,76	24,82	30,88	25,09	2,88	22,25	20,64	22,63
Med,M_1	63,80	0,84	64,16	5,40	66,34	2,94	67,09	26,11	65,37	34,75	65,75	31,54	65,95	3,21	63,81	21,50	60,68
Med,M_2	4,55	0,83	4,53	5,12	4,49	1,35	2,20	23,41	4,18	29,94	4,04	26,06	3,89	3,88	5,50	31,06	6,25
Jalovina	6,86	0,74	6,08	4,34	5,73	1,35	3,31	20,70	5,57	26,53	5,40	22,58	5,07	3,95	8,44	34,40	10,44
Ulaz	**100**	**0,83**	**100**	**5,19**	**100**	**2,79**	**100**	**25,48**	**100**	**33,72**	**100**	**30,51**	**100**	**3,21**	**100**	**22,61**	**100**



Sl. 14. *Grafički prikaz tehnoloških iskorišćenja u proizvodima koncentracije na uzorku "Depo", tretirana klasa krupnoće -1,18 +0 mm (prvi stepen koncentracije)*

Tabela 12. *Uzorak "DEPO" : Tretirana klasa krupnoće 100% -1,18+0 mm (drugi stepen koncentracije)*

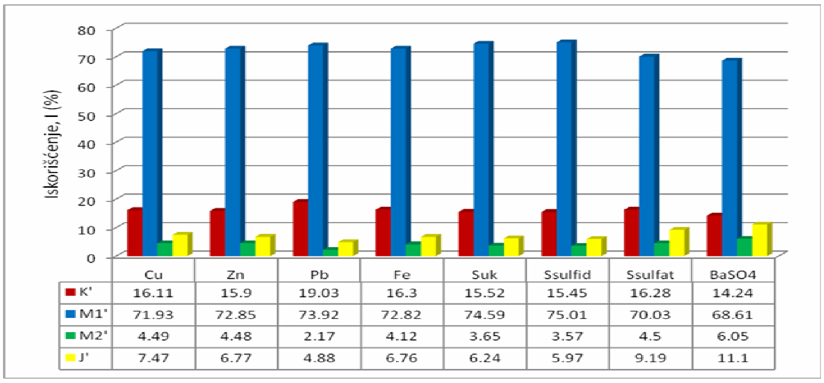
Proizvod	m (%)	Cu (%)	ItCu (%)	Zn (%)	ItZn (%)	Pb (%)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	It Suk (%)	Ssulfidni (%)	ItSsulfid, (%)	Ssulfatni (%)	ItSsulfatni (%)	$BaSO_4$ (%)	$ItBaSO_4$ (%)
Koncentra K'	16,02	0,84	16,11	5,47	15,90	3,38	19,03	25,57	16,30	33,50	15,52	30,54	15,45	2,96	16,28	20,26	14,24
Med,M_1'	71,55	0,84	71,93	5,61	72,85	2,94	73,92	25,57	72,82	36,05	74,59	33,20	75,01	2,85	70,03	21,86	68,61
Med,M_2'	4,63	0,81	4,49	5,33	4,48	1,34	2,17	22,32	4,12	27,23	3,65	24,40	3,57	2,83	4,50	29,78	6,05
Jalovina'	7,80	0,80	7,47	4,78	6,77	1,78	4,88	21,78	6,76	27,67	6,24	24,24	5,97	3,43	9,19	32,44	11,10
Ulaz'	100	0,83	100	5,51	100	2,85	100	25,12	100	34,58	100	31,67	100	2,91	100	22,79	100



Sl. 15. *Grafički prikaz tehnoloških iskorišćenja u proizvodima koncentracije na uzorku "DEPO", klasa 100% -1,18 + 0 mm (drugi stepen koncentracije)*

Tabela 13. *Uzorak "DEPO": Tretirana klasa krupnoće 100% -1,18+0 mm (drugi stepen koncentracije) - U odnosu na ulaz 75,21 %*

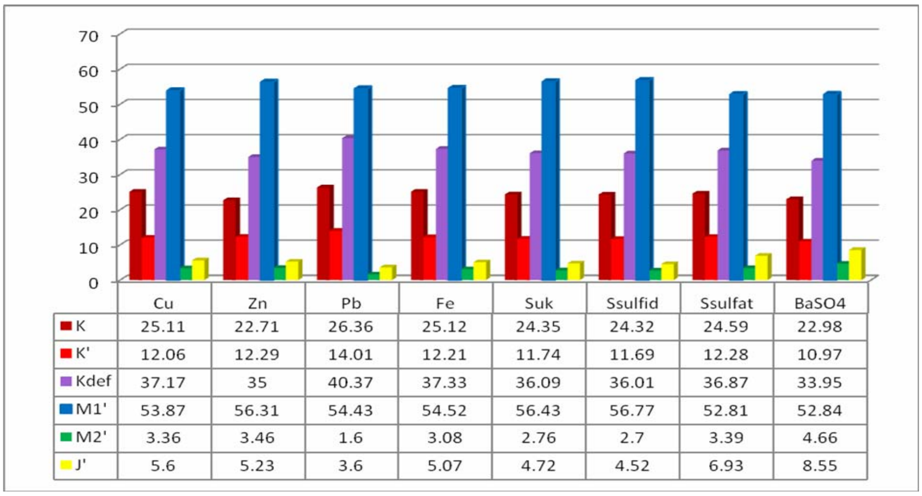
Proizvod	m (%)	Cu (%)	ItCu (%)	Zn (%)	ItZn (%)	Pb (%)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	It Suk (%)	Ssulfidni (%)	ItSsulfid, (%)	Ssulfatni (%)	ItSsulfatni (%)	$BaSO_4$ (%)	$ItBaSO_4$ (%)
Koncentrat K'	12,05	0,84	16,11	5,47	15,90	3,38	19,03	25,57	16,30	33,50	15,52	30,54	15,45	2,96	16,28	20,26	14,24
Med,M_1'	53,81	0,84	71,93	5,61	72,85	2,94	73,92	25,57	72,82	36,05	74,59	33,20	75,01	2,85	70,03	21,86	68,61
Med,M_2'	3,48	0,81	4,49	5,33	4,48	1,34	2,17	22,32	4,12	27,23	3,65	24,40	3,57	2,83	4,50	29,78	6,05
Jalovina'	5,87	0,80	7,47	4,78	6,77	1,78	4,88	21,78	6,76	27,67	6,24	24,24	5,97	3,43	9,19	32,44	11,10
Ulaz'	75,21	0,83	100	5,51	100	2,85	100	25,12	100	34,58	100	31,67	100	2,91	100	22,79	100



Sl. 16. *Grafički prikaz tehnoloških iskorišćenja u proizvodima koncentracije na uzorku "DEPO", klasa 100% -1,18 + 0 mm (drugi stepen koncentracije) –U odnosu na ulaz 75,21 %*

Tabela 14. *Uzorak "DEPO". Konačni bilans proizvoda koncentracije tretirane klase krupnoće 100% -1,18+0 mm*

Proizvod	m (%)	Cu (%)	ItCu (%)	Zn (%)	ItZn (%)	Pb (%)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	It Suk (%)	Ssulfidni (%)	ItSsulfid, (%)	Ssulfatni (%)	ItSsulfatni (%)	$BaSO_4$ (%)	$ItBaSO_4$ (%)
Koncentrat K	24,79	0,85	25,11	4,91	22,71	3,09	26,36	25,57	25,12	33,76	24,35	30,88	24,32	2,88	24,59	20,64	22,98
Koncentrat K'	12,05	0,84	12,06	5,47	12,29	3,38	14,01	25,57	12,21	33,50	11,74	30,54	11,69	2,96	12,28	20,26	10,97
K_{def}(K+K')	36,84	0,85	37,17	5,09	35,00	3,18	40,37	25,57	37,33	33,67	36,09	30,77	36,01	2,91	36,87	20,50	33,95
Med,M_1'	53,81	0,84	53,87	5,61	56,31	2,94	54,43	25,57	54,52	36,05	56,43	33,20	56,77	2,85	52,81	21,86	52,84
Med,M_2'	3,48	0,81	3,36	5,33	3,46	1,34	1,60	22,32	3,08	27,23	2,76	24,40	2,70	2,83	3,39	29,78	4,66
Jalovina'	5,87	0,80	5,60	4,78	5,23	1,78	3,60	21,78	5,07	27,67	4,72	24,24	4,52	3,43	6,93	32,44	8,55
Ulaz	**100**	**0,84**	**100**	**5,36**	**100**	**2,90**	**100**	**25,23**	**100**	**34,38**	**100**	**31,47**	**100**	**2,90**	**100**	**22,26**	**100**



Sl. 17. *Grafički prikaz tehnoloških iskorišćenja u proizvodima koncentracije na uzorku "DEPO", klasa 100% -1,18 + 0 mm - Konačni bilans proizvoda koncentracije*

REZULTATI I DISKUSIJA

Sagledavanjem ostvarenih rezultata, u prvoj seriji ogleda gravitacijske koncentracije tretiranih klasa krupnoće: 100% -3,35+ 0 mm; -3,35+1,18mm i -1,18+0 mm uzoraka "KOP" i "DEPO" na klatnom stolu, izvodi se zaključak o nemogućnosti adekvatne valorizacije korisnih komponenata, prvenstveno sulfidnih minerala i minerala barita. Ovi rezultati su sasvim sigurno posledica strukturno-teksturnih karakteristika sirovine, u pogledu srastanja sulfidnih minerala sa mineralima jalovine, što je i potvrđeno minerološkom analizom. Zapaženo je i visoko učešće sulfidne faze, kod oba tretirana uzorka. Vrlo mala zastupljenost slobodnih zrna, kao i visoka zastupljenost složenih sraslaca i impegnacija, uticalo je na izdvajanje i koncentrisanje sulfidnih minerala zajedno sa baritom u koncentratu i međuproizvodu. Međutim, približno isti kvalitet (sadržaj) analiziranih elemenata prisutan je skoro u svim proizvodima koncentracije u odnosu na ulaz. Time je ujedno potvrđena konstatacija izneta s'početka ovog dela pasusa, zasnovana na saznanjima, da se tretiranjem baritno sulfidne rude, sulfidni minerali koncentrišu zajedno sa baritom, kod svih tretiranih klasa krupnoće. Očigledno je da ova sirovina, masivno sulfidna baritska ruda, iskazuje nepogodnost za gravitacijski tretman klatnim stolom u smislu izdvajanja nekakvog gravitacijskog predkoncentrata. To su nedvosmisleno pokazali, iz prve serije ogleda, ostvareni rezultati na oba tretirana uzorka "KOP" i "DEPO" na svim tretiranim klasama krupnoće i to: 100% -3,35+ 0 mm; -3,35+1.18mm i -1,18+0 mm. Praktično to znači, da je dolazilo samo do fizičkog delenja masa bez značajnije koncentracije minerala u očekivanim proizvodima, koncentratu i eventualno prvom međuproizvodu.

Sagledavanjem rezultata u drugoj seriji ogleda koncentracije, uviđa se ostvarenje većih tehnoloških iskorišćenja u međuproizvodu (M_1'), kod oba tretirana uzoraka. U drugom stepenu koncentracije, na definisanoj klasi krupnoće 100% -1,18 +0 mm, u poređenju sa ostvarenim tehnološkim iskorišćenjima u prvoj seriji ogleda u međuproizvodima je veće tehnološko iskorišćenje. Međutim, u ovom slučaju je došlo do koncentrisanja sulfidnih minerala sa baritom u međuproizvodu, čime nije ostvarena nikakva selekcija istih.

Skupni-konačni bilans proizvoda koncentracije predstavljen na Slici 13 i Slici 17, respektivno prema uzorcima nije dao značajne rezultate. Odnosno, na osnovu tih prikaza tehnoloških iskorišćenja u proizvodima koncentracije kod oba tretirana uzorka „KOP“ i „DEPO“ može se zaključiti sledeće:

Očigledno je, da se i daljim usitnjavanjem sirovine ne postiže dovoljno otvaranje, a to je obzirom da se radi o složenoj polimetaličnoj rudi, sa najzastupljenijim sulfidnim mineralima: piritom, sfaleritom i galenitom, halkopirit itd., neophodno. To je ujedno i glavni razlog ovako dobijenih rezultata. No međutim, daljim otvaranjem mineralne sirovine tj spuštanjem njene krupnoće, izlazi se iz okvira mogućnosti i primenljivosti gravitacijskih metoda koncentracije.

Složenost ovakve mineralne forme i ostvareni rezultati upućuju na zaključak da se ova metoda, kao metoda predkoncentracije, delimično može primeniti na ovoj sirovini samo pod uslovom, da se kao proizvodi spoje dobijeni koncentrati i prvi međuproizvodi klatnoga stola. Generalno za oba tretirana uzorka „KOP“ i „DEPO“, to bi značilo elimnisanje jalove mase reda veličina od 10-15 % dok bi se na metalima, zavisno od kog metala, gubilo oko 8-12 %. Znači postupak predkoncentracije bi se kretao u ovim granicama, što zavisno od kapaciteta prerade može imati smisla samo ako su u pitanju veliki kapaciteti prerade ove sirovine. U protivnom gravitacijska koncentracija se ne preporučuje kao metod predkoncentracije flotacijskoj koncentraciji.

ZAKLJUČAK

Metoda gravitacijske koncentracije na klatnom stolu, pri tretiranju uzoraka "KOP" i "DEPO", nije se pokazala kao metoda kojom se može izvršiti efikasna predkoncentracija, odnosno selekcija sulfidnih minerala, barita i minerala jalovine, uz zadovoljavajuće tehnološke rezultate.
Složenost ovakve mineralne forme koja se tretira gravitacijskom koncentracijom na klatnome stolu i ostvareni rezultati upućuju na zaključak da se ova metoda, kao metoda predkoncentracije, delimično može primeniti na ovoj sirovini. Za oba tretirana uzorka „KOP“ i „DEPO“, to bi značilo eliminisanje jalove mase reda veličina od 10-15 % dok bi se na metalima, zavisno od kog metala, pri tome gubilo oko 8-12 %.

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Daniela Urošević, Dragan Milanović*, Srđana Magdalinović**

RESEARCH THE POSSIBILITY OF TREATMENT THE POLYMETALLIC BARITE ORE BY GRAVITY CONCENTRATION METHOD**

Abstract

The gravity concentration is the most commonly used method in the preparation of polymetallic ore and barite ore, as a pretreatment of flotation concentration method. It is based on a difference in densities of useful and other present mineral components present and different travel paths of grains with different densities in the gravity machine and devices.

Conducted research the possibility of gravity concentration use on submitted polymetallic massive sulfide barite ore, among others, include the experiments of concentration on a shaking table on the certain narrow size classes. The preliminary experiment floating-sinking was previously performed on a representative sample of ore in a heavy liquid - bromoform.

After processing on a shaking table, the obtained results were processed in the laboratory and chemically analyzed.

Keywords: *gravity concentration, floating-sinking analysis, shaking table*

INTRODUCTION

Gravity concentration is carried out on a shaking table in the fluid water, where the resulted segregation of grains in size and density has a great importance for successful concentration, caused by great importance of friction forces and inertial forces of different accelerations of present grains on the surface of table plate. The grains are different both by geometric shape and level of intergrowth to the other mineral forms, present in the ore [1].

As barite has high density (about 4.4-4.5 x 10^3 kg/m^3), it is reasonable to expect that its separation from the usual present barren minerals (quartz, calcite, shale ... whose average densities ranges from 2.5-3.1 x 10^3 kg/m^3) will be successful. However, taking into account that this is a massive sulfide barite ore, it is assumed, that sulfide minerals (whose average density ranges from 6.0-5-4.8-4.6-4.2 x 10^3 kg/m^3) will concentrate together with barite, and which will be determined after performing a series of experiments, using the gravity concentration method on a shaking table [2].

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P-T analysis is an overview of characteristics of mineral resources in terms of separation the treated material per density, which allowed separation of light, in this case barren minerals, from a part of heavy, in this case, the useful minerals, on the subject density of separation, bromoform $\rho = 2\ 820\ kg/m^3$. P-T analysis is normally carried out on a series of different densities, but due to the currently limited capabilities of laboratory, the same was carried out on density of bromoform [3].

In performing the preliminary experiment of P-T analysis, it was started with an assumption that the mass distribution will occur at density separation of 2820 kg/m^3. Thus, the barren minerals, density less than density of bromoform, will go into floating fraction. In this case, based on a consideration the mineralogical analysis results (silicates, quartzites, subordinate carbonates, etc.), while sulfide minerals and barite will be concentrated in the sinking fraction, taking into consideration their densities, much higher than the density of bromoform.

SAMPLES

Treated samples were polymetallic barite ore, marked "KOP" and "DEPO". Samples were prepared in accordance with the standards of laboratory for sampling and sample preparation – the accredited Laboratories for mineral processing and testing of the Mining and Metallurgy Institute in Bor.

PROCEDURES

Gravity concentration on a shaking table

For the experiments of gravity concentration on a shaking table in the water fluid by sieving from the reduced size class, up to 100 % -3.35%, the samples are classified into two narrower size classes: -3.35 + 1.18 mm and -1.18 + 0 mm, which also means that the following size classes were treated in the firsts series of experiments on a shaking table.

Collective class: -3.35 +0 mm;

Separated class: -3.35 + 1.18 mm;

Separated class: -1.18 + 0 mm.

Since the treatment results of these size classes on a shaking table were not satisfactory, in the second series of experiments, the class size -3.35 mm +0, was subsequently crushed and reduced by sieving to the size class of ***100 % -1.18 mm,*** to achieve higher degree of openness the raw material and the same is then treated in a shaking table.

With the completion of sample treatment, the following products (the first series of experiments) are separated on suitable positions of shaking table (Figure 1):

K-concentrate;

M_1-intermediate;

M_2-intermediate;

J_{def}-definite tailings.

Note: Due to small mass participation of intermediate M_2,, in the first series of experiments, this product was merged with tailings, marked as definite tailings, and analyzed as such on the given elements.

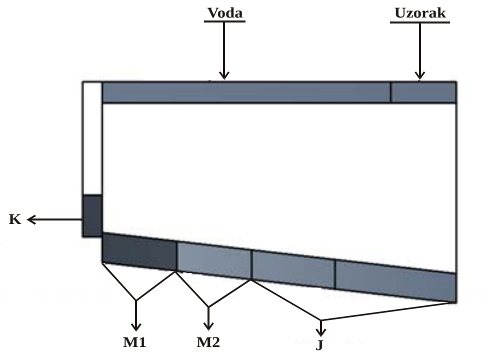


Fig. 1. *Separation the product of concentration experiment on a shaking table in the first series of experiments*

The samples were taken from separated products after dewatering and drying for chemical analysis and analyzed for the following elements: Cu, Pb, Zn, Fe, S_{total}, $S_{sulfide}$, $S_{sulfate}$ and $BaSO_4$.

Schematic flow of the second series of gravity concentration experiments on a shaking,table, with places of sample and places of separation the concentration products is given in Figure 2.

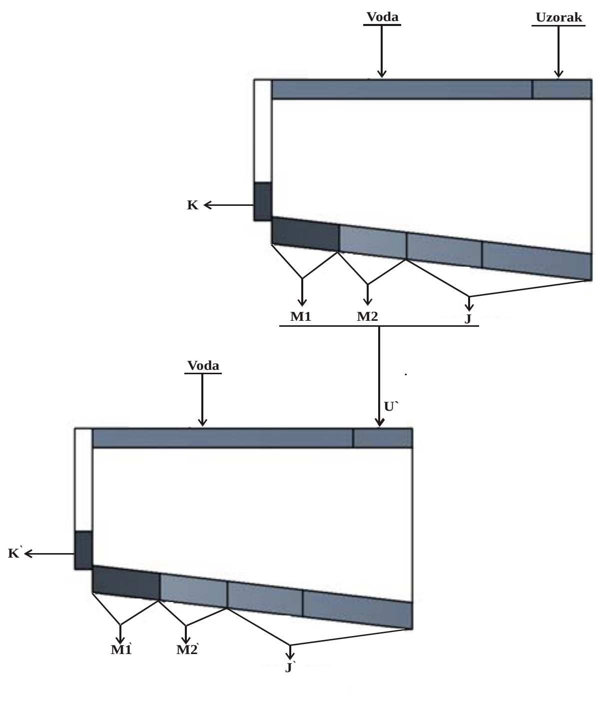


Fig. 2. *Schematic flow the second series of gravity concentration experiments*

Scheme includes two degrees of concentration.

In the first degreee of concentration on a shaking table, there is a separation into the following products:

- Concentrate K;
- Intermediate M_1;
- Intermediate $M_{2;}$
- Tailings.

Input into the second degree of concentration, conditionally called "treatment", is present by merged products from the first degree of concentration: intermediate M_1, intermediate M_2 and tailings, as shown in Figure 2. The following products are obtained by separation on a shaking table in the second degree of concentration:

- Concentrate K';
- Intermediate M_1';
- Intermediate M_2';
- Tailings'.

Merging the concentrate from the first and second degree of concentration, the definite balance of products from the second series of concentration experiments is obtained, i.e. the products:

- Concentrate K;
- Concentrate K';
- (K + K'= K_{def})
- Intermediate M_1';
- Intermediate M_2';
- Tailings'.

The preliminary P-T experiment was carried out as follows: dry sample was immersed in a conical vessel containing the heavy-liquid bromoform, with density (2.820 kg/m^3), Figure 3. After mixing and calming the liquid, a natural layering of bromoform occur into light (LF, -2820 kg/m^3) and heavy fraction (TF, +2820 kg/m^3) of density. The same is then separated from vessel. Density fractions go for further treatment consisting of centrifugation procedure (to remove the residual heavy liquids) and then drying. Finally, the samples of isolated heavy and light fractions were measured.

Considering the densities of present minerals in tested raw material, which has very complex mineralogical composition, and which, as already mentioned, have much higher densities than bromoform, there was a concentration of the entire weight of treated sample in heavy fraction, i.e. the mass participation TF is practically 100% in both treated samples "KOP" and "DEPO". The expected separation of barren minerals in a floating fraction was not occurred, what can be further comment to their intergrowth to other heavy mineral forms, as well as insufficient openness of raw materials, especially if the mineralogical report is considered which suggests that the subject samples are of massive sulfide type barite ore with significant mass participation of sulfide and barite 60-70% and consequently less participation of petrogenic components

Fig. 3. *Experiment P-T*

EXPERIMENTAL PART

The first series of experiments

Presentation the results of the first series of gravity concentration experiments of treated samples, "KOP" and "DEPO", on a shaking table, is shown respectively in Tables (1-6) and Figures (4-6).

Table 1. *Sample "KOP" 100% -3.35+0 mm*

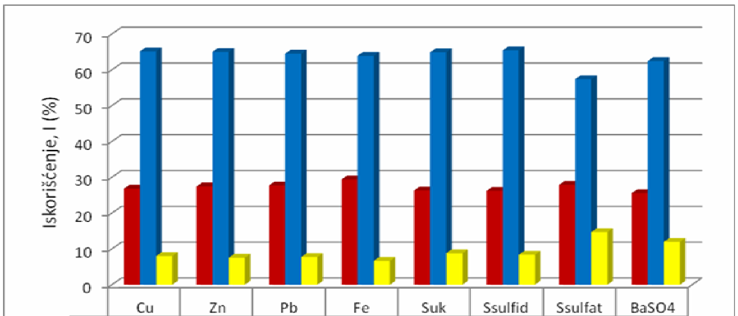
Product	m (%)	Cu (%)	ItCu (%)	Zn (%)	ItZn (%)	Pb (%)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	Itsuk (%)	Ssulfide (%)	ItSsulfide (%)	Ssulfate (%)	ItSsulfate (%)	$BaSO_4$ (%)	$ItBaSO_4$ (%)
Concentrate	25.17	1.47	26.82	5.15	27.43	3.27	27.74	23.62	29.39	38.36	26.31	35.69	26.20	2.67	27.88	15.08	25.56
Intermediate	64.67	1.39	65.16	4.75	65.02	2.96	64.52	20.00	63.95	36.83	64.91	34.69	65.43	2.14	57.41	14.34	62.46
Tailings	10.16	1.09	8.02	3.51	7.55	2.26	7.74	13.26	6.66	31.71	8.78	28.22	8.37	3.49	14.71	17.50	11.98
Input	100	1.38	100.00	4.72	100.00	2.97	100.00	20.23	100.00	36.69	100.00	34.28	100.00	2.41	100.00	14.85	100.00

Table 2. *Sample "KOP": Treated size class -3.35+1.18 mm.*

Product	m (%)	Cu (%)	ItCu (%)	Zn %)	ItZn (%)	Pb %)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	Itsuk (%)	Ssulfide (%)	ItSsulfide (%)	Ssulfate (%)	ItSsulfte (%)	$BaSO_4$ (%)	$ItBaSO_4$ (%)
Concentrate	20.27	1.55	26.10	4.88	25.71	3.12	22.59	21.45	27.76	39.17	24.96	36.35	24.86	2.82	26.32	15.32	25.50
Intermediate	70.36	1.39	70.77	4.41	70.24	3.43	75.09	17.10	66.92	36.86	70.99	34.36	71.06	2.48	69.98	14.24	71.65
Tailings	6.37	0.68	3.13	2.81	4.05	1.17	2.32	15.00	5.32	23.20	4.05	21.75	4.08	1.45	3.70	6.26	2.85
Input	100	1.38	100.00	4.42	100.00	3.21	100.00	17.98	100.00	36.51	100.00	34.02	100.00	2.49	100.00	13.98	100.00

Table 3. *Sample "KOP": Treated size class -1.18 + 0 mm.*

Product	m (%)	Cu (%)	ItCu (%)	Zn (%)	ItZn (%)	Pb (%)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	Itsuk (%)	Ssulfide (%)	ItSsulfide (%)	Ssulfate (%)	ItSsulfare (%)	$BaSO_4$ (%)	$ItBaSO_4$ (%)
Concentrate	17.78	1.30	17.14	4.08	16.61	3.58	20.47	20.00	20.62	38.05	19.74	36.02	20.13	2.03	14.71	15.44	17.44
Intermediate	67.52	1.40	70.10	4.21	65.08	3.12	67.76	15.65	61.28	34.45	67.86	32.04	67.99	2.41	66.30	14.30	61.34
Tailings	14.70	1.17	12.76	5.44	18.31	2.49	11.77	21.23	18.10	28.90	12.40	25.73	11.88	3.17	18.99	22.72	21.22
Input	100	1.35	100.00	4.37	100.00	3.11	100.00	17.24	100.00	34.27	100.00	31.82	100.00	2.45	100.00	15.74	100.00



	Cu	Zn	Pb	Fe	Suk	Ssulfid	Ssulfat	BaSO4
K	26.82	27.43	27.74	29.39	26.31	26.2	27.88	25.56
M	65.16	65.02	64.52	63.95	64.91	65.43	57.41	62.46
J	8.02	7.55	7.74	6.66	8.78	8.37	14.71	11.98

Fig. 4. *Graphical presentation the technological recoveries in concentration products on a sample "Kop", 100% -3.35+0 mm*

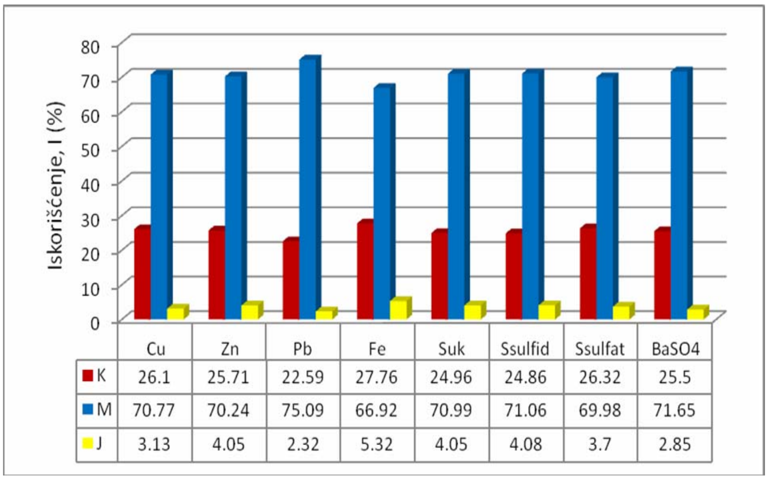


Fig. 5. *Graphical presentation the technological recoveries in concentration products on a sample "Kop", treated size class -3.35+1.18 mm*

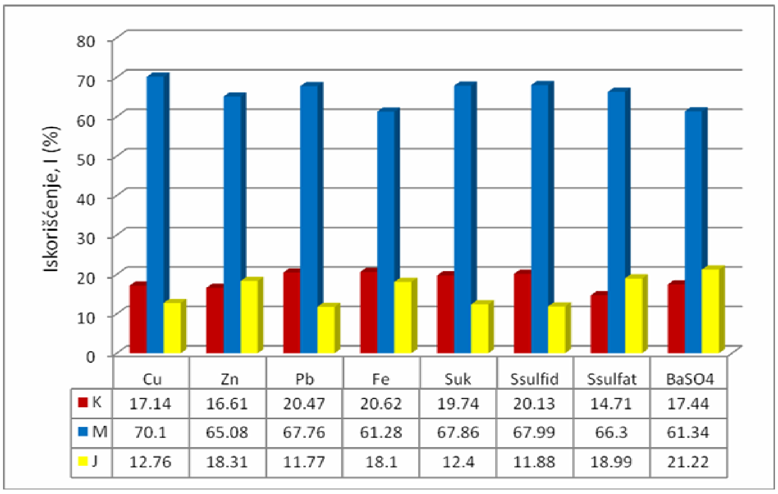


Fig. 6. *Graphical presentation the technological recoveries in concentration products on a sample "Kop", treated size class -1.18 + 0 mm*

Table 4. *Sample "DEPO" 100% -3,35+0 mm*

Product	m (%)	Cu (%)	ItCu (%)	n (%)	ItZn (%)	Pb (%)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	Itsuk (%)	Ssulfide (%)	ItSsulfide (%)	Ssulfate (%)	ItSsulfate (%)	$BaSO_4$ (%)	It$BaSO_4$ (%)
Concentrate	21.41	0.86	23.33	4.55	22.45	3.74	24.00	22.17	22.84	37.00	21.43	33.70	21.47	3.30	21.03	19.76	20.08
Intermediate	68.04	0.77	66.38	4.35	68.21	3.27	66.68	20.72.	67.85	37.38	68.81	34.20	69.25	3.18	64.42	20.28	65.49
Tailings	10.55	0.77	10.29	3.84	9.34	2.95	9.32	18.33	9.31	34.18	9.76	29.55	9.28	4.63	14.55	28.82	14.43
Input	100	0.79	100.00	4.34	100.00	3.34	100.00	20.78	100.00	36.96	100.00	33.60	100.00	3.36	100.00	21.07	100.00

Table 5. *Sample "DEPO": Treated size class -3.35+1.18 mm*

Product	m (%)	Cu (%)	ItCu (%)	Zn (%)	ItZn (%)	Pb (%)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	Itsuk (%)	Ssulfide (%)	ItSsulfide (%)	Ssulfate (%)	ItSsulfate (%)	$BaSO_4$ (%)	$ItBaSO_4$ (%)
Concentrate	24.80	0.87	25.94	4.21	23.82	3.74	26.60	19.28	23.56	36.18	26.89	33.20	27.34	2.98	22.74	20.12	24.15
Intermediate	73.29	0.82	72.24	4.48	74.89	3.43	72.08	20.72	74.85	32.37	71.10	29.05	70.69	3.32	74.87	20.82	73.84
Tailings	1.91	0.79	1.82	2.97	1.29	2.41	1.32	16.88	1.59	35.10	2.01	31.04	1.97	4.06	2.39	21.80	2.01
Input	100	0.83	100.00	4.38	100.00	3.49	100.00	20.29	100.00	33.37	100.00	30.12	100.00	3.25	100.00	20.66	100.00

Table 6. *Sample"DEPO": Treated size class -1.18 + 0 mm*

Product	m (%)	Cu (%)	ItCu (%)	Zn (%)	ItZn (%)	Pb (%)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	ItSuk (%)	Ssulfide (%)	ItSsulfide (%)	Ssulfate (%)	ItSsulfate (%)	$BaSO_4$ (%)	$ItBaSO_4$ (%)
Concentrate	18.77	0.79	18.07	4.15	18.83	3.43	18.60	20.72	18.91	34.89	18.57	31.54	18.21	3.35	22.72	20.24	17.15
Intermediate	64.90	0.85	67.21	4.35	68.26	3.58	67.11	21.45	67.69	36.53	67.21	34.03	67.94	2.50	58.63	20.84	61.04
Tailings	16.33	0.74	14.72	3.27	12.91	3.03	14.29	16.88	13.40	30.72	14.22	27.56	13.85	3.16	18.65	29.60	21.81
Input	100	0.82	100.00	4.14	100.00	3.46	100.00	20.57	100.00	35.27	100.00	32.51	100.00	2.77	100.00	22.16	100.00

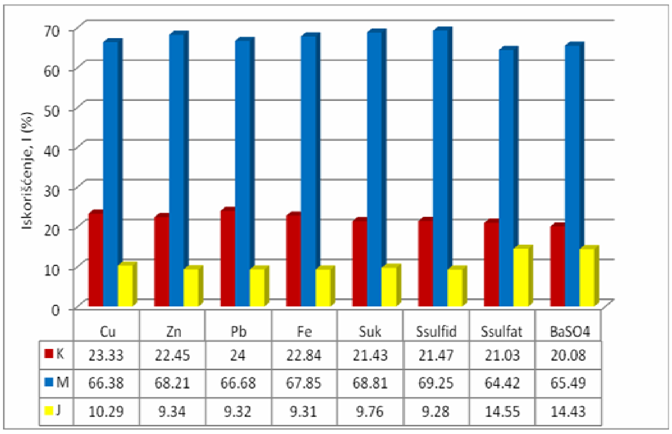


Fig. 7. *Graphical presentation the technological recoveries in concentration products on a sample "Depo", 100% -3.35+0 mm*

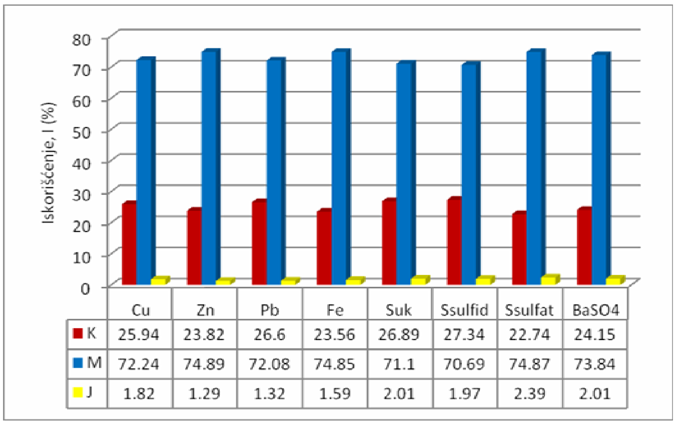


Fig. 8. *Graphical presentation the technological recoveries in concentration products on a sample "Depo", treated size class -3.35+1.18 mm*

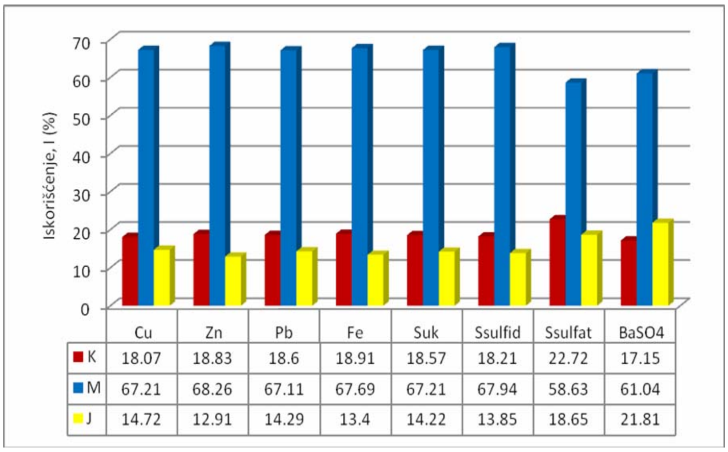


Fig. 9. *Graphical presentation the technological recoveries in concentration products on a sample "Depo", treated size class -1.18+0 mm*

Presentation the realized results of the second series of gravity concentration experiments of treated samples, "KOP" and "DEPO", on a shaking table, is shown respectively in Tables (7-13) and Figures (10-17).

Table 7. *Sample "KOP": Treated size class 100%-1.18+ 0 mm (first degree of concentration)*

Product	m (%)	Cu (%)	ItCu (%)	Zn (%)	ItZn (%)	Pb (%)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	It Suk (%)	Ssulfide (%)	ItSsulfide (%)	Ssulfate (%)	ItSsulfate (%)	$BaSO_4$ (%)	It$BaSO_4$ (%)
Concentrate K	14.98	1.33	14.82	6.31	13.49	3.81	19.95	27.19	15.43	39.75	16.60	37.68	16.84	2.07	13.24	13.94	14.53
Intermed. M_1	72.58	1.37	73.99	7.01	72.62	2.80	71.03	25.57	70.33	35.97	72.80	33.70	72.97	2.27	70.36	13.06	65.94
Intermed. M_2	4.46	1.19	3.95	6.28	3.99	1.30	2.02	23.95	4.05	30.38	3.78	27.89	3.71	2.49	4.74	19.02	5.90
Tailings	7.98	1.22	7.24	8.69	9.90	2.51	7	33.68	10.19	30.64	6.82	27.22	6.48	3.42	11.65	24.56	13.63
Input	**100**	**1.34**	**100**	**7**	**100**	**2.86**	**100**	**26.39**	**100**	**35.86**	**100**	**33.52**	**100**	**2.34**	**100**	**14.37**	**100**

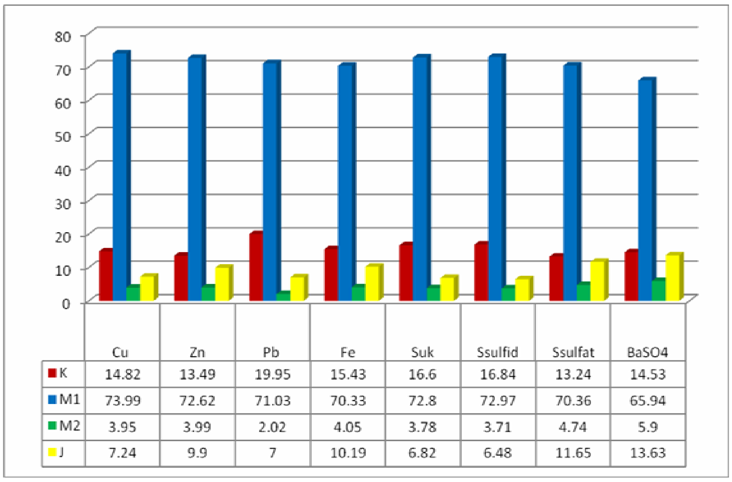


Fig. 10. *Graphical presentation the technological recoveries in concentration products on a sample "KOP", size class 100% -1.18 + 0 mm (first degree of concentration)*

Table 8. *Sample "KOP": Treated size class 100% -1.18+ 0 mm (second degree of concentration)*

Product	m (%)	Cu (%)	ItCu (%)	Zn (%)	ItZn (%)	Pb (%)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	It Suk (%)	Ssulfide (%)	ItSsulfide (%)	Ssulfate (%)	ItSsulfate (%)	$BaSO_4$ (%)	$ItBaSO_4$ (%)
Concentrate K'	13.13	1.33	13.09	7.15	13.71	3.67	15.22	29.35	14.71	37.51	13.73	35.19	13.84	2.32	12.20	14.66	14.03
Intermed. M_1'	75.43	1.33	75.20	6.94	76.44	3.23	76.93	26.11	75.20	36.44	76.61	34.03	76.89	2.41	72.83	12.38	68.07
Intermed. M_2'	3.37	1.26	3.19	6.59	3.24	2.07	2.20	24.49	3.15	31.72	2.98	29.38	2.97	2.34	3.16	17.98	4.42
Tailings'	8.07	1.41	8.52	5.61	6.61	2.22	5.65	22.52	6.94	29.71	6.68	26.06	6.30	3.65	11.80	22.92	13.48
Input	100	1.33	100	6.84	100	3.17	100	26.19	100	35.88	100	33.38	100	2.49	100	13.69	100

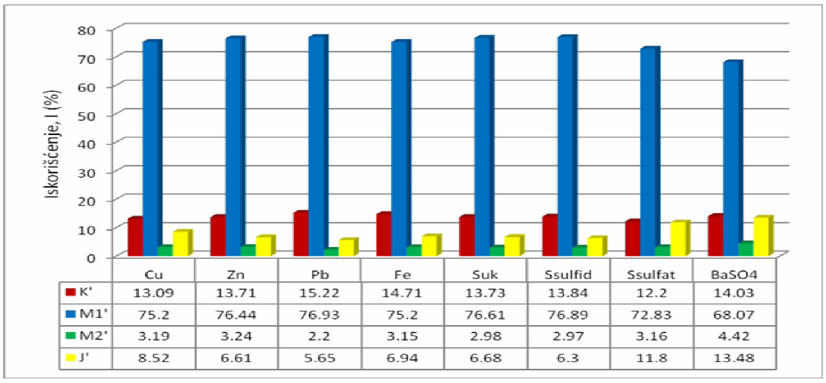


Fig. 11. *Graphical presentation the technological recoveries in concentration products on a sample "KOP", size class 100% -1.18 + 0 mm (second degree of concentration)*

Table 9. *Sample "KOP": Treated size class 100% -1.18+ 0 mm (second degree of concentration) – in relation to the input 85.02%*

Product	m (%)	Cu (%)	ItCu (%)	Zn (%)	ItZn (%)	Pb (%)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	It Suk (%)	Ssulfide (%)	ItSsulfide (%)	Ssulfate (%)	ItSsulfate (%)	$BaSO_4$ (%)	$ItBaSO_4$ (%)
Concentrate K'	11.16	1.33	13.09	7.15	13.71	3.67	15.22	29.35	14.71	37.51	13.73	35.19	13.84	2.32	12.20	14.66	14.03
Intermed. M_1'	64.13	1.33	75.20	6.94	76.44	3.23	76.93	26.11	75.20	36.44	76.61	34.03	76.89	2.41	72.83	12.38	68.07
Intermed. M_2'	2.86	1.26	3.19	6.59	3.24	2.07	2.20	24.49	3.15	31.72	2.98	29.38	2.97	2.34	3.16	17.98	4.42
Tailings'	6.87	1.41	8.52	5.61	6.61	2.22	5.65	22.52	6.94	29.71	6.68	26.06	6.30	3.65	11.80	22.92	13.48
Input	85.02	1.33	100	6.84	100	3.17	100	26.19	100	35.88	100	33.38	100	2.49	100	13.69	100

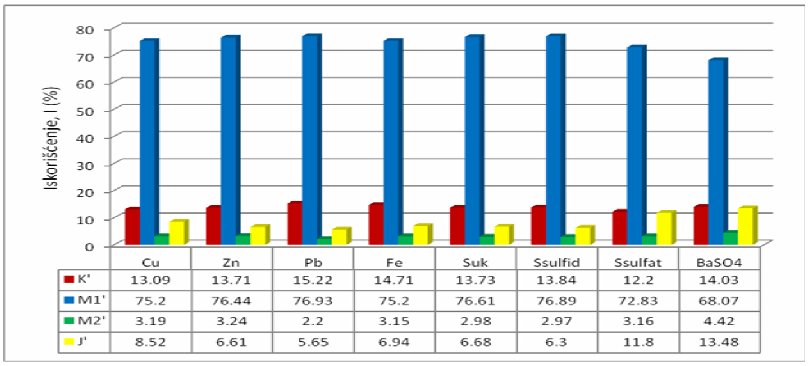


Fig. 12. *Graphical presentation the technological recoveries in concentration products on a sample "KOP", size class 100% -1.18 + 0 mm (second degree of concentration) – in relation to the input 85.02%*

Table 10. *Sample "KOP": Final balance of concentration product of treated size class 100% -1.18+0 mm*

Product	m (%)	Cu (%)	ItCu (%)	Zn (%)	ItZn (%)	Pb (%)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	It Suk (%)	Ssulfide (%)	ItSsulfide (%)	Ssulfate (%)	ItSsulfate (%)	$BaSO_4$ (%)	$ItBaSO_4$ (%)
Concentrate K	14.98	1.33	14.94	6.31	13.97	3.81	17.49	27.19	15.46	39.75	16.33	37.68	16.59	2.07	12.75	13.94	15.19
Concentrate K'	11.16	1.33	11.13	7.15	11.79	3.67	12.55	29.35	12.44	37.51	11.48	35.19	11.54	2.32	10.65	14.66	11.90
K_{def}(K+K')	26.14	1.33	26.07	6.67	25.76	3.75	30.04	28.11	27.90	38.79	27.81	36.62	28.13	2.18	23.40	14.25	27.09
Intermediate M_1'	64.13	1.33	63.96	6.94	65.76	3.23	63.47	26.11	63.57	36.44	64.10	34.03	64.14	2.41	63.54	12.38	57.73
Intermediate M_2'	2.86	1.26	2.70	6.59	2.79	2.07	1.82	24.49	2.66	31.72	2.49	29.38	2.47	2.34	2.75	17.98	3.74
Tailings'	6.87	1.41	7.27	5.61	5.69	2.22	4.67	22.52	5.87	29.71	5.60	26.06	5.26	3.65	10.31	22.92	11.44
Input	**100**	**1.33**	**100**	**6.77**	**100**	**3.26**	**100**	**26.34**	**100**	**36.46**	**100**	**34.03**	**100**	**2.43**	**100**	**13.75**	**100**

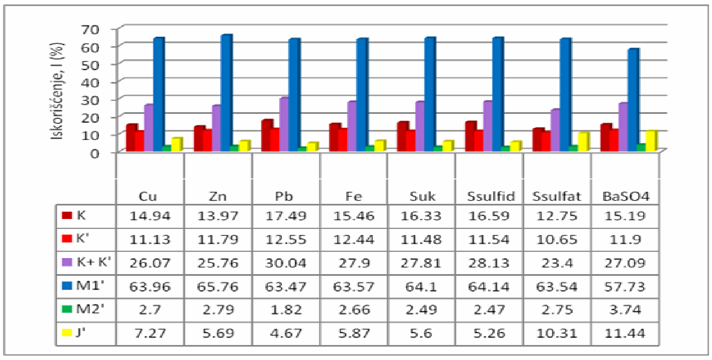


Fig. 13. *Graphical presentation the technological recoveries in concentration products on a sample "KOP", size class 100% -1.18 + 0 mm – Final balance of concentration product*

Table 11. *Sample "DEPO": Treated class size 100% -1.18 + 0 mm (first degree of concentration)*

Product	m (%)	Cu (%)	ItCu (%)	Zn (%)	ItZn (%)	Pb (%)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	It Suk (%)	Ssulfide (%)	ItSsulfide (%)	Ssulfate (%)	ItSsulfate (%)	$BaSO_4$ (%)	$ItBaSO_4$ (%)
Concentrate K	24.79	0.85	25.23	4.91	23.44	3.09	27.40	25.57	24.88	33.76	24.82	30.88	25.09	2.88	22.25	20.64	22.63
Intermediate M_1	63.80	0.84	64.16	5.40	66.34	2.94	67.09	26.11	65.37	34.75	65.75	31.54	65.95	3.21	63.81	21.50	60.68
Intermediate M_2	4.55	0.83	4.53	5.12	4.49	1.35	2.20	23.41	4.18	29.94	4.04	26.06	3.89	3.88	5.50	31.06	6.25
Tailings	6.86	0.74	6.08	4.34	5.73	1.35	3.31	20.70	5.57	26.53	5.40	22.58	5.07	3.95	8.44	34.40	10.44
Input	**100**	**0.83**	**100**	**5.19**	**100**	**2.79**	**100**	**25.48**	**100**	**33.72**	**100**	**30.51**	**100**	**3.21**	**100**	**22.61**	**100**

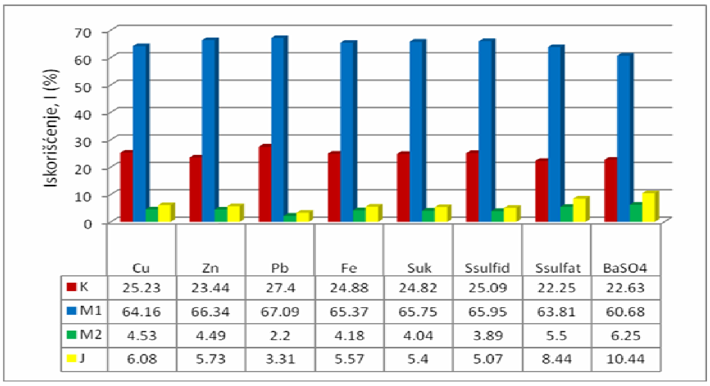


Fig. 14. *Graphical presentation the technological recoveries in concentration products on a sample "Depo", treated size class -1,18 +0 mm (first degree of concentration)*

Table 12. *Sample "DEPO": Treated class size 100% -1.18 + 0 mm (second degree of concentration)*

Product	m (%)	Cu (%)	ItCu (%)	Zn (%)	ItZn (%)	Pb (%)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	It Suk (%)	Ssulfide (%)	ItSsulfide (%)	Ssulfate (%)	ItSsulfate (%)	$BaSO_4$ (%)	$ItBaSO_4$ (%)
Concentrate K'	16.02	0.84	16.11	5.47	15.90	3.38	19.03	25.57	16.30	33.50	15.52	30.54	15.45	2.96	16.28	20.26	14.24
Intermediate M_1'	71.55	0.84	71.93	5.61	72.85	2.94	73.92	25.57	72.82	36.05	74.59	33.20	75.01	2.85	70.03	21.86	68.61
Intermediate M_2'	4.63	0.81	4.49	5.33	4.48	1.34	2.17	22.32	4.12	27.23	3.65	24.40	3.57	2.83	4.50	29.78	6.05
Tailings'	7.80	0.80	7.47	4.78	6.77	1.78	4.88	21.78	6.76	27.67	6.24	24.24	5.97	3.43	9.19	32.44	11.10
Input'	100	0.83	100	5.51	100	2.85	100	25.12	100	34.58	100	31.67	100	2.91	100	22.79	100

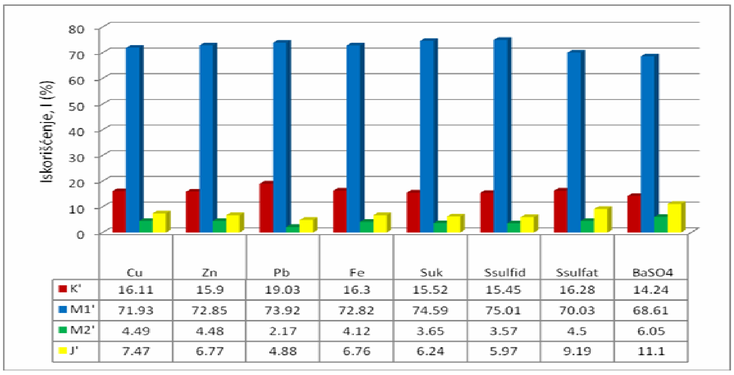


Fig. 15. *Graphical presentation the technological recoveries in concentration products on a sample "Depo", size class 100% -1.18 +0 mm (second degree of concentration)*

Table 13. *Sample "DEPO": Treated class size 100% -1.18 +0 mm (second degree of concentration)- in relation to the input 75.21 %*

Product	m (%)	Cu (%)	ItCu (%)	Zn (%)	ItZn (%)	Pb (%)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	It Suk (%)	Ssulfide (%)	ItSsulfide (%)	Ssulfate (%)	ItSsulfate (%)	$BaSO_4$ (%)	$ItBaSO_4$ (%)
Concentrate K'	12.05	0.84	16.11	5.47	15.90	3.38	19.03	25.57	16.30	33.50	15.52	30.54	15.45	2.96	16.28	20.26	14.24
Intermediate M_1'	53.81	0.84	71.93	5.61	72.85	2.94	73.92	25.57	72.82	36.05	74.59	33.20	75.01	2.85	70.03	21.86	68.61
Intermediate M_2'	3.48	0.81	4.49	5.33	4.48	1.34	2.17	22.32	4.12	27.23	3.65	24.40	3.57	2.83	4.50	29.78	6.05
Tailings'	5.87	0.80	7.47	4.78	6.77	1.78	4.88	21.78	6.76	27.67	6.24	24.24	5.97	3.43	9.19	32.44	11.10
Input'	75.21	0.83	100	5.51	100	2.85	100	25.12	100	34.58	100	31.67	100	2.91	100	22.79	100

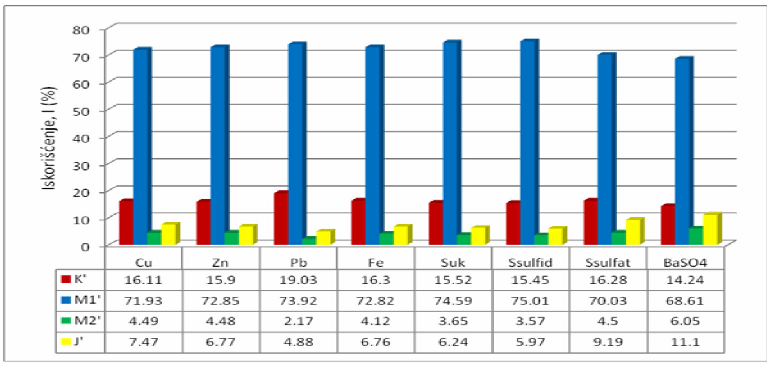


Fig. 16. *Graphical presentation the technological recoveries in concentration products on a sample "Depo", size class 100 % -1.18 +0 mm (second degree of concentration) – in relation to the input 75.21%*

Table 14. *Sample "DEPO": Final balance of concentration product of treated size class 100% -1.18+0 mm*

Product	m (%)	Cu (%)	ItCu (%)	Zn (%)	ItZn (%)	Pb (%)	ItPb (%)	Fe (%)	ItFe (%)	Suk (%)	It Suk (%)	Ssulfide (%)	ItSsulfide (%)	Ssulfate (%)	ItSsulfate (%)	$BaSO_4$ (%)	$ItBaSO_4$ (%)
Concentrate K	24.79	0.85	25.11	4.91	22.71	3.09	26.36	25.57	25.12	33.76	24.35	30.88	24.32	2.88	24.59	20.64	22.98
Concentrate K'	12.05	0.84	12.06	5.47	12.29	3.38	14.01	25.57	12.21	33.50	11.74	30.54	11.69	2.96	12.28	20.26	10.97
$K_{def,}$(K+K')	36.84	0.85	37.17	5.09	35.00	3.18	40.37	25.57	37.33	33.67	36.09	30.77	36.01	2.91	36.87	20.50	33.95
IntermediateM$_1$'	53.81	0.84	53.87	5.61	56.31	2.94	54.43	25.57	54.52	36.05	56.43	33.20	56.77	2.85	52.81	21.86	52.84
IntermediateM$_2$'	3.48	0.81	3.36	5.33	3.46	1.34	1.60	22.32	3.08	27.23	2.76	24.40	2.70	2.83	3.39	29.78	4.66
Taillings'	5.87	0.80	5.60	4.78	5.23	1.78	3.60	21.78	5.07	27.67	4.72	24.24	4.52	3.43	6.93	32.44	8.55
Input	**100**	**0.84**	**100**	**5.36**	**100**	**2.90**	**100**	**25.23**	**100**	**34.38**	**100**	**31.47**	**100**	**2.90**	**100**	**22.26**	**100**

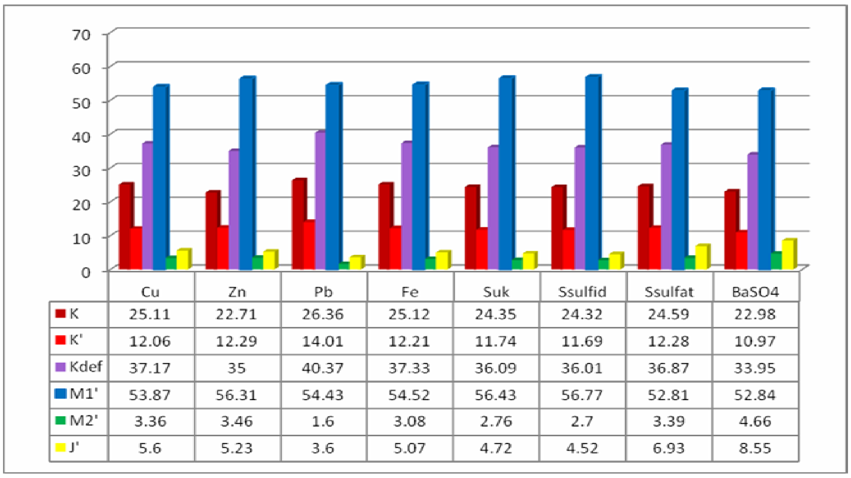


Fig. 17. *Graphical presentation the technological recoveries in concentration products on a sample "Depo", size class 100 % -1.18 +0 mm Final balance of concentration product*

RESULTS AND DISCUSSION

Reviewing the achieved results in the first series of gravity concentration experiments of treated size classes: 100% + 0 -3.35 mm; -3.35 +1.18 mm and -1.18+0 mm of samples "KOP" and "DEPO" on a shaking table, it can be concluded about the impossibility of adequate valorization the useful components, primarily sulfide minerals and mineral barite. These results are certainly a consequence of structural-textural characteristics of raw materials, in terms of intergrowth the sulfide minerals with the barren minerals, which was confirmed by mineralogical analysis. High participation of sulfide phase was also observed in both treated samples.

A very low presence of free grains, as well as high presence of complex inter growings and impregnations has affected the separation and concentration of sulfide minerals with barite in concentrates and intermediate product. However, approximately the same quality (content) of analyzed elements is present in almost all concentration products compared to the input. This also confirmed the statement from the beginning of this paragraph, based on the findings that the treatment of sulfide barite ore results into concentration of sulfide minerals together with barite in all treated size classes. Obviously that this raw material, massive sulfide barite ore, expresses a disadvantage for gravity treatment by shaking table in terms of separation some kind of gravitational pre-concentrate. This is clearly shown by the realized results on both treated samples "KOP" and "DEPO" in all treated size classes as follows: 100% + 0 -3.35 mm, -3.35+1.18mm and -1.18+0 mm. In practice, this means that only physical division of masses occurs without significant concentration of minerals in the expected products, concentrate and possibly the first intermediate product.

Reviewing the achieved results in the second series of gravity concentration experiments, realization of higher technological recoveries is recognized in an intermediate (M_1'), in both treated samples. In the second degree of concentration on defined size class size of 100% -1.18 +0 mm, compared with the realized technological recoveries in the first series of experiments in intermediate products, the technological recovery is higher. However, in this case, there was a concentration of sulfide minerals with barite in intermediate, which did not achieve any selection of the same.

The final balance of concentration products is presents in Figures 13 and 17, respectively according to the samples, did not give the significant results. Respectively, based on a review of those technological recoveries in the concentration products for both treated samples "KOP" and "DEPO", the following can be concluded:

It is obvious that further comminuting of raw material does not achieve enough openness, and that is because it is a complex polymetallic ore with the most represented sulfide minerals: pyrite, sphalerite, and galena, chalcopyrite, etc. is necessary. It is also the main reason for such obtained results. But, however, further opening of raw minerals, i.e. lowering of its coarseness, comes out from the possibilities and applicability of gravity concentration method.

Complexity of such mineral form and the obtained results indicate to a conclusion that this method as the method of pre-concentration, should be partially used to this raw material only on a condition that the obtained concentrates and fist intermediates of a shaking table are connected together as products. Generally, for both treated samples "KOP" and "DEPO", it would mean the elimination of barren mass of the order of 10-15%, while the metals, depending on metal type, would lose about 8-12%. So, the pre-concentration procedure would be moved within these limits, depending on the processing capacity, what can be meaningful only if it is a case with the processing capacity of this raw material. Otherwise, the gravity concentration is not recommended as the pre-concentration method of flotation concentration.

CONCLUSION

Gravity concentration method on a shaking table in treatment the samples "KOP" and "DEPO", has not proved to be a method for efficient pre-concentration or selection the sulfide minerals, barite and barren minerals with satisfactory technological results.

Complexity of this mineral form which is treated by gravity concentration on a shaking table and the obtained results indicate to a conclusion that this method as a method of pre-concentration, can be partially used to this raw material. For both treated samples "KOP" and "DEPO", it would mean the elimination of barren mass of the order of 10-15%, while the metals, depending on metal type, would lose about 8-12%.

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ELEKTROKINETIČKO UKLANJANJE Pb IZ JALOVINE UZ PRIMENU STABILIZACIONIH AGENASA**

Izvod

U ovom radu je ispitivana mogućnost primene određenih stabilizacionih agenasa radi poboljšanja elektrokinetičkog tretmana jalovine sa visokim sadržajem Pb. Različiti stabilizacioni agensi su postavljani u katodni region radi poboljšanja imobilizacije Pb, čime je omogućena kontrola kretanja i ponašanja Pb. Elektrokinetički eksperimenti su vršeni u elektrokinetičkom uređaju pri gradijentu napona od 1 V/cm. Kao stabilizacioni agensi su korišćeni: aktivni ugalj, zeolit, leteći pepeo, Portland cement i kreč, pri čemu su postignute ukupne efikasnosti uklanjanja Pb od 21,4%, 22,6%, 21,4%, 17,6% i 20,6%, redom. Nakon konvencionalnog elektrokinetičkog tretmana uklonjeno je 23,6% Pb. Aktivnim ugljem sorbovano je 31% Pb uklonjenog iz jalovine, zeolitom 9%, letećim pepelom 51%, Portland cementom 78% i krečom 87%. Rezultati ukazuju da Portland cement i kreč imobilizuju Pb u katodnom regionu u značajnoj meri što omogućava njihovu dalju primenu u građevinarstvu.

Ključne reči: *elektrokinetička remedijacija, jalovina, stabilizacioni agensi, olovo.*

1. UVOD

Jalovina je materijal koji nastaje nakon procesa izdvajanja korisne frakcije rude. Nakon separacije jalovina se odlaže i, s obzirom da sadrži visoke koncentracije teških metala kao i da se na odlagalištima akumulira dugo vremena, može ispoljiti brojna neželjena dejstva na životnu sredinu. Metali u jalovini postoje u stabilnim oblicima, ali je uklanjanje rastvorenih oblika od velike važnosti s obzirom na njihov uticaj na životnu sredinu. Elektrokinetička (EK) remedijacija se može koristiti za uklanjanje rastvorenih oblika metala iz jalovine. U toku EK jednosmerna struja se propušta kroz medijum posredstvom uronjenih elektroda [1, 2]. Kao posledica primene struje nekoliko procesa se simultano odvija: elektroliza, elektromigracija, elektroosmoza

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(hemijska osmoza) elektroforeza, difuzija i niz geohemiskih reakcija. Za uklanjanje metala elektromigracija ima najveći značaj. Budući da se pri primenjenom naponu jedino rastvoreni metali ekstrahuju, EK tretman može sprečiti difuziju metala iz jalovine u okolno zemljište kao i njihovo dospevanje u vodene sisteme. Do sada EK tretman jalovine nije istražen u velikoj meri [3, 4]. Kako bi se EK tretman unapredio postoji niz tehnika koje su razvijene radi poboljšanja ekstrakcije zagađujućih materija iz medijuma [4-6], sprečavanja formiranja hidroksida metala [7-11] i smanjenja troškova tretmana [12-14].

Permeabilna reaktivna barijera (eng, Permeable Reactive Barriers, PRB) je barijera koja se sadrži reaktivni materijal koji je postavljen na put protoka zagađenja, pri čemu se zagađujuće materije uklanjaju ili razgrađuju [15]. PRB se mogu koristiti pri EK tretmanu. Kako se PRB simultano koristi sa EK, protok zagađujućih materija kroz barijeru ostvaren je elektromigracijom odnosno elektroforezom (u slučaju kretanja naelektrisanih čestica). Različiti PRB su do sada korišćeni za EK tretman zemljišta: ZVI, eng. zero-valent iron [16-18], ferit [19], atomizirana šljaka [20], crveni mulj [21], ugljenične nanocevi [22] i ugljenisani ostaci hrane [23]. Interakcija teških metala sa različitim materijalima je do sada ispitivana: kreč [24], Portland cement [25], aktivni ugalj [26, 27], gline [28, 29], industrijski otpad kao što je leteći pepeo [24, 25, 30]. Ipak, korišćenje ovih materijala kao PRB pri EK tretmanu nisu do sada korišćeni.

U ovom radu je ispitivana primena pojedinih stabilizacionih agenasa u katodnom regionu kako bi se kontrolisalo ponašanje i migracija Pb u toku EK tretmana, a pri čemu bi se isti nakon tretmana mogli koristiti, na primer, u građevinarstvu. U ovom radu je ispitivana mogućnost primene pojedinih stabilizacionih agenasa za EK tretman jalovine sa niskim kapacitetom katjonske izmene i visokim sadržajem Pb. Stabilizacioni agensi mogu znatno stabilnije da vezuju kontaminante nego medijum kog odlikuje nizak kapacitet katjonske izmene, a i manja količina agensa je potrebna za postizanje iste efikasnosti u odnosu na primenu medijuma takvih osobina. Pored cementa i kreča koji se najčešće koriste u svrhu stabilizacije/solidifikacije u radu su korišćeni leteći pepeo, aktivni ugalj i zeolit.

2. EKSPERIMENTALNI USLOVI

pH vrednost jalovine je merena pomoću pH-metra (340i, WTW) u supernatantu nakon mešanja jalovine i dejonizovane vode u odnosu 1:5, primenom SenTix®21 elektrode. Amonijum acetatni metod je korišćen za merenje kapaciteta katjonske izmene (eng. Cation Exchange Capacity, CEC). Kapacitet kisele neutralizacije (eng. Acid Neutralizing Capacity, ANC) je određene titracijom sa 0,1 M HCl i izračunat primenom Gran metode. Električna struja je praćena pomoću ampermetra. Ekstrakcija za određivanje pseudo-ukupnog sastava Pb u jalovini je sprovođena u skladu sa USEPA Method 3051A. Uzorak jalovine (0,5 g, suvog uzorka) je pomešan sa 10 mL koncentrovane HNO_3 u teflonskoj kiveti. Ekstrakcija je vršena pomoću mikrotalasne peći (Milestone, Stare E microwave) prema sledećem programu: 5,5 min temperatura raste do 175°C, nakon čega se održava na 175°C u toku 4,5 min. Nakon ekstrakcije smeša se filtrira u odmerni sud od 50 mL. Analiza Pb je vršena pomoću Atomskog apsorpcionog spektrofotometra, plamena tehnika, (PerkinElmer, AAnalyst 700) u skladu sa with USEPA method 7000b. Granica detekcije metode za Pb je (MDL) 0,25 mg/L, a granica kvantitacije (PQL) 0,51 mg/L. Jalovina je klasifikovana pre i nakon tretmana prema [31] i [32]. Efikasnost materijala za imobilizaciju Pb je procenjena na osnovu testova toksičnosti, eng. Toxicity Characterization Leaching Procedure (TCLP) koji je razvijen radi utvrđivanja mobilnosti organskih i neorganskih analita u tečnim, čvrstim i mešovitim otpadima. Odgovarajući ekstrakcioni fluid je određen prema proceduri definisanoj u TCLP testu. 100 g odgovarajućeg materijala i 2 L određenog ekstrakcionog fluida su postavljene u plastične boce od 2 L i mešane 18 h na horizontalnoj mućkalici (30±2 rpm). Na kraju ekstrakcionog perioda vršena je filtracija kroz 0,45 μm membranski filter. Svi ekstrakti su zakišeljeni sa 1 N HNO_3 do pH<2 radi prezervacije.

Eksperimentalni uslovi i karakteristike imobilizacionih agenasa su date u Tabeli 1. Kako bi se ispitala sorpciona aktivnost agenasa sprovedeni su je sledeći testovi: 1,0 g svakog sorbenta je postavljeno u Erlenmajer od 250 mL, dodato je 100 ml 500 mg/l Pb rastvora i mešanje je vršeno 10 min na horizontalnoj mućkalici. Eksperimenti su sprovođeni na pH 10 na temeraturi od 25°C. Nakon mešanja sadržaj je filtriran i određena je koncentracija Pb u filtratu. Preostala koncentracija Pb u sorbentu q_e (mg/g) je izračunata na sledeći način:

$$q_e = \frac{(C_0 - C_e) \cdot V}{m_a}$$

gde je:

C_0 - početna koncentracija Pb u mg/L,

C_e - ravnotežna koncentracija metala u mg/l,

V - zapremina rastvora (L) i

m_a - masa sorbenta (g). Svaki eksperiment je rađen u duplikatu i za račun je korišćena srednja vrednost.

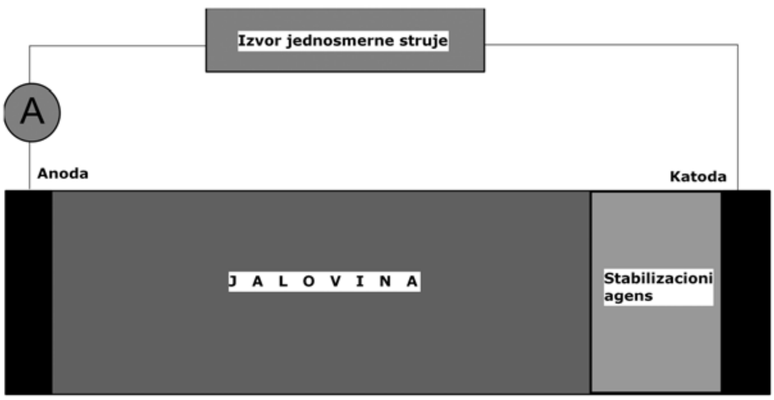
EK tretmani su vršeni u uređaju koji je prikazan na slici 1. Korišćene su grafitne elektrode (anoda i katoda) dimenzija 10 x 5 x 1 cm. Gradijent napona u toku eksperimenata je održavan na 1 V/cm, pri čemu su eksperimenti trajali 7 dana na 25°C. Na kraju svakog eksperimenta jalovina je podeljena na 5 jednakih delova. Svaki deo je označen kao nor-malizovano rastvojanje od anode z/L (z = rastojanje od anode, L = rastvojanje između elektroda): 0,1, 0,3, 0,5 i 0,7. Stabilizacioni agensi su smešteni na z/L= 0,9. Koncentracija Pb i pH vrednost su mereni u početnom uzorku i u svakom delu nakon tretmana. Ukupna efikasnost uklanjanja Pb je izračunata prema:

$$\% = \left(\frac{m_i - m_s}{m_i} \right) \cdot 100$$

gde je:

m_i - masa Pb u jalovini (mg), a

m_s - masa Pb koja preostaje u jalovini nakon tretmana (mg).



Sl. 1. *Elektrokinetički uređaj*

Tabela 1. Eksperimentalni uslovi

Oznaka eksperimenta	Stabilizacioni agens	pH	q_e (mg/g)
CON	-	-	29,0
ACB	Aktivni ugalj	7,50	52,2
ZEO	Zeolit	7,82	36,0
CFA	Leteći pepeo	10,55	62,3
PCE	Portland cement	10,95	99,3
LME	Kreč	12,50	>99,9

3. REZULTATI I DISKUSIJA

3.1. Karakteristike jalovine

Niske vrednosti ANC (4,75 meq/100g) i CEC (0,75 meq/100g) ukazuju da se kiseli front može formirati u jalovini u toku EK tretmana, kretanjem H^+ jona formiranih na anodi. Kiseli front omogućava rastvaranje i desorpciju metala sa čestica medijuma [2]. Početna pH vrednost jalovine je 7,80. Početna vrednost Pb u jalovini je 1184 mg/kg dok je koncentracija Zn 1084 mg/kg. Jalovina se može klasifikovati kao opasan otpad prema sadržaju Pb na osnovu kriterijuma datih u [31] i [32], dok prema sadržaju Zn na osnovu [31].

3.2. Promene pH vrednosti jalovine nakon EK tretmana

Promene pH vrednosti jalovine nakon EK tretmana su date u Tabeli 2. Kao što je i očekivano nije bilo značajnih razlika u pH vrednostima jalovini na različitim rastojanjima od anode nakon tretmana osim pri korišćenju letećeg pepela, cementa i kreča koji doprinose povećanju pH vrednosti na z/L=0,7 i 0,9 (Tabela 1). Na osnovu pH vrednosti sorbenta može se utvrditi da se OH^- joni, formirani u toku elektrolize vode na katodi, zadržavaju u sorbentu što može rezultovati precipitacijom hidroksida metala, a i određena količina OH^- jona iz sorbenta migrira ka jalovini.

Tabela 2. pH vrednosti jalovine nakon EK tretmana

z/L	pH					
	CON	ACB	ZEO	CFA	PCE	LME
0,1	4,89	5,27	5,31	5,25	5,40	5,34
0,3	6,36	6,75	6,84	6,87	6,75	6,78
0,5	7,15	7,22	7,12	7,19	7,16	7,25
0,7	7,78	7,82	8,40	9,50	9,42	10,11
0,9	8,54	8,40	8,65	10,50	11,15	11,01

3.3. Distribucija Pb u jalovini nakon EK tretmana

Ukupna efikasnost uklanjanja Pb nakon CON je bila 23,6% (izuzimajući sadržaj Pb na z/L=0,9), dok Zn nije uklonjen iz jalovine. Na osnovu navedenog praćena je samo imobilizacija Pb. Ukupne efikasnosti uklanjanja Pb nakon tretmana sa primenom agenasa su: 21,4%, 22,6%, 21,4%, 17,6% i 20,6%, uz primenu aktivnog uglja, zeolita, letećeg pepela, Portland cementa i kreča, redom. Aktivni ugalj sorbovao je 31% Pb uklonjenog iz jalovine, zeolit 9%, leteći pepeo 51%, cement 78% i kreč 87%. U jalovini se na z/L=0,9 akumuliralo 38% uklonjenog Pb. Dobijeni rezultati se slažu sa q_e vrednostima za agense datim u Tabeli 1. Na z/L=0,7 nakon tretmana sa agensima dolazi do povećanja pH vrednosti jalovine u odnosu na CON, ali do akumulacije na ovom rastojanju nije došlo nakon tretmana sa agensima.

Primenjeni agensi imaju različite stabilizacione mehanizme. Svi agensi su dodati u istim količinama, kontaktno vreme, temeratura i koncetracija Pb su iste.

Aktivni ugalj. COOH grupe u aktivnom uglju su odgovorne za vezivanje Pb budući da se deprotonacija COOH grupa vrši na pH>4 [33]. Na nižim pH vrednostima COOH grupe su u protonovanom obliku što onemogućava vezivanje pozitivnih jona. Na pH>4 deprotonovana COOH grupa (COO^-) može vezati pozitivno naelektrisane Pb jone. Vezivanje se zasniva na jonskoj izmeni koja uključuje elektrostatičko privlačenje između negativno naelektrisanih grupa aktivnog uglja i Pb katjona. Dodatno, alkalni uslovi uzrokuju precipitaciju Pb što doprinosi stabilizaciji. Iako je aktivni ugalj efikasan za uklanjanje Pb iz vodenih rastvora [34], nije postignuta željena efikasnost u kombinaciji sa EK. To je najverovatnije posledica ograničene jonske izmene pri primenjenom naponu budući da je kretanje jona elektromigracijom suviše brzo da bi se jonska izmena mogla izvršiti. Koncentracija Pb nakon izluživanja prema TCLP testu je bila ispod granične vrednosti (5 mg/L za pH vrednosti 7 i 11).

Zeolit. Zeoliti se često koriste za uklanjanje različitih toksičnih materija na principu jonske izmene. CEC zeolita korišćenog u ovom radu je 164 meq/100g. Struktura zeolita je zasnovana na SiO_4 i AlO_4 tetrahedru. Zamenom Si^{4+} jona Al^{3+} formira se negativno naelektrisanje površine zeolita koje je neutralisano Na^+, Ca^{2+} i K^+. Ovi katjoni se mogu izmeniti katjonima kao što su Pb, Cd, Zn i Mn [35]. Činjenica da Na^+, Ca^{2+} i K^+ koji se oslobađaju iz zeolita nemaju negativne efekte po životnu sredinu čine zeolite poželjnim za uklanjanje teških metala. Količina sorbovanih metala iz rastvora raste sa porastom početne pH vrednosti rastvora. Pri nižim pH vrednosima zeoliti vezuju H^+ jone pre nego jone teških metala tako da se u alkalnim uslovima teški metali mogu nesmetano vezati za zeolite [36, 37]. Prema [38] eletrično polje je uzrokovalo da se Cu^{2+} joni kreću suviše brzo kroz zeolit, tako da je jonska izmena bila ograničena. Ovim se može objasniti mala efikasnost sorbovanja Pb pomoću zeolita u toku EK tretmana, slično primeni aktivnog uglja. Dodatno, na osnovu Tabele 1 može se uvideti da pri ispitivanim zeolit nije efikasan za sorpciju Pb^{2+}. Koncentracija Pb nakon izluživanja prema TCLP testu je bila ispod granične vrednosti (5 mg/L za pH vrednosti 7 i 11).

Leteći pepeo. Sastav letećeg pepela je (% wt.): SiO_2 (39,4), Al_2O_3 (20,1), Fe_2O_3 (4,95), MgO (4,01), CaO (23,2), K_2O (0,64), Na_2O (2,12) i SO_3 (1,88). Visok sadržaj CaO je odgovoran za hidrauličke dok su silikati odgovorni za pozolanske osobine letećeg pepela. Kao što je i očekivano sorpcija metala na visokim pH vrednostima je značajnija nego u kiselim uslovima. Ovo je posledica smanjene kompeticije H^+ jona i ciljnih jona za vezivanje, a koja se u značajnoj meri javlja pri nižim pH vrednostima. Prema [30], sorpcija Pb u alkalnim uslovima je ireverzibilna. Dodatno, sadržaj karbonata raste sa porastom pH vrednosti [24]. Rastvorljivost karbonata i hidroksida metala je značajan faktor pri sorpciji metala, jer formiranje karbonata i hidroksida može uticati na sorpciju.

Formiranje karbonata je izuzetno značajno kod materijala kao što je leteći pepeo odnosno onih sa visokim sadržajem soli. Proizvod rastvorljivosti $PbCO_3$ je $10^{-12.95}$ M^2, a $Pb(OH)_2$ $10^{-15.3}$ M^3. $PbCO_3$ je nerastvorni mineral koj se može taložiti u reakciji sa letećim pepelom. Imobilizacija Pb se javlja formiranjem pozolanskih proizvoda na površini ili inkorporacijom Pb hemijskom inkluzijom [25].

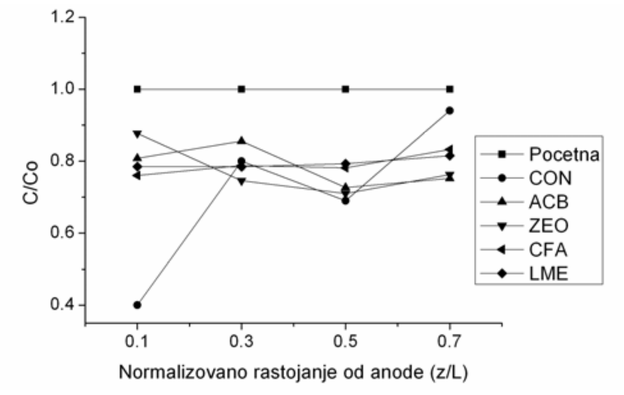
Portland cement i kreč. Kreč i cement su sposobni za stabilizaciju i istovremenu solidifikaciju. Stabilizacija teških metala cementom i krečom se vrši na osnovu pozolanskih reakcija i usled alkalnih uslova u tretiranom materijalu.

Portland cement se sastoji od kalcijum-silikata i kalcijum-aluminata koji kada se mešaju sa vodom grade cementne komponente: kalcijum-silikat-hidrat, kalcijum-aluminat-hidrat kao i kalcijum-hidroksid. Sastav korišćenog Portland cementa je (% wt.): SiO_2 (23,4), Al_2O_3 (6,12), Fe_2O_3 (3,21), MgO (1,01), CaO (63,2), K_2O (0,54), Na_2O (0,12) i SO_3 (1,18), a gubitak žarenjem (1,4). Kada se cement koristi za tretman odvijaju se pozolanske reakcije, jer su kalcijum-silikat, jedinjenja aluminijuma i gvožđa u cementu dostupna za reakcije [28]. Teški metali se uklanjaju fizičko-hemijskim reakcijama. Cement se pokazao izuzetno efikasnim za vezivanje Pb formiranjem $Pb(OH)_2$ kao i mikroenkapsulacijom u formiranu cementnu masu. Formiranje tvrde, cementne mase nije poželjno, jer se time ograničava protok struje i elektromigracija metala.

Primenom kreča za tretman, teški metali primarno podležu fizičkoj enkapsulaciji. Pozolanska reakcija se javlja između kalcijum-hidroksida i Al i Si koji potiču iz jalovine na kontaktu materijala. Kreč je efikasan materijal za imobilizaciju Pb (vezuje 87% uklonjenog Pb) reakcijama precipitacije, ali i enkapsulacije.

Poznato je da je $Pb(OH)_2$ najmanje rastvorljiv na pH 9,5 i da njegova rastvorljvost raste pri pH vrednostima većim od 11. Budući da izlužene koncentracije ne prevazilaze 5 mg/l mehanizam koji je odgovoran za vezivanje Pb pri pH vrednostima 12.5–13 nije samo precipitacija u obliku hidroksida. Iz tog razloga se može tvrditi da su pozolanske reakcije odgovorne za imobilizaciju Pb, sorpcijom i/ili hemijskom inkluzijom, kada je reč o letećem pepelu, cementu i kreču.

Efikasnost pojedinih agenasa je procenjena na osnovu količine Pb koja je sorbovana pored TCLP testova, s obzirom da je cilj bio kontrolisanje kretanja i migracije ekstrahovanog Pb iz jalovine.



Sl. 2. *Distribucija Pb u jalovini nakon EK tretmana*

4. ZAKLJUČAK

U ovom radu je ispitivana mogućnost primene odabranih imobilizacionih agenasa za kontrolisanje kretanja i ponašanja Pb u jalovini u toku EK tretmana. Aktivni ugalj je vezao 31% jona Pb uklonjenih iz jalovine, zeolit 9%, leteći pepeo 51%, Portland cement 78% i kreč 87%.

1. Navedeni rezultati ukazuju da aktivni ugalj i zeolit nisu bili efikasni za imobilizaciju Pb. Ovo je posledica ograničene jonske izmene jona Pb i materijala pri primenjenom naponu. Pri primenjenom naponu elektromigracija prenosi jone kroz materijal brzinom koja onemogućava jonsku izmenu.
2. Leteći pepeo, Portland cement i kreč imobilizuju Pb na račun pozolanskih reakcija i precipitacije Pb. Rezultati ukazuju da se cement i kreč mogu uspešno koristiti za lokalizaciju Pb ekstrahovanog iz jalovine.

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Ljiljana Rajić, Božo Dalmacija*, Milena Dalmacija**

ELECTROKINETIC REMOVAL OF Pb FROM TAILINGS AND THE APPLICATION OF STABILIZATION AGENTS**

Abstract

In this study, the possibility of applying the certain stabilization agents was investigated in order to improve the electrokinetic treatment of tailings with high concentrations of Pb. Different stabilization agents were inserted in the cathode region in order to improve the immobilisation of Pb ions that migrate towards the cathode, and thus control Pb movement and behaviour. EK treatments were carried out in the electrokinetic setup using the voltage gradient of 1 V/cm. The applied stabilization agents in investigation were: activated carbon, zeolite, coal fly ash, Portland cement and lime. The stabilization agents were inserted in the cathode region. The overall removal efficiencies were: 21.4%, 22.6%, 21.4%, 17.6% and 20.6%, after using the activated carbon, zeolite, coal fly ash, Portland cement and lime, respectively, compared to 23.6% after the conventional electrokinetic treatment. Activated carbon bound 31% of the Pb ions removed from tailings, zeolite 9%, coal fly ash 51%, Portland cement 78% and lime 87%. The results indicate that utilization of Portland cement and lime can improve the electrokinetic remediation by controlling the movement and behaviour of heavy metals during electrokinetic treatment, with both showing sufficient stability after treatment for potential use in civil engineering projects.
Keywords*: electrokinetics remediation; tailings; stabilization agents; lead*

1. INTRODUCTION

Mine tailings contain high concentrations of chemicals and elements that are of concern to the environment. Mine tailings are transported in pulp form to specially conditioned sites called tailing ponds. The metals in tailings are mainly present in stable forms, but removal of soluble metal fractions is of great importance since they have an impact on the environment. Electrokinetic (EK) remediation can therefore be used for tailings treatment. During EK remediation, a weak direct current is applied through electrodes immersed in the medium [1, 2]. As a consequence of current application, several individual processes take place: electrolysis, electromi-

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gration, electroosmosis (and chemical osmosis), electrophoresis, diffusion and a series of geochemical reactions where electromigration is the most important process for metals removal. Since only soluble metals can be extracted under the applied voltage, EK can prevent heavy metals entering into water systems and diffusing into surrounding soil from tailings. So far, the electrokinetic treatment of tailings has not been widely studied [3, 4]. In order to enhance the electro remediation, a range of techniques have been developed to improve the extraction of contaminants from the medium [4-6], to prevent the formation of heavy metals hydroxides, as in the cathode region the pH value increases due to OH^- ions formation [7-11] and to reduce the costs of treatment [12-14].

Permeable reactive barriers (PRB) are already used in the electrokinetic remediation. PRB is an engineered barrier, made of reactive treatment media, placed across the flow path of a contaminant plume, originally in an aquifer, which removes or degrades the contaminants in the groundwater flowing through it [15]. PRB is coupled with electrochemical remediation when the flow of contaminants through the barrier is driven by the electroosmotic flow of soil pore fluid, the electromigration of charged species, and/or the electrophoresis of charged particulates. PRB may affect the sorption and degradation mechanisms of reactive medium in the PRB. Different PBR have been used for soil EK treatment thus far: zero-valent iron [16-18], ferrite [19], atomizing slag as an inexpensive PRB reactive medium [20], PRB made of transformed Red Mud [21], and carbon nanotubes [22] and carbonized foods waste [23]. There has been a lot of investigation of heavy metals sorption on different materials such as: lime [24], Portland cement [25], activated carbon [26, 27], clays [28, 29] and industrial by-products such as coal fly ash [24, 25, 30]. However, the use of these materials as the reactive barriers during EK treatment has not yet been investigated.

In this study, the possibility of applying the certain stabilization agents in the cathode region was investigated in order to: a) control heavy metal movement and behaviour during electrokinetic treatments (to localize the contamination) and b) use these after treatment in civil engineering, for example. If metals accumulate in the medium near the cathode, this part of the medium can be also used after treatment, but this is only possible if the medium has a high possibility for metals sorption (high cationic exchange capacity (CEC), for example). If the medium has a low sorbing activity, metals can be easily released from the medium. This study investigates the use of stabilization agents in order to improve the electrokinetic treatment of tailings with low CEC values and high Pb concentrations. Stabilization agents can more strongly bond the metal ions than the medium itself, and thus less stabilisation agents are needed for the same purpose than medium. As well as the commonly used cement and lime solidification/stabilization agents, coal fly ash, activated carbon and zeolite were also used in this study.

2. EXPERIMENTAL CONDITIONS

The pH of the tailings was measured by pH meter (340i, WTW). The tailings pH measurements were carried out in deionised water (tailings:water=1:5) using the SenTix®21 electrode. The ammonium acetate method was used to measure the cation exchange capacity (CEC). Acid neutralizing capacity (ANC) was measured and calculated according to the Gran method. Electric current was measured by ampermeter. The protocol for chemical extraction the determination of pseudo-total Pb contents in tailings was followed in accordance with USEPA Method 3051A. Dry tailings sample (0.5 g) was mixed with 10 mL of concentrated nitric acid in Teflon beakers. Extraction was carried out using the microwave oven (Milestone, Stare E microwave) by the following programme: temperature increased over 5.5 minutes to 175°C, then held at 175°C for another 4.5 minutes. The liquid after extraction was separated from the solid particles by vacuum through a 0.45 µm filter and diluted to 50 mL. Pb analysis was carried out using the Flame Atomic Absorption Spectrophotometer (PerkinElmer, AAnalyst 700) in accordance with USEPA method 7000b. The method detection limit (MDL) for Pb was 0.25 mg/L and the practical quantification level (PQL) was 0.51 mg/L. Tailings classification before and after treatments was made according to [31] and the Waste [32]. The effectiveness of additives on Pb immobilization was evaluated using the Toxicity Characterization Leaching Procedure (TCLP) developed by the U.S. EPA to determine the mobility of both organic and inorganic analytes present in liquid, solid and multiphase wastes. The appropriate extraction fluid for all mixtures was determined based on pH of the agent as described in the TCLP. 100 g of each agent and 2 L of the appropriate extraction fluid were put into 2 L plastic vessels and rotated for 18 hr in a horizontal shaft mixer with speed of 30±2 rpm. At the end of the 18 hr extraction period, the liquid in each vessel was separated from the solid phase by vacuum filtration through a 0.45 µm membrane filter. The pH of separated TCLP extracts was measured and all extracts were acidified with 1 N HNO_3 to pH less than 2 for long term preservation.

Experimental conditions and the characteristics of the stabilization agents are given in Table 1. In order to investigate the sorption activity of stabilization agents, the following experiments were carried out: 100 ml of 500 mg/l Pb solution (prepared from lead acetate trihydrate) was transferred into different 250 cm^3 Erlenmeyer flasks, 1.0 g of each adsorbent was weighed into the different flasks and agitated in a shaker for 10 minutes. The experiments were conducted at pH 10 and at 25°C. After each agitation, the contents of each flask were filtered. The equilibrium concentration of the Pb in each of the filtrates was determined. The Pb concentration retained in the adsorbent phase q_e (mg/g) was calculated using the following equation:

$$q_e = \frac{(C_0 - C_e)\cdot V}{m_a} \qquad (1)$$

where:

- C_0 - is the initial metal concentration in mg/L,
- C_e - is the equilibrium concentration of metal ion in mg/l,
- V - is the volume of solution (l) and m_a is the mass of adsorbent (g). Each experiment was carried out in duplicate and the average of two values used in the calculations.

EK treatments were carried out in the electrokinetic setup shown in Figure 1. The anode and cathode were graphite (10x5x1 cm). During the experiments the voltage gradient was 1 V/cm. The experiments were carried out over 7 days at 25°C. At the end of the process, the tailings samples were divided into five parts. Each part was labelled with its normalized distance z/L (z = distance from the anode, L = distance between electrodes) from the anode: 0.1, 0.3, 0.5 and 0.7. Stabilization agents were implemented at normalized distance z/L= 0.9. The pH and Pb pseudo-total concentrations of the initial tailings sample and in each of its sections were measured. The overall treatment efficacies were calculated as follows:

$$\% = \left(\frac{m_i - m_s}{m_i}\right)\cdot 100 \qquad (2)$$

where:

m_i - is the initial amount of Pb in the tailings (mg) and

m_s - is amount of Pb that remains in the tailings after treatment (mg).

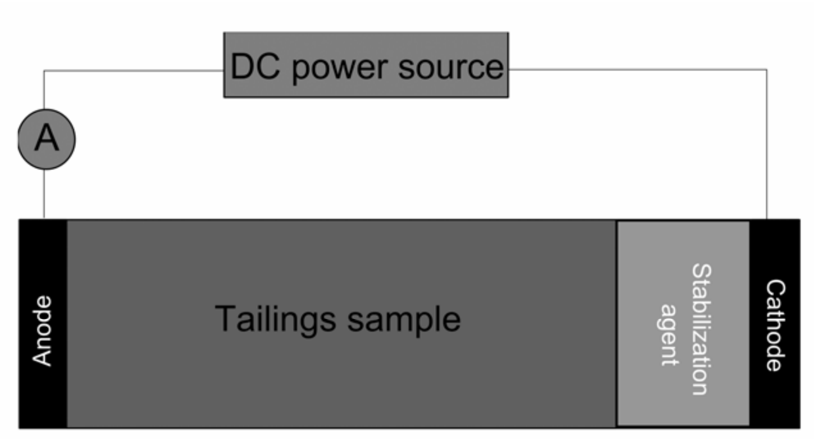

Fig. 1. *Diagram of electrokinetic setup*

Table 1. *Experimental conditions*

Experiment label	Stabilization agent	pH	q_e (mg/g)
CON	-	-	29.0
ACB	Activated carbon	7.50	52.2
ZEO	Zeolite	7.82	36.0
CFA	Coal fly ash	10.55	62.3
PCE	Portland cement	10.95	99.3
LME	Lime	12.50	>99.9

3. RESULTS AND DISCUSSION

3.1. Tailings characteristics

The low ANC (4.75 meq/100g) and CEC (0.75 meq/100g) indicate that an acid front can easily be formed in the tailings. The pH of tailings was 7.80. Acid front formation enables dissolution and desorption of metals from particles [2]. The Pb concentration in tailings was 1184 mg/kg. The Zn concentration was 1084 mg/kg. The tailings are classified as hazardous due to their Pb content, based on [31] and [32], and according to their Zn content based on [31].

3.2. Changes in the tailings pH after the EK treatments

The changes in the tailings pH after the EK treatments are shown in Table 2. As expected, the pH distribution was similar for each experiment. The pH value of sorbent after treatment indicates that OH^- ions generated at the cathode penetrate into the sorbent that can cause precipitation of metals. Some OH^- ions penetrate into the tailings from the stabilization agents.

Table 2. *Tailings pH after the EK treatments*

z/L	pH					
	CON	**ACB**	**ZEO**	**CFA**	**PCE**	**LME**
0.1	4.89	5.27	5.31	5.25	5.40	5.34
0.3	6.36	6.75	6.84	6.87	6.75	6.78
0.5	7.15	7.22	7.12	7.19	7.16	7.25
0.7	7.78	7.82	8.40	9.50	9.42	10.11
0.9	8.54	8.40	8.65	10.50	11.15	11.01

3.3. Distribution of Pb in the tailings after the EK treatments

The overall Pb removal efficiency was 23.6% after the conventional treatment (excluding the Pb content in the tailings at z/L=0.9), but no Zn was removed. Due to this result, only Pb immobilization was monitored. The overall removal efficiencies after using the stabilization agents were: 21.4%, 22.6%, 21.4%, 17.6% and 20.6%, after using activated carbon, zeolite, coal fly ash, Portland cement and lime, respectively. Activated carbon bound 31% of the Pb ions removed from the tailings, zeolite 9%, coal fly ash 51%, cement 78% and lime 87%. The tailings at z/L=0.9 retained 38% of the Pb, but this was also the overall content in the tailings at the other normalized distances after treatment. Note that the q_e values (Table 1) for all stabilization agents correspond to the sorbed Pb percentages after treatment. Although the pH increases at z/L=0.7 (Table 2), there was no significant accumulation of Pb as in CON.

The used agents have different stabilization mechanisms. All sorbent agents were added in the same amounts, the contact time was the same, as well as the temperature and Pb concentration. So, only pH value and type of agent had the influence on sorption. The reaction mechanisms of the used individual agents are given in the text below.

Activated carbon. COOH groups in activated carbon may be responsible for binding Pb, since the ionization constant for a number of COOH groups ranges between 4.0 and 6.0 [33]. At lower pH the COOH groups retain their protons, reducing the probability of binding a positively charged ion. At pH>4, the ionized COO^- ligands attract the positively charged Pb ions and binding occurs. The binding follows an ion-exchange mechanism that involves electrostatic interaction between the negatively charged groups in the walls of substrate and Pb cations. Additionally, alkaline conditions cause Pb precipitation that contributes to Pb stabilization. Although activated carbon is effective at Pb removal from aqueous solutions [34], it was ineffective in combination with EK. This is probably due to the limited ion exchange during current application. This occurs as during electromigration, ions move too fast for ion exchange. The Pb leachate concentration from the activated carbon was below the US EPA acceptable TCLP limit of 5 mg/L for pH values between 7 and 11.

Zeolite. Zeolites are commonly used in environmental remediation for selective removal of toxic materials by cation exchange. The zeolite used in this study had a cation exchange capacity of 164 meq/100g. The structure of zeolite consists of three-dimensional frameworks of SiO_4 and AlO_4 tetrahedra. The aluminium ion is small enough to occupy the position in the centre of tetrahedron of four oxygen atoms, and the isomorphous replacement of Si^{4+} by Al^{3+} produces a negative charge in the lattice. The net negative charge is balanced by the exchangeable cation (sodium, potassium, or calcium). These cations are exchangeable with the certain cations in the solutions such as Pb, Cd, Zn, and Mn [35]. The fact that zeolite exchangeable ions are relatively innocuous (sodium, calcium, and potassium ions) makes them particularly suitable for removal the undesirable heavy metal ions. The amount of heavy metal ions, adsorbed from solution, increases with an increase in initial solution pH. Natural zeolite preferentially adsorbs H^+ ions from solution to heavy metal ions [36, 37], and thus in more acidic conditions more H^+ ions are adsorbed from solution. At higher pH values the H^+ ions concentration is lower, giving way to more heavy metal ions being adsorbed from solution. According to [38] the electric field caused Cu^{2+} ions to move too fast for the zeolite to undergo a cation exchange reaction. This explanation could be also applied to the low exchange of Pb^{2+} ions with zeolites. Additionally, Table 1 shows that the used zeolite was not as effective as the other used agents at Pb^{2+} binding over the same time interval. The Pb leachate concentration from zeolite was below the US EPA acceptable TCLP limit of 5 mg/L for pH values between 7 and 11.

Coal fly ash. The coal fly ash composition was (% wt.): SiO_2 (39.4), Al_2O_3 (20.1), Fe_2O_3 (4.95), MgO (4.01), CaO (23.2), K_2O (0.64), Na_2O (2.12) and SO_3 (1.88). The high CaO content of fly ash is responsible for its excellent hydraulic properties while glassy silicate phases are responsible for the pozzolanic ones. As expected, metal sorption increased significantly with increasing solution pH. Solution pH significantly affects metal species distribution and as the result affects metal sorption. This may be attributed to less competition from protons for sites on the ash particle at higher pH. According to [30], the Pb adsorption process in alkaline conditions is irreversible. In addition, carbonate in solution increased with increasing solution pH [24]. The solubility of metal carbonates and hydroxides may also be an important factor in determining the metal sorption since they may form during the sorption reactions. Carbonate formation is especially important in materials like ash, which have high salt contents. The solubility product of metal carbonate $PbCO_3$ is $10^{-12.95}$ M^2 and for hydroxide $Pb(OH)_2$ is $10^{-15.3}$ M^3. $PbCO_3$ is a highly insoluble mineral and as the result $PbCO_3$

was precipitated after Pb reaction with the fly ash. Pb immobilization appears also due to formation of pozzolanic products that either adsorb Pb on the fresh surfaces or incorporate Pb by chemical inclusions [25].

Portland cement and lime. Lime and cement are capable of stabilization and solidification (double action agents). The stabilization of heavy metals by lime and cement-based technologies is attributed to alkaline pH and pozzolanic reactions in treated materials.

Portland cement is composed of calcium-silicates and calcium-aluminates that, when combined with water, hydrate to form the cementing compounds of calcium-silicate-hydrate and calcium-aluminate-hydrate, as well as an excess of calcium hydroxide. The used Portland cement in this study had the following composition (% wt.): SiO_2 (23.4), Al_2O_3 (6.12), Fe_2O_3 (3.21), MgO (1.01), CaO (63.2), K_2O (0.54), Na_2O (0.12), SO_3 (1.18) loss on ignition (1.4). When cement is used to treat contaminated materials, the pozzolanic reactions occur rapidly because calcium silica, aluminium and iron compounds in cement particles are readily available for the reactions [28]. Heavy metals are immobilized by physical-chemical interactions. Cement showed very high efficiency on immobilization of Pb through formation of insoluble Pb hydroxides and microencapsulation of them in the resultant hardened mass (chemical inclusion in the newly formed pozzolanic products). Formation of hardened mass (cement) is not preferred since no current can pass through the system and so metals electromigration is limited.

In the lime treated materials, physical encapsulation of heavy metals is the primary containment mechanism. A pozzolanic reaction between the calcium hydroxide and tailings alumina and silica occurs upon contact of these materials. Lime was found to be a very effective agent for Pb immobilization through precipitation of formed Pb hydroxides fand chemical inclusion in the newly formed pozzolanic products.

It is known that $Pb(OH)_2$ is the least soluble at pH 9.5 and its dissolubility increases at pH values higher than 11. Since the leached concentrations do not exceed 5 mg/l, the responsible mechanism for Pb binding is not only precipitation in the form of hydroxide. Based on this, it can be argued that the pozzolanic reactions are responsible for Pb immobilization by sorption and/or chemical inclusion when using the coal fly ash, cement and lime.

The efficiency of some agents was accessed according to the adsorbed Pb amount using the TCLP tests, since the main goal was to control the movements and migrations of the extracted Pb. According to the results, lime and cement can be ascribed as the most effective for Pb immobilization.

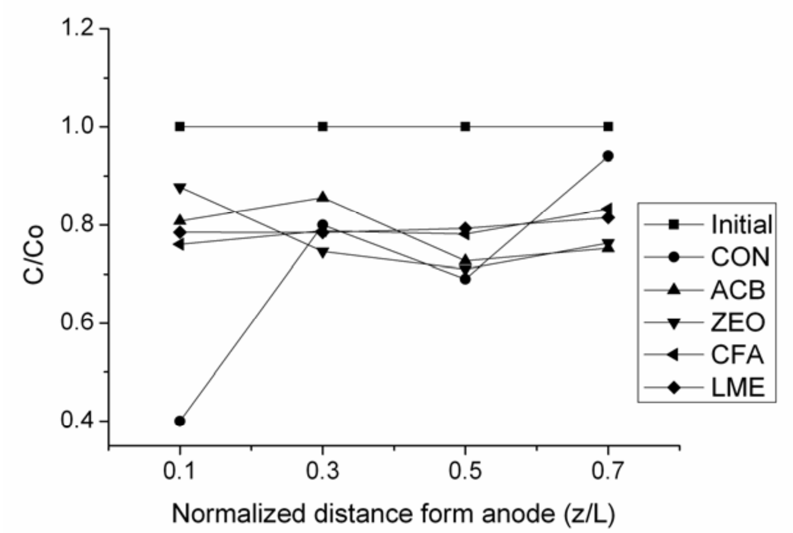

Fig. 2. *Distribution of Pb in tailings after EK treatments*

4. CONCLUSIONS

In this work, the possibility of using the certain stabilization agents was present for control of Pb movement and behaviour during electrokinetic treatment. These agents had not previously been investigated in a combination with electrokinetics thus far. Activated carbon bound 31% of the Pb ions removed from tailings, zeolite 9%, coal fly ash 51%, Portland cement 78% and lime 87%.

1. According to these results, the activated carbon and zeolite were not effective at immobilizing a high percentage of Pb. This is due to the limited ion exchange during voltage application, since the ions move too fast through the material.
2. Coal fly ash, Portland cement and lime immobilized Pb due to pozzolanic reactions and Pb precipitation. Coal fly ash was effective enough to immobilize large amounts of Pb.
3. The results show that cement and lime can be successfully used for the localization of Pb extracted from tailings.

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POTREBA PRIMENE NOVIH TEHNOLOGIJA U PODZEMNOJ EKSPLOATACIJI LEŽIŠTA UGLJA U SRBIJI

Izvod

U referatu se razmatraju potrebe aktiviranja novih ležišta uglja koje su predisponirane sistemu podzemne eksploatacije. Sadašnja proizvodnja, u JP PEU Resavica ostvaruje se u 8 rudnika od oko 700.000 tku godišnje, a ukupne verifikovane bilansne rezerve $A+B+C_1$ kategorije iznose 270 mil t uglja.

Pojedini rudnici iscrpljuju svoje rezerve, te je potrebno u narednom periodu naći zamenu i povećati proizvodnju, otvaranjem novih rudnika na potencijalno perspektivnim ležištima, a sada neaktiviranih kao što su: Aleksinačko područje, Melenice, Poljana, Zabela Kosa, Zapadno-Moravski basen, Dragačevski basen, Ćirikovac (dublji delovi) i dr. u kojima je sadržano oko 417 mil t rezervi uglja, kategorije $A+B+C_1$. Takođe na Aleksinačkom području evidentirano je nešto iznad 2 milijarde tona ugljenih škriljaca.

Za ostvarenje ovih ogromnih zadataka nužno je sačiniti novu strategiju, studije i projekte i uvesti nove tehnologije eksploatacije sa primenom mehanizovanih i automatizovanih sistema i novih alternativnih tehnologija.

Na ovome treba koordinirano da rade svi stučnjaci iz rudnika, naučnih i stručnih Institucija, Akademija nauka i državnih organa.

Ključne reči: *Strategija razvoja, otvaranje novih ležišta uglja, nove tehnologije.*

1. UVOD

Mnogo puta je ukazano na stanje u podzemnoj eksplotaciji uglja Srbije, na stručnim i naučnim skupovima, poslovnim sastancima i na druge načine. Već dve decenije rudnici su u stagnaciji, a tehnološki procesi u retrogradnom procesu. Rudarska mapa stanja u rudarstvu uglja mnogo se izmenila u poslednje vreme kako u svetu, Evropi, tako i u našem okruženju. Svi traže nova održiva rešenja. Sadašnja aktuelna tema je aktiviranje novih ležišta uglja predisponiranih za podzemnu eksploataciju i veoma je značajna, jer pored sada aktivnih ležišta, iz kojih se iscrpljuju

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sve rezerve, postoje i brojna ležišta u Srbiji, koja se uz doistraživanja mogu aktivirati, odnosno otvoriti, posebno ležišta sa većim rezervama i povoljnim prirodno geološkim uslovima. Perspektiva razvoja rudnika je u velikoj potrebi izgradnje termoenergetskih kapaciteta što zahteva potrebu osavremenjivanja rudnika i povećanje proizvodnje, kao i otvaranje neaktvnih ležišta i izgradnju novih rudnika za podzemnu eksploataciju.

Može se koncentrisati na nekoliko glavnih pravaca i to:

1. Doistraživanja i aktiviranje novih ležišta u Srbiji
2. Rešavanje eksploatacije dubljih ležišta osvajanjem novih tehničko-tehnoloških rešenja
3. Uvođenje novih visokomehanizovanih i automatizovanih procesa za otkopavanje uglja
4. Povećanje baze bilansnih rezervi uglja i eksploatacije slojeva uglja mogućnosti ispod 1,5 m u povoljnim uslovima
5. Priprema i uvođenje novih alternativnih tehnologija (PGU, PSU, hidrodobijanje i dr.)

2. POTREBE DEFINISANJA STANJA U OBLASTI NAUČNOISTRAŽIVAČKOG RADA I NOVIH TEHNOLOGIJA

Da bi se prevazišlo sadašnje stanje u oblasti rudarstva potrebno je preispitati i inovirati strateške i programske ciljeve u ovoj oblasti na svim nivoima stručnih, naučnih, društvenih, ekonomskih i društvenih institucija.

U domenu naučno-istraživačkog rada u oblasti rudarstva i geologije koji je sada većinom dezintegrisan, potrebno je definisati i odrediti strateške ciljeve koji su u skladu sa potrebama razvoja rudarstva u svim njegovim segmentima, razvijajući već dostignuti nivo rada u zemlji uz transfer svetskih dostignuća.

a) U tom smislu potrebno je detaljno sagledavati potrebu za reorganizacijom Institucija (Instituta i Projektnih organizacija) koje bi bile prilagođene novim ciljevima uz daleko veću opremljenost institucija i osposobljenost kadrova.

b) Da bi se rudarstvo dalje razvijalo primorano je da brže primenjuje nova tehnička dostignuća i nove tehnologije. U tom razvojnom procesu, računarske integracione tehnologije će imati značajnu ulogu jer integrišu niz inženjerskih znanja od računarstva, informatike, primenjene robotike, automatizacije i upravljanja procesima menadžmenta, edukacije i dr. Ovakav pristup vodi ka razvoju informaciono-upravljačkih sistema višestepene logike sa ugrađenim funkcijama veštačke inteligencije i visokom nadzorno-upravljačkom efikasnošću. Rezultat ovog koncepta je i ideja o razvoju ”inteligentnih” rudarskih mašina ”robota”. U viziji bliske budućnosti rudarski inženjer moći će da iz komandnog centra kompjuterski dostavlja tehničke naloge i uputstva do operativno-izvršnih mesta na radilištima u rudniku, za izvođenje radnih operacija, npr. bušenja, miniranja, utovara, transporta, odlaganja, za izvođenje pomoćnih operacija i dr.

U sklopu takvih trendova, sve je značajnije uvođenje satelitskog sistema za globalno pozicioniranje. Uvođenjem ovog sistema u rudarstvu omogućeno je lociranje, u realnom vremenu, pozicija i mašina i opreme na površinskim kopovima, praćenje dinamike izvođenja rudarskih radova, precizne navigacije mašinama i dr.

Vodeći svetski proizvođači rudarske opreme i mašina daju značaj istraživanjima i ulažu značajna sredstva u razvoj ”inteligencije” svojih mašina. Primer su ”inteligentni kamioni-damperi” i druge mašine.

Najnovija istraživanja i intenzivna saradnja između rudnika i proizvođača rudarskih mašina omogućili su izradu nove koncepcije u primeni automatizovanih informatičko-upravljačkih procesa u cilju podizanja produktivnosti i sigurnosti rada u rudnicima, kao što je istraživački projekat ”intelitentni rudnik” koji je istraživan 8 godina, a čiji su rezultati primenjeni u više rudnika u Finskoj.

c) Sadašnje tradicionalne tehnologije podzemne eksploatacije mineralnih sirovina više ne mogu značajnije uticati na povećanje produktivnosti i ekonomske opravdanosti proizvodnje zbog istrošenosti tehnoloških šema i modela, zbog veoma duge mreže rudarskih prostorija i mnogo operativnih procesa dobijanja.

d) Nužno je pristupiti razvoju nove doktrine eksploatacije mineralnih sirovina posebno za ležišta na velikim dubinama (preko 500 m). Zato poseban značaj u strategiji buduće eksploatacije ima istraživanje i primena novih alternativnih tehnologija (bušotinska eksploatacija, podzemnog luženje metala, podzemna gasifikacija uglja, PSU specifične metode biotehnologije i dr.

U uslovima eksploatacije ležišta mineralnih sirovina u zemljama tranzicije, ove strateške ciljeve navedene pod a, b, c i d nužno je izvoditi postepeno i fazno, polazeći od uvođenja mehanizacije većeg kapaciteta u tehnološke procese eksploatacije mineralnih sirovina, zatim njihova automatizacija i robotizacija i u budućnosti stvaranje uslova za primenu modela tzv. ”inteligentnih rudnika” kao i većih razvoja i primenu ”alterativnih” tehnologija.

3. ISKUSTVA U REŠAVANJU PRI MENE NOVIH TEHNOLOGIJA EKSPLOATACIJE UGLJA U NEKIM ZEMLJAMA SA RAZVIJENIM RUDARSTVOM

U poslednje vreme, mnoge zemlje su se suočile sa velikim problemima, koji se javljaju u njihovom rudarstvu. Navodimo neke primere iz Poljske, Ukrajine, Rusije i Finske čija rešenja su hrabra i na visokom nivou tehničke inteligencije, koji mogu poslužiti i nama kao ideje, koje bi prilagođavanjem u našim uslovima, mogle biti od velike koristi, uvodeći ih kroz transfer znanja i međusobne saradnje.

3.1. Iskustva poljskog rudarstva

Poljsko rudarstvo, a najviše podzemna eksploatacija uglja, prolazi kroz intenzivnu primenu koja se ogleda u sledećem:

- Smanjenje proizvodnje (kod uglja), ali uz povećanje produktivnosti u rudnicima, koji su ostali da egzistiraju,
- Racionalizuje se model rudnika na racionalni nivo smanjenja broja pripremnih jamskih prostorija,
- Vrši se intenzivno mehanizovanje i automatizacija rudnika,
- Ostvaruju se nova tehničko-tehnološka rešenja kao:

a. Izrada kapitalnih prostorija kroz naslage gline.
b. Složena kombinovana rešenja otkopavanja dubljih delova ležišta (do 1000 m) sa kaptiranjem i degazacijom metala na dubljim nivoima eksploatacije.
c. Pretvaranje likvidiranih rudnika i površina u spomen muzeje sa poslovnim i rekreacionim sadržajima.
d. Veći nivo podgrađivanja jamskih prostorija sa metodom ankerisanja i na dubinama od preko 1000 m.
e. Mnoga druga rešenja, od kojih je sada najznačajnije uvođenje automatizacije strugova nove generacije za otkopavanje tankih slojeva uglja ispod 1,5 m moćnosti sloja.

Prema strategiji koju je izradio Glavni institut rudarstva Poljske – Katovice, o razvoju i eksploaatacijі uglja, dokazuje se, da bi rudarstvo moglo funkcionisati moraju se povećati eksploatacione rezerve i investicije. Ukoliko do toga ne bi došlo, do 2020. godine bi se smanjila proizvodnja na 2/3 sadašnjeg stanja. Strategijska šansa poboljšanja efekata u rudarstvu jeste u primeni tehnologije sa strugovima nove konstrukcije i upravljanja. Od pre nekoliko godina koncentracija otkopavanja u poljskim rudnicima na širokočelnim otkopima primenom kombajna smanjuje se ispod 3000 t/dan.

Razvoj tehnike otkopavanja sa strugovima je na najboljem putu da se realizuje operacija dobijanja na otkopu bez prisustva ljudi. Dalji razvoj ove tehnike je sasvim moguć iz sledećih razloga: zbog brzog razvoja elektronike, povećanja kapaciteta sistema strugova, razvoj elektromotora sa mogućnošću neprekidnog regulisanja brzine radne glave i uticaja na kapacitet uređaja.

Ovo je omogućilo ukupnu modernizaciju strugova starog tipa koji se generalno odnosi na:

– Povećanje pogonskog kapaciteta struga od 2400 kW do 2800 kW,
– Povećanje preseka pogonskog lanca struga do 42 m/m,
– Povećanje maksimalne brzine glave struga do 3,6 m/sec,
– Uvođenje automatizovanog sistema struganja definisana je dubina zahvata uglja pri otkopavanju od 5 do 25 cm
– Tehnikom struganja omogućeno je dobijanje tankih slojeva.

Moćnost ugljenog sloja je jedan od glavnih parametara koji odlučuje o izboru tehnologije otkopavanja, a takođe i za izbor uređaja za dobijanje. Sa ekonomskog stanovišta može biti limit ispod 1,5 m za primenu kombajna za otkopavanje. Dodatna teškoća često postoji zbog otkopavanja i dela krovine (jalovina) što čini eksploataciju manje isplativom zbog stvaranja velike količine otpadnih materijala.

U rudnicima kamenog uglja u Poljskoj proizvodi se oko 30 mil t otpada, kojeg treba uskladiti prema novim propisima EU i svesti na najmanju meru.

Postignuti rezultati otkopavanja uglja sa strugovima su impozantni i iznose u rudniku ”Bogdanka” prosečno 8200 t/dan (maksimalno 16.984 t/dan sa jedno otkopa), u rudniku ”Zafiowka” oko 3400 t/dan (maksimalno 4600 t/dan) i rudniku Jas-Mos oko 3000 t/dan (maksimalno 5050 t/dan).

Može se potvrditi da dosadašnja istraživanja i primena vezana za uvođenje tehnike sa strugovima nove generacije, stvara strategijsku šansu za poboljšanje efekta rada u rudarstvu.

3.2. Iskustva iz rudarstva Ukrajine

U Ukrajini se eksploatacija našla u vrlo složenim uslovima, posebno posle raspada SSSR-a, a ogleda u sledećem:

1. Potrebe u energetici iz uglja podmiruju sa samo 30%, a ostalo zavisi od uvoza iz Rusije.
2. Uglavnom je završena eksploatacija do 500 m dubine, a u Donbaskom basenu do 1800 m dubine, ima još 220 milijardi gona uglja, što je 2/3 ukupnih.
3. Rudarsko-geološke karakteristike uglja su nedovoljne, uglavnom su to tanki slojevi uglja do 1 m debljine i strmog pada.
4. Zato su u Ukrajini pristupili novoj doktrini otkopavanja tankih slojeva i konstrukciji takvih mašina za izradu prostorija i otkopavanja, koji odgovaraju ovim uslovima. To je novi pravac u razvoju tehnologija u podzemnoj eksploataciji ležišta, sa mehanizacijom i robotizacijom.

3.3. Iskustva iz rudarstva Rusije

Primena i mogućnost uvođenja tehnologije podzemnog sagorevanja uglja (PSU)

Tehnologija PSU je namenjena za sagorevanje rezervi uglja koje se ne mogu dobiti tradicionalnim tehnologijama, ili zbog tehničko-tehnoloških poteškoća, ili zbog ekonomskih nepovoljnosti. Predstavlja najjednostavniju alternativnu tehnologiju.

Glavni produkti podzemnog sagorevanja uglja su:

- Vrela voda, koja se može koristiti za potrebe toplotnih agregata za lokalne potrošače (toplifikacija), zatim staklenike voća i povrća, a posle rashlađivanja voda se može koristiti, za zalivanjem sa dopunskim efektom kao biološki aktivan produkt.
- Generatorski (goreći) gas, kao gorivo za industrijske i stambeno-komunalne potrebe, a takođe i kao sirovina za dobijanje gasa za motore sa unutrašnjim sagorevanjem.
- Električna energija, za potrebe lokalnog elektrosnabdevanja.

Sporedni produkti PSU mogu biti visokomolekularna organska jedinjenja, koja se mogu koristiti za dalju preradu pomoću poznatih hemijskih metoda.

Oblast moguće primene tehnologije PSU je:

- Rezerve uglja ostavljene u ležištu, kao tehnološki stubovi različite namene, veličine i konfiguracije u već zatvorenim rudnicima, takođe i na eksploatacionim horizontima i otkopanim delovima aktivnih rudnika.
- Rezerve uglja u delovima ležišta povoljne moćnosti i kvalitetu uglja, ali neotkopani zbog veoma složenih rudarsko-geoloških uslova (delova ležišta koji su veoma skloni požarima, kao i zone opasne zbog gorskih udara i izbojnih gasova na eksploatisanim slojevima, itd.).
- Vanbilansne rezerve uglja nekondicionalne po moćnosti, kvalitetu ili geološkim uslovima sloja, a takođe i pojedni nekondicionalni delovi na eksploatisanim slojevima.
- Rezerve uglja malih ležišta nerentabilne za eksploataciju tradicionalnim metodama, kao i ugljonosne površine koje gravitiraju velikim tektonskim rasedima i strukturi.

Pojedini stubovi koji mogu sagorevati treba da sadrže ne manje od 10000 t uglja.

Više manjih stubova može se dobijati samo grupisanjem ka jamskoj prostoriji, koja može da se koristi kao gasovodna magistrala pri sagorevanju, a koji su joj blisko grupisani.

3.4. Iskustva iz rudarstva Finske

I u drugim zemljama, pored navedenih i analiziranih, radi se na razvoju i unapređenju novih tehnologija.

Ovom prilikom navedimo jedan, ali veoma značajan istraživački program za primenu tzv. ”inteligentnih rudnika”, koji je razrađen i primenjen u Finskoj u intenzivnoj saradnji Univerziteta za tehnologiju u Helsinkiju i rudarske industrije proizvođača rudarskih mašina.

4. ZAKLJUČNA RAZMATRANJA

- Navedeni primeri u rešavanju razvoja rudarstva u drugim zemljama ukazuju na činjenicu, da je došao period pristupa i snažnih zaokreta za novu strategiju. Iznesene ideje i iskustva mogu poslužiti za potencijalna sagledavanja i određenih rešavanja koja se mogu prihvatiti i primeniti u našim rudnicima sa složenim rudarsko-geološkim uslovima.
- Istraživanja sistema podzemne eksploatacije u ugljenim ležištima Srbije treba usmeriti ka primeni automatizovane kompleksne opreme kod konvencionalnih sistema i mogućnostima osvajanja savremenih sistema, hidrodobivanja, podzemne gasifikacije, podzemnog sagorevanja uglja i dr.
- Sva rešenja sadašnje i buduće eksploatacije, moraju se zasnivati na principima i kriterijumima održivog razvoja. Ovo znači da se njima, na odgovarajući način obuhvata zaštita životne sredine, kao problematika od posebnog nacionalnog značaja i šire.

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A NEED OF USE THE NEW TECHNOLOGIES IN THE UNDERGROUND MINING OF COAL DEPOSITS IN SERBIA

Abstract

This paper deals with a need to activate the new coal deposits, predetermined for the underground exploitation system. In order to realize this is needed to work out a new development strategy. The current production in JP PEU Resavica is achieved in 8 mines (with 11 production systems-pit) around 700.000 t/year, and total verified balance reserves of A+B+C_1 category are 270mil t of coal.

Some mines exhaust their own reserves, so a replacement is to be found in the future period as well as increasing of production by opening the new mines on the potential deposits, and now inactive like: the Aleksinac region, Melenica, Poljana, Zabela Kosa, Zapadno-Moravski Basin, Dragacevo Basin, Cirikovac (deeper parts) and other in which around 417 mil t of coal reserves, of A+B+C_1 category. Also. in the Aleksinac region, there are more than 2 bil t of oil schist.

For the achievment of these great tasks it is necessary to make a new strategy, studies and projects and to introduce new technologies with the application of new mechanized and automated systems and new alternative technologies.

All experts from mines, scientific and expert institutions, Academies of science and state authorities should work on this coordinately.

Keywords: *development strategy, opening of new coal deposits, new technologies.*

1. INTRODUCTION

Many times it points out the condition of underground coal exploitation of Serbia, at professional conferences, business meetings and in other ways. For two decades of stagnation in the mining and process technologies in the retrograde process. Mining site in the state of coal mining much has changed in recent years throughout the world, Europe, and in our environment. Everyone is looking for new sustainable solutions. The current hot topic is the activation of new coal susceptible to groundwater exploitation and it is very important, because now in addition to the active deposit, from which exhaust all reserves, there are numerous deposits in Serbia, which can be activated by additional research, or open, especially with the large

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reserves of deposits and low natural geological conditions. Prospects of development of the mine is in great need of building the capacity of thermal power, which requires the need to modernize the mine and increase production, as well as opening not actives reservoirs and construction of new mines for underground exploitation.

Can concentrate on a few main directions, namely:

1. Additional research and activation of new deposits in Serbia.
2. Solving the exploitation of deeper reservoirs winning new technical and technological solutions
3. The introduction of new highly mechanized and automated processes for coal mining
4. Increasing the base of balance reserves of coal and coal exploitation possibilities layers below 1.5 m favorable
5. Preparation and introduction of new alternative technologies (PGU, PSU, etc.).

2. THE NEEDS OF DEFINING THE SITUATION IN THE FIELD OF SCIENTIFIC RESEARCH AND NEW TECHNOLOGIES

To address the current situation in the mining industry should review and update the strategic and programmatic objectives in this area at all levels of professional, scientific, social, economic and social institutions.

In the domain of scientific research in the field of mining and geology, which is now largely disintegrated, it is necessary to define and determine the strategic objectives that are consistent with the needs of development of mining in all its segments, developing the work already achieved level in the country with the transfer of world achievements.

a) In this sense, it is necessary to thoroughly perceive the need to reorganize the institution (the Institute and Project organization) that would be adapted to new targets with far greater equipment capacity of institutions and personnel.

b) To further develop the mining industry was forced to quickly apply new technical developments and new technologies. In this development process, integration of computer technology will play an important role because they integrate a number of engineering knowledge of computer science, computer science, applied robotics, automation and process control management, education and others. This approach leads to the development of information-management system with integrated multi-level logic functions of artificial intelligence and high supervision and control efficiency. The result of this concept is the idea of developing "intelligent" mining machine "robot". The vision of the near future mining engineer will be able to command the computer center delivers technical orders and instructions to the operational and executive of the workings in the mine, to perform the operations, for example, drilling, blasting, loading, transporting, storing, to perform auxiliary operations and others.

Within these trends, the introduction of the satellite Global Positioning System is more and more important. The introduction of this system has enabled the mining location, in real time, and place machines and equipment for surface mining, monitoring the schedule performance of mining operations, precision navigation and other machines.

The world's leading manufacturers of mining equipment and machinery give importance to research and invest heavily in the development of "intelligence" of their machines. The "intelligent-tipper trucks" and other machines are an example.

The latest research and intensive cooperation between the mine and mining machinery manufacturers have enabled development of new concepts in the implementa tion of automated information-management processes to enhance the productivity and work safety in mines, such as the research project "intelligent mine", studied for eight years, and whose results are applied in several mines in Finland.

c) Present the traditional technology of underground mineral extraction can no longer significant impact on increasing productivity and economic feasibility of production due to exhaustion of technological schemes and models, for very long network of mining facilities and many operational processes to obtain.

d) It is necessary to approach the development of new doctrine of exploitation of mineral resources particularly for deposits at great depths (over 500 m). Therefore, special importance in the strategy of future research is the exploitation and application of alternative technologies (drilling exploitation, underground leaching of metals, underground coal gasification, PSU specific methods of biotechnology and others.

In the exploitation conditions of mineral deposits in the transition countries, the strategic objectives, set out in a, b, c and d, are necessary to be carried out gradually and in phases, starting with the introduction of larger capacity machinery in technological processes of mineral extraction, then their automation and robotization in the future to create conditions for application the so-called model "Smart mines" as well as the major development and use of "alternatives" technology.

3. EXPERIENCE IN SOLVING THE APPLICATION OF NEW TECHNOLOGY COAL MINING IN SOME COUNTRIES WITH DEVELOPED MINING

In recent years, many countries have faced major problems, which occur in their mining operations. Here are some examples from Poland, Ukraine, Russia and Finland, whose solutions are the brave and the high level of technical intelligence, which can serve us as an idea, adjusted in our conditions, could be of great benefit, introducing them to the transfer of knowledge and mutual cooperation.

3.1. Polish mining experience

Polish mining industry, mostly underground coal mining, going through the intense usage that is reflected in the following:

- Reduction of production (for coal), but with the increase in productivity in the mines, which remain to exist,
- Rationalize the model of the mine on a rational level reductions of preparatory parts of the mine,
- Conducts intensive mechanization and automation of mining,
- Achieve new technical and technological solutions as:

a. Production of capital facilities through the layers of clay.

b. Complex combination solution mining of deeper parts of the deposit (up to 1000 m) to capture and degassing of metal on the deeper levels of exploitation.

c. Conversion of land mines and settled into a memorial museum with business and recreational facilities.

d. Higher levels of supporting parts of the mine with the method of anchorage and at depths of over 1000 m.

e. Many other solutions, one of which is now the most significant introduction of a new generation of automated lathes for mining of thin coal layers below 1.5 m thick layer.

According to the strategy prepared by the Chief Mining Institute of Poland - Katowice, on the development and exploitation coal, it is argued, that the mining might have to work to increase the exploitation reserves and investments. If it would not come until 2020, in order to reduce the production of 2/3 of the current situation. The strategic opportunity to improve the effects of mining is the application of technology, lathe with new construction and management. Since a few years ago the concentration of mining in the field of mines dug using long walls combines reduced below 3000 t/day.

Development of mining technology with the lathe is on track to realize the operation of obtaining the spoil without the presence of people. Further development of this technique is quite possible for the following reasons: due to the rapid development of electronics, increasing system capacity lathes, motor development with the possibility of regulating the speed of continuous working of the head and impact on device capacity.

This allowed the overall modernization of the old type lathes that generally refers to:

- Increase the capacity of the drive lathe from 2400 kW to 2800 kW,
- Increasing the drive chain section lathes up to 42 m / m,
- Increase the maximum speed of the head lathe to 3.6 m / sec,
- Introduction of an automated scraping system is defined by the depth of the coal mining operation from 5 to 25cm
- Scraping technique allows obtaining thin layers.

Thick of coal seam is one of the main parameters that determines the choice of technology, mining, and also to select the devices to obtain. From the economic point of view may be 1.5 m below the limit for the application combines the excavation. An additional difficulty is often due to the excavation of top soil and (tailings), which makes exploitation less profitable due to formation of large quantities of waste materials.

In coal mines in Poland produced about 30 million tons of waste that must be matched by new EU legislation and minimized.

The results achieved with coal mining lathes are impressive and the amounts in the mine "Bogdanka" approximately 8200 t / day (maximum of 16 984 t / day with a stope) in the mine "Zafiowka" about 3400 t / day (maximum of 4600 t / day) and mine Jas-Mos about 3000 t/day (maximum of 5050 t / day).

One can confirm that current research and applications related to the introduction of techniques with a new generation of lathes, creates a strategic opportunity to enhance the effects of mining.

3.2. Experience of the mining in Ukraine

In Ukraine, the operation itself in very difficult conditions, especially after the collapse of the USSR, and reflected in the following:

- The needs of the energy from coal settled with only 30% and remained dependent on imports from Russia.
- It is mostly completed harvesting up to 500 m depth, and Donbasks basin to 1800 m depth, there are 220 billion t of coal, which is 2/3 of the total.
- Mining and geological characteristics of coal are scarce, mainly to thin coal seams up to 1 m thick and steep decline.
- Therefore, in the Ukraine access to the new doctrine of thin layers of the excavation and construction of such machines for the premises and excavation, which correspond to these conditions. This is a new direction in the development of technology in underground mining deposits, with the mechanization and robotization.

3.3. Experience of the mining in Russia

The application of technology and the possibility of introducing an underground coal combustion (PSU).

Technology PSU is designed for combustion of coal reserves which are not obtainable with traditional technologies, due to technical or technological difficulties, or because of economic disadvantages. It is the simplest alternative technology.

The main products of underground coal combustion are:

- Hot water, which can be used for heat generators for local consumers (district heating), followed by fruit and vegetable greenhouses, and after the cooling water can be used for watering the additional effect as a biologically active product.
- Generator (burning) gas as fuel for industrial and housing and communal needs, and also as a raw material for obtaining gas for internal combustion engines.
- Electric power, for the local electricity supply. PSU secondary products can be high molecular organic compounds, which can be used for further processing by known chemical methods.

Area of possible applications of the technology PSU:

- Coal reserves left in the cradle, as technological poles for various purposes, sizes and configurations for the closed mines, and also the exploitation horizons and mined out areas of active mines.
- Coal reserves in parts of the bearing and thick good quality coal, but because not digged very complex mining-geological conditions (bearing parts that are very prone to fires and hazardous because of the mountainous zone and discharge gas attack on the exploited classes, etc..).
- Off-balance reserves of coal non-conventional by thick, quality or geological conditions, seams, and also simplifies non-conventional parts of the exploited classes.
- Small deposits of coal reserves unprofitable for mining using the traditional methods, and coal-bearing areas to gravitate to major faults and tectonic structure.

Some columns that can burn should contain not less than 10,000 t of coal. Several smaller pillars can only be obtained by grouping to shafts room, which can be used as the main combustion gas pipeline, and that it closely grouped.

3.4. Experience of the mining in Finland

In other countries, in addition to the above and analyzed, it is development and improvement of new technologies.

On this occasion, let us mention one, but a very important, research program for the implementation of the so-called "Smart mines", which was developed and implemented in Finland in the intensive cooperation of the University of Technology in Helsinki and mining industries manufacturers of mining machinery.

4. CONCLUSIONS

- The above examples in addressing the development of mining in other countries indicate that access period has come and the strong shift to a new strategy. Presented ideas and experiences can be used for certain contingent consideration and resolution that can be accepted and applied in our mines with complex mining-geological conditions.
- Research systems in underground mining coal deposits of Serbia should be directed towards the application of complex automated equipment and systems for conventional capabilities conquests of modern systems, underground gasification of underground coal combustion and others.

- All decisions of the present and future exploitation must be based on the principles and criteria of sustainable development. This means that they are, appropriately includes environmental protection, as well as issues of particular importance and beyond.

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IZBOR OPTIMALNIH PARAMETARA BUŠAČKO-MINERSKIH RADOVA NA POVRŠINSKOM KOPU 'MOŽURA-ORLOVO' KOD BARA

Izvod

Bušačko - minerski radovi (BMR) na površinskom kopu su jedan od osnovnih proizvodnih procesa pri otkopavanju stenskih masa. Obzirom da se radi o brdskom tipu površinskog kopa u povoljnim prirodno-geološkim uslovima, određivanje optimalnih parametara BMR vršeno je u skladu sa istim, što je i predmet ovog rada.

Ključne reči: *tehničko-građevinski kamen, površinski kop, bušački parametri, minerski parametri*

1. UVOD

Istražno-eksploatacioni prostor 'Možura-Orlovo' nalazi se na udaljenosti od oko 10km vazdušne linije, jugoistočno od Bara. Lociran je na severnim i severoistočnim padinama zapadnog dela masiva Možura.

Površinski kop 'Možura-Orlovo' projektovan je da bude klasičan visinski kop. Sam kop prirodno je podeljen na dva dela dolinom, severni i južni deo. Na južnom-višem krilu planirano je razraditi ukupno 10 etaža, dok je na severnom-nižem krilu 7 visinskih etaža.

Predmet eksploatacije je tehničko-građevinski kamen.

Na bazi overenih eksploatacionih rezervi od 8.543.700 m^3 i god proizvodnje od 100.000 m^3 čvrste mase vek eksploatacije bio bi 85 god.

Optimalno izabrana - definisana tehnika bušačko-minerskih radova, ima za cilj da obezbedi zadovoljavajuću fragmentaciju minirane stenske mase do 700 mm, postizanje planirane geometrije kopa i sigurnu i efikasnu eksploataciju u celini.[1]

2. OPTIMALNI PARAMETRI BUŠAČKO-MINERSKIH RADOVA

Optimalni parametari bušačko-minerskih radova zavise od:

- fizičko-mehaničke karakteristike stena u kojim se minira,
- njihovo ponašanje na dejstvo eksploziva,
- zahtevana fragmentacija,
- raspoloživa eksplozivna sredstva,
- raspoloživu opremu za bušenje,

2.1. Oprema za bušenje

Za radove na bušenju koristi se ATLAS COPCO ROC D7, koja može izrađi-

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vati bušotine prečnika od 64-115 mm, (nabavljena je sa garniturom za bušenje od 89 mm). Težina bušilice je 13t. Bušilica se pokreće sa dizel motorom Caterpilar, snage 149kw, oznaka moto ra je CAT 3126 B.[2]

2.2. Geometrija bušenja

Sa aspekta geometrije bušenja odredene su velicine sledecih parametara:

- prečnik bušenja (d)
- linija najmanjeg otpora (W)
- rastojanje izmedu bušotina u jednom redu (E)
- nagib bušenja (α)
- velicina podbušenja(h)

Prečnik bušenja je definisan na osnovu preporuka i nomograma u našoj i stranoj literaturi. Polazeci od očekivanog maksimalnog gabarita (700 mm) za date karakteristike stena u kojima se vrši miniranje, optimalni precnik bušenja je **89mm**, a proveren po preporukama Dyno Nobela (Surface Mining PSO 2007).

Saglasno tome, optimalni precnik bušenja je d = 89 mm, tako da se time nalazimo u dijapazonu najekonomicnijeg načina bušenja, odnosno eksplotacije.

Za ovaj standardni precnik bušenja odgovara standardni precnik patrona od 70 mm, dužine od 330 do 350 mm i težine od 1500 gr.

Linija najmanjeg otpora racuna se iz sledeceg obrazca:

W (mm) = 25 do 40 x d [mm] = 30 x 89 =
= 2670 ~ 2,7 (m)

W – l.n.o. u mm

Na osnovu k-ka stena za koeficijent je uzeta vrednost 30, tako da je **W = 2,7 m** što u potpunosti odgovara vrednostima datim u empiriskim tabelama i nomogramima.

Ovako odredena linija najmanjeg otpora ujedno predstavja **i rastojanje izmedu redova bušotina.**

Rastojanje izmedu bušotina u jednom redu u normalnim uslovima se određuje kao odnos:

E=1,25 x W = 1,25 x2,7 = **3,4 (m)**

Nagib bušenja α i veličina podbušenja Lp

Uobičajeno, nagnute bušotine postižu značajno veće efekte u odnosu na vertikalne bušotine.

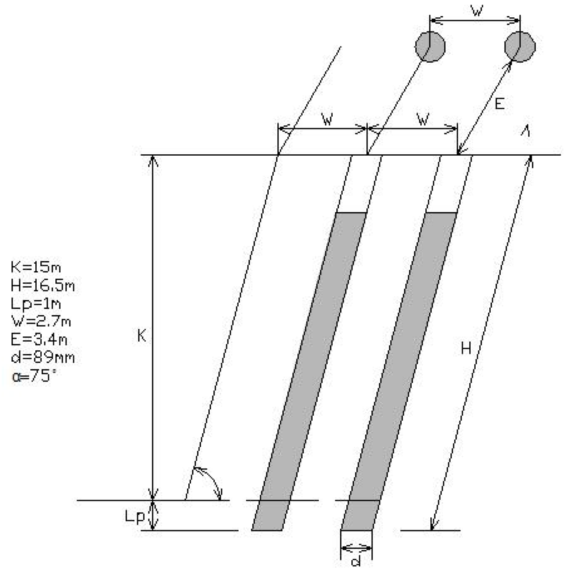
U osnovi, ugao bušotine definisan je uglom radne etaže i za dati slučaj iznosi **α=75°.** Podbušenje je neophodno kako bi se pojačalo punjenje u delu bušotine gde je tovar najveći i postiglo što ravnije dno iskopa (izbegla pojava „nogu“).

Podbušenje se odredjuje geometrijski ili oko 1/3 W, kao

Lp= 0,33xW = 0,33x2,7 = 0,89 (m) ili

Lp= 12 x d = 12 x 0,89 = 1,068 (m)

Iz ovih proračuna proizlazi da podbušavanje treba iznositi **Lp= 1m.**



Sl. 1. *Geometrija bušenja – šematski prikaz*

2.3. Parametri miniranja

Eksplozivna sredstva koja ce se koristiti prilikom miniranja su: eksplozivi, sredstva za pove zivanje, sredstva za inciranje i sredstva za postizanje intervala usporenja izmedu eksplozivnih punjenja u bušotinama.

Izbor eksploziva

Eksploziv koji će se koristiti i stena koja će da se minira treba da imaju što približniju impedancu. Za konkretne uslove koristiti će se amonijum nitratski praškasti patronirani eksploziv, koji ima sledeće karakteristike:

~ specifična težina …… 1.2 t/m^3
~ brzina detonacije …… 4300 m/s
~ prenos detonacije … 40 mm
~ trauzl test …… 370 cm^3

Izbor sredstva veze

Osnovni princip povezivanja eksplozivnih punjenja treba da obezbedi da sva eksplozivna punjenja u jednom aktiviranju budu inicirana i dovedena do eksplozije. Zato se koriste ili detonatorski štapin ili sistemi vatroporvodnih creva (tipa NONEL ili POLINEL).

Vatroprovodna creva su savremenja, jeftinija i sigurnija sredstva veze uz manju mogućnost za prekid detonacije. Vatroprovodna creva za povezivanje minskog polja Starter and Lead Line iz programa Nonel imaju sledeće karakteristike: dijametar 3 mm i brzina detonacije 2100±200 m/s. Svakako da se osim NONEL-a mogu i vatroprovodna creva i drugih proizvodaca sa istim ili slicnim karakteristikama (Polinel sistemi, proizvodac Poliex-Berane, Crna Gora).

Povezivanje eksplozivnih punjenja u mrežu minskog polja, mora se izvoditi pravilno kako bi se obezbedilo kompletno aktiviranje minskog polja jednim iniciranjem.

Izbor sredstva usporenja/detoniranja

Sredstva za usporenje imaju osnovni zadatak da osiguraju optimalne efekte miniranja uz smanje nje intenziteta seizmičkih branova, vazdušnog udara i razletanja komada pri miniranju. Smanjenjem intervala usporenja postiže se sitnija fragmentacija, a većim intervalom krupnija fragmentacija.

Usvojilismo detonatore sa usporenjem iz NONEL MS serije i to za vertikalno usporenje (u bušotini = MS Series), a za horizontalno usporenje (na površini) NONEL MS Conector.

2.4. Parametri eksplozivnog punjenja

Osnovni parametri eksplozivnog punjenja koji su razradeni su:

- distribucija i količina punjenja,
- optimalni interval usporenja.
- specificna potrošnja eksplozivnih sredstava

Distribucija i količina punjenja

Izdužena eksplozivna punjenja kakva su u primeni u našem slucaju, treba da budu konstruisana tako da raspored energije eksplozije obezbedi veću energiju u zonama većeg opterećenja, a manju sa manjim optrećenjem. Zone većeg opterećenja su zone pri dnu bušotine, dok su delovi bušotine pri vrhu/površini zone sa manjim opretećenjem.

Dužina eksplozivnog punjenja se određuje kao razlika izmedu dužine bušotine i dužine čepa.

Dužina bušotine zbog nagiba H iznosi;

H = 15,5 + Lp

H = 15,5 + 1 =**16,5 (m)**

Dužina eksplozivnog punjena je:

Lep = H – Lč

Lep = 16,5 - 2 = **14,5 (m)**

Začepljenje bušotina

Na osnovu definisanog prečnika bušotine d = 89 (mm), kao i ostali definisani parametri mini ranja, dužina čepa se može odrediti iz empiriske zavisnosti (Dyno Nobel):

Lč= 20 x D = 20 x 89 = 1780 mm ili

Lč= 0,8 x W = 0,8 x 2,7 = 2,16

Usvaja se veća vrednost ili približno **Lč = 2 m.**

Proračun potrebne količine eksploziva za jednu bušotinu dobija se:

Qc= c x E x H x W= 0,435 x 3.4 x 16.5 x x 2.7 = 65,88 kg

Na osnovu proračuna dobija se **Qc=66,0 kg.**

Koncentracija punjenja dobija se kao:

Qc/Lep = 66/14,5 = **4,55 (kg/m)**

Optimalni interval usporenja

Redosled inciranja eksplozivnih punjenja po bušotinama je element od izuzetnog značaja. Posle pravilno odbrane i tačno izvedene geometrije bušenja i načina punjenja eksploziva, redosled inciranja je svakako najuticijaniji faktor na postignute rezultate miniranja.

Imajući u vidu sve uticajne faktore, kao i niz predpostavki i preporuka, a da bi se postiglo sa dejstvo grupa eksplozivnih punjena u sukcesivnim intervalima, te da ne bi došlo do super poniranja pri manjim intervalima (17 ms), a u cilju postizanja zahtevanih rezultata preporuču je se interval usporenja **25 ms ili 42 ms**, kao standardna usporenja **za NONEL** sisteme, dok se za usporenje klasičnim usporivačima predlaže interval usporenja od 13 ms ili 20 ms.

Specifična potrošnja eksplozivnih sredstava

Prosečna specifična potrošnja eksploziva dobija se kad kolicina punjenja Qc podeli sa zapreminom minirane stene jednom bušotinom.

Zapremina minirane stene jednom bušotinom je:

V = W x E x K = 2,7 x 3,4 x 15 = **137,7 m^3**

Kako je Qc=66 kg, za **specifičnu potrošnju eksploziva** sledi :

qc = Qc/V = 66/137,7 = **0,479 kg/m^3**

Specifična potrošnja detonatorskog štapina i detonatora odnosno vatroprovodnog creva određuje se na isti način.

Ukupna dužina detonatorskog štapina za jednu bušotinu iznosi:

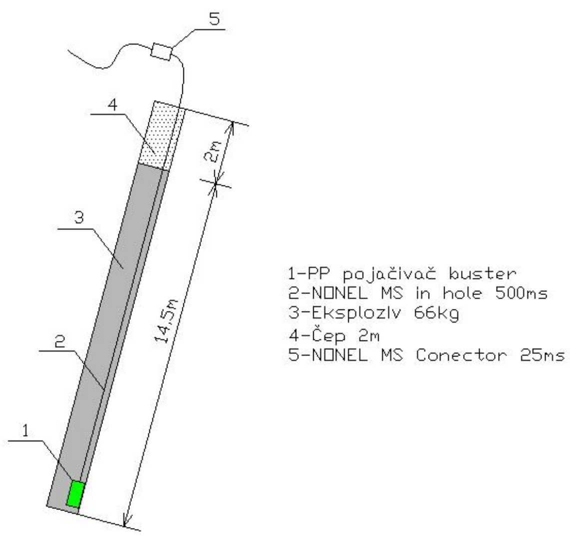
ld= 0,20 + 0,30 + E + H = 19,34 m

Iz toga proizlazi da specificna potrošnja detonatskog štapina je:

qds=19,34/137,7=0,14 m/m^3

Sa obzirom da se vatroprovodno crevo ne priprema na licu mesta već se sa definisanom dužinom i instaliranim detonatorima i konektorima naručuje od proizvođača kao komplet, tako da je za jednu bušotinu potreban:

- jedan komplet **za vertikalno usporenje MS – 500 ms** (dužina crijeva ~ 19,34 m).
- jedan komplet **za horizontalno usporenje MS - 25 ms** (dužina crijeva ~ 1,0 m)



Sl. 2. *Konstrukcija eksplozivnog punjenja*

2.5. Parametri proizvodnog miniranja

Operativni parametri se biraju na osnovu optimalnih vrednosti uz prethodno određivanje geometrije konkretnog minskog polja. Veličina minskog polja određuje se na osnovu više faktora, a pre svega uslove sigurnog i bezbednog rada, dinamiku ukupne proizvodnje, međusobni uticaj radnih operacija i sl.

Saglasno ovim faktorima, *prosečno proizvodno minsko polje* bi trebalo imati dubinu napredovanja od oko 11 m i dužinu cela oko 68 m ili 4 reda bušotina za 20 minskih bušotina po redu. Za visinu etaže od 15 m, ukupna kolicina stenske mase koja se dobija iz jednog polja iznosi približno 11.000 m^3.

Parametri miniranja prosečnog polja dati su u tabeli 3.

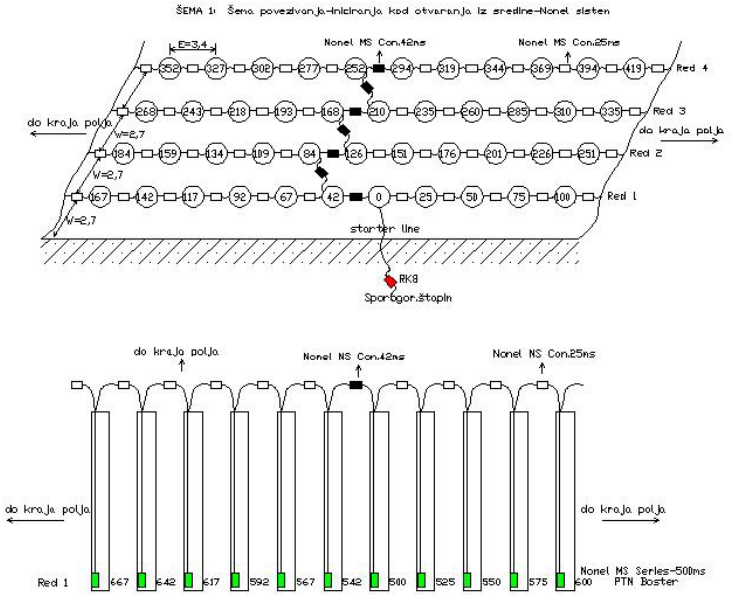
Tabela 3.

Parametar	Oznaka	Jedinice	Vrednost
1. Visina etaže	K	m	15
2. Naklon bušotine	a	o	75
3. Zapreminska težina stena		kg/m^3	2,662
4. Linija najmanjeg otpora	W	m	2,7
5. Udaljenost izmedu bušotina u redu	E	m	3,4
6. Dužina bušotina	H	m	16,5
7. Dužina podbušenja	Lp	m	1,0
8. Dužina cepa	Lč	m	2,0
9. Dužina eksplozivnog punjenja	Lep	m	14,5
10. Neophodna kolicina eksploziva u bušotini	Qc	kg	66
11. Zapremina oborenog materijala od jedne bušot.	V	m^3	137,7
12. Specifična potrošnja eksploziva	Qc	kg/m^3	0,479
13. Broj redova sa bušotinama	nr	br	4
14. Broj bušotina u jednom redu	n1	br	20
15. Broj bušotina u jednoj minskoj seriji	Nb	br	80
16. Ukupna dužina bušotina za minsko polje	Le	m	1320
17. Zapremina oborenog materijala iz bloka	Vbl	m^3	11016
18. Masa oborenog materijala iz bloka	Qbl	t	29325
19. Faktička potrošnja eksploziva	Qe	kg	5280

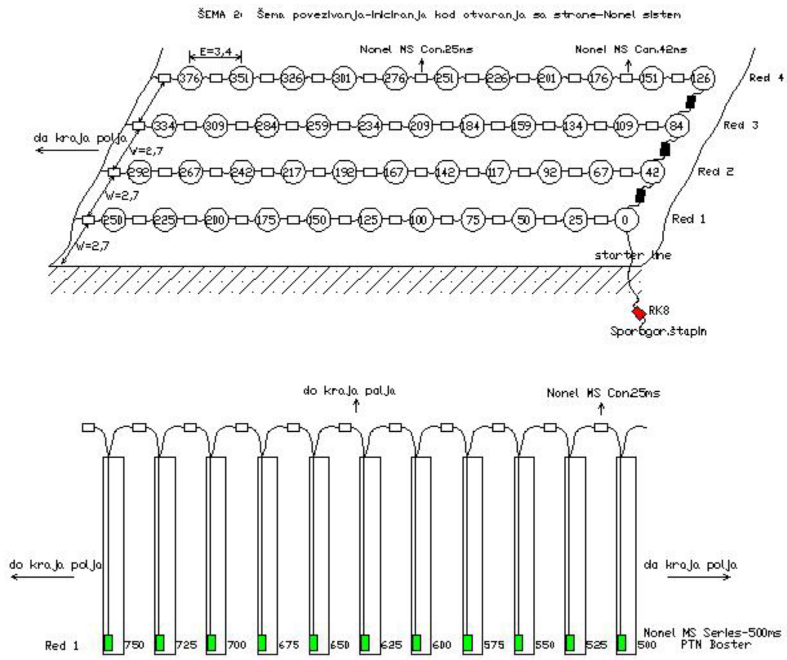
Generalno na kopovima građevinsko – tehničkog kamena najčešće u primeni su dve osnovne šeme iniciranja minskog polja. Jedan način je „otvaranje iz sredine“ šema 1, a drugi „otvaranje sa strane“ šema 2. U zavisnosti od željenih rezultata u pogledu fragmentacije, kao i lokalnih uslova radne sredine bira se način otvaranja minskog polja, imajući u vidu da se otvaranjem iz sredine postiže veće usitnjavanje stenske mase.

Najavljena izgradnja regionalne ili opštinske sanitarne deponije sa jedne strane odnosno verto generatora sa druge strane PK MOŽURA ORLOVO kod Bara, uslovili su izbor NONEL sistema – kao najbezbjednijeg načina miniranja.

Na šemama su prikazani svi elementi horizonatlnog povezivanja i redosled iniciranja, kao i elementi vertikalnog povezivanja i redosled iniciranja prvog reda bušotina (za ostatak redova povezivanje i redosled rade se analagno prvome).



Šema 1. *Šema povezivanja/inciranja kod „otvaranja iz sredine" (NONEL sistemi)*



Šema 2. *Šema povezivanja/inciranja kod „otvaranja sa strane" (NONEL sistemi)*

Mora se napomenuti da su prikazane oznaka originalnih NONEL sistema, iako za datu namenu mogu se koristiti proizvodi drugih proizvodača istih ili sličnih karakteristika.

Nezavisno od sistema iniciranja, vatroprovodno crevo se može zameniti detonatorskim štapinom kod horizontalnog povezivanja, ali se konektori moraju nabaviti u kompletu.[3]

3. ZAKLJUČAK

Sa stanovišta optimalnih parametara bušačko-minerskih radova, za svako minsko polje nadležni operativni inženjer mora izrađivati uputstva za izvođenje BMR i voditi detaljnu knjigu BMR na kopu. Neophodno je preduzimati sve opšte i posebne mere zaštite na radu za vreme vršenja radova na bušenju i miniranju, kako bi se obezbedila sigurnost rada u svim fazama, od početka bušačko-minerskih radova pa do finalizacije odnosno dobijanja predviđenih frakcija tehničko-građevinskog kamena. Predlo ženi parametri BMR uz poštovanje mera zaštite na radu, omogućuju ostvarenje planirane proizvo dnje na površinskom kopu i omogućavaju siguran rad zaposlenog ljudstva i angažovane opreme u svim fazama rada.

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SELECTION THE OPTIMUM PARAMETERS OF DRILLING-BLASTING WORKS AT THE OPEN PIT MINE 'MOŽURA-ORLOVO' NEAR BAR

Abstract

Drilling-blasting works (DBW) at the open pit mine are one of the main production processes in the excavation of rock masses. Since the matter is about hilly open pit mine in favourable natural-geological conditions, determination of optimum DBW parameters is made in accordance with the same as it is the subject of this paper.

Keywords: *technical-construction stone, open pit mine, drilling parameters, blasting parameters.*

1. INTRODUCTION

The research - exploitation area 'Možura-Orlovo' is situated about 10 kilometers by air, southeast of Bar. It is situated on northern and northeastern slopes of the western part of Možura massif.

The open pit mine 'Možura-Orlovo' was designed to be a classic hilly open pit mine. The open pit mine itself is divided in two parts by a valley, the northern and southern part. On the southern- higher wing, 10 levels are planned to be developed, while on the northern-lower wing, 7 levels are planned to be developed.

The subject of exploitation is a technical-construction stone.

On the basis of verified mineable reserves of 8,543,700 m^3 and annual production of 100,000 m^3 of solid masses, the exploitation life would last 85 years.

The aim of optimally selected – defined technique of drilling-blasting works is to ensure a satisfying fragmentation of blasted rock masses up to 700 mm, to achieve the planned geometry of open pit and certain and efficient overall exploitation [1].

2. OPTIMUM PARAMETERS OF DRILLING-BLASTING WORKS

The optimum parameters of the drilling-blasting works depend on:

- physical-mechanical characteristics of blasted rock
- their reaction to explosive action
- demanded fragmentation
- available explosives
- available drilling equipment.

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2.1. Drilling equipment

For drilling works ATLAS COPCO ROC D7 is used, which can drill boreholes from 64-115 mm in diameter (supplied with drilling rig up to 89 mm). Drill weight is 13 t with diesel drive Caterpillar, power of 149 kW, mark of drive is CAT 3126 B [2].

2.2. Geometry of drilling

From the aspect of drilling geometry, the sizes of following parameters were determined:

- diameter of drilling (d)
- line of the lowest resistance (w)
- space between boreholes in a line (e)
- slope of drilling (a)
- size of sub-drilling (h)

Diameter of drilling is defined based on recommendations and nomograms in our and foreign literature. Starting with expected maximum size (700 mm) for the given characteristics of rock which is blasted, optimum diameter of drilling is **89 mm,** tested according to the recommendation of Dyno Nobela (Surface Mining PSO 2007).

In accordance with this, optimum diameter of drilling is d = 89 mm, so in this way, the most economic way of drilling and exploitation is present.

For this standard diameter of drilling, the suitable cartridge standard diameter is 70 mm, 330 to 350 mm long and weight of 1500 g.

Line of the lowest resistance is calculated from the following formula:

W (mm) = 25 do 40 x d [mm] = 30 x 89 =
= 2670 ~ 2.7 (m)

W – l.n.o. in mm

Based on the characteristics of rocks, the coefficient is 30, so that **W = 2.7 m**, what is completely in accordance with the given values in empiric tables and nomograms.

Line of the lowest resistance, determined in this way, also represents at the same time **a distance between the lines of boreholes.**

Distance between boreholes in a line, in normal conditions, is calculated as relation:

E =1.25 x W = 1.25 x 2.7 = 3.4 (m)

Slope of drilling a and the size of sub-drilling Lp

Commonly, the inclined boreholes achieve greater effects related to the vertical boreholes. Basically, the angle of borehole is defined by the angle of working level and for the given case is **α=75°.** Sub-drilling is necessary in order to enhance the charge in a part of borehole where the load is the biggest and to achieve the flatness of excavation bottom (to avoid the effect of “legs”).

Sub-drilling is determined geometrically or around 1/3 W, as

Lp = 0.33 x W = 0.33 x 2.7 = 0.89 (m)
or

Lp= 12 x d = 12 x 0.89 = 1.068 (m)

From these calculations, it is calculated that sub-drilling should be **Lp= 1m.**

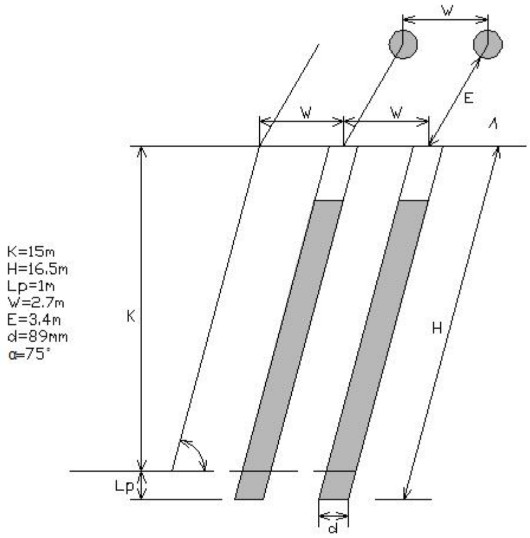


Fig. 1. *Geometry of drilling - schematic diagram*

2.3. Blasting parameters

Explosive materials, used in mining are: explosives, materials for connection, materials for initiation and materials for creating a deceleration interval between explosive charges in boreholes.

The selection of explosives

The explosive being used and the rock being mined must have, as much as possible, similar impedance. For particular conditions, the ammonium-nitrate powder cartridge explosive is used, which has the following characteristics:

~ specific weight …… 1.2 t/m^3
~ speed of detonation … 4300 m/s
~ transfer of detonation …… 40 mm
~ trauzl test …… 370 cm^3

Selection of materials for connection

The basic principle of connecting explosive charges should ensure that all explosive charges are initiated and blasted at once upon activation. That is why a detonating cord or a system of shock tubes (NONEL or POLINEL type) is used.

Shock tubes are more modern, cheaper and safer material for connection, with less possibilities of disrupting detonation. Shock tubes for connecting mine field Starter and Lead Line from Nonel program have the following characteristics: diameter 3 mm and speed of detonation 2100±200 m/s. Surely, except NONEL shock tubes, shock tubes from other manufacturers can be used, with similar or the same characteristics (Polinel systems, manufacturer Poliex-Berane, Montenegro).

Connection of explosive charges into a minefield network has to be done correctly in order to ensure a complete activation of minefield with one initiation.

Selection of material for deceleration /detonation

Materials for deceleration have the basic task to ensure optimum blasting effects and decrease the intensity of seismic waves, air blasts and dispersing parts inblasting. Decreasing the interval of deceleration finest fragmentation is accomplished, while with longer interval bigger fragmentation is ensured.

We accepted a detonator with deceleration from NONEL MS series, for vertical deceleration (in boreholes =MS Series), and for horizontal deceleration (on surface) NONEL MC Connector.

2.4. Parameters of explosive charges

Basic parameters of explosive charges, which are elaborated, are:

- distribution and amount of charges
- optimal interval of deceleration
- specific usage of explosive materials.

Distribution and amount of charges

Prolonged explosive charges, which are used in our case, should be constructed in such a way that the pattern of explosive energy can ensure greater energy in zones with greater weight, and weaker energy in zones with lighter weight. Zones with greater weight are zones at the bottom of a borehole, while parts a borehole at the top of it are zones with lighter weight.

The length of an explosive charge is determined as a difference between the length of borehole and length of bung.

Length of borehole, due to the slope H, is:

$$H = 15.5 + Lp$$

$$H = 15.5 + 1 = 16.5 \text{ (m)}$$

Length of explosive charge is:

$$Lep = H - Lc$$

$$Lep = 16.5 - 2 = 14.5 \text{ (m)}$$

Bung of boreholes

According to the defined diameter of borehole d = 89 (mm), like other defined blasting parameters, the length of bung can be determined from the empiric correlation (Dyno Nobel):

$$Lc = 20 \times D = 20 \times 89 = 1780 \text{ mm, or}$$

$$Lc = 0.8 \times W = 0.8 \times 2.7 = 2.16$$

Higher or approximate value is adopted **Lc = 2 m.**

Calculation of needed amount of explosives for one borehole is obtained:

$$Qc = c \times E \times H \times W = 0.435 \times 3.4 \times 16.5 \times 2.7 = 65.88 \text{ kg}$$

According to the calculation, the following is obtained **Qc= 66.0 kg.**

Concentration of a charge is calculated as:

$$Qc/Lep = 66/14.5 = \mathbf{4.55\ (kg/m)}$$

Optimum interval of deceleration

Sequence of initiating explosive charges in boreholes is a very crucial element. After properly selected and correctly executed drilling geometry and charging explosives, the sequence of initiation is by far the most influential factor for achieving the results of blasting.

Bearing in mind all influential factors, as well as a number of assumptions and recommendations, in order to accomplish co-effect of a group of explosive charges in successive intervals, and to avoid super plunge when intervals are shorter (17 ms), towards achieving demanded results deceleration intervals of **25 ms or 42 ms** are recommended, as the standard decelerations **for NONEL** systems, but for deceleration with classic deceleration materials the interval of 13 or 20 ms is recommended.

Specific usage of explosive materials

The average specific usage of explosive materials is calculated when the amount of charges Qc is divided by volume of blasted rock of one borehole.

Volume of blasted rock of one borehole is:

$$V = W \times E \times K = 2.7 \times 3.4 \times 15 = 137.7 \text{ m}^3$$

Since Qc=66 kg, for **specific explosive consumption**, it follows:

$$qc = Qc/V = 66/137.7 = \mathbf{0.479\ kg/m^3}$$

Specific usage of detonating cord and detonators, i.e. shock tubes, is determined by the same way.

Overall length of detonating cord for one borehole is:

ld= 0,20 + 0.30 + E + H = 19.34 m

It follows that the specific usage of detonating cord is:

qds=19.34/137.7=0,14 m/m^3

Since the shock tube is not prepared on the spot, but with defined length and installed detonators and connectors as a set, it is ordered from the manufacturer, it follows that for one borehole is needed:

- one set for vertical deceleration MS – 500 ms (tube length ~ 19.34 m).
- one set for horizontal deceleration MS - 25 ms (tube length ~ 1.0 m)

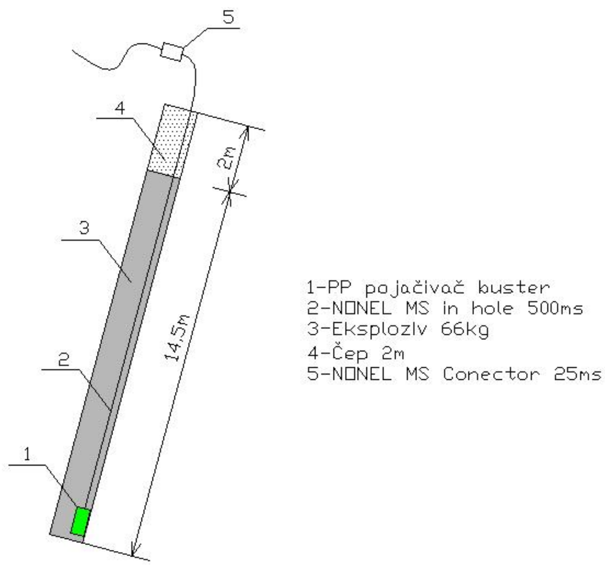


Fig. 2. *Construction of explosive charge*

2.5. Productive blasting parameters

Operational parameters are selected on the basis of optimum values, after determining the geometry of specific minefield. The size of minefield is determined according to a number of factors, but most of all conditions of stable and safe work, dynamics of overall production, mutual effects of operations, etc.

According to these factors, *the average productive minefield* should advance about 11 m in depth, with the bung length of 68 m or it should have 4 rows of boreholes for 20 boreholes per row. For the level height of 15 m, the overall rock mass, obtained from one minefield is approximately 11.000 m^3

Parameters for mining one average mine field are given in Table 3.

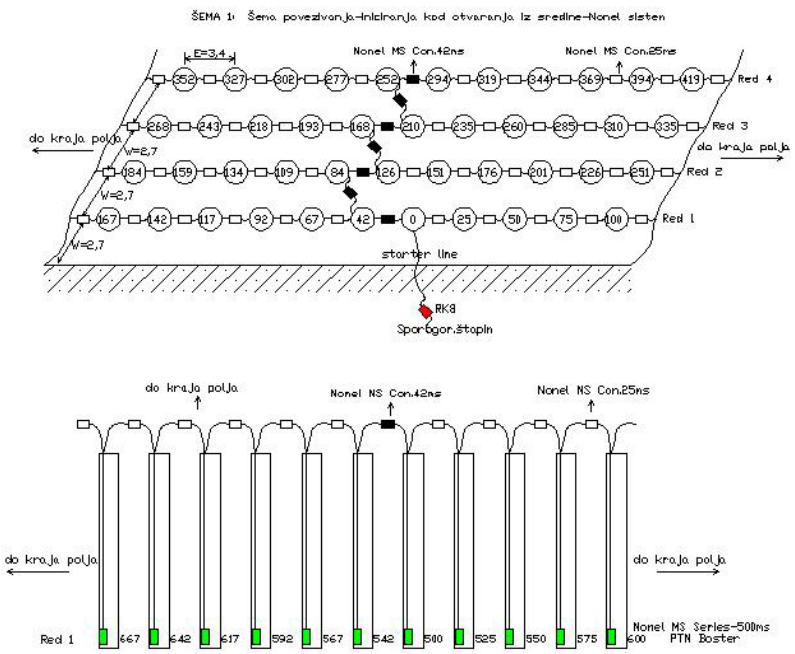
Table 3.

Parameter	Mark	Unit	Value
1. Level height	K	m	15
2. Slope of borehole	a	o	75
3. Volumetric weight of rocks		kg/m^3	2.662
4. Line of the least resistance	W	m	2.7
5. Space between boreholes in a row	E	m	3.4
6. Boreholes length	H	m	16.5
7. Sub-drilling length	Lp	m	1.0
8. Bung length	Lč	m	2.0
9. Length of explosive charge	Lep	m	14.5
10. Amount of explosive needed in borehole	Qc	kg	66
11. Volume of material taken down in one borehole	V	m^3	137.7
12. Specific explosive usage	Qc	kg/m^3	0.479
13. Number of rows with boreholes	nr	Num.	4
14. Number of boreholes per row	n1	Num.	20
15. Number of boreholes in one mine series	Nb	Num.	80
16. Overall length of boreholes for mine field	Le	m	1320
17. Volume of material taken down from a block	Vbl	m^3	11016
18. Mass of material taken down from a block	Qbl	t	29325
19. Actual explosive usage	Qe	kg	5280

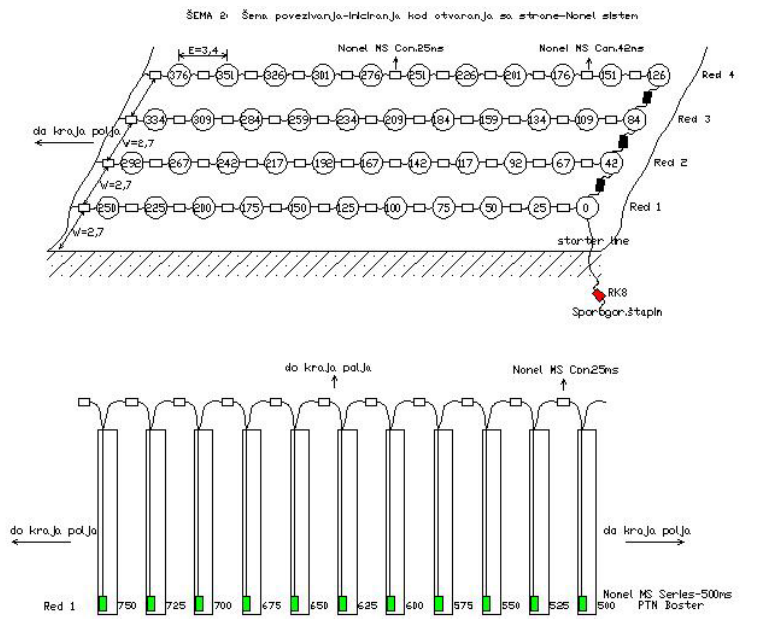
Generally, at the open pit mines of technical-construction stone, two basic schemes of initiation are used. One way is "opening from the middle", scheme 1, and the other is "opening from the side", scheme 2. Depending on the fragmentation results, as well as local conditions of working environment, the way how to open a minefield is selected, with taking into consideration that opening from the middle results with greater crushing of rock masses.

Announcement of a plan to build the regional and municipal sanitary depot on one side, that is a wind turbine on the other side of the OPEN PIT MOŽURA-ORLOVO near Bar, was stipulated the selection of NONEL systems as the safest way of blasting.

All elements of horizontal connection and sequence of initiations are shown on schemes, as well as elements of vertical connection and initiation sequence of the first row of boreholes (for the rest of row connections and sequence is done analogue to the first one)



Scheme 1. *Scheme of connection/ initiation in the "opening from the middle" (NONEL systems)*



Scheme 2. *Scheme of connection/ initiation in the "opening from the side" (NONEL systems)*

It has to be noted that the original labels of NONEL systems are shown, even though for the given purpose, products of other manufacturers, with the similar or same characteristics, can be used.

Independently of initiation systems, a shock tube can be replaced with detonating cord when connection is done horizontally, but connectors have to be ordered as a set [3].

3. CONCLUSION

From the standpoint of optimum parameters of drilling-blasting works, for every minefield, a responsible operational engineer has to make instructions for DBW and must have a detailed book of DBW at the open pit mine. It is important to take all general and special working precaution measures during mining and drilling works in order to ensure the safety of works in all phases, from the beginning of drilling-blasting works to the finalization that is production of required fractions of technical-construction stone. Suggested parameters of DBW with following working precaution measures, enable achieving the planned production at the open pit mine and enable safety work of people and involved equipment at all stages of operation.

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Ratomir Popović, Milenko Ljubojev*, Dragan Ignjatović**

DEFINISANJE ZAŠTITNOG STUBA DRUMSKOG TUNELA IZNAD EKSPLOATACIONOG POLJA RUDNIKA SA NEIZUČENIM PROCESOM SLEGANJA**

Izvod

U radu se definiše zaštitni sigurnosni pojas oko tunela i granica otkopavanja ispod tunela. Na bazi tih parametara definišu se granični uglovi uticaja, a samim tim i geometrija zaštitnog stuba.

Ključne reči: *pomeranje površine terena, korito sleganja, vertikalno sleganje, horizontalna specifična deformacija, nagib tangente na krivu sleganja*

UVOD

Retka su ležišta mineralnih sirovina koja se nalaze van urbanih naselja, ili koja ne presecaju veliki vodotokovi ili, pak, drumske i železničke saobraćajnice. Već u dalekoj prošlosti se javlja potreba za prognozom uticaja podzemne eksploatacije na površinu zemlje i objekte na njoj i u stenskom masivu.

U drugoj polovini XIX veka javljaju se prvi radovi o mehanizmu pomeranja krovinskih naslaga i površine zemlje, kao posledica podzemne eksploatacije mineralnih sirovina, koji su izazivali velike štete na izgrađenim objektima.

Podzemnom eksploatacijom određenog ležišta i likvidacijom praznog prostora zarušavanjem krovinskih naslaga, dolazi do pojave obrušavanja i znatnog pomeranja krovinskih naslaga, što posledično izaziva pomeranje površine terena. Vertikalne komponente pomeranja, koje se nazivaju sleganje površine terena W, utiču na nagib korita sleganja i njegovu krivinu, čije ispoljavanje ima uticaja na stabilnost površinskih objekata i objekata izgrađenih u stenskom masivu u smislu građevinske statike. Horizontalne komponente pomeranja u, nazivaju se horizontalno pome-

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ranje i direktno utiču na promenu naponsko-deformacijskog stanja u građevinskom objektu, a time i na samu stabilnost i funkcionalnost objekta.

Prognoziranje uticaja podzemne eksploatacje na površinu, odnosno na objekte koji se nalaze na površini terena ili su izgrađeni u samom stenskom masivu (tuneli), svodi se na određivanje rasporeda pojedinih komponenti pomeranja u funkciji udaljenosti od granice eksploatacije

W = f(x), vertikalno sleganje

u = f(x), horizontalno pomeranje

1. OPŠTE KARAKTERISTIKE UTICAJA PODZEMNE EKSPLOATACIJE NA POVRŠINU TERENA SA NEIZUČENIM PROCESOM POMERANJA

Pod rudnicima sa neizučenim procesom pomeranja podrazumevaju se rudnici u kojima nisu vršena dugogodišnja geodetska praćenja pomeranja površine terena, te prema tome nisu poznate osnovne geometrijske karakteristike procesa pomeranja. Da bi se objekti od vitalnog značaja na površini terena i u stenskom masivu zaštitili od negativnog uticaja podzemne eksploatacije ili njen uticaj sveo na dozvoljenu meru, u ležištu mineralne sirovine ostavljaju se zaštitni potporni stubovi.

Zaštitni stub predstavlja deo mineralnog ležišta koji se ne otkopava, a geometrijski se determiniše ispod objekta koji se štiti, sl. 1. Geometrija stuba se konstruiše pomoću graničnig uglova uticaja ψ, čija vrednost zavisi od fizičko-mehaničkih i deformacionih svojstava krovinskih naslaga i dozvoljenih deformacija objekta koji se štiti.

- horizontalna deformacija, ε_x [mm/m]
- tangenta na krivu sleganja, T [mm/m]
- zakrivljenost krive sleganja, K [km]

Postavlja se pitanje koju vrstu deformacije treba usvojiti kao opšti kriterijum pri određivanju uglova zaštitnog potpornog stuba. Zavisno od vrste deformacija i njihove uslovljenosti, postoje objekti, koji su u smislu oštećenja osetljivi samo na određenu vrstu deformacija, dok su druge vrste deformacija, u tom smislu, sekundarne po značaju. Zgrade i slični zidani objekti su najosetljiviji na horizontalne deformacije temelja, koje u objektima izazivaju napone zatezanja, a samim tim i pojavu pukotina. Visoki objekti, dimnjaci i tornjevi, osetljivi su na promenu nagiba tangente. Železničke pruge, autoputevi, cevovodi, osetljivi su na promenu krivine sleganja. Svi objekti na površini terena po kriterijumu dozvoljenih deformacija, svrstani su u šest grupa, tabela 1.

Tabela 1.

Kategorija objekata	Oštećenja	Dozvoljene vrednosti deformabilnosti		
		ε_x [mm/m]	T [mm/m]	R [km]
0	Monumentalne zgrade, magistralni gasovodi, rezervoari za vodu i železničke pruge za brzine 200 [km/h] - bez vidljivih pukotina	< 0,5	< 2	> 20
I	Zgrade, regionalni gasovodi, rezervoari za vodu i dr. - oštećenja neznatna, na zidovima male pukotine	0,5 – 2,5	2 – 3	15– 20
II	Izvozna okna, železničke pruge, mostovi, vodovodi, višespratne zgrade dužine preko 20 [m] - oštećenja se lako otklanjaju uz redovno održavanje	2.5 – 5.0	5 – 10	8 – 12

III	Autoputevi, zgrade sa specijalnim temeljenjem, vodotokovi - veća oštećenja, objekti ne gube funkcionalnost uz redovno održavanje	5 – 8	10 – 15	5 – 8
IV	Regionalni putevi, zgrade dužine ispod 20 [m] - oštećenja su velika i objekti zahtevaju veću rekonstrukciju	8 – 12	15 – 20	3 – 5
V	Prizemne zgrade, manje rečice, sporedne pruge - oštećenja su takva da neki objekti gube funkcionalnost i zahtevaju rušenje	12 – 15	20	5

2. PRORAČUN I KONSTRUKCIJA ZAŠTITNOG POTPORNOG STUBA DRUMSKOG TUNELA

Tunel, koji predstavlja deo autoputa, prolazi iznad eksploatacionog ugljonosnog polja. Prečnik tunela je 20 [m] i leži 50 [m] ispod površine terena i 900 [m] iznad krovine ugljenog sloja moćnosti 6 [m].

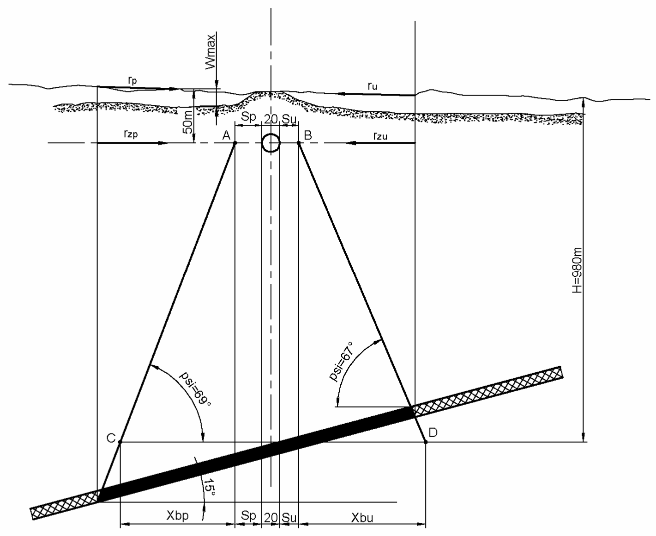
Ugljeni sloj je pod uglom $\alpha = 15°$, sl. 1.

Krovinske naslage izgrađuju laporci 98,4 [%] i podpovršinske gline 1,6 [%].

Osnovni fizičko-mehanički parametri su prikazani u tabeli 2.

Tabela 2.

Litološki član	Zapreminska težina, γ [kN/m^3]	Koeficijent čvrstoće, f	Otpornost na zatezanje, σ_z [kN/m^2]
Laporac	23,38	4,81	3500



Sl. 1. *Geometrija zaštitnog potpornog stuba ispod saobraćajnog tunela*

U stenskom masivu oko tunela ostavlja se sigurnosni pojas S. U zavisnosti od važnosti objekta i kategorije zaštite, njegova vrednost je prikazana u tabeli 3.

Tabela 3.

Kategorija zaštite	0	I	II	III	IV	V
Zona sigurnosti	25	20	15	10	5	5

Za nagib slojeva α < 10°, veličina zaštitnog pojasa S se izračunava na sledeći način:

$$S = 0{,}16\sqrt{\frac{HR_z}{\gamma_{sr}}} \ \text{[m]}$$

gde je:

- S [m], širina sigurnosnog pojasa oko objekta
- H [m], dubina
- R_z [kN/m^2], srednja vrednost na zatezanje krovinskih stena
- γ_z [kN/m^3], srednja vrednost zapreminske težine krovinskih stena

Za slojeve nagiba 10 ≤ α < 90°, širina zaštitnog pojasa se određuje na sledeći način:

- u pravcu pada sloja, sl. 1

$$S_p = S \cdot \sqrt{\cos\alpha} = 25 \cdot \sqrt{\cos 15} = $$
$$= 24{,}57[m] = 25{,}0[m]$$

- u pravcu uspona sloja

$$S_u = S \cdot \frac{1}{\sqrt{\cos 15^o}} = 25 \cdot \frac{1}{\sqrt{\cos 15^o}} =$$
$$= 25{,}4\,[m] = 26{,}0\,[m]$$

Prognozno maksimalno sleganje površine terena je:

$$W_{max} = m \cdot q_u \cdot i\,[m]$$

- m = 6,0 [m], moćnost ugljenog sloja
- q_u, koeficijent sleganja krovinskih naslaga. Za metodu eksploatacije sa obrušavanjem krovine, određuje se na sledeći način:

$$q_u = 0{,}9 - 0{,}03 \cdot f = 0{,}9 \cdot 0{,}03 \cdot 4{,}81 = 0{,}76$$

- i = 0,9, eksploatacioni gubici

$$W_{max} = 6 \cdot 0{,}76 \cdot 0{,}9 = 4{,}10\,[m]$$

2.1. Određivanje granice otkopavanja ugljenog sloja ispod tunela za 10 ≤ α < 90°

- u pravcu pada sloja

$$x_{bp} = \sqrt{\frac{k \cdot H \cdot \sigma_z \cdot \cos\alpha}{2\gamma_{sr}}} =$$

$$= \sqrt{\frac{1{,}5 \cdot 980 \cdot 3500 \cdot \cos 15^o}{2 \cdot 23{,}38}}$$

k = 1,5 za H < 1000 [m]

x_{bp} = 326 [m]

- u pravcu uspona sloja

$$x_{bu} = \sqrt{\frac{k \cdot H \cdot \sigma_z}{2\gamma_{sr} \cdot \cos\alpha}} =$$
$$= \sqrt{\frac{1{,}5 \cdot 870 \cdot 3500}{2 \cdot 23{,}38 \cdot \cos 15^o}}$$

x_{bu} = 318 [m] ≈ 320 [m]

Zaštitni pojas na nivou ugljenog sloja ispod tunela za 10 ≤ α < 90°

- u pravcu pada sloja

$$x_{bsp} = x_{bp} + S_p = 326{,}0 + 25{,}0 = 351{,}0\ [m]$$

- u pravcu uspona sloja

$$x_{bsu} = x_{bu} + S_u = 320{,}0 + 26{,}0 = 346{,}0\ [m]$$

Spajanjem tačaka AC i BD dobije se ugao nagiba zaštitnog stuba u pravcu pada i uspona sloja, a može se i izračunati kao tg ugla visine i horizontalne udaljenosti zaštitnog pojasa na nivou krovine ugljenog sloja.

- u pravcu pada sloja

$$tg\psi_p = \frac{850}{326} = 69^o$$

- u pravcu uspona sloja

$$tg\psi_u = \frac{750}{318} = 67^o$$

2.2. Provera deformacija stenskog masiva oko saobraćajnog tunela

Poluprečnik dometa uticaja podzemne eksploatacije na površini terena je funkcija maksimalnog sleganja površine terena.

$$f_{(x)} = \frac{W_{max}}{r} \cdot e^{-\frac{\pi x^2}{r^2}}$$

Poluprečnik r se računa od granice završene eksploatacije, čiji je uticaj teoretski beskonačan, a praktično se ograničava na dozvoljenu deformaciju.

Poluprečnik dometa glavnih uticaja podzemne eksploatacije na površini terena je:

- u pravcu pada sloja

$$r_p = \frac{H}{tg\psi} = \frac{1110}{tg69^o} = 425{,}3[m]$$

- u pravcu uspona sloja

$$r_u = \frac{H}{tg67^o} = \frac{980}{tg67^o} = 415{,}3[m]$$

Posledice podzemne eksploatacije na stanje objekta unutar stenskog masiva, mogu se odrediti na način koji je sličan onom kojim se određuje uticaj na površini terena. U tom slučaju, umesto poluprečnika dometa r glavnih uticaja na površini, utvrštava se poluprečnik dejstva eksploatacije unutar stenskog masiva r_z. U ovom slučaju za saobraćajni tunel r_z je:

$$r_z = r\left(\frac{z}{H}\right)^n$$

- z [m], vertikalna udaljenost krovine ugljenog sloja do ose tunela
- H [m], dubina eksploatacije

$$n = \sqrt{2} \cdot \pi \cdot tg\psi$$

$$n_p = \sqrt{2} \cdot \pi \cdot tg69^o = 11{,}59$$

$$n_u = \sqrt{2} \cdot \pi \cdot tg67^o = 10{,}43$$

- u pravcu pada sloja

$$r_{zp} = r_p\left(\frac{z}{H}\right)^{11,59} =$$

$$= 425{,}3 \cdot \left(\frac{980}{1110}\right)^{11,59} = 100{,}0[m]$$

- u pravcu uspona sloja

$$r_{zu} = r_u\left(\frac{z}{H}\right)^{10,43} =$$

$$= 415{,}3 \cdot \left(\frac{780}{870}\right)^{10,43} = 133{,}0[m]$$

Deformacije stenskog masiva oko tunela su izračunate na sledeći način:

- Specifična horizontalna deformacija

$$\varepsilon_x = \frac{\sqrt{2\pi} \cdot W_{max}}{r_z^2} \cdot x \cdot e^{-\frac{\pi x^2}{r_z^2}} \left[\frac{mm}{m}\right]$$

- Tangenta na krivu sleganja

$$T = \frac{W_{max}}{r_z} \cdot e^{-\frac{\pi x^2}{r_z^2}} \left[\frac{mm}{m}\right]$$

- Zakrivljenost krive sleganja

$$K = \frac{2\pi \cdot W_{max}}{r_z^2} \cdot x \cdot e^{-\frac{\pi x^2}{r_z^2}} \left[\frac{m}{m}\right]$$

- Radijus zakrivljenja

$$R = \frac{1}{K}$$

Dobijene vrednosti deformacija su prikazane u tabelama 4 i 5.

Tabela 4. *Deformacije na nivou tunela u pravcu pada sloja*

Udaljenost od granice otkopavanja [m]	Maksi-malno sleganje W_{max} [m]	Specifična horizontalna deformacija ε_{xp} [mm/m]	Tangenta na krivu sleganja T_p [mm/m]	Krivine krive sleganja K [m/m]	Radijus zakrivljenja $R=\frac{1}{K}$ [km]
100,0	4,10	$1,11 \cdot 10^{-2}$	$1,77 \cdot 10^{-3}$	$1,114 \cdot 10^{-4}$	8973
200,0		$1,81 \cdot 10^{-6}$	$1,44 \cdot 10^{-7}$	$9,036 \cdot 10^{-11}$	$1,1 \cdot 10^{10}$
326,0 granica sigurnos-nog pojasa tunela		$2,70 \cdot 10^{-15}$ praktično nema uticaja	$1,32 \cdot 10^{-16}$	$8,29 \cdot 10^{-20}$	$1,2 \cdot 10^{19}$

Tabela 5. *Deformacije na nivou tunela u pravcu uspona sloja*

Udaljenost od granice otkopavanja [m]	Maksi-malno sleganje W_{max} [m]	Specifična horizontalna deformacija ε_{xp} [mm/m]	Tangenta na krivu sle-ganja T_p [mm/m]	Krivine krive sleganja K [m/m]	Radijus zakrivljenja $R=\frac{1}{K}$ [km]
133,0	4,10	$8,38 \cdot 10^{-3}$	$1,33 \cdot 10^{-3}$	$6,3898 \cdot 10^{-5}$	15650
200,0		$1,02 \cdot 10^{-6}$	$1,08 \cdot 10^{-7}$	$7,79 \cdot 10^{-9}$	$128 \cdot 10^{6}$
320,0 granica sigurnos-nog pojasa tunela		$1,50 \cdot 10^{-15}$ praktično nema uticaja	$3,92 \cdot 10^{-11}$	-	-

ZAKLJUČNA RAZMATRANJA

Pod rudnikom sa neizučenim procesom pomeranja se podrazumeva rudnik u kojem nisu poznate osnovne geometrijske karakteristike procesa pomeranja krovinskih naslaga iznad otkopanog prostora.

U takvim slučajevima, neophodni su osnovni podaci za prognozu proračuna pomeranja i deformacija stenske mase oko izgrađenog objekta. U ovom slučaju nismo primenili inženjersku analogiju sa drugim rudnicima, nego smo definisali zaštitni stub na bazi osnovnih fizičko-mehaničkih svojstava krovinskih naslaga.

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DEFINING THE SAFETY PILLAR OF ROAD TUNNEL ABOVE THE EXPLOITATION FIELD OF MINE WITH UNSTUDIED SUBSIDENCE PROCESS**

Abstract

This work defines a protective safety belt around the tunnel and excavation limit below the tunnel. Based on these parameters, the limit impact angles are defined, and therefore the geometry of safety pillar.

Keywords: *ground surface movement, subsidence trough, vertical subsidence, horizontal specific strain, tangent slope on subsidence curve*

INTRODUCTION

Mineral deposits, located outside of urban areas, are rare or which are not intersected by large watercourses or the road and rail junctions. But, in the distant past, there is a need to forecast the impact of underground mining on ground surface and objects on it and in a rock massif.

In the second half of the nineteenth century, the first works appeared on mechanism of movement the overlying strata and ground surface as the result of underground mining of mineral resources which caused great damages to the constructed facilities.

Underground mining of a certain deposit and liquidation of empty space the overlying strata caving, result into a collapse and substantial movement of overlying sediments, which consequently causes the movement of ground surface. Vertical components of displacement, called W subsidence of ground surface, affect the slope of subsidence troughs and its curvature, whose expression has an impact on the stability of surface structures and constructed structures in the rock massif in terms of construction statics. Horizontal components of movement are called hori-

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zontal movement and have direct impact on change in the stress-strain state in a construction structure, and thus to the stability and functionality of the structure.

Forecasting the impact of underground mining on surface or on structures, situated on the ground surface or built into the rock massif (tunnels), comes to arrangement of individual components of movement in a function of distance from the border of exploitation.

W = f(x), vertical subsidence

u = f(x), horizontal movement

1. GENERAL CHARACTERISTICS OF EFFECTS THE UNDERGROUND MINING ON GROUND SURFACE WITH UNSTUDIED MOVEMENT PROCESS

Under mines with unstudied process of movement are the mines which did not have long-term geodetic monitoring of ground surface movement, and thus the basic geometric characteristics of moving process are not known. To protect the vital structures on the surface and in the rock massif from negative impact of underground mining and to reduce its impact impact to the permitted extent, the safety supporting pillars are left in the mineral deposit. Safety pillar presents a part of mineral deposit that is not mined, geometrically is defined determine under the structure that is protected, Figure 1. The pillar geometry is constructed using the boundary impact angles ψ, with value which depends on physical-mechanical and deformation properties of roof overlying strata and allowed deformations in the structure that has to be protected.

- horizontal strain ε_x [mm/m]
- tangent on the subsidence curve T [mm/m]
- curvature of subsidence curve K [km]

The question arises what type of strain should be adopted as a general criterion for determining the angles of safety supporting pillar. Depending on the type of strains and their conditioning, there are structures that are sensitive in terms of damage to a specific type strain, while the other types of strains, in this sense, are secondary in importance. Buildings and similar built structures are the most sensitive to horizontal strains of foundations, causing tensile stresses in the structures, and therefore cracking. High structures, chimneys and towers are sensitive to a change of tangent inclination. Railways, highways, pipelines, chimneys and towers are sensitive to a change of subsidence curve. All structures on the ground surface according to the criteria of deformation are categorized into six groups, Table 1.

Table 1.

Category of structure	Damages	Allowed values of deformability		
		ε_x [mm/m]	T [mm/m]	R [km]
0	Monumental buildings, main pipelines, water reservoirs and railways for speeds of 200 [km / h] - without visible cracks	< 0.5	< 2	> 20
I	Buildings, regional gas pipelines, water reservoirs, etc. - minor damages, small cracks in the walls	0.5 – 2.5	2 – 3	15 – 20
II	Hoisting shafts, railways, bridges, water supply systems, multi-story buildings length of 20 lengths [m] - damages are easily removed with regular maintenance	2.5 – 5.0	5 – 10	8 – 12

III	Highways, buildings with special foundation works, water flows - heavy damages, the structures do not lose functionality with regular maintenance	5 – 8	10 – 15	5 – 8
IV	Regional roads, buildings length below 20 [m] - damages are large and the structures require larger reconstruction	8 – 12	15 – 20	3 – 5
V	Ground floor buildings, smaller rivers, side railways - damages are such that some structures lose their functionality and require demolition	12 – 15	20	5

2. CALCULATION AND CONSTRUCTION THE SAFETY SUPPORTING PILLAR OF ROAD TUNNEL

The tunnel, which is part of the highway, passes over exploitation coal bearing field. Diameter of the tunnel is 20 [m] and it lies 50 [m] below ground surface and 900 [m] above the roof of coal seam 6 [m]. The coal seam is at angle $\alpha = 15°$, Figure 1.

Overlying deposits are built of marls 98.4 [%] and subsurface clay 1.6 [%].

The basic physical-mechanical parameters are shown in Table 2.

Table 2.

Lithological member	Bulk density γ [kN/m^3]	Strength coefficient f	Resistance to strain σ_z [kN/m^2]
marl	23.38	4.81	3500

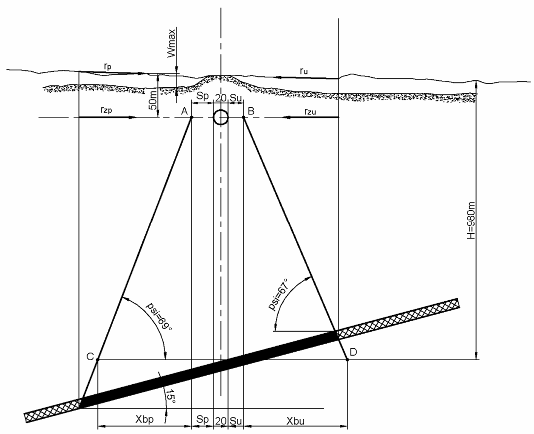

Fig. 1. *Geometry of safety supporting pillar below the traffic tunnel*

In the rock massif around tunnel, the safety belt S is left. Depending on importance of structure and protection category, its value is shown in Table 3.

Table 3.

Protection category	0	I	II	III	IV	V
Safety zone	25	20	15	10	5	5

For the slope of seams α < 10°, the size of protective band S is calculated as follows:

$$S = 0{,}16\sqrt{\frac{HR_z}{\gamma_{sr}}}\ \text{[m]}$$

where:

- S [m], width of protective band around structure
- H [m], depth
- R_z [kN/m^2], average value to tension of roof rocks
- γ_z [kN/m^3], average value of bulk density of roof rocks

For the seam of slope 10 ≤ α < 90°, width of protective band is determined as follows:

- in a direction of seam fall, Figure 1

$$S_p = S \cdot \sqrt{cos\,\alpha} = 25 \cdot \sqrt{cos\,15} = \\ = 24{,}57[m] = 25{,}0[m]$$

- in a direction of seam rise

$$S_u = S \cdot \frac{1}{\sqrt{cos\,15^o}} = 25 \cdot \frac{1}{\sqrt{cos\,15^o}} = \\ = 25{,}4\,[m] = 26{,}0\,[m]$$

Forecasting maximum subsidence of the ground surface is:

$$W_{max} = m \cdot q_u \cdot i\,[m]$$

- m = 6.0 [m], thickness of coal seam
- q_u, subsidence coefficient of the roof sediments. For the mining method with roof falling, is determined as follows:

$$q_u = 0{,}9 - 0{,}03 \cdot f = 0{,}9 \cdot 0{,}03 \cdot 4{,}81 = 0{,}76$$

- i = 0.9, exploitation losses

$$W_{max} = 6 \cdot 0{,}76 \cdot 0{,}9 = 4{,}10\,[m]$$

2.1. Determining the limit of mining the coal seam under the tunnel for 10 ≤ α <90 °

- in a direction of seam fall

$$x_{bp} = \sqrt{\frac{k \cdot H \cdot \sigma_z \cdot cos\,\alpha}{2\gamma_{sr}}} =$$

$$= \sqrt{\frac{1{,}5 \cdot 980 \cdot 3500 \cdot cos\,15^o}{2 \cdot 23{,}38}}$$

k = 1,5 za H < 1000 [m]

x_{bp} = 326 [m]

- in a direction of seam rise

$$x_{bu} = \sqrt{\frac{k \cdot H \cdot \sigma_z}{2\gamma_{sr} \cdot cos\,\alpha}} = \\ = \sqrt{\frac{1{,}5 \cdot 870 \cdot 3500}{2 \cdot 23{,}38 \cdot cos\,15^o}}$$

x_{bu} = 318 [m] ≈ 320 [m]

Protective bend at the level of coal seam under the tunnel for 10 ≤ α < 90°

- in a direction of seam fall

$$x_{bsp} = x_{bp} + S_p = 326{,}0 + 25{,}0 = 351{,}0\ [m]$$

- in a direction of seam rise

$$x_{bsu} = x_{bu} + S_u = 320{,}0 + 26{,}0 = 346{,}0\ [m]$$

By connecting the points AC and BD, the angle of slope the safety pillar is obtained to the direction of seam fall and rise, and it can be calculated as tg of height angle and horizontal distance from protective band at the level of coal seam roof.

- in a direction of seam fall

$$tg\psi_p = \frac{850}{326} = 69^o$$

- in a direction of seam rise

$$tg\psi_u = \frac{750}{318} = 67^o$$

2.2. Checking the rock mass deformation around the traffic tunnel

Radius of range the underground mining impact on the ground surface is a function of maximum subsidence of the ground surface.

$$f_{(x)} = \frac{W_{max}}{r} \cdot e^{-\frac{\pi x^2}{r^2}}$$

Radius r is calculated from the border of completed exploitation, whose impact is theoretically infinite, but practically is limited to the allowable deformation.

Radius of range the key impacts of underground mining on the ground surface is:

- in a direction of seam fall

$$r_p = \frac{H}{tg\psi} = \frac{1110}{tg69^o} = 425{,}3[m]$$

- in a direction of seam rise

$$r_u = \frac{H}{tg67^o} = \frac{980}{tg67^o} = 415{,}3[m]$$

The effects of underground mining on the structure state within the rock mass can be defined in a manner similar to that which determines the impact on the ground surface. In this case, instead of radius range r of major impacts on the surface, the radius of exploitation effects is determined within the rock mass r_z. In this case, r_z for traffic tunnel is:

$$r_z = r\left(\frac{z}{H}\right)^n$$

- z [m], vertical distance of the coal seam roof to the tunnel axis
- H [m], mining depth

$$n = \sqrt{2} \cdot \pi \cdot tg\psi$$

$$n_p = \sqrt{2} \cdot \pi \cdot tg69^o = 11{,}59$$

$$n_u = \sqrt{2} \cdot \pi \cdot tg67^o = 10{,}43$$

- in a direction of seam fall

$$r_{zp} = r_p\left(\frac{z}{H}\right)^{11{,}59} =$$

$$= 425{,}3 \cdot \left(\frac{980}{1110}\right)^{11{,}59} = 100{,}0[m]$$

- in a direction of seam rise

$$r_{zu} = r_u\left(\frac{z}{H}\right)^{10{,}43} =$$

$$= 415{,}3 \cdot \left(\frac{780}{870}\right)^{10{,}43} = 133{,}0[m]$$

Deformations of the rock mass around the tunnel are calculated as follows:

- Specific horizontal deformation

$$\varepsilon_x = \frac{\sqrt{2\pi} \cdot W_{max}}{r_z^2} \cdot x \cdot e^{-\frac{\pi x^2}{r_z^2}} \left[\frac{mm}{m}\right]$$

- Tangent to the subsidence curve

$$T = \frac{W_{max}}{r_z} \cdot e^{-\frac{\pi x^2}{r_z^2}} \left[\frac{mm}{m}\right]$$

- Curvature of the subsidence curve

$$K = \frac{2\pi \cdot W_{max}}{r_z^2} \cdot x \cdot e^{-\frac{\pi x^2}{r_z^2}} \left[\frac{m}{m}\right]$$

- Radius of curvature

$$R = \frac{1}{K}$$

The obtained deformation values are present in Tables 4 and 5.

Table 4. *Deformations at the tunnel level in a direction of seam fall*

Distance from mining limit [m]	Maximum subsidence W_{max} [m]	Specific horizontal deformation ε_{xp} [mm/m]	Tangent to subsidence curve T_p [mm/m]	Curvatures of subsidence curve K [m/m]	Radius of curvature $R = \frac{1}{K}$ [km]
100.0	4.10	$1.11 \cdot 10^{-2}$	$1.77 \cdot 10^{-3}$	$1.114 \cdot 10^{-4}$	8973
200.0		$1.81 \cdot 10^{-6}$	$1.44 \cdot 10^{-7}$	$9.036 \cdot 10^{-11}$	$1.1 \cdot 10^{10}$
326.0 Protective band limit of tunnel		$2.70 \cdot 10^{-15}$ Practically no effect	$1.32 \cdot 10^{-16}$	$8.29 \cdot 10^{-20}$	$1.2 \cdot 10^{19}$

Table 5. *Deformations at the tunnel level in a direction of seam rise*

Distance from mining limit [m]	Maximum subsidence W_{max} [m]	Specific horizontal deformation ε_{xp} [mm/m]	Tangent to subsidence curve T_p [mm/m]	Curvatures of subsidence curve K [m/m]	Radius of curvature $R = \frac{1}{K}$ [km]
133.0	4.10	$8.38 \cdot 10^{-3}$	$1.33 \cdot 10^{-3}$	$6.3898 \cdot 10^{-5}$	15650
200.0		$1.02 \cdot 10^{-6}$	$1.08 \cdot 10^{-7}$	$7.79 \cdot 10^{-9}$	$128 \cdot 10^{6}$
320.0 Protective band limit of tunnel		$1.50 \cdot 10^{-15}$ Practically no effect	$3.92 \cdot 10^{-11}$	-	-

CONCLUSIONS

The term mine with unstudied process of movement involves the mine in which the basic geometric characteristics of moving process the roof sediments above the excavated space.

In such cases, the basic data are needed for the forecast of movement calculation and deformations of the rock mass around the constructed structure. In this case, the engineering analogy was not used with the other mines, but the safety pillar was defined on the basis of fundamental physical-mechanical properties of the roof sediments.

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PROBLEMI PRI PRIMENI METODE PODETAŽNOG ZARUŠAVANJA U JAMI BOR**

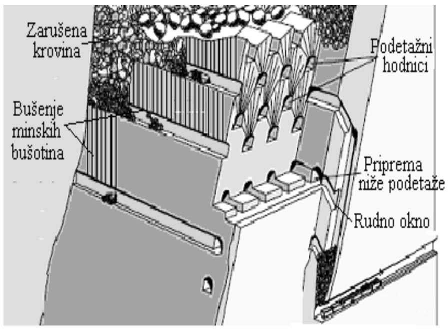
Izvod

Metoda podetažnog zarušavanja, koja se često naziva i «švedskom varijantom», primenjivana je dugi niz godina u borskoj jami u nekoliko rudnih tela. Vremenom, menjani su osnovni parametri metode otkopavanja, primenjena oprema, menjali su se i uslovi otkopavanja, ali su rezultati primene često bili uslovljeni neadekvatnom primenom projektovanih rešenja. Zbog toga su se ispoljavali neki nedostatci svojstveni ovoj metodi otkopavanja, koji su dovodili do pogoršanja njenih osnovnih pokazatelja, o čemu se govori u ovom radu.

Ključne reči: *Metoda podetažnog zarušavanja, problemi primene, ostvareni rezultati.*

UVOD

Razvoj metode podetažnog zarušavanja u najvećoj meri je posledica odgovarajućeg razvoja rudarske opreme, pre svega mašina za bušenje i miniranje i mašina za utovar i transport rude. Kada se hronološki sagledava razvoj ovih mašina, naročito u drugoj polovini prošlog veka, jasno se uočava velika zavisnost ovih okolnosti. Poznati svetski proizvodjači rudarske opreme permanentno su usavršavali, pre svega mašine za bušenje, namenjene primeni metoda podetažnog zarušavanja, u okviru toga prevashodno za varijantu ove metode koja se naziva «švedskom varijantom (slika 1, [1])



Sl. 1. *Švedska varijanta podetažnog zarušavanja sa romboidalnim oblikom rudnog bloka u kome se ruda obara dubokim minskim bušotina sa specifičnim rasporedom*

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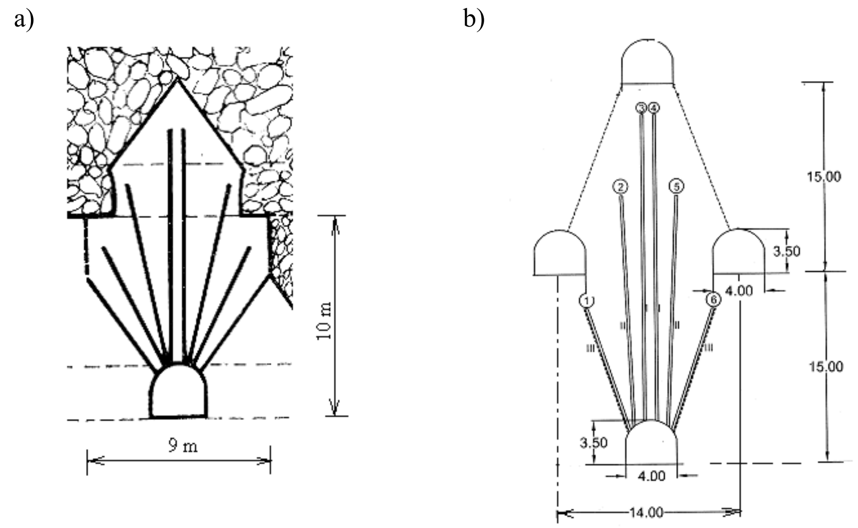
U borskoj jami metoda podetažnog zarušavanja je primenjivana u toku cele druge polovine prošlog veka i to prvo u rudnom telu «Kamenjar» iznad IX horizonta, delom i ispod njega, a kasnije i u rudnim telima «Tilva Roš» i «P_2A». U poslednja dva rudna tela podetažno otkopavanje sa zarušavanjem rude primenjivano je nakon prestanka otkopavanja na površinskom kopu.

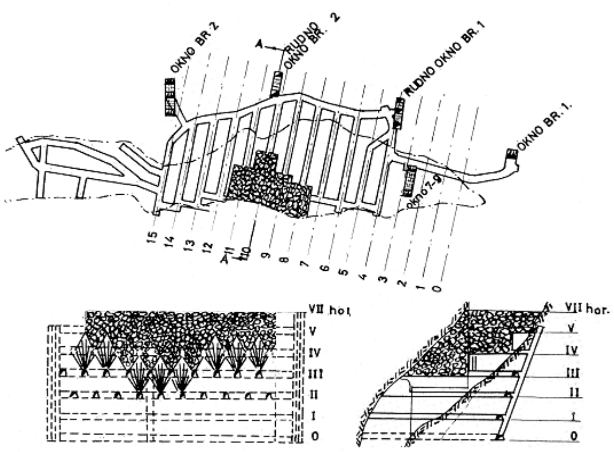
U toku primene ove metode otkopavanja postupno su menjani parametri metode u smislu povećanja visine podetaža i rastojanja izmedju podetažnih hodnika. Na početku primene ove metode otkopavanja visina izmedju podetaža bila je 9 m, a rastojanje izmedju podetažnih hodnika 10 m. Minske bušotine u «lepezi» bušene su sa rasporedom prikazanom na slici 2a. Početkom sedamdesetih godina prošlog veka, sa očekivanjem prestanka rada na površinskom kopu, projektovana je metoda sa visinom podetaža od 12 m, da bi kasnije u projektima po kojima je vršeno otkopavanje, visina podetaža usvojena na 15 m, a rastojanje izmedju podetažnih hodnika 14 m, (slika 2b).



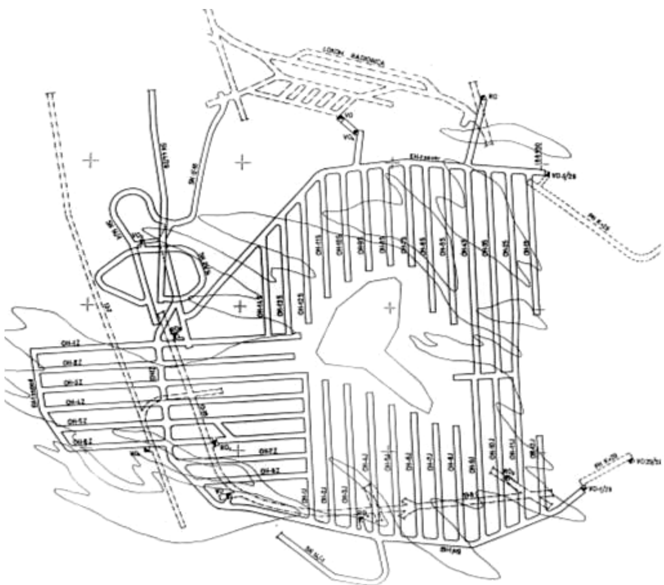
Sl. 2. *Parametri metode otkopavanja:*
a) u rudnom telu «Kamenjar» na početku primene metode;
b) u rudnom telu «Tilva Roš» u kasnijem periodu

Način pripreme u rudnom telu «Kamenjar» iznad nivoa IX horizonta bio je klasičan, a prikazan je na slici 3, [2]. Primenjena je šema sa izradom osnovnih podetažnih hodnika u podinskom boku rudnog tela, a otkopni podetažni hodnici su radjeni popreko na rudno telo. Pri otkopavanju dela rudnog tela ispod IX horizonta, zbog neodgovarajućeg nagiba rudnog tela, osnovni podetažni hodnici su radjeni u krovini.

Nasuprot tome, metoda podetažnog zarušavanja primenjena je u rudnim telima «Tilva Roš» i «P_2A» u specifičnoj situaciji, tj. u preostalim delovima rudnih tela, koja su većim delom otkopana površinskim kopom. To je i razlog što je ovaj način otkopavanja primenjen tek posle prekida otkopavanja na površinskom kopu. Ovo se, pre svega, odnosi na rudno telo «Tilva Roš». Priprema rudnog tela je specifična po tome što su posebno pripremani preostali delovi rudnog tela ispod kosina površinskog kopa, (slika 4), [5]. Otkopavanje je započeto iznad nivoa XI horizonta, tačnije na podetaži na K+59 m. Najveći deo rudnog tela je otkopan izmedju XI i XIII horizonta, a pri otkopavanju dela ležišta ispod XIII horizonta, došlo je do prodora vode i mulja iz akumulacije na dnu kopa, pa je dalje otkopavanje obustavljeno. Pri tome, ispd nivoa podetaže na K -31 m ostalo je još dosta rude, koja bi mogla da se otkopava u slučaju da se to obavlja na tačno predvidjen način , koji će obezbediti potrebnu sigurnost rada u rudnom telu. Pri tome ne treba apriori odbaciti mogućnost da se pojedini delovi rudnog tela otkopavaju i nekom dugom metodom otkopavanja.



Sl. 3. *Metoda podetažnog zarušavanja primenjena u rudnom telu «Kamenjar» iznad IX horizonta u borskoj jami*



Sl. 4. *Projektovan raspored podetažnih hodnika u rudnom telu «Tilva Roš» iznad XIII horizonta*

PROBLEMI PRI PRIMENI METODE PODETAŽNOG ZARUŠAVANJA

Metoda podetažnog zarušavanja, a pre svega njena «švedska varijanta», spada u grupu savremenih visokoproizvodnih i visokoproduktivnih metoda otkopavanja, pre svega zbog mogućnosti primene savremene rudarske opreme za bušenje minskih bušotina, miniranje, utovar i prevoz rude do rudnih okana. Medjutim, ova metoda zahteva veoma striktnu primenu projektovanih rešenja, pod uslovom da su ona data kao optimalna. Najznačajniji pokazatelji metode, osim proizvodnosti i produktivnosti, su nesumnjivo iskorišćenje i osiromašenje rude, koji bitno utiču na ukupnu ekonomičnost primene metode otkopavanja.

U praksi se, nažalost, javljaju brojni problemi koji dovode do povećanja gubitaka rude pri istovremenom povećanju i njenog osiromašenja. Najbolji rezultati otkopavanja mogu se postići pri odredjivanju optimalnog odnosa gubitaka i osiromašenja rude, na koji najveći uticaj ima vrednost otkopavane rude, a zatim i efikasnost otkopavanja koja se manifestuje kroz ukupan iznos troškova otkopavanja.

Neki od najčešće uočavanih problema pri primeni metode podetažnog zarušavanja, konkretno njene «švedske varijante», su:

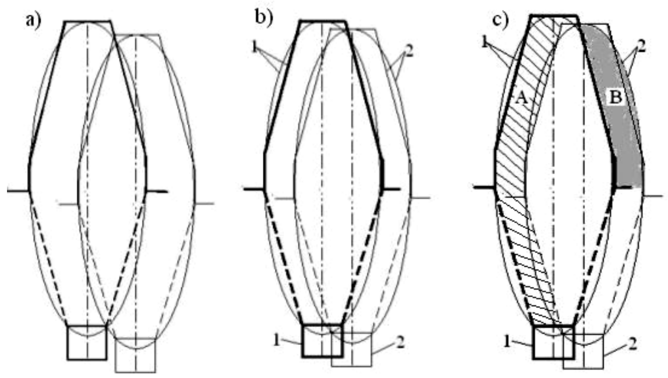
- eregularna izrada podetažnih hodnika koja nije u skladu sa njihovim projektovanim položajem,
- nepravilno odredjena širina pojasa miniranja rude,
- loš raspored minskih bušotina usled čega se ruda neravnomerno usitnjava pri miniranju,
- nepravilno miniranje koje dovodi pre prevelikog sabijanja rude, kada dolazi do otežanog njenog istakanja pri utovaru,
- neregularno istakanje rude u procesu utovara zbog neodgovarajuće utovarne ili utovarno-transportne mašine, zbog neravnomernog zahvatanja rude, uticaja negabaritnih komada i sl.,
- oštećenje krova podetažnog hodnika, koje dovodi do poremećaja procesa istakanja i smanjenja iskorišćenja rude, itd.

Očigledno je da je moguć broj problema pri primeni metode podetažnog zarušavanja vrlo veliki, što čini ovu metodu vrlo osetljivom na bilo kakva odstupanja od projektovanih rešenja, pod uslovom da su i ona usvojena kao optimalna. Poznato je da je ovo metoda koja je u najvećoj meri istraživana i u laboratorijskim uslovima, pri čemu se mora imati u vidu da se, zbog nemogućnosti simuliranja prirodnih uslova u ležištu, rezultati dobijeni laboratorijskim istraživanjima na fizičkim modelima moraju korigovati za primenu pri projektovanju i konkretnoj primeni i prirodnim uslovima ležišta. Za pravilno sprovodjenje ovog procesa neophodno je da se odgovarajuća istraživanja vrše i u konkretnim uslovima otkopavanja rudnih tela.

Što se tiče primene ove metode otkopavanja u navedenim rudnim telima u borskoj jami, kao najčešći problemi se ističu smanjeno iskorišćenje rude i njeno veće osiromašenje. Šta više i u tehničkoj dokumentaciji se neki od navedenih pokazatelja usvajaju nekritički bez osnovanih obrazloženja. Tako se, na primer, često bez jače argumentacije usvajaju podaci o osiromašenju rude u granicama 10 – 15 % što se može smatrati potpuno neopravdanim s obzirom na njen ekonomski uticaj na ukupne troškove dobijanja i prerade rude. Pored toga, u praksi se ne primenjuju nikakve mere za praćenje sadržaja metala u dobijenoj rudi, što ne daje mogućnost tačnog odredjivanja momenta prestanka istakanja minirane rude.

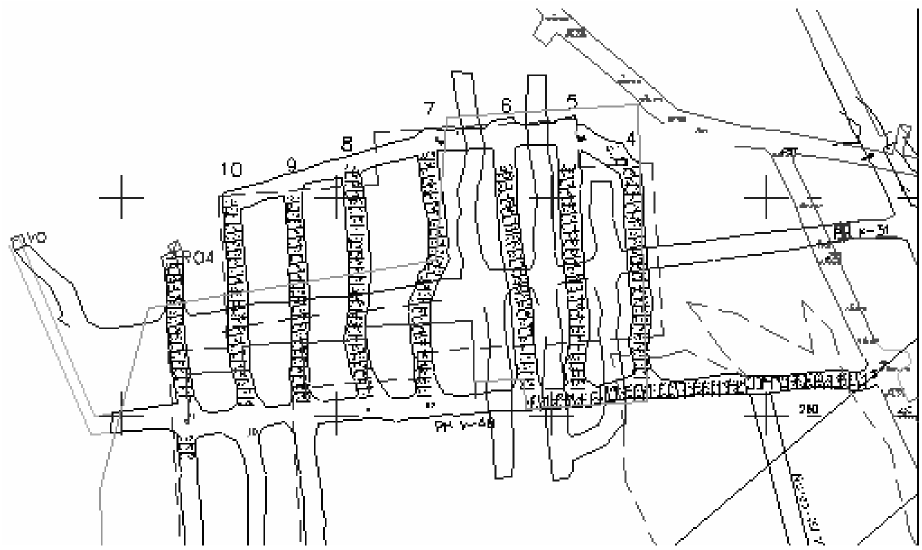
Nadalje se daje kratak osvrt na najznačajnije probleme, koji su napred navedeni, a utiču na konačan rezultat primene metode, pre svega na veličinu iskorišćenja i osiromašenja rude.

1. Raspored podetažnih hodnika. Metoda podetažnog zarušavanja, konkretno njena «švedska varijanta» zahteva vrlo preciznu izradu otkopnih podetažnih hodnika, koji se obično izradjuju iz osnovnih (smernih) podetažnih hodnika i to popreko na pružanje rudnog tela. To je neophodno zbog toga što je geometrijom metode otkopavanja predvidjeno formiranje romboidalnih rudnih blokova, čiji oblik u poprečnom preseku najviše odgovara obliku elipsoida točenja rude, na bazi kojih je i svojevremeno predložena konstrukcija ove metode, (vidi slike 1; 2 i 3). Ukoliko, pri pripremi niže podetaže, dodje do odstupanja položaja podetažnog hodnika od projektovane lokacije, blok rude koji se otkopava neće svojim oblikom odgovarati onom koji je neophodan za pravilnu primenu metode. Budući da se minske bušotine buše po tačno utvrdjenom rasporedu, deo rudnog bloka neće biti bušen, (na slici 5-c označena šrafirana površina «A»), a na suprotnoj strani doći će do prodora minskih bušotina u obrušene stene na gornjoj podetaži, (površina «B» koja je u prostoru ispunjenim zarušenim stenama).



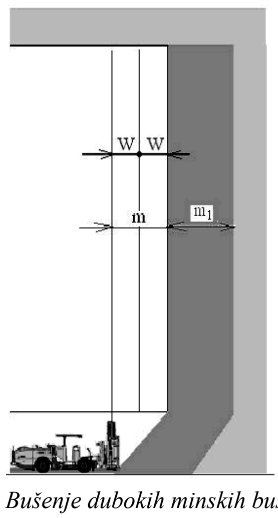
Sl. 5. *Prikaz položaja podetažnih hodnika pri njihovoj nepreciznoj izradi:*
a) pri većem odstupanju podetažnog hodnika od njegovog projektovanog položaja kada je odstupanje veće od širine hodnika;
b) pri odstupanju manjem od širine hodnika javlja se, takodje, veliko nepodudaranje kontura elipsoida točenja;
c) kao posledica pomeranja podetažnog hodnika površina «A» neće biti minirana, a površina «B» predstavlja deo jalovine koja se istače iz miniranog pojasa rude;
1- projektovane konture bloka i elipsoida točenja,
2- konture koje se odnose na slučaj nepravilne izrade podetažnog hodnika

Očigledno je da se ni bušenje minskih bušotina, samim tim i miniranje ne mogu izvesti na potreban način, što će u kasnijem procesu istakanja minirane rude dovesti do drastičnog pogoršanja rezultata primene metode, odnosno do značajnog smanjenja iskorišćenja rude uz verovatno njeno veliko osiromašenje. Da ove konstatacije nisu samo primer teoretskog razmatranja, na slici 6 prikazan je raspored podetažnih hodnika u jednom delu rudnog tela «Tilva Roš» na podetaži na K.-46 m. Ispitivanja izvedena od strane stručnjaka Instituta za bakar u Boru, pokazala su da se ova situacija često sreće u rudnim telima otkopavanim metodom podetažnog zarušavanja. Sa slike se jasno vidi da hodnici nisu ni medjusobno pravilno rasporedjeni, niti se izradjuju precizno po pravcu, što dovodi do odstupanja od projektovanog oblika rudnih blokova i svih problema o kojima je govoreno. Situacija prikazana na detaljima slike 5 ima tako velike posledice da onaj ko nije u stanju da precizno izradjuje podetažne hodnike ne treba da primenjuje metodu podetažnog zarušavanja!



Sl. 6. *Deo situacije podetažnih hodnika na K-46 m u rudnom telu «Tilva Roš»*

2. Širina pojasa miniranja i pojasa minirane rude. Minirana ruda se istače iz pojasa minirane rude «m_1», koji se dobija miniranjem pojasa rude «m», (v. sl. 7). Raspored minskih bušotina u potpunosti odgovara romboidalnom obliku bloka rude koji se otkopava, a u zavisnosti od mehaničkih i strukturnih karakteristika rude, kao i veličine bloka, miniranje se može izvoditi sa jednim ili dva reda minskih bušotina. U jednom redu («lepezi») se obično buše 6 – 8 minskih bušotina, što takodje zavisi od navedenih karakteristika.



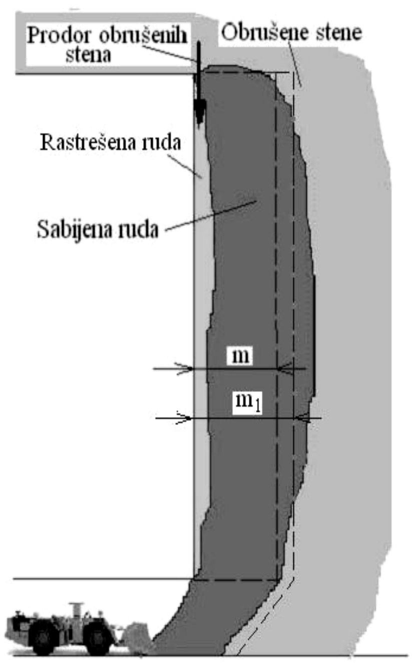
Sl. 7. *Bušenje dubokih minskih bušotina*

Istakanje minirane rude iz pojasa širine «m_l» zavisi od kvaliteta miniranja i karakteristika rude. Pojas minirane rude «m_l» ima nešto veću širinu od pojasa miniranja «m», i to za veličinu rastrešenja rude, tj. $m_l = K_r \cdot m$, gde je K_r – koeficijent rastrešenja rude. Budući da se miniranje kod razmatrane metode obavlja u «stešnjenoj sredini», koeficijent rastrešenja se kreće u granicama K_r = 1,2 – 1,3, izuzetno i manje. U slučaju kada su uslovi otkopavanja normalni, širina pojasa minirane rude «m_l» treba da odgovara širini elipsoida točenja, koja zavisi od karakteristika rude i njenih «sipućih svojstava», kao i od sabijenosti rude pri miniranju.

Širina pojasa minirane rude se uspešno odredjuje modelskim ispitivanjima u laboratorijskim uslovima, medjutim, za praktične uslove potrebno je tu širinu korigovati srazmerno uticaju navedenih faktora koji utiču na uslove istakanja rude. Širina elipsoida, kao i veličina njegovog ekscentriciteta treba da odgovara širini pojasa minirane rude, odnosno treba da bude tolika da samo manjim delom elipsoid točenja zahvata i jalovinu sa čeonog kontakta izmedju minirane rude i obrušenih stena (v. sl. 8 i 9).

Budući da uspeh istakanja rude zavisi i od granulacije minirane rude i eventualne pojave krupnijih negabaritnih komada, veoma je važno odrediti potreban broj minskih bušotina u jednoj «lepezi» :Zbog toga nije sve jedno da li se u «lepezi» buše 6 ili 8 minskih bušotina. Isto tako, pojas rude koja se minira, može se minirati sa jednom ili dvema «lepezama» minskih bušotina, što je, takodje, od izuzetnog značaja. U borskoj jami se miniranje rude obavlja jednom «lepezom» sa 6 minskih bušotina u njoj, što verovatno ne odgovara uslovima i karakteristikama rude u svakom delu rudnog tela.

3. Uticaj prevelikog sabijanja rude pri miniranju. Na slici 8 prikazana je situacija, kada se, zbog većeg sabijanja rude pri miniranju, stvaraju vrlo nepovoljni uslovi za istakanje minirane rude, zbog čega iskorišćenje rude može biti vrlo nisko i da se i kao takvo postigne sa visokim osiromašenjem rude.



Sl. 8. *Istakanje sabijene rude*

Do prevelikog sabijanja rude dolazi u slučaju kada se miniranje rude obavlja trenutno sa većom količinom eksploziva od potrebne. Posebno i kada se miniranje obavlja sa jednim redom minskih bušotina. Tome pogoduje i veća rastrešenost obrušenih stena, koje su ispunile prostor prethodnog pojasa minirane rude iz koga je ruda u potpunosti istočena.

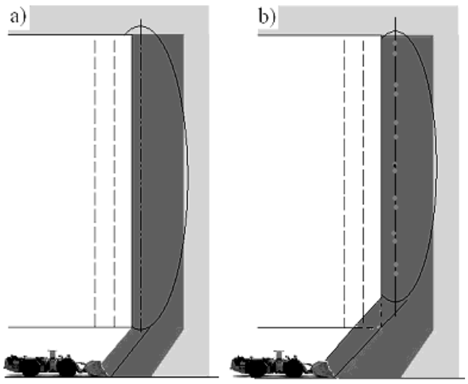
Kao što je navedeno, miniranje se kod metode podetažnog zarušavanja izvodi u uslovima stešnjene sredine, a rastresanje rude se obezbedjuje na račun sabijanja rastrešenih stena u prostoru prethodno istočenog pojasa minirane rude.

Energijom eksploziva se ruda snažno potiskuje napred, dolazi do sabijanja stena na vertikalnom kontaktu izmedju rude i obrušenih stena, a minirana ruda se potiskuje za odredjenu širinu, koja je uslovljena količinom eksploziva i svojstvom sabijanja stena. To pokretanje minirane rude može biti i više desetina santimetara, tako da se u ravni miniranig minskih bušotina stvara prazan prostor, koji se potom ispunjava komadima rude koja se obrušava.

Ukoliko dodje do prevelikog sabijanja rude, o čemu se ovde govori, ona ostaje tako sabijena sa samo delimičnim ispunjavanjem praznog prostora do masiva rude. Zbog toga se, odmah po početku utovara minirane rude odmah i relativno lako istače rastresita ruda iz tog prostora, u koji vrlo brzi počinje da propada jalovina sa gornjeg i bočnog kontakta izmedju minirane rude i obrušenih stena. U praksi se dešavaju slučajevi da se već posle istakanja 20 – 30 % minirane rude pojavi jalovina u podetažnom hodniku, i da se dalje istakanje vrši sa sve većim prisustvom jalovine (i osiromašenjem rude), pa se istakanje prekida pri izuzetno malom iskorišćenju rude. Nije potrebno posebno naglašavati koliko je izuzetno važno da se izbegne nepovoljno sabijanje rude, a to se može postići: smanjenjem količine eksploziva, višerednim miniranjem, miniranjem sa posebnim intervalima usporenja u pojedinim minskim punjenjima, ali i odgovarajućom dinamikom istakanja minirane rude.

4. Oštećenje krova podetažnog hodnika. I ova, bez sumnje, štetna pojava nastaje kao posledica miniranja rude. Raspored minskih bušotina je takav da se u krovu podetažnog hodnika minske bušotine vrlo guste (v. sl. 2), a ukoliko se o tome ne vodi računa, već se minske bušotine pune do kraja, velika koncentracija eksploziva dovešće, pri miniranju, do većeg ili manjeg oštećenja krova podetažnog hodnika. Ukoliko se minske bušotine buše sa većim prethodjenjem može doći do potpunog gubljenja jedne «lepeze» minskih bušotina zbog toga što je donji deo bušotina obrušen, a ispunjen prostor miniranom rudom ne omogućava pristup do «usta» bušotina u cilju njihovog punjenja. Ukoliko se o tome ne vodi računa već se pune bušotine naredne, pristupačne «lepeze» minskih bušotina, izgubljena «lepeza» znači i da se miniranje narednim redom bušotina obavlja u uslovima dvostruko veće moćnosti rude koja se minira. Miniranje će biti neuspešno, doći će do pojave nepovoljne granulacije minirane rude, a iz dobijenog pojasa minirane rude, koji je dvostruko veće širine neće doći do istakanja celokupne minirane rude, pa će iskorišćenje rude biti nisko.

Na slici 9 prikazana je situacija sa bitno izmenjenim uslovima istakanja minirane rude čak i ako se regularno miniraju naredne «lepeze» minskih bušotina. Oštećenje krova podetažnog hodnika uslovilo je pomeranje unapred kosine minirane rude u hodniku, samim ti i pomeranje «ispusnog otvora» kroz koji se ruda istače. Ruda se istače kroz relativno uzan prostor ograničen površinom oštećenog krova hodnika i kosinom koja se formira zavisno od dubine uranjanja kašike utovarne mašine u kosinu rude. U tom prostoru mnogo lakše dolazi do zaglava negabaritnih komada, njihovo se pokretanja može postići potkopavanjem kosine rude, što može usloviti iznenadno pokretanje rude i ugrožavanje sigurnosti i mašine i njenog rukovalaca.



Sl. 9. *Promena uslova istakanja rude usled oštećenja krova podetažnog hodnika*

Sa slike se očigledno vidi i da je elipsoid točenja znatno manje visine, time i zapremine, odnosno istakanje rude pri pojavi oštećenja krova podetažnog hodnika odvija se u uslovima istakanja iz pojasa manje širine od normalne. Očigledno je, takodje, da se znatno veća količina rude gubi u donjem delu pojasa minirane rude, što sve doprinosi bitnom pogoršanju rezultata istakanja minirane rude.

Spečavanje pojave ovog nepovoljnog uticaja postiže se, pre svega, pažljivijim izvodjenjem procesa punjenja minskih bušotina eksplozivom, tako da se sve bušotine ne pune do kraja, a po potrebi i primenom mera za sprečavanje oštećenja krova podetažnog hodnika.

Napred su pomenuti još neki uticajni faktori, osim onih koji u ovde detaljnije obrazloženi. Osim faktora vezanih za konstrukciju metode otkopavanja, tu su i uticaji neodgovarajućih tehničkih rešenja, koja se prevashodno odnose na primenu neadekvatnih parametara bušenja i miniranja, ali i neodgovarajućih uslova istakanja rude. Odnosi se to na nepravilan raspored minskih bušotina i njihov nedovoljan broj, kada se postiže loše usitnjavanje rude, miniranje sa neodgovarajućom širinom pojasa, dobijanje većeg broja negabaritnih komada koji remete gravitacioni tok rude pri istakanju i dr. S druge strane proces istakanja minirane rude u velikoj meri zavisi od karakteristika utovarne ili utovarno-transportne mašine od širine utovarnog organa, a posebno i od moguće dubine uranjanja utovarnog organa mašine u kosinu minirane rude u podetažnom hodniku. S obzirom i na ove uticajne faktore treba pravilno odrediti širinu pojasa miniranja odnosno i širinu pojasa minirane rude.

ZAKLJUČAK

Metoda podetažnog zarušavanja, a u radu je razmatrana njena «švedska varijanta», predstavlja izuzetno kvalitetnu i savremenu metodu za otkopavanje, posebno siromašnijih rudnih ležišta, budući da, zahvaljujući primeni savremene mehanizacije, omogućava dobijanje rude sa niskim troškovima. Medjutim, primenu ove metode otkopavanja mogu ugroziti brojni problemi koji se javljaju kao subjektivni ili objektivni, a koji u tolikoj meri mogu pogoršati rezultate otkopavanja ležišta da metodu učine neracionalnom. To se, pre svega, manifestuje kroz značajno smanjenje iskorišćenja rude, ali i povećanje njenog osiromašenja, što sve ima negativne ekonomske posledice na ukupnu ekonomičnost eksploatacije ležišta. Zbog toga projektom predvidjena i u praksi primenjena rešenja moraju biti optimalna i da u najvećoj meri umanje mogućnost pojave razmatranih problema. Pri odredjivanju takvih rešenja neophodno je uzimati u obzir i uticaj ekonomskih parametara, pre svega vrednosti rude i mogućih troškova njenog dobijanja.

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PROBLEMS IN THE APPLICATION OF SUBLEVEL CAVING METHOD IN THE UNDERGROUND MINE JAMA BOR**

Abstract

Sublevel caving, i.e. the "Swedish variant", as it is usually called, was applied for a long period of time in several ore bodies of the uunderground mine "Jama" Bor. In time, some parameters of mining method were changed, as well as the equipment and mining conditions. However, the results were not always satisfactory. Designed mining parameters did not match the actual ones in the mine. Therefore, some typical difficulties, related to the sublevel caving method, have frequently occurred. This paper shows some of characteristic problems.
Keywords*: sublevel caving, mining method application, mining results.*

INTRODUCTION

Development of sublevel caving method is strongly related to development, first of all the mining equipment, mainly drilling, blasting, loading and hauling equipment. Leading global producers of mining equipment permanently improved the equipment used for sublevel caving, especially the Swedish variant (Figure 1).

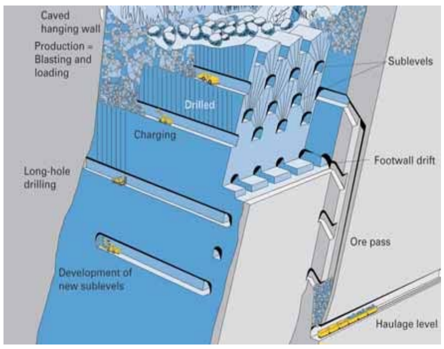

Fig. 1. *Sublevel caving, the Swedish variant*

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In the underground mine Jama Bor, this mining method was applied during the entire second half of last century. It started in the ore body Kamenjar, around Horizon IX, and then continued in the ore bodies Tilva Ros and P_2A. In two former ore bodies, sublevel caving was applied after the end of mining at the open pit situated above them.

During years of application in Jama, the method geometry was changed. Sub level height was increased, as well as spacing between sublevel drifts. At the beginning, sublevel height was 9 m, and spacing between sublevel drifts 10 m.

At first, the ring drill pattern was like it is shown in Figure 2a. Later, the sublevel height increased to 12 m, and finally up to 15 m, with 14 m spacing between sublevel drifts (Figure 2b).

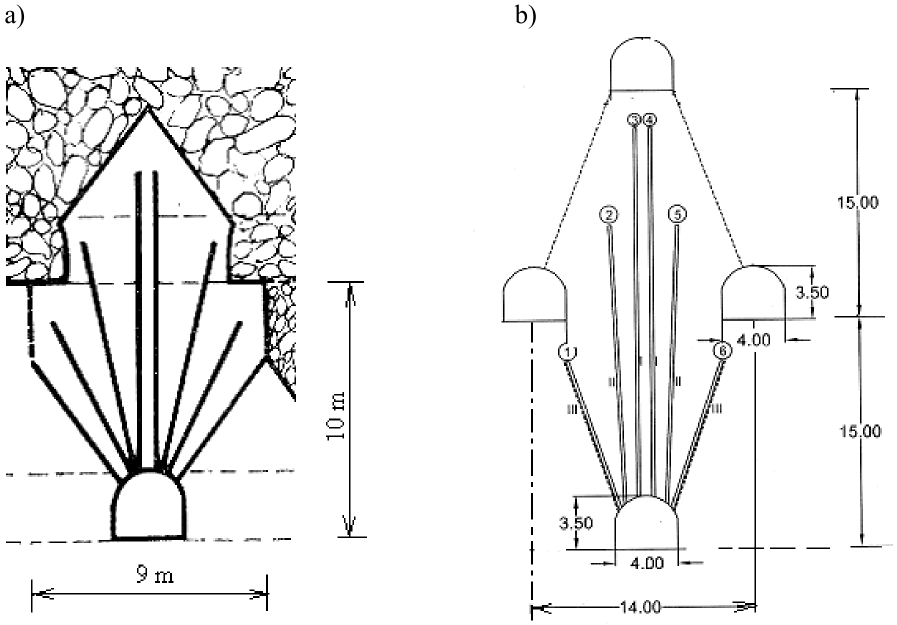

Fig. 2. *Sublevel caving geometry: a) in the ore body Kamenjar at the beginning of method application; b) in the ore body Tilva Ros*

Development of the ore body Kamenjar above Horizon IX was typical (Figure 3) [2]. Basic development pattern includes the main sublevel drifts in footwall and other sublevel drifts across the ore body strike. Bellow Horizon IX, due to the unfavorable ore body inclination, the main sublevel drifts were made in the hanging wall.

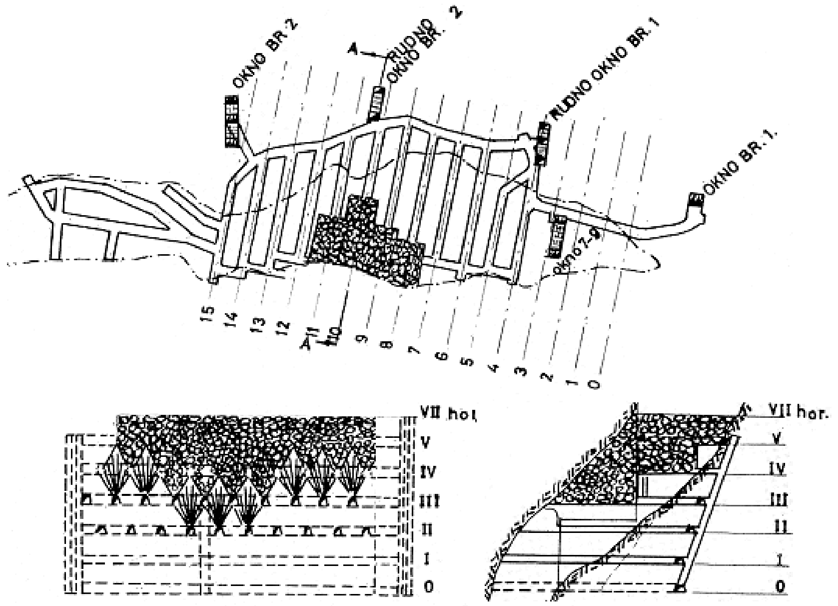

Fig. 3. *Application the sublevel caving in the ore body Kamenjar*

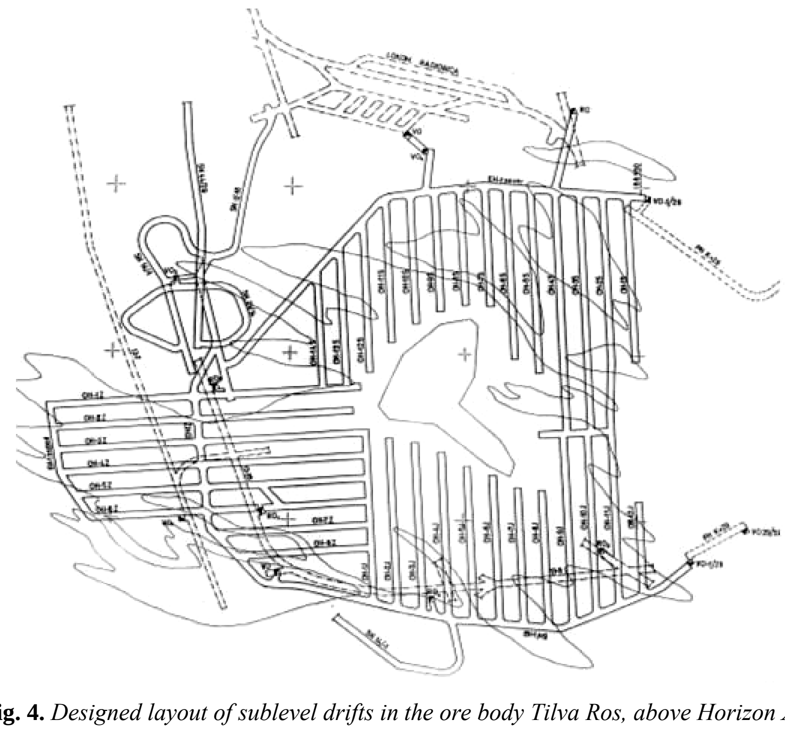

Fig. 4. *Designed layout of sublevel drifts in the ore body Tilva Ros, above Horizon XIII*

Contrary to this, in the ore bodies Tilva Ros and P_2A, development was specific due to the ore body shape. Actually, these are the remaining parts of the ore bodies left after surface mining. Parts of the ore body Tilva Ros, situated bellow the open pit slope, were developed separately (Figure 4) [5]. Excavation started above Horizon IX, at sublevel K+59 m. Most of the ore was excavated between Horizons IX and XIII. Bellow Horizon XIII, the excavation was stopped due to the inflow of mud and water from the bottom of the open pit into the underground stope. During this, the significant ore reserves were left bellow the sublevel K-31 m, and there are considerations of mining renewal. It will be possible only if the strict safety measures are taken in order to prevent the new accidents. Due to the irregular shape of remaining parts of the ore bodies, it is possible that some mining method would be applied.

PROBLEMS IN APPLICATION THE SUBLEVEL CAVING METHOD

Sublevel caving is a high-productive mining method, due to the use of modern high-productive equipment for drilling, blasting, loading and hauling. However, this mining method requires high accuracy in application the designed geometry in the underground stope. The most important mining method parameters are: productivity, ore dilution and ore recovery. Unfortunately, in practice, there are many factors that cause the increased ore dilution, or decreased ore recovery.

Some of the most common problems, occurring in application the sublevel caving method, are the following:

- Deviation of sublevel drifts,
- Incorrect width of blasting zone,
- Deviation of drill holes, causing irregular ore fragmentation after blasting,
- Incorrect blasting pattern, causing compression of blasted ore and difficulties in its drawing,
- Irregular ore drawing, due to the irregular loading from draw points,
- Damaging of sublevel drift roof, causing irregular ore drawing and excessive ore dilution, etc.

It is obvious that there are many possible problems in application of this method, which means that it is very sensitive to deviations from designed parameters. Designed mining method geometry and parameters also have to be very accurate. Sublevel caving has been studied a lot in the laboratory tests, but the obtained results from models in laboratories should be adjusted depending on the conditions in ore deposit. In order to design the method correctly, it is necessary to perform in situ tests, too.

In the underground mine “Jama” Bor, the main problems in application the sublevel caving were related to the ore dilution and ore recovery. Unfortunately, even in the mine designing process, mistakes were made. For instance, in some cases, predicted ore dilution was 10 – 15%, without any argumentation or economic analysis of its influence on the mining costs. Besides, there is no accurate control of ore grades in drawn ore, which means that the ore was drawn too short or too long. More detailed analysis of noticed problems is given bellow.

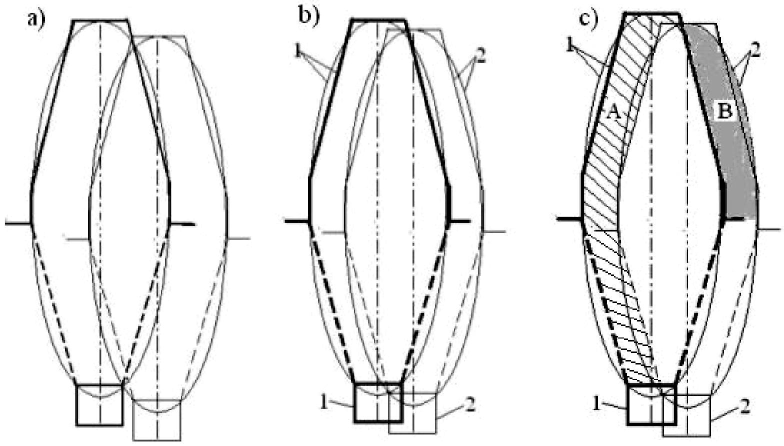

Fig. 5. *Deviation of sublevel drifts and its influence to stope shape: a) in case of larger deviation; b) in case of smaller deviation; c) as a cause of deviation, surface "A" will not be drilled, while drill holes will enter the caved ore in surface "B"; 1 – designed stope; 2 – deviated stope.*

1. Layout of sublevel drifts. Sublevel caving requires very accurate driving of sublevel drifts. They are usually driven from the main sublevel drift, across the ore body strike, towards the hanging wall. The goal is to form a rhomboid stopes, which are closest to match ellipsoid formed by drawn ore (Figures 1, 2 and 3). In case of deviation the sublevel drift and its location differ from designed, the stope will have irregular shape. Since the position of drill holes in ring drill is related to the sublevel drift, it means that a part of stope will not be drilled (surface "A" in Figure 5c), while on the other side, the drill holes will enter the caved ore from upper sublevel (surface "B" in Figure 5c).

It is obvious that in case of deviation, both drilling and blasting cannot be regularly performed, which would cause huge problems in ore drawing, like increase of dilution and decrease of ore recovery. This situation is not only theoretical, it actually happens in the underground mine "Jama" Bor. Figure 6 shows the actual layout of sublevel drifts in a part of the ore body Tilva Ros at sublevel K-46 m. As it can be seen, the sublevel drifts do not match designed parameters regarding their position and direction. As a consequence, stopes are irregular and the all above mentioned problems occur. Furthermore, overall results with such application of mining method are poor. Accurate geometry is a key of sublevel caving, and if it cannot be provided, the method should not be applied at all.

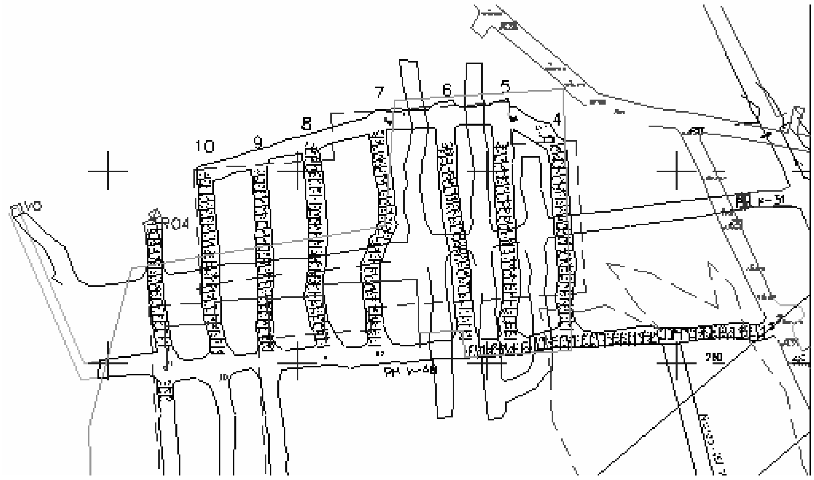

Fig. 6. *Actual layout of sublevel drifts in a part of the ore body Tilva Ros at sublevel K-46 m*

2. Width of blasting zone. Blasted ore is drawn from the zone m_1, formed after blasting of zone m (Figure 7). Depending on mechanical and structural properties of ore, blasting may be performed in a single ring drill or in two of them simultaneously. One ring drill usually contains 6 – 8 drill holes.

Ore drawing depends on quality of blasting and ore properties. Zone m_1 is wider than zone m, due to the increase of ore volume after blasting, i.e. $m_1 = K_r \cdot m$, where K_r is volume increase ratio. For blasting in tight conditions, as it is a case in the sublevel caving, this ratio is K_r = 1.2 – 1.3. Width of zone m_1 should match width of ellipsoid of drawn ore, which depends on ore properties and its drawing characteristics, as well as the level of ore compression due to blasting.

Width of blasting zone can be successfully determined by modeling in laboratories. However, it should also be adjusted according to the ore drawing properties. Width of ellipsoid of drawn ore, as well as its eccentricity should match width of zone of blasted ore. In that case, ellipsoid of drawn ore will only slightly catch the burden from face contact between the caved ore and burden (Figures 8 and 9).

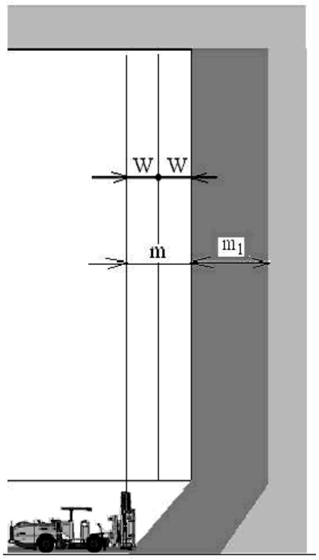

Fig. 7. *Drilling of long drill holes and layout of zones m and m_1*

Since drawing success depends also on ore fragmentation, it is necessary to design drilling and blasting in order to avoid drawing jams. That is why, depending on ore properties, it is necessary to determine whether there should be 6 or 8 drill holes in a ring drill. Also, the ore properties affect whether a single zone should be blasted or two of them at the same time. In the underground mine "Jama" Bor, there are always six drill holes in a ring drill, and a single zone is blasted. Since the ore properties are different, this is probably not an optimal solution.

3. Influence of ore compression after blasting. Figure 8 shows the situation when, due to the excessive ore compression, ore drawing process is disturbed, with the increased ore dilution.

Excessive ore compression occurs in cases when volume of explosive is too large, especially when a single ring drill is blasted. Also, this process could be boosted by well fragmented waste which fulfills the space made by the previous ore drawing.

As it was said previously, in the sublevel caving, the blasting is performed in tight conditions, and the ore fragmentation is enabled due to the compression of waste which fulfilled the space made by previous ore drawing. Energy of blasting strongly pushes the ore forward, compression occurs at the vertical contact between the ore and waste, and blasted ore is compressed to a certain width, dependable on volume of explosive and compression properties of ore. In such situation, it is possible to open a gap between blasted ore and stope face, which could reach several dozens of cm. If the gap is big enough, it will be fulfilled by caved waste from above (Figure 8).

In that case, waste can reach the draw point very quickly, after only 20 – 30% of ore is drawn, thus increasing the ore dilution and forcing abort of drawing. So, it is very important to avoid the excessive ore compression. This could be achieved in different ways: decreasing the explosive volume, adjusting the blasting pattern, or adjusting the drawing dynamics.

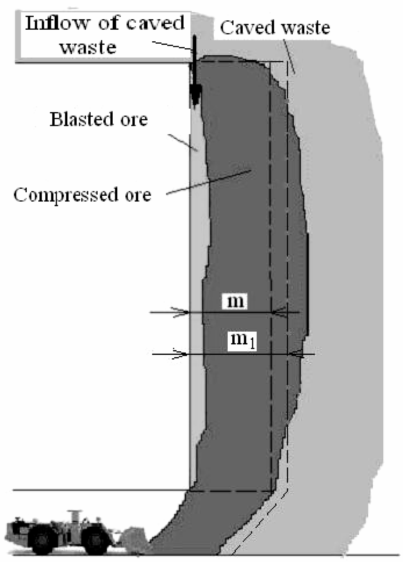

Fig. 8. *Drawing of compressed ore*

4. Damaging the sublevel drift roof. This is another problem caused by blasting. Layout of ring drill causes the existence of very narrow space between drill holes near the roof of sublevel drift (Figure 2). If drill holes are loaded by explosive in their entire length, the concentration of explosive will be very high near the roof and blasting will cause damage of roof. If ring drills are drilled in advance, there is a big probability that they will be damaged or lost after blasting. Losing a ring drill means that the next blasting is performed with doubled width of blasting zone, thus causing poor ore fragmentation and problems with drawing and ore recovery.

Figure 9 shows changes of drawing parameters in a case of damaged roof. Damaged roof causes moving forward of a slope of drawn ore and consequently moving of draw point forward. In that case, the draw point is much tighter and there is higher probability of jamming.

Also, height of ellipsoid of drawn ore is decreased. Decrease of height causes decrease of ellipsoid volume, which affects the drawing results. Furthermore, in this case more ore will be lost in the bottom part of blasted zone.

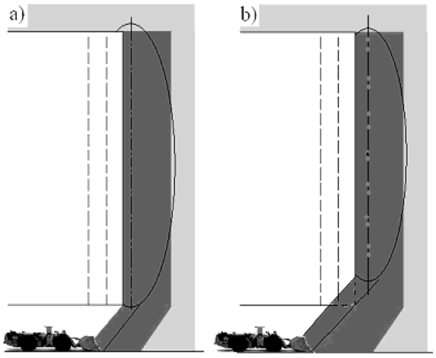

Fig. 9. *Change of drawing parameters due to roof damage of sublevel drift*

In order to prevent these problems, it is necessary to perform a careful loading of drill holes. They should not be loaded to the end, at least not all of them. Also, there are some measures that can be taken in order to avoid the roof damaging.

Beside these main problems, there are several additional factors which affect mining results. These factors are related to the method design, parameters of drilling and blasting, as well as parameters of ore drawing. For instance, poorly designed layout and number of drill holes or inadequate width of blasting zone may cause poor ore fragmentation and drawing problems. Ore drawing process is also affected by loading equipment properties, such as shovel width, depth of loading, etc. All of these factors have to be included in the method design, in order to determine the optimal width of blasting zone.

CONCLUSION

Sublevel caving, especially the Swedish variant, is a very well designed and productive mining method. It is very convenient for low-graded ore, since it provides high productivity with low costs. However, the application of this method is followed by numerous problems, mainly related to difficulties with maintaining the accurate method geometry. If method design and its application are not optimal, numerous problems cause poor mining results, mainly visible through the poor ore recovery and increased ore dilution. That is why accuracy is the key in both designing process and application in the mine.

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NELINEARNA NAPONSKO-DEFORMACIJSKA ANALIZA TERENA PRIMENOM METODE KONAČNIH ELEMENATA***

Izvod

U radu je izvršena naponsko-deformacijska analiza, primenom metode konačnih elemenata, terena u naselju Medaković u Beogradu u toku izgradnje i eksploatacije stambene zgrade od osam spratova. Proračun stabilnosti na klizanje izvršen je korišćenjem podataka dobijenih metodom konačnih elemenata. Primena metode konačnih elemenata, uz korišćenje predloženog inkrementalnog postupka, pokazala je određene prednosti u odnosu na standardne metode analize stabilnosti padina i kosina. Pre svega, na ovaj način moguće je, u svakom trenutku, realno proceniti stanje napona i deformacija u terenu. Na osnovu toga utvrđujemo:
- *zone lokalnog i/ili opšteg loma tla*
- *kritičnu kliznu površinu*
- *pouzdani faktor sigurnosti*

Dobijeni rezultati imaju i širi značaj zbog analogije ispitivane padine sa terenima središnjeg dela Beograda koji je poslednjih decenija doživeo intenzivnu urbanizaciju. Posebno naglašavamo da se prikazani naponsko-deformaciski postupak može da primeni kod izgradnje saobraćajnica i deponija i to kako kod građevinskih tako i kod rudarskih radova.
Ključne reči: *naponsko-deformacijska analiza, metoda konačnih elemenata, koeficijent sigurnosti*

UVOD

Brojni su primeri u inženjerskoj praksi koji pokazuju da je zbog nedovoljnog poznavanja međusobnog uticaja objekta i terena, u toku izgradnje ili eksploatacije objekta, došlo do narušavanja prirodne ravnoteže. To se ispoljava pomeranjima u terenu koja izazivaju znatna oštećenja postojećih objekata.

Činjenica je da smo često prinuđeni da konstruktivno vrlo složene objekte gradimo

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na uslovno stabilnim terenima – na primer, umirenim klizištima. To nas obavezuje da problemima stabilnosti padina pristupimo sa posebnom odgovornošću, odnosno da primenimo najsavremenije metode istraživanja terena i geostatičkih proračuna.

Ovaj rad predstavlja prilog takvom nastojanju, jer je na osnovu bogatog fonda podataka terenskih i laboratorijskih istraživanja dat savremen postupak proračuna interakcije objekta i terena pomoću metode konačnih elemenata.

U radu je analizirano ponašanje severo-istočne padine Mokroluškog potoka u Beogradu, u području naselja Medaković, pod opterećenjem jednog višespratnog stambenog objekta.

Ovo područje je izabrano stoga što je po svom sastavu i geotehničkim osobinama karakteristično za područje središnjeg dela Beograda u kome je poslednjih decenija izvršena intenzivna urbanizacija i stoga je važno da se utvrdi interakcija već izgrađenih objekata i terena.

OSNOVNE KARAKTERISTIKE TERENA I OBJEKTA U NASELJU MEDAKOVIĆ

Na levoj, severo-istočnoj padini Mokroluškog potoka, izgrađeno je stambeno naselje Medaković i u okviru njega prateći objekti društvene namene i objekti infrastrukture. U ovom radu analizira se uticaj jednog, višespratnog stambenog objekta na stabilnost padine [1].

Geotehničke karakteristike terena

Teren u ovome području, kao i u široj okolini (Slika 1), izgrađuju sledeći lito-genetski članovi [2]:

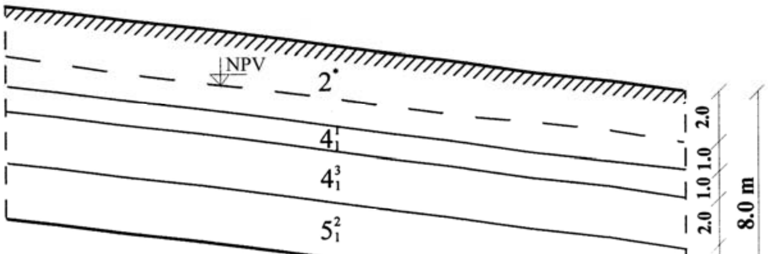
2^* Izmenjeni les prašinasto peskovit sa retkim nakupinama karbonatnog praha, čestim pegama mangana i oolita limonita: žuto smeđe boje; hidrogeološki kolektor-sprovodnik;

4_1^1 Laporovita glina, glinoviti lapori, gline i lapori (panon) zona potpunog raspadanja: mrvice (mm i cm dimenzija); bledo žute boje; hidrogeološki kolektor.

4_1^3 Glinoviti lapori i laporci (panon) izdeljeni u blokove (dm i m dimenzija) i izmenjeni; svetlo žute boje; hidrogeološki izolator;

5_1^2 Glinoviti lapori i gline i peskovite gline sa retkim sočivima peska-uslojeni (sarmat), zona raspadanja: krupno izdeljeni, žuto mrki; hidrogeološki izolator;

5_2 Glinoviti lapori i laporci (sarmat) – uslojeni, neizmenjeni, sivi; hidrogeološki izolator. Debljina ove sredine nije tačno utvrđena, ali prelazi 10 m.



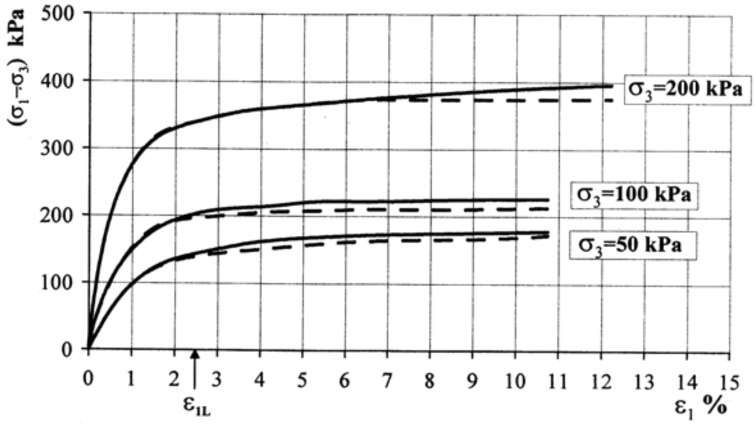
Sl. 1. *Inženjersko geološki presek terena*

Navedeni litološki članovi su međusobno približno paralelni i nagnuti niz padinu oko 5°. Maksimalni nivo podzemne vode (NPV) je na 2,0 m ispod površine terena.

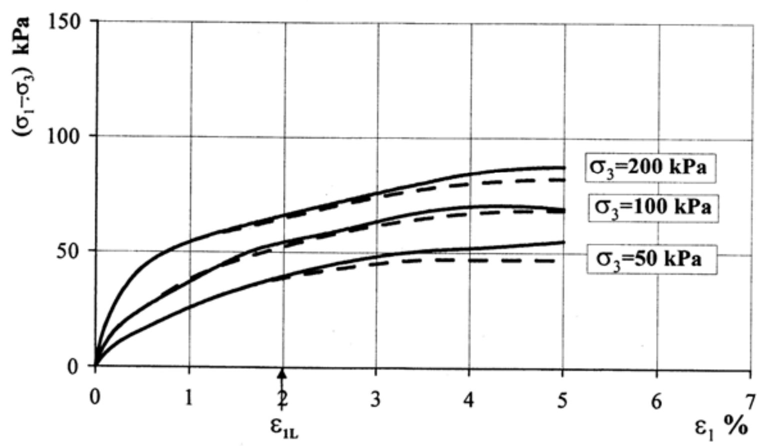
Standardnim laboratorijskim triaksijalnim ispitivanjima reprezentativnih uzoraka merodavnih prirodnih sredina (CD opiti) utvrđeni su karakteristični odnosi napona i deformacija (Slike 2, 3, 4, 5 i 6).

Analitički modeli naponsko-deformacijskih zavisnosti

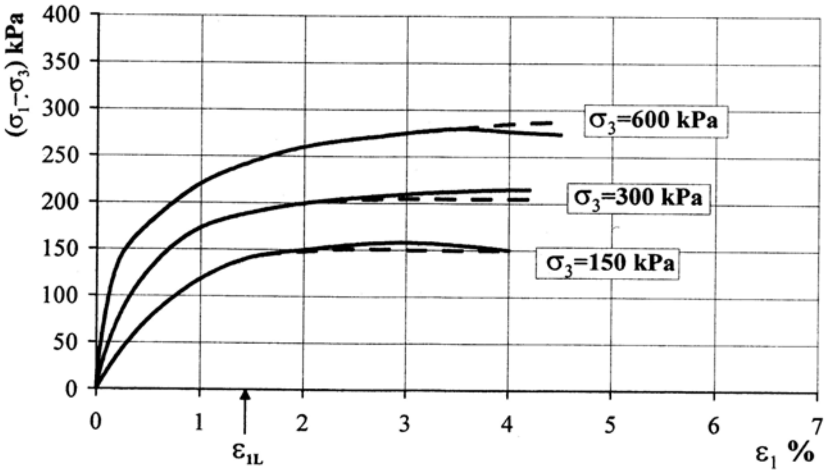
Savremeni pristup rešavanju geotehničkih problema zahteva da se naponsko-deformacijske zavisnosti analitički predstave [3].



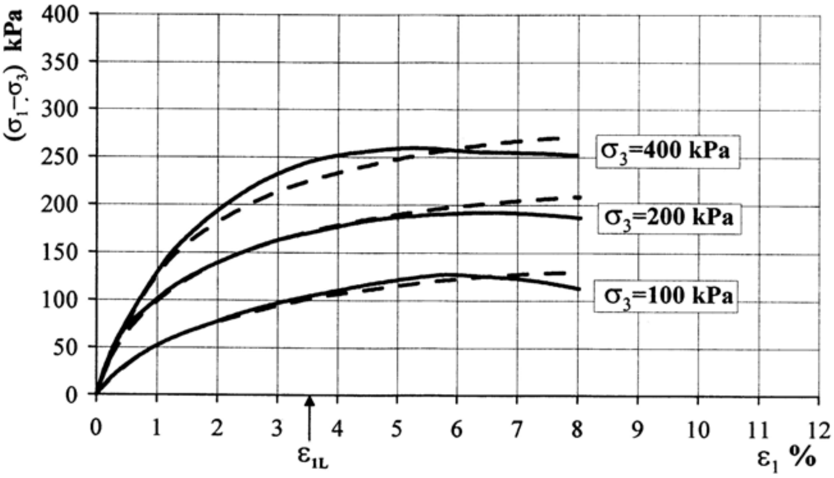
Sl. 2. *Naponsko-deformacijske zavisnosti karakterističnih kompleksa za sredinu 2*[*]



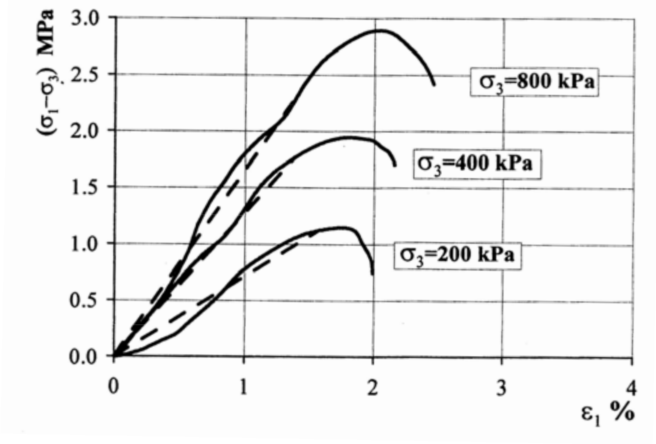
Sl. 3. *Naponsko-deformacijske zavisnosti karakterističnih kompleksa za sredinu* 4_1^1



Sl. 4. *Naponsko-deformacijske zavisnosti karakterističnih kompleksa za sredinu* 4_1^3



Sl. 5. *Naponsko-deformacijske zavisnosti karakterističnih kompleksa za sredinu* 5_1^2



Sl. 6. *Naponsko-deformacijske zavisnosti karakterističnih kompleksa za sredinu* 5_2

S obzirom na prirodu ovih funkcija za sredine 2^*, 4_1^1, 4_1^3, 5_1^2 usvajamo da je:

$$F = \sigma_1 - \sigma_3 = \frac{A \cdot \varepsilon_1}{B + \varepsilon_1} \qquad (1)$$

$$A = \alpha_1 + \beta_1 \cdot \sigma_3 + \gamma_1 \cdot \sigma_3^2 \qquad (2)$$

$$B = \alpha_2 + \frac{\beta_2}{\sigma_3} + \frac{\gamma_2}{\sigma_3^2} \qquad (3)$$

gde je:

σ_1, σ_3 - glavni naponi

ε_1 - glavna dilatacija

U ovim jednačinama su α_1, α_2, β_1, β_2 γ_1, γ_2 parametri koji se za svaku sredinu određuju posebno, u zavisnosti od njenih deformacijskih karakteristika.

Činjenica je da se u jednačini (3) naponi σ_3 pojavljuju u imeniocu, ne umanjuje kvalitet numeričke analize, jer se inkrementalni postupak primenjuje za već poznate primarne napone tj. za $\sigma_3 > 0$.

Predloženi analitički model može vrlo efikasno da se upotrebi u nelinearnim analizama, jer pruža mogućnost da se odredi tangentni modul elastičnosti u proizvoljnoj tački naponsko-deformacijske funkcije. Kada je manji glavni napon konstantan, onda se modul elastičnosti dobija kao

$$E = \frac{d(\sigma_1 - \sigma_3)}{d\varepsilon_1} = \frac{A \cdot B}{(B + \varepsilon_1)^2} \qquad (4)$$

U sredini 5_2 može se, s obzirom na prirodu funkcije $F=F(\sigma_1-\sigma_3, \varepsilon_1)$, usvojiti linearna zavisnost

$$F = \sigma_1 - \beta_3 = E \cdot \varepsilon_1 \qquad (5)$$

odnosno, za modul elastičnosti zavisnost

$$E = \alpha_3 + \beta_3 \cdot \sigma_3 + \gamma_3 \cdot \sigma_3^2 \qquad (6)$$

gde su α_3, β_3, γ_3 parametri koji se određuju zavisno od deformacijskih karakteristika sredine 5_2.

Na Slikama 2, 3, 4, 5 i 6 prikazane su uporedo funkcije dobijene analitički - isprekidane linije i odgovarajuće funkcije F eksperimentalno utvrđene - pune linije [4].

Tehničke karakteristike objekta

Objekat, čiju interakciju sa terenom analiziramo, izgrađen je od armiranog betona i ima osam spratova. Fundiran je plitko, na betonskoj ploči širine 20 m i dužine 100 m. S obzirom na to, opterećenje od objekta na teren je vertikalno, jednako podeljeno i iznosi 100 kPa.

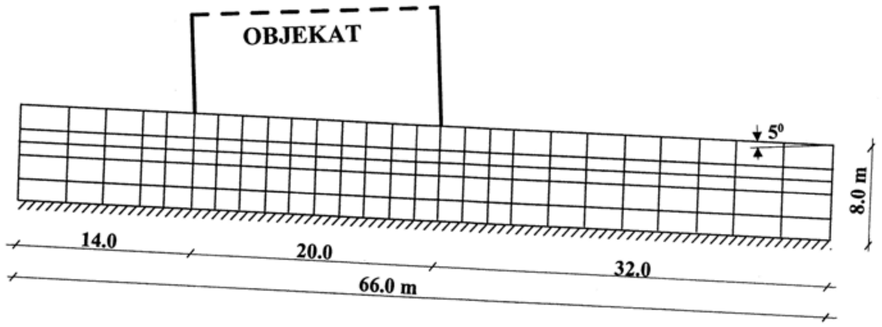
Prilikom naponsko-deformacijske analize usvojeno je da opterećenje od objekta deluje na površini terena što je, s obzirom na način fundiranja, opravdano.

Formiranje modela terena

Definisanjem geotehničkih karakteristika terena i tehničkih karakteristika objekta, određeni su svi potrebni parametri za formiranje mreže konačnih elemenata. S obzirom da su dimenzije temeljne ploče znatno veće od dimenzija monolita stena (deset, sto i više puta) i da monoliti nisu slobodni nego su zglobno povezani, opravdano je da se teren oko objekta (Slika 1) posmatra kao deo kontinuma. Dalje, zbog položaja objekta u odnosu na pravac pružanja padine, može se smatrati da su zadovoljeni uslovi za ravno stanje deformacije.

Analizom naponsko - deformacijskih funkcija $F=F(\sigma_1-\sigma_3,\ \varepsilon_1)$ zaključujemo da neizmenjeni, sivi lapori (sredina 5_2), predstavljaju oslonac sredinama iznad njih.

Teren neposredno oko objekta modeliran je mrežom konačnih elemenata i za to su korišćeni ravanski (asolid) konačni elementi (Slika 7).



Sl. 7. *Model terena prikazan mrežom konačnih elemenata*

S obzirom na dimenzije temeljne ploče i visinu diskretnog sistema, može se smatrati da se uticaj objekta neće osećati na bočnim stranama modela. Fizičke karakteristike konačnih elemenata, kao što je uobičajno, zadate su preko modula elastičnosti i Poasonovog koeficijenta.

Uslov loma definišemo preko granične deformacije ε_{1L} koju istraživač uslovljava zavisno od merodavnih karakteristika terena i objekta, odnosno interakcije sistema teren-objekat (Slike 2, 3, 4 i 5).

ODREĐIVANJE STANJA NAPONA I DEFORMACIJA U TERENU

Određivanje napona i deformacija u terenu vršimo u dva dela, i to za [5]:

(1) - sopstvenu težinu tla i strujni pritisak

(2) - dopunsko opterećenje od objekta

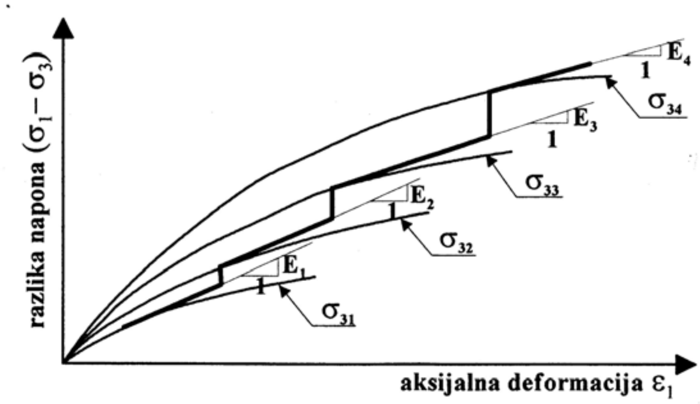
Ovakva podela je opravdana stoga što se za (1) padina može tretirati kao beskonačna sa pravcem filtracije koji je paralelan nagibu padine. U tom slučaju napone i deformacije određujemo neposredno iz uslova ravnoteže i funkcije $F=F(\sigma_1-\sigma_3,\ \varepsilon_1)$.

Proračun napona i deformacija za (2) obavljen je metodom konačnih elemenata [6], korišćenjem programskog paketa SAP 2000.

Početni naponski uslovi su određeni uz predpostavku da se teren pre gradnje nalazi u stanju mirovanja i da je zapreminska težina svih prirodnih sredina $\gamma = 20$ kN/m^3.

Prikaz inkrementalnog postupka

Određivanje napona i deformacija u terenu vrši se inkrementalnim postupkom, u četiri koraka. U prvom koraku određuju se uticaji od sopstvene težine tla i strujnog pritiska. Opterećenje od objekta nanosi se postupno, u preostala tri inkrementa i to: prvo 20 kPa, zatim 30 kPa i na kraju 50 kPa. Na ovaj način simuliran je proces izgradnje objekta i uticaj izgradnje na naponsko-deformacijsko stanje u terenu. Shematski prikaz inkrementalnog postupka dat je na Slici 8.



Sl. 8. *Shema inkrementalnog postupka*

U skladu sa predloženim inkrementalnim postupkom, fizičko-mehaničke karakteristike prirodnih sredina izražavamo Poasonovim koeficijentom i tangentnim modulom elastičnosti. S obzirom na izvedene CD opite i činjenicu da je uticaj Poasonovog koeficijenta na stanje napona i deformacija u terenu znatno manji nego što je uticaj modula elastičnosti, usvojeno je da je u svim sredinama ν konstantno, i to za sredine 2^*, 4_1^1 usvojeno je $\nu = 0.45$, a za sredine 4_1^3, 5_1^2 usvojeno je $\nu = 0.35$. Što se tiče modula elastičnosti E_i (i=1,...4) oni se određuju iz jednačine (4). Napominjemo da predloženi inkrementalni postupak uvažava kako nelinearnost naponsko-deformacijske funkcije, tako i uticaj manjeg glavnog napona σ_3.

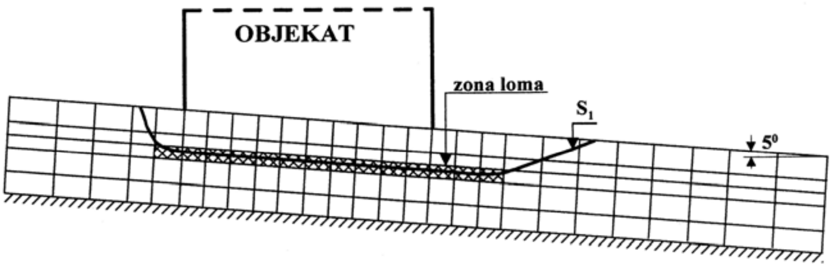
Ocena sračunatih rezultata

Obradom izračunatih podataka, a u skladu sa predloženim inkrementalnim postupkom, određeno je stanje napona i deformacija u terenu i to kako u toku građenja objekta tako i po završenoj izgradnji.

Utvrđeno je da:

- maksimalno pomeranje u pravcu upravno na nagib padine iznosi 10.17 cm;
- maksimalno pomeranje u pravcu nagiba padine iznosi 8,86 cm;
- deformacije ε_1 najveće su u sredini 4_1^1 (laporovita glina, zona mrvica); maksimalna deformacija je $\varepsilon_1 = 4{,}52$ %;

- promena modula elastičnosti je najveća u sredini 4_1^1, a maksimalna promena je E4/E1= 0.083; u sredini 2* (izmenjeni les) nastaje povećanje modula elastičnosti, a najveće povećanje je E_4/E_1= 1.91;
- zona loma prolazi kroz sredinu 4_1^1 u delu terena koji je ispod objekta (Slika 9).



Sl. 9. *Model terena sa zonom loma*

Intenzitet promena napona i deformacija opada relativno brzo sa udaljavanjem od objekta, tako da bokovi diskretnog sistema praktično ne osećaju njegovo dejstvo. Ovo potvrđuje ispravnost usvojenih dimenzija modela.

S obzirom na sličnost ispitivane padine Mokroluškog potoka sa terenima središnjeg dela Beograda, ovi rezultati imaju širi praktičan značaj.

ANALIZA STABILNOSTI PADINE

S obzirom na utvrđenu zona loma u sloju 4_1^1, predpostavljena je klizna površina S_1 (Slika 9). Njenu stabilnost određujemo za dva granična slučaja:

- pre početka izgradnje objekta i
- po završenoj izgradnji objekta

Metodom konačnih elemenata, korišćenjem programskog paketa SAP 2000, ne može direktno da se odredi koeficijenat sigurnosti padine u odnosu na lom tla klizanjem. S obzirom da je taj podatak bitan za inženjera geotehničara, predlažemo da se rezultati dobijeni metodom konačnih elemenata iskoriste kako bi se odredio koeficijent sigurnosti. S tim u vezi, poznato je da su deformacije u terenu od primarnog inženjerskog značaja, jer njihova veličina uslovljava početak loma. Stoga, u daljem tekstu, predlažemo određivanje koeficijenta sigurnosti koje vodi računa o deformacijama u terenu. U skladu sa tim, koeficijent sigurnosti definišemo kao količnik čvrstoće na smicanje duž klizne površine za graničnu deformaciju ($\varepsilon_1 = \varepsilon_{1L}$) i odgovarajućeg smičućeg napona za ostvarenu deformaciju ($\varepsilon_1 = \varepsilon_{1S}$). Na taj način sračunati koeficijenti sigurnosti za kliznu površinu S_1 iznose:

- pre početka izgradnje objekta
  FS = 3.76
- po završenoj izgradnji objekta
  FS = 1.69

Prikazanom numeričkom analizom utvrđeno je da izgradnja objekta smanjuje koeficijent sigurnosti. Međutim njegova vrednost je i dalje zadovoljavajuća, tako da bezbednost objekta nije dovodena u pitanje.

U vezi sa dobijenim rezultatima treba naglasiti da opterećenje od objekta ne izaziva zone loma koje bi mogle da dovedu u pitanje nosivost temeljnog tla. Naime, poznato je da se ove zone prvo pojavljuju ispod ivica temelja i da se, sa povećanjem opterećenja, proširuju sve dok ne dođe do njihovog spajanja [7]. To je i bio razlog zašto nismo posebno analizirali nosivost temeljnog tla. Međutim, interesantno je da opterećenje od objekta izaziva zonu loma, po širini temelja u sredini 4_1^1 (laporovita glina, raspadnuta), što može da izazove klizanje tog dela padine i objekta na njoj. Zbog toga smo stabilnost na klizanje padine i objekta posebno analizirali.

ZAKLJUČCI

Proračun stabilnosti padine Mokroluškog potoka u naselju Medaković ukazao je na određene mogućnosti koje u ovoj oblasti Geotehnike obezbeđuje metoda konačnih elemenata, tj.:

- predloženi postupak proračuna omogućava realnu procenu stanja napona i deformacija koja uvažava stvarne fizičko-mehaničke osobine prirodnih sredina. Ovde naročito treba istaći mogućnost dobijanja realnih deformacija i pomeranja jer su one često od izuzetnog značaja za budući objekat, a jedino se mogu dobiti metodom konačnih elemenata;
- inkrementalni postupak pruža mogućnost da se prati promena naponskog i deformacijskog stanja u terenu, zavisno od toka izgradnje objekta. Na taj način stabilnost terena posmatramo kao aktivan proces koji je uslovljen faktorima na koje možemo, po potrebi, uticati;
- dobijeni rezultati omogućavaju da se odrede zone lokalnog i/ili opšteg loma tla;
- poznavanje zona loma, i uopšte deformacija u terenu, obezbeđuje određivanje potencijalnih kliznih površina;
- brojni naponsko-deformacijski podaci koje daje metoda konačnih elemenata omogućavaju određivanje pouzdanijeg koeficijenta sigurnosti nego što je to slučaj kod ostalih metoda analize stabilnosti terena i kosina. U ovom radu je predloženo određivanje koeficijenta sigurnosti u zavisnosti od veličine deformacija u terenu – vodeći istovremeno računa o sigurnosti objekta.

Sve ovo omogućava da se realno sagleda sadejstvo terena i objekta i da se problem stabilnosti padine, u celini, reši na optimalan način. Pri tome, na ovaj način određena pomeranja i faktori sigurnosti su u dozvoljenim granicama za višespratne armirano betonske objekte što omogućava njihovo bezbedno korišćenje [8]. Osim toga, ovako dobijene vrednosti su dragocene prilikom odlučivanja o nadgradnji objekata.

Na kraju želimo da istaknemo da se navedeni postupak naponsko-deformacijske analize može u potpunosti da primeni kod izgradnje saobraćajnica i deponija i to kako kod građevinskih tako i kod rudarskih radova [9], [10].

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NONLINEAR STRESS-STRAIN ANALYSIS OF TERRAIN USING THE FINITE ELEMENT METHOD***

Abstract

This paper presents the stress-strain analysis of terrain using the finite element method in the settlement Medaković in Belgrade during the construction and occupation of the eighth floor residential building. The slope stability analysis was performed using the finite element method. Application the finite element method, with the use of proposed incremental procedure has shown some advantages compared to the classical methods of stability analysis. First of all, using this method, it is possible to assess at any time the stress and strain values in terrain. Based on these values, it is possible to determine: zones of failure (local and/or general), critical sliding surface and reliable safety factor

The obtained results are of great significance for the most part of the Belgrade terrain which was built up in a similar way and in the last few decades has been intensively urbanized.

It has to be emphasized that the proposed stress-strain procedure has its application in construction of highways and landfills, both in civil engineering and mining engineering.

Keywords: *stress-strain analysis, finite element method, safety factor*

INTRODUCTION

There are many examples in the engineering practice, showing that the lack of knowledge the interactions between the object and terrain, during the construction or occupation of object, there was a disruption of the natural balance. That reflects in shifts of the ground, which cause considerable damages to the existing structures.

The fact is that we are often forced to constructively build very complex structures on the conditionally stable grounds -

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for example, soothed landslides. It obliges us to approach the problems of stability the slopes with a special responsibility, and to apply the latest methods of field research and geostatic calculations.

This paper is a contribution to such efforts, as based on a rich fund of data from the field and laboratory research, it gives a modern procedure for calculation the interaction of objects and terrain using the finite element method.

This paper analyzes the behavior of the north-eastern slopes of the Mokroluški stream in Belgrade, in the area of the settlement Medaković under the load of a multi-storey residential building.

This area was chosen because it is, by its composition and geotechnical properties, characteristic for the area of the central part of Belgrade, where an extensive urbanization has been made in the last decades, and it is therefore important to determine the interaction of already constructed buildings and terrains.

BASIC CHARACTERISTICS OF TERRAIN AND OBJECTS IN THE SETTLEMENT MEDAKOVIĆ

On the left, north-eastern slope of the Mokroluški stream, a residential settlement Medaković was built with its social purpose outbuildings and infrastructure facilities. In this paper, impact of a single, multi-storey residential building is analyzed on the slope stability [1].

Geotechnical characteristics of the terrain

Terrain in this area, as well as in the wider area (Figure 1), is built by the following lithogenetical members [2]:

2^* Altered silty sandy loess with rare clusters of carbonate powder, frequent spots of manganese and limonite oolite limonite: yellow-brown color; hydrogeological collector;

4_1^1 Marly clay, clayey marl, clay and marl (Pannonian) zone of complete decomposition crumbs (mm and cm dimensions); pale yellow; hydrogeological collector;

4_1^3 Clayey marls and marls (Pannonian), divided into blocks (dm and m dimensions) and alteres; bright yellow; hydrogeological insulator;

5_1^2 Clayey marl and clay and sandy clay with rare lenses of sand-stratified (Sarmatian), zone of decomposition: coarse divided, yellow brown; hydrogeological insulator;

5_2 Clayey marls and marls (Sarmatian) - stratified, nonaltered, gray; hydrogeological insulator. Thickness of this region is not precisely defined, but more than 10 m.

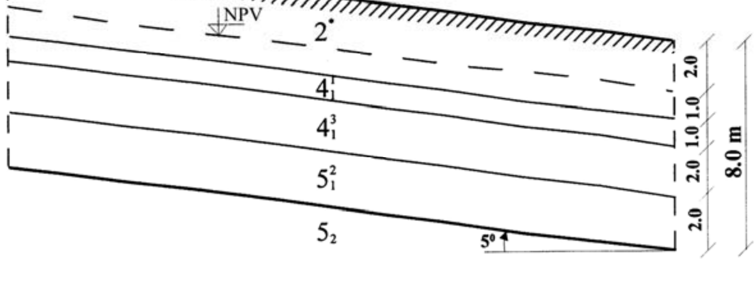

Fig. l. *Engineering-geological section of the terrain*

The aforementioned lithologic members are approximately parallel to each other and inclined down the slope about 5°. Maximum groundwater level (NPV) is 2.0 m below the ground surface.

Standard laboratory triaxial testing the representative samples of competent natural environments (CD experiments) have determined the characteristic relations of stress and strain (Figures 2, 3, 4, 5 and 6).

Analytical models of stress-strain dependence

Modern approach to solving the geotechnical problems requires the analytical presentation of the stress-strain dependence [3].

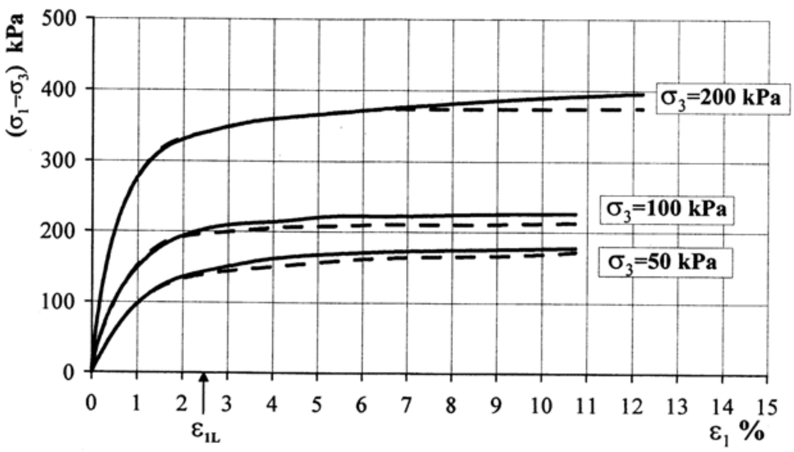

Fig. 2. *Stress-strain dependences of characteristic complexes for area 2*[*]

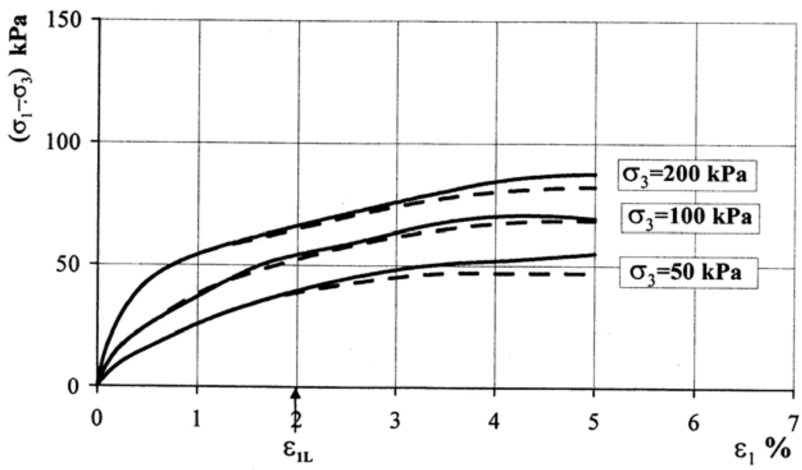

Fig. 3. *Stress-strain dependences of characteristic complexes for area* 4_1^1

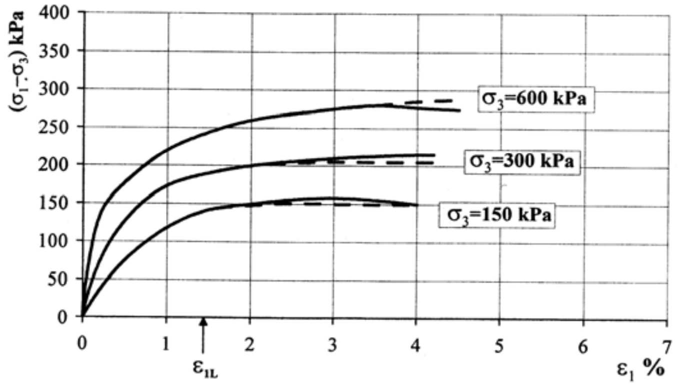

Fig. 4. *Stress-strain dependences of characteristic complexes for area* 4_1^3

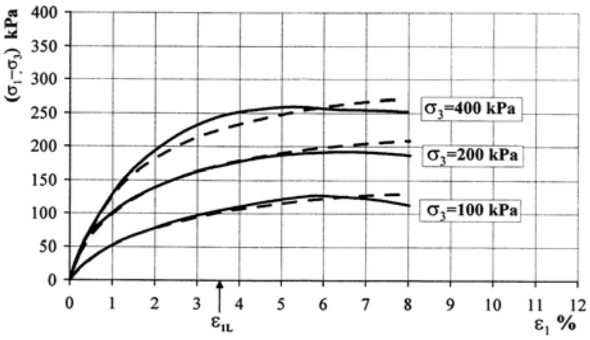

Fig. 5. *Stress-strain dependences of characteristic complexes for area* 5_1^2

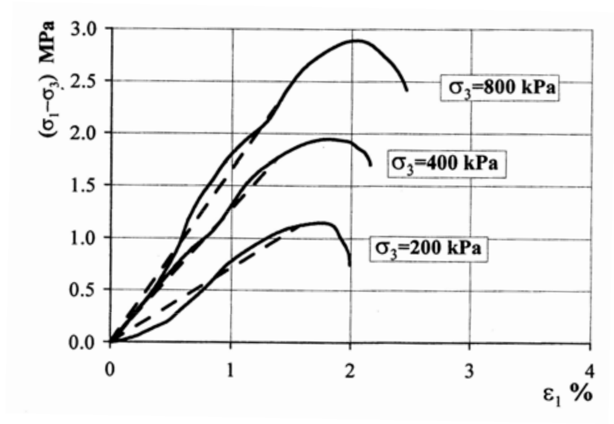

Fig. 6. *Stress-strain dependences of characteristic complexes for area* 5_2

Considering the nature of these functions for areas 2^*, 4_1^1, 4_1^3, 5_1^2, it is adopted that:

$$F=\sigma_1-\sigma_3=\frac{A\cdot\varepsilon_1}{B+\varepsilon_1} \qquad (1)$$

$$A=\alpha_1+\beta_1\cdot\sigma_3+\gamma_1\cdot\sigma_3^2 \qquad (2)$$

$$B=\alpha_2+\frac{\beta_2}{\sigma_3}+\frac{\gamma_2}{\sigma_3^2} \qquad (3)$$

where:

σ_1, σ_3 – principal stresses

ε_1 - principal dilatation

The parameters α_1, α_2, β_1, β_2 γ_1, γ_2 are in these equations that are determined for each area particularly, depending on its deformation characteristics.

The fact that in equation (3) stresses $\sigma_{3,}$ appear in denominator, do not diminish the quality of numerical analysis, because an incremental process is used for primary voltages already known primary stresses, i.e. for $\sigma_3 > 0$.

The proposed analytical model can be effectively used in nonlinear analyses, as it provides the ability to determine the tangent modulus of elasticity at an arbitrary point of the stress-strain function. When lower principal stress is constant, then the modulus of elasticity is obtained as

$$E=\frac{d(\sigma_1-\sigma_3)}{d\varepsilon_1}=\frac{A\cdot B}{(B+\varepsilon_1)^2} \qquad (4)$$

In the area $5_{2,}$ due to the nature of function $F=F(\sigma_1-\sigma_3, \varepsilon_1)$, the linear dependence can be adopted

$$F=\sigma_1-\sigma_3=E\cdot\varepsilon_1 \qquad (5)$$

That is, dependence for the elasticity modulus

$$E=\alpha_3+\beta_3\cdot\sigma_3+\gamma_3\cdot\sigma_3^2 \qquad (6)$$

where α_3, β_3, γ_3 are parameters that have to be determined depending on the deformation characteristics of area 5_2.

Figures 2, 3, 4, 5 and 6 show in parallel the functions obtained analytically - dashed lines and corresponding experimentally determined functions F – full lines [4].

Technical characteristics of object

The analyzed object with terrain was built of reinforced concrete and has eight floors. It is shallow founded on a concrete slab, width of 20 m and length of 100 m. Since, the load of the building on the ground is vertically, equally divided and it is 100 kPa.

During the stress-strain analysis, it was assumed that the load of building acts on terrain surface which is, due to the way of funding, justified.

Formation of terrain model

Defining the geotechnical characteristics of terrain and technical characteristics of building, all necessary parameters were determined for formation the network of finite elements. Since the given dimensions of the base plate are much higher than dimensions of monolith rocks (ten, a hundred or more times) and that the monoliths are not free but are hingedly connected, it is reasonable that the area around the building (Figure 1) is seen as part of the continuum. Furthermore, due to the position of object relative to the direction of slope, it can be considered that the requirements for plane state of strain are met.

Analyzing the stress-strain functions $F=F(\sigma_1-\sigma_3, \varepsilon_1)$, it is concluded that non-altered gray marl (area 5_2), are the mainstay of areas above them.

Terrain immediately around the building was modeled using the network of finite elements and the plane (asolid) finite elements were used for this (Figure 7).

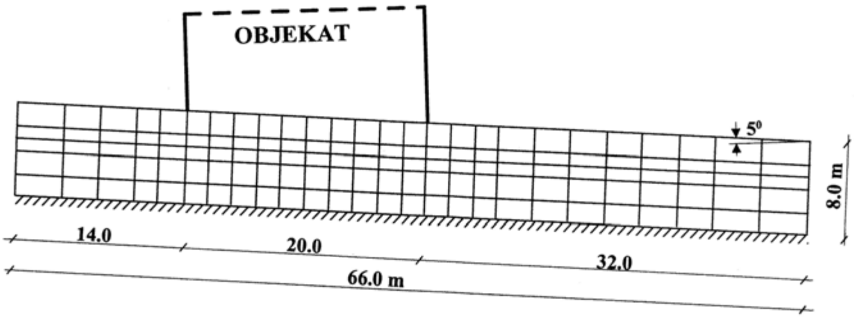

Fig. 7. *A terrain model is shown by the network of finite elements*

Considering the base plate dimensions and discrete system height, it can be considered that the impact of object will not be on the lateral sides of model. Physical characteristics of finite elements, as it is common, are given through the elasticity modulus and the Poisson coefficient.

The condition of fracture is defined through the fracture limit strain ε_{1L} which is conditioned by researcher depending on the characteristics of terrain and object, i.e. the interaction of terrain-object system (Figures 2, 3, 4 and 5).

DETERMINATION THE STRESS-STRAIN CONDITIONS IN THE GROUND

Determination the stress-strain conditions in the ground is carried out in two parts, as well as for [5]:

(1) – own weight of ground and current pressure

(2) – additional stress of the object

Such division is justified because it can be treated for (1) slope as an infinite with direction of filtration that is parallel to the slope angle. In this case, the stresses and strains are directly determined from the equilibrium condition and function $F=F(\sigma_1-\sigma_3,\ \varepsilon_1)$. Calculation of stress and strains for (2) was performed by the finite element method [6] using the software package SAP 2000.

The initial stress conditions are determined assuming that the area, prior to the construction, is in the idle mode and that the bulk density of all natural environment is $\gamma = 20$ kN/m^3.

Preview of incremental method

Determination of stresses and strains in the ground is carried out using the incremental method, in four steps. The first step determines the effects of the soil own weight and current pressure. Load of the building is applied gradually, and the other three increments are: the first 20 kPa, then 30 kPa, and at the end 50 kPa. In this way, the simulated process of object construction and the impact of construction on the stress-strain condition in the ground. Schematic representation of the incremental method is given in Figure 8.

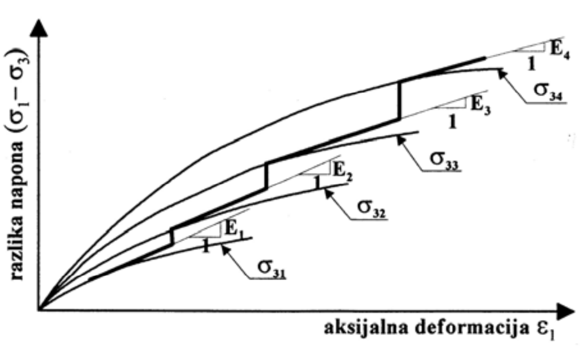

Fig. 8. *Diagram of incremental method*

In accordance with the proposed incremental method, the physical-mechanical properties of the natural environment are expressed by the Poisson coefficient and tangent modulus of elasticity. Since the performed CD experiments and the fact that the influence of the Poisson coefficient of the stress and strain condition in the ground are much smaller than the impact of elasticity, it is assumed that in all areas ν is constant as well as for the area * 2, adopted ν = 0.45, and the areas 4_1^3, 5_1^2, adopted ν = 0.35. As for the elastic modulus E_i (i = 1,...4), they are determined from the equation (4). We note that the proposed incremental method take into account both the non-linearity of the stress-strain function, and the impact of a smaller principal stress σ_3.

Evaluation of calculated results

Processing the calculated data in accordance with the proposed incremental method has determined the stress and strain condition in the ground both during construction and after completion of construction.

It was found that:

- maximum displacement in a perpendicular direction to the slope inclination is 10.17 cm;
- maximum displacement in a direction of inclination of the slope is 8.86 cm;
- strains ε_1 are the largest in the area 4_1^1 (marly clay, zone of crumbs); maximum deformation $\varepsilon_1 = 4.52\%$;
- change in the elasticity modulus is the largest in the area 4_1^1, and maximum change is $E_4/E_1 = 0.083$; in the area 2* (altered loess) is the result of increase the elasticity modulus, and the largest increase is $E_4/E_1 = 1.91$;
- fracture zone runs through the area 4_1^1 in the ground part which is below the object (Figure 9).

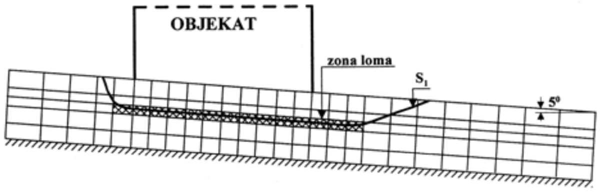

Fig. 9. *A terrain model with the fracture zone*

The intensity of change the stress and strain decreases relatively quickly with distance from the object, so that the sides of a discrete system do not practically feel its effect. It is confirmed by the validity of adopted model dimensions.

Considering the similarity of tested slope of the Mokroluški stream with the terrains of the central part of Belgrade, these results have broader practical significance.

ANALYSIS OF THE SLOPE STABILITY

Considering the established fracture zone in the layer 4_1^1, the sliding surface S_1 is presumed (Figure 9). Its stability is determined for two boundary cases:

- before the start of construction the object, and
- after completion the construction of object

By the finite element method, using the software package SAP 2000, the coefficient of slope safety cannot be determined compared to the fracture of soil sliding. Since that this data is essential for the engineers of geotechnics, we suggest that the results obtained by the finite element method would be used to determine the factor of safety. In this regard, it is known that the strains in the ground have the primary engineering importance, because their size is caused by the fracture initiation. Therefore, in further text, we suggest determining the safety coefficient which takes into account the strains of the ground. In accordance to this, the safety factor is defined as the quotient of shear strength along the sliding surface for boundary strain ($\varepsilon_1 = \varepsilon_{1L}$) and the appropriate shearing stress for achieved strain ($\varepsilon_1 = \varepsilon_{1S}$). In this way, the calculated safety factors for sliding surface S_1 are as follows:

- before the start of construction the object, $F_S = 3.76$
- after completion the construction of object, $F_S = 1.69$

The present numerical analysis has shown that the construction of object reduces the safety coefficient. However, its value is still satisfactory, so that the safety of object is not brought into question.

In connection with the obtained results, it should be noted that the load of object does not cause a fracture zone that could compromise the capacity of foundation soil. It is known that these zones first appear under the edges of foundation, and with increasing load, expanding until their connection [7]. That was the reason why we did not specifically analyze the capacity of the foundation soil. However, it is interesting that the load of object causing the fracture zone, along the width of foundation in the area 4_1^1 (marly clay, decomposed), which can cause sliding of that part of the slope and the buildings on it. Therefore, the stability of slope sliding was specifically analyzed.

CONCLUSIONS

Calculation of the slope stability of the Mokroluški stream in the settlement Medaković pointed to the specific possibilities in this area of geotechnics, provided by the finite element method, that is:

- the proposed method of calculation provides a realistic assessment of the stress and strain condition that takes into account the actual physical-mechanical properties of natural environments. Here, it should be noted in particular the possibility of obtaining the real strains and displacements because they are often of great importance for the future object, and they can be only obtained by the finite element method;
- the incremental method provides the possibility to monitor the changes in stress and strain condition in the ground, depending on the course of construction. In this way, the stability of the ground, viewed as an active process, which is determined by factors that can, if necessary, be affected;
- the obtained results allow to determine the zones of local and/ or general soil failure;
- knowing the fracture zones, and general strains in the ground, provides determination of the potential sliding surfaces;
- a number of stress-strain data provided by the finite element method allows determination of the coefficient of reliable safety than it is the case for other methods of analysis the stability of terrain and slopes. This work proposes determination the safety coefficient depending on the size of strains in the ground - at the same time taking into account the safety of object.

All this makes it possible to realistically look at the terrain and synergy the facility and that the problem of the stability of the slope, in general, solved in an optimal way. In fact, in this way the certain shifting and safety factors are within acceptable limits for multi-story reinforced concrete buildings allowing their safe use [8]. In addition, the values obtained in this way are valuable when deciding on superstructure of building.

At the end we want to emphasize that given procedure of the stress-strain analysis can be completely used in construction of highways and landfills, both in civil engineering and mining engineering [9], [10].

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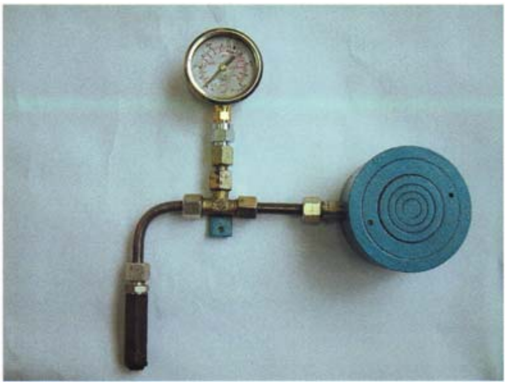

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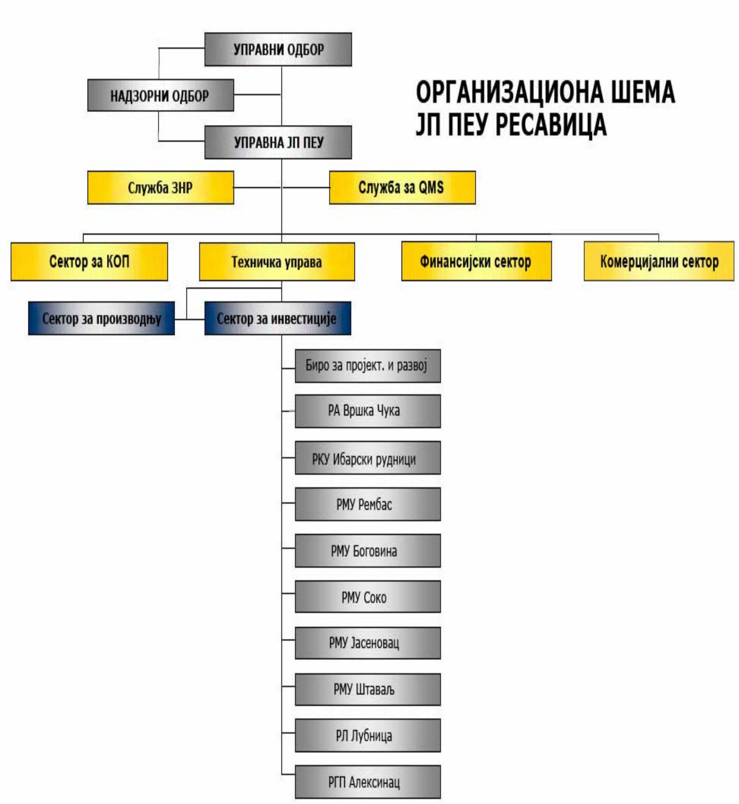

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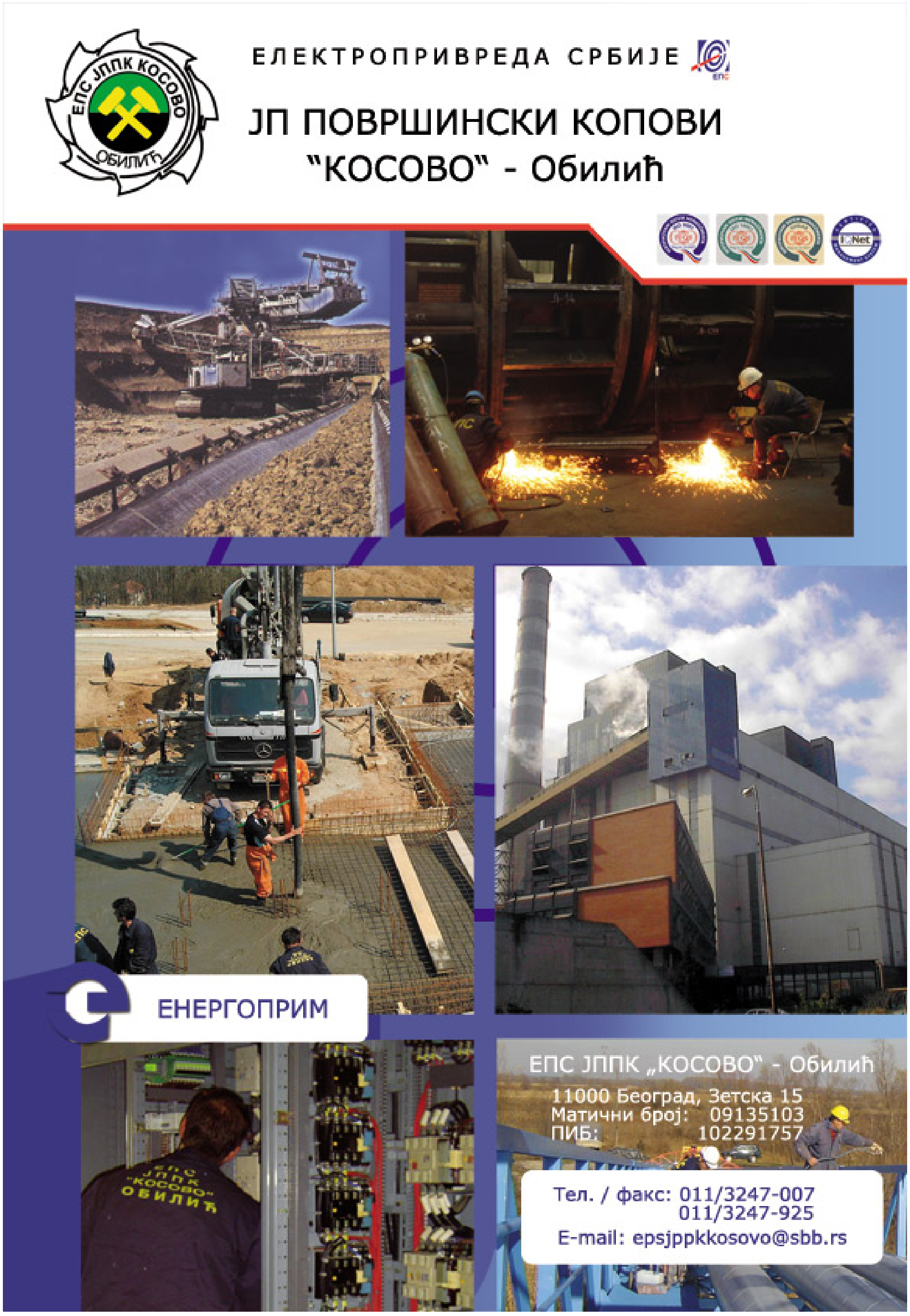
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