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Mile Bugarin, Miroslava Maksimović*, Vesna Ljubojev**

REZERVE BAKRA I ZLATA U ISTRAŽNO - EKSPLOATACIONOM POLJU RTB-A BOR**

Izvod

RTB Bor raspolaže značajnom mineralno-sirovinskom bazom, odnosno rezervama bakra i zlata, koje omogućavaju eksploataciju za više decenija. Istražna-eksploataciona polja RTB-a smeštena su u okviru Borske metalogenetske zone, koja se prostorno i genetski poklapa sa „timočkim magmatskim kompleksom" (TMK), i obuhvata prostore sledećih rudnih polja; Bor, Cerovo, Majdanpek i Čoka Marin. Ekonomičnost rezervi rude bakra je u funkcionalnoj zavisnost pre svega od cene bakra na LME berzi, potražnje bakarnih proizvoda, svetske proizvodnje bakra i troškova valorizaije rude bakra. Detaljnim istraživanjem nedovoljno istraženih delova ležišta, uvođenjem novih metoda eksploatacije, savremenijih tehničko-tehnoloških metoda u pripremi i preradi bakra, otvara se mogućnost da se veći deo vanbilansnih rezervi prevede u bilansne. Trend visokih cena bakra i zlata, takođe utiće i na smanjenje graničnog sadržaja, što može dovesti do značajnog povećanja rezervi mineralne sirovine.

Ključne reči: *geološka-ekonomska procena rezervi rude, ležište bakra i zlata Bor, ležište rude, rudno polje, mineralne sirovine, istražno-eksploataciono polje RTB-a Bor.*

UVOD

Mineralni resursi istražno-eksploataciona polja RTB-a Bor istaržuju se više od jednog veka, a istraživanja u zadnjih pedeset godina kao i eksploatacija rude bakra je veoma intezivana. Obezbeđene su velike rezervi rude bakra i zlata unutar timočkog magmatskog kompleksa i stečena su bogata iskustva na valorizaciji bakra i zlata. Istražno-eksploataciona polja RTB-a smeštena su u okviru Borske meta-

* *Institut za rudarstvo i metalurgiju Bor*

** *Ovaj rad je proistekao kao rezultata Projekta TR-37001 „Uticaj rudarskog otpada iz RTB-a Bor na zagađenje vodotokova sa predlogom mera i postupka za smanjenje štetnog dejistva na životnu sredinu" i 33021 „Razvoj tehnologija flotacijske prerade ruda bakra i plemenitih metala radi postizanja boljih tehnoloških rezultata", koga finansira Ministarstvo za prosvetu, nauku i tehnološki razvoj Republike Srbije*

logenetske zone, koja se prostorno i genetski poklapa sa „timočkim magmatskim kompleksom“ (TMK), i obuhvata prostore sledećih rudnih polja; Bor, Cerovo, Majdanpek i Čoka Marin. Ekonomičnost eksploatacije rude bakra u funkcionalnoj je zavisnosti od: kapaciteta eksploatacije, iskorišćenja metala u preradi, cene metala i troškova valorizacije rude bakra, tako da borska ruda koja sadrži u proseku od 0,3-0,6% bakra spada u siromašne rude, ali povoljna cena bakra sa kontrolisanjem troškova eksploatacije prerade i iskorišćenja kao i razvijene infrastrukture na rudnicima, omogućuje rentabilnu proizvodnju bakra u narednih nekoliko decenija.

RUDNO POLJE BOR

Rudno polje Bor, nalazi se istočnom delu Borske metalogenetske zone u prostornoj i genetskoj vezi sa gornjokrednim magmatskim kompleksima i to; ležišta bakra i zlata Bor (Tilva Roš sa brojnim rudnim telima koja su uglavnom izvađena), Borska Reka, Borski Potok.

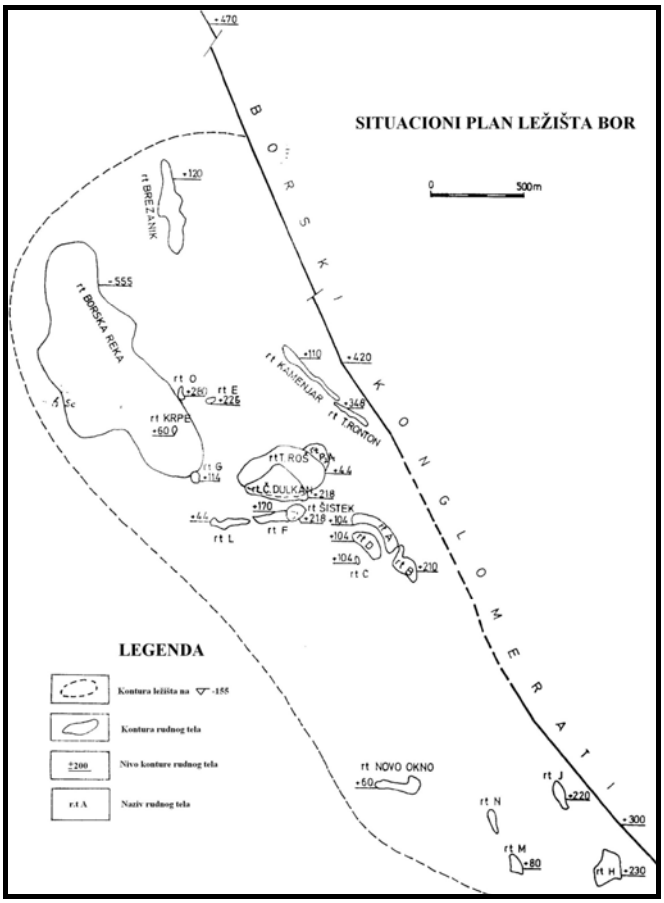
Ležište bakra i zlata Bor – „Tilva Roš“, nalazi se se u centralnom delu istoienog rudnog polja Bor. Ležište se nalazi na istočnom obodu grada Bor, pruža se SZ-JI u dužini oko 5 km, a u širinu oko 500 m.

Osnovna karakteristika borskog ležišta je prisustvo više desetina rudnih tela različitih razmera i strukturno-teksturnog tipa orudnjenja, nastalih u periodu gornje krede-paleogen, u složenim procesima strukturno-geološkog uobličavanja TMK. U tom prostoru je dosad indentifikovano 30 rudnih tela, koja su razvrstana u tri grupe: rudna tela severozapadnog, centralnog i jugoistočnog dela ležišta (slika 1).

Najveći broj rudnih tela nalazi se u centralnom delu ležišta, gde se istovremeno nalaze najveće količine bakra u borskom ležištu. Mineralizovani sistem u ovom delu ležišta dug je oko 2 km. Rudna tela centralnog dela ležišta su: rudno telo Čoka Dulkan, grupa 5 rudnih tela Tilva Mika (1, A, B, C, D), rudno telo E, rudno telo F, rudno telo Tilva Ronton, rudno telo Šistek, rudno telo Kamenjar, rudno telo G, rudno telo Silifikacija, rudno telo L, rudno telo Tilva Roš, rudno telo P2A, rudno telo O, rudno telo Kamenjar 2, rudno telo Krpe, rudno telo Cementacija, rudno telo T, T1. td.

U severozapadnom delu Borskog ležišta bakra poznato je za sada, samo jedno rudno telo – Brezanik a potencijalnost je interesantna dalje u pravcu kriveljskog kamena. U jugoistočnom delu borskog ležišta nalaze se: rudno telo Novo okno, rudno telo H, rudno telo J, rudno telo I, rudno telo M, rudno telo N i rudno telo Borski Potok.Skoro sva naznačena rudna tela ležišta u sklopu “Tilva Roš” – su izvađena do nivoa kote -40, odakle se nastavlja rudno ležište Borska Reka.

Rudno ležište Borska reka - nalazi se u krajnjim severozapadnim delovima ležišta Bor, a sl. br. 1. Smešteno je u intenzivno hidrotermalno izmenjenim andezitima i njihovim vulkanitima. Prema razmerama, porfirsko ležište Borska reka raspolaže sa preko 1.000.000 tona bakra. Prosečni sadržaj bakra kreće se oko 0,55%. Karakteriše ga štokverkno-impregnacioni tip orudnjenja. Njegov pravac pružanja je SZ-JI, zaleže prema zapadu, odnosno, jugozapadu pod uglom 45^0-55^0. Maksimalna dužina rudnog tela je 1.410 m. izmerena na K-395. Maksimalna širina od 635 m. izmerena je na istom nivou, a prosečna je oko 360 m.

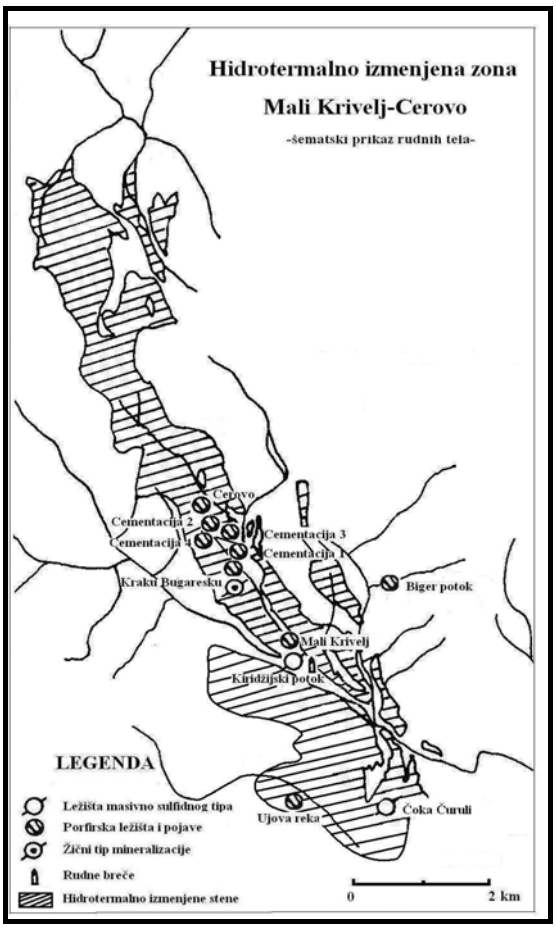


Sl. 1. *Prostorni razmeštaj rudnih tela ležišta Bor*

Ležište bakra Veliki Krivelj nalazi se na udaljenosti oko 4 km severoistočno od Bora. Ležište bakra Veliki Krivelj pripada porfir-skim ležištima velikih razmera, karakteriše se štokverkno-impregnacionim tipom orudnje-nja i zonalnim rasporedom hidrotermal-nih alteracija. Ovo ležište nosi sva obeležja koja su karakteristična za porfirska ležišta, smeštena u vulkanoge-nim kalko - alkalnim komleksima. Porfirska mineralizacija bakra je smeštena u zoni izgrađenoj od hidroter-malno izmenjenih andezitskih stena, dugoj preko 2 km, maksimalne širine oko 700 m (prosečna širine 400 m), koja zaleže ka jugozapadu.

Rudno polje Cerovo

Rudno polje Mali Krivelj – Cerovo, nalazi se desetak kilometara severozapadno od Bora, prostire se od Čoke Čuruli i Kriveljskog kamena na jugu, preko samog sela Mali Krivelj do Balačonje na severu, zahvatajući područje izvorišnog dela Božine reke i područje sliva Cerove reke. U okviru ovog rudnog polja nalazi se nekoliko ležišta i pojava mineralizacije bakra, među kojima su najznačajnija: ležište Cerovo i ležište Kraku-Bugaresku- Cementacija (sl.br.2).



Sl. 2. *Šematski prikaz rudnih tela u rudnom polju Mali Krivelj - Cerovo*

Ležište Cerovo nalazi se na oko 13 km, vazdušne linije, severozapadno od centra Bora, u dolini Cerove reke, između brda Šušulajka i Kraku Bugaresku sa zapadne i jugo-zapadne strane, sa najvišim kotama +667 m i +612 m. i brda Drenova sa istočne strane, sa najvišom kotom +739 m. Nivo Cerove reke je na koti +460 m. Neposredno iznad ležišta nalazi se trasa regionalne železničke pruge Bor-Majdanpek (dužina trase koja prolazi iznad ležišta je 800 m), i trasa visokonaponskog dalekovoda. Pored navedenih objekata, u prostoru iznad ležišta nalazi se železnička stanica i jedan tunel, (dužina tunela je 300 m), koji je smešten na severnom obodu, kao i železnički most na južnom obodu ležišta.

Ležište bakra Kraku Bugaresku - cementacija, nalazi se na oko 13 km, vazdušnom linijom, severozapadno od Bora, i na 2 km od najbližeg sela Mali Krivelj.

Iznad siromašne porfirske mineralizacije, u reonu Kraku Bugaresku, SZ od Malog Krivelja, obrazovano je ležište sekundarnog sulfidnog obogaćenja, Cementacija – Kraku Bugaresku. U okviru ležišta Cementacija – Kraku Bugaresku, U konturi graničnog

sadržaja bakra 0,2% Cu, izdvajaju se 3 rudna tela: Cementacija 1, Cementacija 2-4, i Cementacija 3, koji predstavljaju delove jednog ležišta, naknadno erozijom razdvojenih. Rudno telo „C2 – C4“ je izdeljeno u dva segmenta na bazi distribucije, odnosno sadržaja oksidnog bakra, pri čemu segment „C4“ predstavlja deo sa povišenim sadržajem oksidnog bakra (iznad 10% procentualnog učešća u ukupnom bakru).

Mineralizacija bakra smeštena je u zoni izgrađenoj od hidrotermalno izmenjenih stena, dugoj oko 2 km, sa maksimalnom širinom oko 800 m (prosečno oko 600 m), koja zaleže ka istoku. Ležište je, u horizontalnoj projekciji (u konturi graničnog sadržaja 0,05% Cu), izduženo u pravcu SZ – JI. U vertikalnoj projekciji je nepravilnog oblika i zaleže ispod kote +5 m.

Rudno polje Majdanpek

Rudno polje Majdanpek nalazi se na severnom delu senonskog rova i TMK. U okviru ovog polja najznačajnija ležišta su: Južni revir, Severni revir.

Ležište Južni revir je najveće ležište u majdanpečkom rudnom polju i tipično je porfirsko ležište. Duža osa pravca pružanja sever-jug iznosi preko 2km. Moćnost (debljina) rudnog tela (osa istok-zapad) se kreće od 270 do 350 m (srednje 300 m) na višim etažama (+110), da bi se sa povećanjem dubine redukovala na 250 do 170 m (nivo –100 m).

Porfirsko orudnjenje je deponovano u hidrotermalno izmenjenim andezitima, gnajsgranitima i gnajsevima amfibolitske facije.

Ležište Severni Revir je drugo po veličini ležište u majdanpečkom rudnom polju i u njemu se nalaze:

- porfirska rudna tela: „Centralno rudno telo“ i „Dolovi-1“;
- Cu-piritska rudna tela: „Dolovi-2“ i „Stari Dušan“.
- polimetalično rudno telo Tenka

Lokalizovno je u krednim andezitima, delom i u malim intruzijama, granit-gnajsevima i jurskim krečnjacima. Stene, u kojima je smeštena rudna mineralizacija, su pod uticajem hidrotermalnih rastvora pretrpele intenzivne izmene. Hidrotermalne alteracije magmatskih stena i kristalastih škriljaca, koje su u tesnoj vezi sa stvaranjem porfirske mineralizacije bakra, obuhvataju nekoliko facija alteraci: kalijsku-silikatnu metasomatozu, sericitizaciju, silifikaciju, hloritizaciju, argilitizaciju.

Rudno telo Tenka nalazi se u severnom obodnom delu severnog revira, koje je po svojim tektonskim, fizičko-mehaničkim i termodinamičkim uslovima, bilo pogodno za deponovanje olovo-cinkove mineralizacije sa promenljivim sadržajima zlata, srebra, bakra i pirita. Ima oblik nepravilnog trapeza pruzanja S-J, čija je duža stranica oko 650 m, a kraća od 150 do 250 m. U zapadnom pojasu Tenke lokalizovana je polimetalična sulfidna mineralizacija.

Rudno polje Vlaole-Jasikovo

U rudnom polju Vlaole - Jasikovo geološkim istraživanjima otkriveno je ležište Čoka Marin sa tri rudna tela - Čoka Marin 1, Čoka Marin 2 i Čoka Marin 3.

Ležište Čoka Marin nalazi se vazdušnom linijom na oko 14 km južno od Majdanpeka i na oko 2,5 km od sela Leskovo, Jasikovo i Vlaole.

Ležište Čoka Marin je smešteno unutar hidrotermalno izmenjene zone andezita, pravca pružanja SZ-JI. Rudonosna zona duga je oko 2,5 km. Ležište je istraživano istražnim bušotinama dubine između 45 i 600 m, pri čemu su istražena i okunturena tri rudna tela.

Rudno telo Čoka Marin 1, u morfogenetskom smislu pripada masivno sulfidnom orudnjenju, sa izraženom mineralizacijom zlata, koju prate štokverkno i štokverkno-impregnaciona orudnjenjnja. Zlato se javlja kao samorodno, u vidu individualnih zrna, vezano za minerale jalovine (kvarc i ređe barit), ili kao dispergovana metalna faza u sulfidnim mineralima. U okviru masivno

sulfidne mineralizacije jasno se mogu izdvojiti: masivno sulfidni-polimetalični i masivno sulfidni tip orudnjenja. U okviru masivnosulfidnog-polimetaličnog orudnjenja zastupljeni su zlato (sadržaji Au >10 g/t) i sulfidi olova, cinka i bakra (sadržaji Pb, Zn i Cu>1 %), dok se masivno sulfidnom orudnjenju javljaju zlato (sadržaji Au >1,5 g/t), i sulfidi bakra i podređeno olova u cinka (sadržaj Cu>1 %, dok su sadržaji Pb i Zn <1%). U okviru štokverknog i štokverkno-impregnacionog orudnjenja javlja se zlato sa sadržajem i do 1 g/t, najčešće oko 0,6 g/t, bakar, oko 0,3 %, olovo i cink, oko 0,4 %.

Rudno telo Čoka Marin 2 nalazi se jugoistočno od rudnog tela Čoka Marin 1, na oko 1,5 km. Istraženo je vertikalnim i kosim istražnim bušotinama, po mreži 50×50 i 50×40m, u periodu od 1983-1999. godine. Ukupno je izbušeno 31 bušotina, odnosno 12.624 m bušenja.

Rudno telo Čoka Marin 3 nalazi se na 2,2 km jugoistočno od rudnog tela "Čoka Marin 1", odnosno 0,7 km južno od rudnog tela Čoka Marin 2. Istraživanje rudnog tela izvođeno je sistemom vertikalnih i kosih istražnih bušotina, po mreži 50×50 m. Istraživanja su izvedena tokom 1989-1999. godine. Izbušene su ukupno 8 bušotine, odnosno 2.554 m.

Tabelarni prikaz bilansnih rudnih rezervi eksploatacionog rudnog polja RT-a Bor;

Tabela 1. *Proračun rezervi „B+C_1" kategorije rudnog tela „Čoka Marin 1" metodom vertikalnih preseka po klasama kvaliteta u štokverkno-impregnacionom tipu orudnjenja*

Kklasa	Količina rude (t)	Srednji sadržaj Au (g/t)	Količina metala Au (kg)	Srednji sadržaj Ag (g/t)	Količina metala Ag (kg)	Srednji sadržaj Cu (%)	Količina metala Cu (t)	Srednji sadržaj S (%)	Koli-čina S (t)	Srednji sadržaj Pb (%)	Količina metala Pb (t)	Srednji sadržaj Zn (%)	Količina metala Zn (t)
A	B	C	D	E	F	G	H	I	J	K	L	M	N
0,0-0,5 g/t Au	141.578	0,459	65	5,114	724	0,247	350	5,773	8.174	0,660	934	0,403	571
0,5-1,0 g/t Au	74.720	0,501	37	3,824	286	0,182	137	7,498	5.636	0,163	122	0,194	146
1.0-1.5 g/t Au	58.078	1,178	68	6,830	397	0,592	344	12,783	7.424	0,139	81	0,186	108

Vanbilansne rezerve C1 kategorije iznose 202.156 t rude sa srednjim sadržajem Au 0,633 g/t, Ag 14,429 g/t, Cu 0,397%, Zn 0,573% i Pb 0,428%. Istraživanjem rudnog tela pre svega po dubini ove rezerve najvećim delom mogu se prevesti u bilansne rezerve.

Tabela 2. *Geološke rezerve rude bakra i zlata RTB-a*

Ležište/rudno telo	Granični sadržaj	Kategorija rezervi	Q (t)	Cu (t)	Cuox (t)	Cu-sulfid (t)	Au (kg)	Ag (kg)	Zn (t)	Pb(t)	Mo(kg)
Cerovo	0,20% Cu	B+C1	319.377.890	990.392	-	-	46.168	275.399			-
Kraku Bugaresku-cementacija	0,20% Cu	B+C1	70.092.712	208.235	17.887	190.348	6.104	83.983	-	-	-
Veliki Krivelj	0,15% Cu	B+C1	621.921.288	1.978.514	-	-	34.719	151.516	-	-	10.135.650
Borska reka	0,30% Cu	A+B+C1	556.910.629	3.151.164	-	-	114.619	932.080	-	-	20.631.532
Južni revir	0,15% Cu	A+B+C1	463.127.844	1.465.556	-	-	82.156	632.274	-	-	-
Severni revir	0,10% Cu	B+C1	176.356.633	524.789	-	-	41.928	305.021	-	-	-
Tenka3	0,10% Cu	C1	17.626.856	48.966	-	-	3.307	29.175	-	-	-
(Tenka1+Tenka2)	0,50% Zn+Pb	B+C1	1.435.930	3.176	-	-	908	12.988	23.422	6.445	-
Čoka Marin		B+C1	673.016	7.531	-	-	1.859	17.167	5.771	3.796	-

Tabela 3. *Bilansne rezerve rude bakra i zlata RTB-a*

Ležište/rudno telo	Granični sadržaj	Kategorija rezervi	Q (t)	Cu (t)	Cuox (t)	Cu-sulfid (t)	Au (kg)	Ag (kg)	Zn (t)	Pb(t)	Mo(kg)
Cerovo	0,20% Cu	B+C1	150.138.317	492.136	-	-	20.235	145.809			-
Kraku Bugaresku-cementacija	0,20% Cu	B+C1	45.800.129	141.353	11.121	130.232	130.232	11.121	-	-	-
Veliki Krivelj	0,15% Cu	B+C1	474.291.085	1.533.821	-	-	26.343	117.721	-	-	7.453.802
Borska reka	0,30% Cu	A+B+C1	319.969.179	1.601.091	-	-	65.232	517.488	-	-	11.447.399
Južni revir	0,15% Cu	A+B+C1	246.947.462	834.492	-	-	47.184	348.287	-	-	-
Severni revir	0,10% Cu	B+C1	138.431.743	423.597	-	-	35.332	252.488	-	-	-
Tenka3	0,10% Cu	C1	8.073.532	27.085	-	-	1.798	12.910	-	-	-
(Tenka1+Tenka2)	0,50% Zn+Pb	B+C1	918.398	2.175	-	-	600	8.497	16.331	4.474	-
Čoka Marin	Au	B+C1	470.860	6.729	-	-	1.731	14.250	4.612	2.930	-

Tabela 4. *Vanbilansne rezerve rude bakra i zalata RTB-a*

Ležište/rudno telo	Granični sadržaj	Kategorija rezervi	Q rude (t)	Cu (t)	Cuox (t)	Cu-sulfid (t)	Au (kg)	Ag (kg)	Zn (t)	Pb(t)	Mo(kg)
Cerovo	0,20% Cu	B+C1	169.239.573	498.256	-	-	25.933	129.590			-
Kraku Bugaresku-cementacija	0,20% Cu	B+C1	24.292.583	66.882	6.766	60.116	2.262	29.161	-	-	-
Veliki Krivelj	0,15% Cu	B+C1	147.630.203	444.693	-	-	8.376	33.795	-	-	2.681.848
Borska reka	0,30% Cu	A+B+C1	236.941.450	1.550.073	-	-	49.387	414.592	-	-	9.184.133
Južni revir	0,15% Cu	A+B+C1	216.180.382	631.064	-	-	34.972	283.987	-	-	-
Severni revir	0,10% Cu	B+C1	37.924.890	101.192	-	-	6.596	52.533	-	-	-
Tenka3	0,10% Cu	C1	9.553.324	21.881	-	-	1.509	16.265	-	-	-
(Tenka1+Tenka2)	0,50% Zn+Pb	B+C1	517.532	1.001	-	-	308	4.491	7.091	1.971	-
Čoka Marin		B+C1	202.156	802	-	-	128	2.917	1.159	866	-

ZAKLJUČAK

RTB Bor raspolaže značajnom mineralno-sirovinskom bazom, odnosno rezervama bakra i zlata, koje omogućavaju eksploataciju za više decenija. Ekonomičnost rezervi rude bakra su u funkcionalnoj zavisnost pre svega od cene bakra na LMI berzi, potražnje bakarnih proizvoda, svetske proizvodnje bakra i troškova valorizaije rude bakra.

Prema sadašnjim sagledavanjima raspoloživih kapaciteta i infrastrukturno raspoloživih mogućnosti svih aktivnih ležišta RTB-a uz dodatna ulaganja od oko 250-300 miliona eura, moguće je povećati kapacitet proizvodnje katodnog bakra sa sadašnjih od 25.000,00 tona od oko 60.000,00 tona godišnje i taj kontunuitet održavati oko deset godina, pri čemu treba još uložiti oko 350 miliona eura investicija za narednih deset godina da se taj kapacitet održi za dodatnih deset godina.

Osim istraženih i overenih rezervi bakra u rudnim telima i ležištima koja nisu u eksploataciji pored bilansnih bilansnih rezervi u ležištima koja se eksploatišu postoje potencijalni prostori za dalja istraživanja radi pronalaženja dodatnih količina rude bakra. Stepen istraženosti u okviru samih ležišta nije ravnomeran, odnosno postoje delovi ležišta koji zahtevaju pogušćenje mreže istražnih radova, praćenih hidrogeološkim, inženjersko-geološkim, tehnološkim i drugim ispitivanjima.

Detaljnim istraživanjem nedovoljno istraženih delova ležišta, uvođenjem novih metoda eksploatacije, savremenijih tehničko - tehnoloških metoda u pripremi i preradi bakra, otvara se mogućnost da se veći deo vanbilansnih rezervi prevede u bilansne.

Deo vanbilansnih rezervi, sa sadašnjom cenom 8000 Eura/t bakra i 45.000 eura/kg

zlata na svetskoj berzi metala, novom tehničko-ekonomskom ocenom mogao bi da se prevede u bilansne. Ovakav trend visokih cena bakra i zlata, takođe utiće i na smanjenje graničnog sadržaja, što može dovesti do značajnog povećanja rezervi mineralne sirovine.

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COPPER AND GOLD RESERVES IN THE EXPLORATORY – MINING FIELD OF RTB BOR**

Abstract

RTB has the significant mineral-raw materials base or the reserves of copper and gold, which allow the exploitation for several decades. The exploratory-mining fields of RTB are located within the Bor metallogenic zone, which is spatially and genetically coincides with the "Timok Magmatic Complex" (TMK), and includes the areas of Bor, Cerovo, Majdanpek and Čoka Marin ore fields. The cost-effectiveness of copper ore reserves are in the functional dependence primarily of the copper price on the LME stock market, copper product demand, world production of copper and costs of copper ore valorization. By detailed explorations the insufficiently explored parts of deposits, introduction the new mining methods, modern technical-technological methods for copper preparation and processing, there is a possibility that the most of off-balance reserves would be transferred into the balance reserves. The trend of high prices of copper and gold also helps the reduction of limit content, which could led to a significant increase in the reserves of mineral resources.

Keywords: *Geological-economical evaluation of ore reserves, copper and gold deposit Bor, ore deposit, ore field, mineral resources, exploratory-mining field of RTB Bor*

INTRODUCTION

Mineral resources of the exploratory-mining field of RTB Bor have been researched for more than a century, and in the last fifty years the explorations as well as the copper ore are very intensive. Large reserves of copper and gold ore were pro-

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vided within the Timok Magmatic Complex and rich experiences were gained in gold and copper evaluation. The exploratory-mining fields of RTB are located within the Bor metallogenic zone, which is spatially and genetically coincides with the "Timok Magmatic Complex" (TMK), and includes the areas of the following ore fields: Bor Cerovo, Majdanpek and Čoka Marin. Economy of copper ore mining is in the functional dependence on: the capacity of mining, recovery of metals in treatment, metal prices and costs copper ore evaluation, so that the Bor ore containing an average of 0.3 - 0.6 % copper belongs to the low-grade ore, but the favorable copper price with controlling the operating costs of processing and recovery as well as developed infrastructure in the mines, enables the cost-effective production of copper in the next few decades.

ORE FIELD BOR

The ore field Bor is located in the eastern part of the Bor metallogenic zone in the spatial and genetic relation with the Upper Cretaceous magmatic complexes as well as: the copper and gold deposit Bor (Tilva Ros with numerous ore bodies that are mostly mined), the Bor River and the Bor Stream.

Copper and Gold Deposit Bor - "Tilva Ros" is located in the central part of the same named ore field Bor. The deposit is located on the eastern edge of the town of Bor, in the NW-SE direction in the length of about 5 km and width of about 500 m.

The main feature of the Bor deposit is the presence of dozens ore bodies of different scales and structural-textural type of mineralization, formed in the Upper Cretaceous-Paleogene period, in the complex processes of structural-geological shaping the TMC. In this area, 30 ore bodies have been indentified so far, which are classified into three groups: the ore bodies of northwest, central and south-eastern part of the deposit (Figure 1).

The largest number of ore bodies is located in the central part of the deposit with the largest quantities of copper in the Bor deposit. Mineralized system in this part of deposit is long about 2 km. Ore bodies of the central part of deposit are: the ore body Čoka Dulkan, a group of five ore bodies Tilva Mika (1, A, B, C, D), the ore body E, the ore body F, the ore body Tilva Ronton, the ore body Šistek, the ore body Kamenjar ,the ore body G, the ore body Silifikacija, the ore body L, the ore body Tilva Ros, the ore body P2A, the ore body O, the ore body Kamenjar 2, the ore body Krpe, the ore body Cementacija, the ore body T, the ore body T1, etc.

In the northwestern part of the Bor copper deposit, only one ore body - Brezanik is known until now, and a potentiality is still interesting in the direction of the Krivelj Stone. In the southeastern part of the Bor deposit are : the ore body New Shaft, the ore body, H, the ore body J, the ore body I, the ore body M, the ore body N and the ore body Bor Stream. Almost all indicated ore bodies of the deposit within "Tilva Ros" were mined to the level of elevation -40, from here the ore deposit Bor River is continued.

Ore Deposit Bor River is located in the extreme northwest parts of the Bor deposit, Figure 1. It is located in the intensely hydrothermally altered andesites and their volcanics. According to the scales, the porphyritic Bor River deposit has more than 1,000,000 tons of copper. The average copper content is about 0.55 %. It is characterized by the stockwork-impregnation type of mineralization. Its direction is the NW-SE, dipping to the west, i.e. the southwest at angle of 45°-55°. Maximum length of the ore body is 1410 m, measured at K-395. Maximum width of 635 m was measured at the same level, and the average is about 360 m.

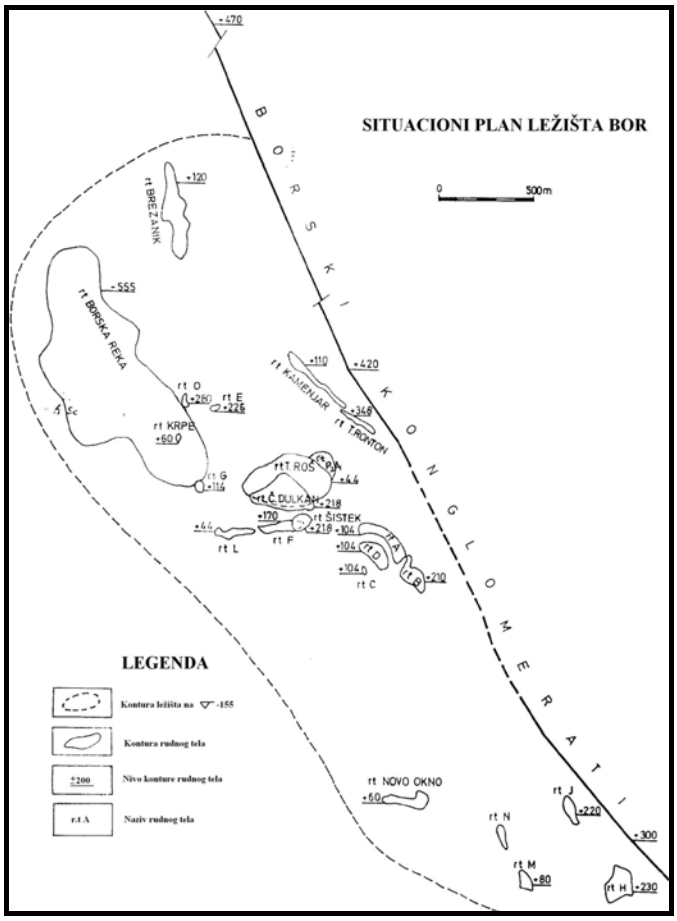

Fig. 1. *Spatial distribution of the ore bodies of the Bor deposit*

Copper Deposit Veliki Krivelj is located at a distance of about 4 km northeast of bor. the copper deposit veliki krivelj belongs to the porphyritic deposits of large scales, characterized by the stockwork-impregnation type of mineralization and zonal distribution of hydrothermal alterations. This deposit has all features that are characteristic for the porphyritic deposits, located in the volcanogenic calc-alkaline complexes. Porphyritic copper mineralization is situated in a zone of hydrothermally altered andesite rocks, over 2 km long with maximum width of about 700 m (average width of 400 m), dipping to the southwest.

Ore field Cerovo

The ore body Mali Krivelj – Cerovo is located about ten kilometers northwest of Bor, extending from Čoke Čuruli and Krivelj Stone in the south, through the village of Mali Krivelj to Balačonje in the north, including the area of source part of the Božina River and the basin area of the Cerova River. Within this ore field, there are several deposits and occurrence of copper mineralization, the most important are: the deposit Cerovo and the deposit Kraku-Bugaresku-Cementacija (Figure 2).

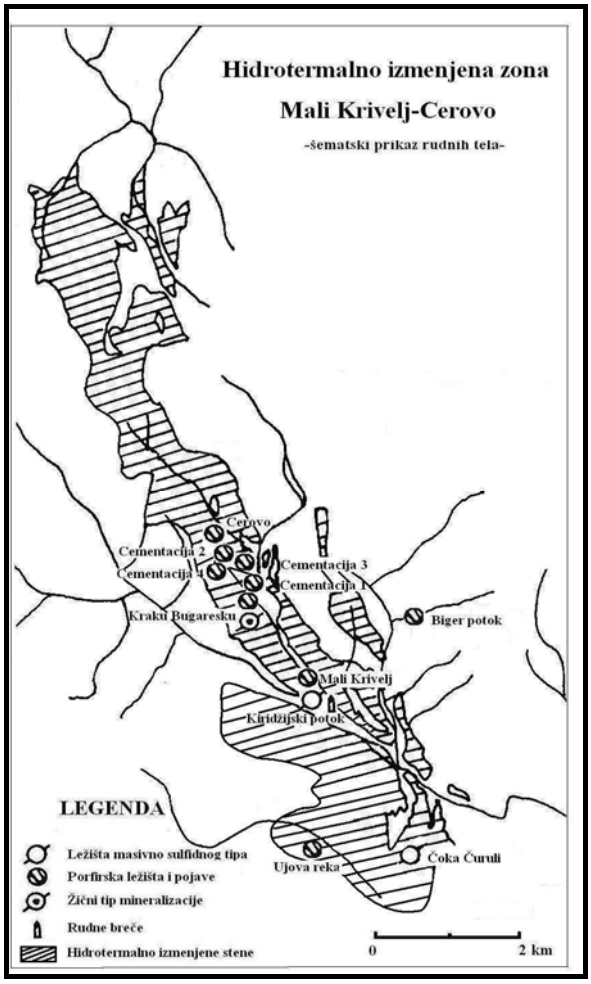

Fig. 2. *Schematic view of the ore bodies in the ore field Mali Krivelj – Cerovo*

Deposit Cerovo is located about 13 km by air line, north-west of the center of Bor, in the valley of the Cerova River, between the hill Šušulajka and Kraku Bugaresku to the west and south-west side, with the highest elevations of +667 m and +612 m and the hill Drenova to the east, with the highest elevation of +739 m. The Cerova River level is at elevation of +460 m. Directly, above the deposit, is the regional railroad tracks Bor-Majdanpek (length of the route that passes over the deposit is 800 m), and the high-voltage power line. In addition to these facilities, in the area above the deposit, there is a railway station and a tunnel (tunnel length is 300 m), located on the northern edge, as well as the railway bridge on the southern edge of the deposit.

Copper Deposit Kraku Bugaresku is located about 13 km by air line, north-west of Bor, and 2 km from the nearest village Mali Krivelj.

Above the poor mineralization, in the region Kraku Bugaresku, NW of Mali Krivelj, the deposit of secondary sulphide

enrichment, Cementacija - Kraku Bugaresku, was formed. Within the deposit Cementacija - Kraku Bugaresku, in a contour of limit copper content 0.2% Cu, the three ore bodies are separated: Cementacija1, Cementacija 2-4 and Cementacija 3, which are parts of one deposit, subsequently separated by erosion. The ore body "C2 - C4" is divided into two segments based on distribution, i.e. content of oxide copper, where the segment "C4" is a part of high content of oxide copper (above 10% of percentage participation in total copper).

Copper mineralization is situated in the zone built of hydrothermally altered rocks, about 2 km long with maximum width of about 800 m (average about 600 m), dipping to the east. The deposit is in the horizontal projection (in a contour of limit Cu content of 0.05%), elongated in the direction of NW - SE. In the vertical projection, it is irregular in shape and dipping below the level of +5 m.

Ore field Majdanpek

The ore field Majdanpek is located in the northern part of the Senonian trench and TMC. In this field, the most important deposits are: South Mining District and North Mining District.

South Mining District the largest deposit in the ore field Majdanpek and it is typical porphyritic deposit. The longer axis of direction extending from north to south is more than 2 km. Thickness of the ore body (east-west axis) ranges from 270 to 350 m (average 300 m) at the upper benches (+110) and it is reduced with increasing depth from 250 to 170 m (-100 m level) .

Porphyritic mineralization was deposited in hydrothermally altered andesites, gneiss granites and gneisses of amphibolitic facies.

North Mining District is the second largest deposit in the Majdanpek ore field and it contains:

- porphyritic ore bodies: "Central ore body" and "Dolovi-1",
- Cu-pyrite ore bodies: "Dolovi-2" and "Old Dusan",
- Polymetallic ore body Tenka

It is localized in the Cretaceous andesites, partly also in small intrusions, granite-gneisses and Jurassic limestones. Rocks, which include the ore mineralization, have undergone the intensive changes under the influence of hydrothermal solutions. Hydrothermal alterations of magmatic rocks and crystalline schists, which are closely related with the formation of porphyritic copper mineralization, include several facies of alterations: potassium-silicate metasomatism, sericitization, silicification, chloritization and argillitization.

The ore body Tenka is located in the northern peripheral part of the North Mining District, which according to its tectonic, physical-mechanical and thermodynamic conditions, was suitable for disposal the lead-zinc mineralization with variable contents of gold, silver, copper and pyrite. It has a form of irregular trapezoid, extending the NS, with longer edge of about 650 m, and shorter edge from 150 to 250 m. In the western zone of Tenka, the polymetallic sulfide mineralization is localized.

Ore field Vlaole-Jasikovo

The deposit Čoka Marin, discovered in the ore field Vlaole-Jasikovo by geological prospecting works, includes three ore bodies: Čoka Marin 1, Čoka Marin 2 and Čoka Marin 3.

Deposit Čoka Marin is located about 14 km by air line to the south of Majndapek and about 2.5 km of the villages Leskovo, Jasikovo and Vlaole.

The deposit Čoka Marin is situated within the hydrothermal altered zone of andensite, extending the NW-SE. The mineralization zone is about 2.5 km long.

The deposit was explored by prospecting-drill holes, depth between 45 and 600 m, where three ore bodies were explored and contoured.

The ore body Čoka Marin 1, in a morphogenetic sense, belongs to the massive sulphide mineralization, with significant gold mineralization, accompanied with stockwork and mineralizations. Gold occurs as native, in the form of individual grains, bonded to the gangue minerals (quartz and rarely barite), or as a dispersed metal phase in sulphide minerals. Within the massive sulphide mineralization, the followings can be clearly distinguished: massive sulphide-polymetallic and massive sulphide type of mineralization. Within the massive sulphide-polymetallic mineralization, the followings are present: gold (Au contents >10g/t) and sulphides of lead, zinc and copper (Pb, Zn and Cu >1%), while in the massive sulphide mineralization, the followings are present: gold (Au contents > 1.5 g/t), and sulphides of copper and subordinated lead in zinc (Cu content > 1%, until Pbi Zn contents <1%). Within the stockwork and stockwork impregnation mineralization, the gold occurs with content up to 1g/t, usually copper of about 0.6 g/t, lead 0.3% and zinc of about 0.4%.

The ore body Čoka Marin 2 is located to the southeast of the ore body Čoka Marin 1, about 1.5 km. It was explored by the vertical and oblique prospecting drill holes per network 50×50 and 50×40m, in the period 1983-1999. Total of 31 drill holes was drilled, i.e. 12,624 m of drilling.

The ore body Čoka Marin 3 is located 2.2 km to the southeast of the ore body Čoka Marin 1, that is 0.7 km south of the ore body Čoka Marin 2. Exploration of the ore body by the system of vertical and oblique prospecting drill holes per network on the 50 x 50 m. Explorations were carried out during 1989-1999. Total of 8 drill holes was drilled, i.e. 2554 m.

Tabular presentation the balance reserves of mineral exploitation the ore body RT Bor.

Table 1. *Calculation of reserves, B+C_1 category, the ore body Čoka Marin 1 by the method of vertical cuts per quality classes in stockwork-impregnation type of mineralization*

Class	Ore quantity	Mean cont. Au	Metal quant. Au	Aver. Cont. Ag	Metal quant. Ag	Mean cont. Cu	Metal quant. Cu	Mean cont. S	Quantity S	Mean cont. Pb	Metal quant. Pb	Mean cont. Zn	Metal quant. Zn
	(t)	(g/t)	(kg)	(g/t)	(kg)	(%)	(t)	(%)	(t)	(%)	(t)	(%)	(t)
A	B	C	D	E	F	G	H	I	J	K	L	M	N
0.0-0.5 g/t Au	141,578	0.459	65	5.114	724	0.247	350	5.773	8,174	0.660	934	0.403	571
0.5-1.0 g/t Au	74,720	0.501	37	3.824	286	0.182	137	7.498	5,636	0.163	122	0.194	146
1.0-1.5 g/t Au	58,078	1.178	68	6.830	397	0.592	344	12.783	7,424	0.139	81	0.186	108

The off-balance reserves, C1 category, amount 202,156 t of ore with the average content of Au 0.633 g/t, Ag 14.429 g/t, Cu 0.397%, Zn 0.573% and Pb 0.428%. By exploration of the ore body primarily in depth, these reserves could be transferred into the balance reserves.

Table 2. *Geological reserves of coper and gold ore of RTB*

Deposit/ore body	Limit content	Reserve category	Q ore (t)	Cu (t)	Cu-ox (t)	Cu-sulphide (t)	Au (kg)	Ag (kg)	Zn (t)	Pb (t)	Mo (kg)
Cerovo	0.20% Cu	B+C1	319,377,890	990,392	-	-	46,168	275,399			-
Kraku Bugaresku-Cementacija	0.20% Cu	B+C1	70,092,712	208,235	17,887	190,348	6,104	83,983	-	-	-
Veliki Krivelj	0.15% Cu	B+C1	621,921,288	1,978,514	-	-	34,719	151,516	-	-	10,135,650
Bor River	0.30% Cu	A+B+C1	556,910,629	3,151,164	-	-	114,619	932,080	-	-	20,631,532
South Mining District	0.15% Cu	A+B+C1	463,127,844	1,465,556	-	-	82,156	632,274	-	-	-
North Mining District	0.10% Cu	B+C1	176,356,633	524,789	-	-	41,928	305,021	-	-	-
Tenka3	0.10% Cu	C1	17,626,856	48,966	-	-	3,307	29,175	-	-	-
(Tenka1+Tenka2)	0.50% Zn+Pb	B+C1	1,435,930	3,176	-	-	908	12,988	23,422	6,445	-
Čoka Marin		B+C1	673,016	7,531	-	-	1,859	17,167	5,771	3,796	-

Table 3. *Balance reserves of copper and gold ore of RTB*

Deposit/ore body	Limit content	Reserve category	Q ore (t)	Cu (t)	Cu-ox (t)	Cu-sulphide (t)	Au (kg)	Ag (kg)	Zn (t)	Pb (t)	Mo (kg)
Cerovo	0.20% Cu	B+C1	150,138,317	492,136	-	-	20,235	145,809			-
Kraku Bugaresku-Cementacija	0.20% Cu	B+C1	45,800,129	141,353	11,121	130,232	130,232	11,121	-	-	-
Veliki Krivelj	0.15% Cu	B+C1	474,291,085	1,533,821	-	-	26,343	117,721	-	-	7,453,802
Bor River	0.30% Cu	A+B+C1	319,969,179	1,601,091	-	-	65,232	517,488	-	-	11,447,399
South Mining District	0.15% Cu	A+B+C1	246,947,462	834,492	-	-	47,184	348,287	-	-	-
North Mining District	0.10% Cu	B+C1	138,431,743	423,597	-	-	35,332	252,488	-	-	-
Tenka3	0.10% Cu	C1	8,073,532	27,085	-	-	1,798	12,910	-	-	-
(Tenka1+Tenka2)	0.50% Zn+Pb	B+C1	918,398	2,175	-	-	600	8,497	16,331	4,474	-
Čoka Marin	Au	B+C1	470,860	6,729	-	-	1,731	14,250	4,612	2,930	-

Table 4. *Off-balance reserves of copper and gold ore of RTB*

Deposit/ore body	Limit content	Reserve category	Q ore (t)	Cu (t)	Cu-ox (t)	Cu-sulphide (t)	Au (kg)	Ag (kg)	Zn (t)	Pb (t)	Mo (kg)
Cerovo	0.20% Cu	B+C1	169,239,573	498,256	-	-	25,933	129,590			-
Kraku Bugaresku-Cementacija	0.20% Cu	B+C1	24,292,583	66,882	6,766	60,116	2,262	29,161	-	-	-
Veliki Krivelj	0.15% Cu	B+C1	147,630,203	444,693	-	-	8,376	33,795	-	-	2,681,848
Bor River	0.30% Cu	A+B+C1	236,941,450	1,550,073	-	-	49,387	414,592	-	-	9,184,133
South Mining District	0.15% Cu	A+B+C1	216,180,382	631,064	-	-	34,972	283,987	-	-	-
North Mining District	0.10% Cu	B+C1	37,924,890	101,192	-	-	6,596	52,533	-	-	-
Tenka3	0.10% Cu	C1	9,553,324	21,881	-	-	1,509	16,265	-	-	-
(Tenka1+Tenka2)	0.50% Zn+Pb	B+C1	517,532	1,001	-	-	308	4,491	7,091	1,971	-
Čoka Marin		B+C1	202,156	802	-	-	128	2,917	1,159	866	-

CONCLUSION

RTB has the significant mineral-raw materials base or the reserves of copper and gold, which allow the exploitation for several decades. The cost-effectiveness of copper ore reserves are in the functional dependence primarily of the copper price on the LME stock market, copper product demand, world production of copper and costs of copper ore valorization.

According to the current perception of

available capacities and infrastructure options of all active deposits of RTB with the additional investments of around 250-300 million Euros, it is possible to increase the production capacity of cathode copper from the current 25,000.00 tons of about 60000.00 tons per year and to maintain this continuity for about ten years, with the required investment of about 350 million Euros over the next ten years to maintain this capacity for additional ten years.

In addition to the explored and verified reserves of copper in the ore bodies and deposits that are not in operation, besides the balance reserves in the deposits, which are mined, there are the potential areas for further explorations to find the additional quantities of copper ore. The degree of exploration within the deposits is not very smooth, and there are parts of deposits that require denser network of prospecting works, followed by hydrogeological, engineering-geological, technological and other tests.

By detailed explorations the insufficiently explored parts of deposits, introduction the new mining methods, modern technical-technological methods for copper preparation and processing, there is a possibility that the most of off-balance reserves would be transferred into the balance reserves.

A part of off- balance reserves, with the current price of 8,000 Euro/ t of copper and 45,000 Euro/kg of gold on the world metal market by the new technical-economic evaluation could be transferred into the balance reserves. This trend of high prices of copper and gold also helps the reduction of limit content, which could led to a significant increase in the reserves of mineral resources.

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MINEROLOŠKA, HEMIJSKA I FIZIČKA KARAKTERIZACIJA RUDE BAKRA IZ LEŽIŠTA „SEVERNI REVIR“ RUDNIKA BAKRA MAJDANPEK***

Izvod

U radu su prikazani rezultati mineraloške, hemijske i fizičke karakterizacije uzoraka rude bakra iz ležišta „Severni Revir“ Rudnika bakra Majdanpek. Mineraloška analiza uzoraka je pokazala da su od minerala najzastupljeniji pirit, halkopirit i sfalerit. Na osnovu određenog hemijskog sastava se vidi da je sadržaj bakra u rudi oko 0,6%, sumpora oko 20%, zinka 0,7-0,85% i zlata 4,7 g/t. Od fizičkih karakteristika su određeni granulometriski sastav, meljivost, nasipna masa, gustina i prirodna Ph vrednost.

Analizirajući dobijene rezultate date su sugestije za optimizaciju procesa prerade ove rude u cilju dobijanja što boljih pokazatelja.

Ključne reči: *ruda bakra, Severni Revir, karakterizacija*

1. UVOD

Prve rezerve rude bakra u Majdanpeku, oko 85 miliona tona rude sa prosečnim sadržajem bakra od 0,83%, utvrđene su još pedesetih godina prošlog veka, a sa preradom rude bakra iz ležišta „Južni revir“ krenulo se nakon završetka svih pripremnih radova 1961. godine.

Eksploatacija površinskog kopa „Severni revir“ u Rudniku bakra Majdanpek je počela 1983. godine. U početku je tamo otkopavana samo ruda bakra a kasnije je počelo i sa otkopavanjem rude cinka i olova.

Dosadašnja iskustva, stečena istraživanjima a posebno u toku industrijske prerade

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*** *Autori rada se zahvaljuju Ministarstva prosvete i nauke Republike Srbije. koje je finansijski podržalo istraživanja u okviru projekta TR 33023 „Razvoj tehnologija flotacijske prerade ruda bakra i plemenitih metala radi postizanja boljih tehnoloških rezultata“ finansiranog od strane Ministarstva prosvete, nauke i tehnološki razvoj Republike Srbije*

rude iz ležišta „Severni Revir“ Rudnika bakra Majdanpek, su pokazala da je ovo ležište heterogenog sastava i da sadrži razne tipove rude sa veoma različitim geomorfološkim i mineraloškim karakteristikama, što iziskuje primenu različitih tehnologiju za njihovu preradu. Kao posebni tipovi rude se izdvajaju porfirska ruda, bakrovo-piritična ruda, masivna bakrovo-piritična ruda, polimetalična ruda i limonitska ruda. Sa stanovišta tehnologije prerade, ovi tipovi ruda se znatno razlikuju i predstavljaju mineološki, strukturno-teksturno i tehnološki, mnogo složenije sirovine. Zbog toga je nivo tehnoloških rezultata ostvaren tekućom preradom nekih tipova rude (porfirska ruda, bakrovo-piritična) u industrijskom postrojenju flotacije RBM-a ispod nivoa rezultata ostvarenih dugogodišnjom preradom porfirske rude „Južnog Revira“.

Imajući u vidu ovakve karakteristike ruda „Severnog Revira“, izvršena je laboratorijska karakterizacija uzorka rude “Dolovi”, čija se eksplotacija predviđa u narednom periodu. Cilj ovih ispitivanja je da se definišu mineološke, fizičke i hemijske karakteristike rude bakra iz ležišta Severni Revir na osnovu kojih bi se u naknadnim istraživanjima izvršio i odabir odgovarajuće tehnologije za preradu ove rude.

2. EKSPERIMENTALNI DEO

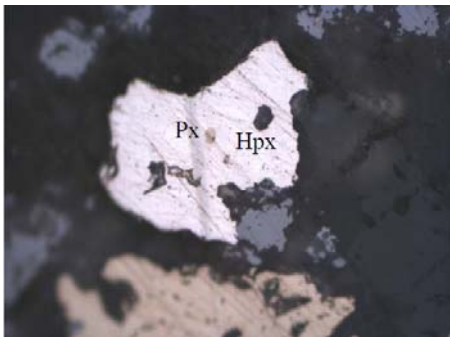
Za ispitivanja je korišćen uzorak rude bakra iz rudnog tela „Dolovi“. Na pripremljenom uzorku je izvršena detaljna karakterizacija. Određene su mineraloške, hemijske i fizičke karakteristike.

1. Mineralni sastav

Na osnovu utvrđenog mineralnog sastava i paragenetskih odnosa, kao i na osnovu strukturno – teksturnih karakteristika minerala, možemo reći da je na lokalitetu Dolovi, prisutna polimetalična mineralizacija masivno sulfidnog tipa.

Pregledom rudnih preparata, koji su izrađeni od komada uzorka, sa lokaliteta Dolovi (Severni Revir – Majdanpek), determinisani su sledeći rudni minerali: pirit, halkopirit, sfalerit, Ti-Fe oksidi (hematit, magnetit), halkozin, kovelin, tenantit. Od nerudnih minerala uočavaju se kalcit i kvarc. Minerali su navedeni na osnovu učestalosti pojavljivanja.

Pirit je najzastupljeniji rudni mineral (slika 1). Obrazuje sitna zrna (retko ispod 1,93 μm) i krupne 100,96 μm ili pokazuje masivne koncentracije. Oblici zrna i polja se kreću od ksenomorfnih do idiomorfnih, kada pokazuje pravilne preseke teseralnog habitusa (pentagondodekaedra i heksaedra). Pirit se obrazuje kristalizacijom kad i I generacija minerala bakra, gvožđa, cinka i olova. Ovaj pirit pokazuje kristalne forme bez uklopaka, koje su potiskivane i zahvaćene mlađim fazama halkopirita, sfalerita, kao i Ti-Fe oksida, a ređe su to halkozin i kovelin. Ove kristalne forme pirita su usled kasnijeg tektonskog dejstva kataklazirane. Ove forme pirita najčešće srastaju sa halkopiritom i Ti-Fe oksidima.



Sl. 1. *Inkluzija halkopirita u piritu (Py), uvećanje 500 x*

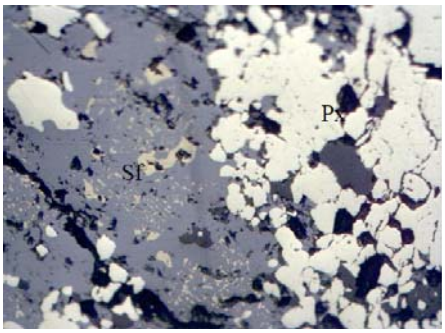
Halkopirit formira sitna do krupna polja (3,16 – 57,51 μm), ksenomorfnog do hipidiomorfnog razvića. Najčešće se javlja u vidu uklopljenih agregata u piritu kao starija faza. Takođe često srasta sa piritom (slika 2), a kao mlađa faza ga i potiskuje. Retko se javlja u vidu izdvajanja po sfaleritu, a još ređe se transformiše u halkozin.

Sl. 2. *Pirit (Py) srastao sa halkopiritom (Hpy), uvećanje 100 x*

Pored halkopirita, od minerala bakra javljaju se halkozin, kovelin i tenantit. Uglavnom su to nepravilna, sitna zrna uklopljena u pirit. Halkozin, kovelin i tenantit se retko javljaju. Halkozin se, osim kao uklopljen u piritu, javlja zajedno sa halkopiritom, kada srastaju ili kada ga halkozin zamenjuje.

Od Pb-Zn minerala javlja se sfalerit. Sfalerit obrazuje ksenomorfne do hipidiomorfna zrna i agregate, veličine 2,65 – 25,12 µm. Najčešće kao mlađa faza srasta sa halkopiritom i potiskuje i uklapa zrna pirita. Sfalerit pokazuje emulzionu strukturu, prilikom neorijentisanog izdvajanja sitnog kapljičastog halkopirita. Retko je uklopljen u piritu.

Od Ti-Fe oksida najčešći su hematit i magnetit. Pokazuju nepravilne do hipidiomorfne oblike različite veličine (od 4,46 do 15,23 µm). Uglavnom su uklopljeni u pirit ili su impregnisani u stensku masu kad samostalno ili sa halkopiritom srastaju ili potiskuju pirit.



Sl. 3. *Izdvajanja u sfaleritu (Sf), pirit (Py), uvećanje 100 x*

2. Hemijski sastav

Hemijski sastav uzoraka je određen na dva načina: odgovarajućim analitičkim metoda i pomoću rentgenske fluorescentne analize.

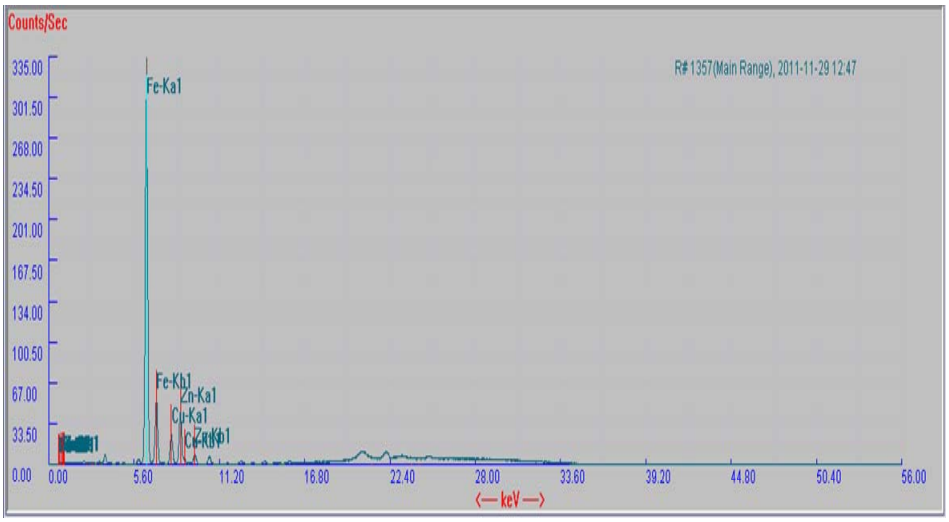
Rezultati hemijske analize kompozitnog uzorka određen analitičkim putem su dati u tabeli br. 1

Tabela 1. *Hemijski sastav uzoraka određen analitičkim putem*

Element / Jedinjenje	Sadržaj	Metoda / Uređaj	Oznaka metode
Cu	0,57 %	Atomska apsorpciona spektrofotometrija Atomski apsorpcioni spektrofotometar PERKIN ELMER 2380	AAS
Cu-ox	0,033 %	Atomska apsorpciona spektrofotometrija Atomski apsorpcioni spektrofotometar PERKIN ELMER 2380	AAS
Cu-sulf.	0,537 %	Računski	R
S	21,13 %	Gasna volumetrija	S
Fe	21,82 %	Volumetrija	V
Pb	0,038 %	Atomska apsorpciona spektrofotometrija	AAS

		Atomski apsorpcioni spektrofotometar PERKIN ELMER 2380	
Zn	0,69 %	Atomska apsorpciona spektrofotometrija Atomski apsorpcioni spektrofotometar PERKIN ELMER 2380	AAS
SiO_2	31,02 %	Gravimetrija	G
Al_2O_3	9,07 %	Atomska apsorpciona spektrofotometrija Atomski apsorpcioni spektrofotometar PERKIN ELMER 2380	AAS
Fe_3O_4	0,738 %	Analizator magnetita	A Fe_3O_4
As	0,048 %	Atomska emisiona spektrometrija sa induktivno kuplovanom plazmom Atomsko emisioni spektrometar sa induktivno kuplovanom plazmom	ICP-AES
K_2O	1,70 %	Atomsko-emisiona spektrometrija PERKIN ELMER 2380	AES
Na_2O	0,36 %	Atomsko-emisiona spektrometrija PERKIN ELMER 2380	AES
MgO	4,28 %	Atomska apsorpciona spektrofotometrija PERKIN ELMER 2380	AAS
Ag	45,0 g/t	Plamena analiza plemenitih metala/ kupelacija / dokimastička metoda Peć za kupelaciju	FA
Au	4,7 g/t	Plamena analiza plemenitih metala/ kupelacija / dokimastička metoda Peć za kupelaciju	FA
Hg	0,4 g/t	Bezplamena atomska apsorpciona spektrofotometrija Analizator žive/PERKIN ELMER, FIMS 100	AHg
Cd	0,020 g/t	Atomska apsorpciona spektrofotometrija Atomski apsorpcioni spektrofotometar PERKIN ELMER 2380	AAS
Pt	<0,025 %	Atomska emisiona spektrometrija sa induktivno kuplovanom plazmom Atomsko emisioni spektrometar sa induktivno kuplovanom plazmom SPECTRO CIROS VISION	ICP-AES
Mo	<0,0010 %	Atomska emisiona spektrometrija sa induktivno kuplovanom plazmom Atomsko emisioni spektrometar sa induktivno kuplovanom plazmom SPECTRO CIROS VISION	ICP-AES

Rezultati hemijske analize uzorka određen rendgensko flurocentnom analizom su dati u tabeli br. 2.



Sl. 4. *Rendgenogram uzorka rude*

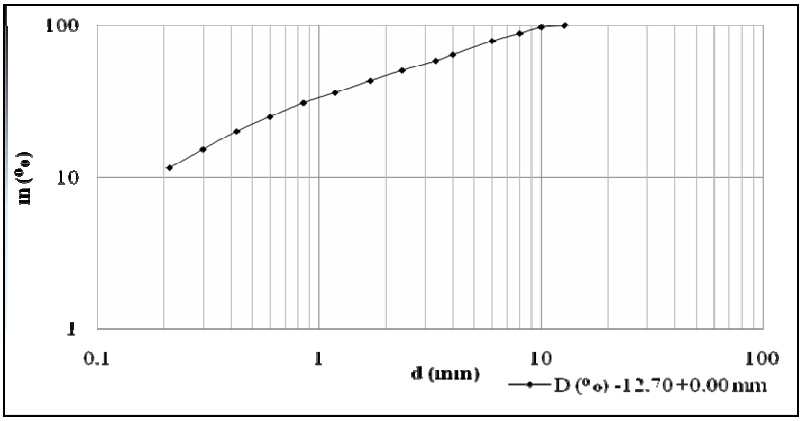
Tabela 2. *Hemijski sastav uzoraka određen rendgensko flurocentnom analizom*

Element	Sadržaj (%)	Metoda / Uređaj	Oznaka
Fe	15,12	Rengensko flurocentna analiza RENDGEN NITON XL3t	XRFA
Mn	0,30		
Cu	0,662		
Zn	0,845		
As	0,073		
Si	21,73		
Al	10,01		
S	8,35		
Ca	3,68		
K	3,67		

3. FIZIČKE KARAKTERISTIKE

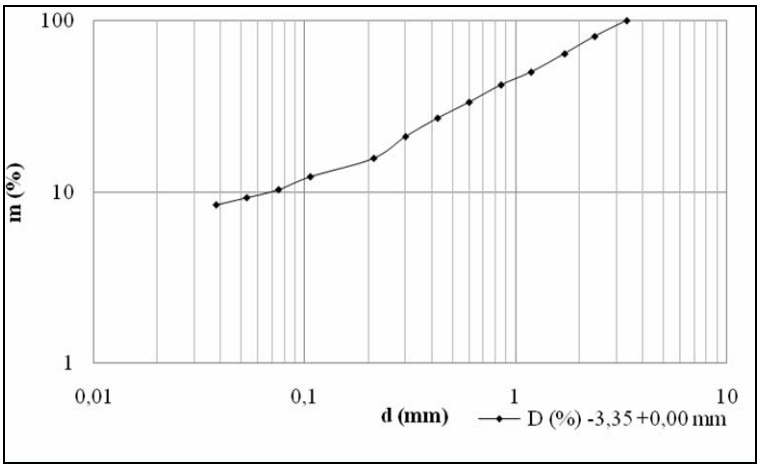
a) Granulometrijski sastav uzorka

Granulometrijski sastav uzorka, izdrobljenog do krupnoće -12,7 +0,0 mm, određen je mokrim prosejavanjem na seriji standardnih laboratorijskih sita. Rezultati granulometrijske analize su dati na slici br. 5.



Sl. 5. *Granulometrijski sastav uzorka "Dolovi -12,7 +0,0 mm"*

Granulometrijski sastav uzorka, izdrobljenog do krupnoće -3,35 +0,0 mm, određen je mokrim prosejavanjem na seriji standardnih laboratorijskih sita. Rezultati granulometrijske analize su dati na slici br. 6.



Sl. 6. *Granulometrijski sastav uzorka "Dolovi -3,35 +0,0 mm"*

b) Meljivost rude

Meljivost rude je definisana vrednostima Bondovog radnog indeksa određenih standardnim Bondovim testom u Bondovom mlinu sa šipkama i Bondovom mlinu sa kuglama. Dobijene su sledeće vrednosti radnog indeksa:

$Wi_{mš}$ = 12,22 kWh/t

Wi_{mk} = 8,80 kWh/t

c) Gustina uzoraka

Gustina uzorka rude je određena metodom staklenih piknometara sa vakuumiranjem. Srednja vrednost gustine iz tri merenja je:

ρ=3 246 kg/m^3

d)Nasipna masa

Nasipna masa je određena na uzorku krupnoće 100 % -12,7 mm i 100 % -3,35 mm. Dobijeni su sledeći rezultati:

$\Delta_{(-12,7\ mm)}$= 1890,7 kg/m^3

$\Delta_{(-3,35\ mm)}$= 1723,0 kg/m^3

e) Prirodna pH vrednost uzorka

Prirodna pH-vrednost uzorka rude je određena merenjem pH vrednosti tečne faze, nakon mešanja pijaće vode sa rudom (Č:T=1:1) u trajanju od 30 minuta

pH-prirodno = 6,79

4. DISKUSIJA REZULTATA

Karakterizacija uzoraka rude bakra iz Rudnika bakra Majdanpek, ležišta „Severni Revir“ je pokazala sledeće:

- Na osnovu određenog mineralnog sastava se vidi da je reč o bakarnopiritičnoj rudi u kojoj su najdominantniji minerali pirit i halkopirit, kao i sfalerit kao glavni nosioc cinka. Ovi minerali se retko sreću u samorodnom obliku, već uglavnom u vidu sraslaca i kao inkluzija jednih minarala u druge, što nam govori o neophodnosti ispitivanja usitnjavanja takve sirovine a u cilju postizanja najoptimalnijeg oslobađanja.
- Rezultati hemijskih analiza su pokazali da je reč o srednje bogatoj rudi, sa sadržajem bakra od oko 0,6% i dominantnim učešćem sulfidnog bakra, što nam ukazuje na pogodnost prerade takve sirovine metodom flotacijske koncentracije. Sa druge strane sadržaj sumpora od preko 20% pokazuje da su u rudi pored sulfidnih minerala bakra u visokom procentu prisutni i drugi sulfidni minerali, kao što je pirit, te da bi se teško postigla selekcija ovih minerala u procesu flotacije i da bi se primenom ove metode koncentracije dobio kolektivni koncentrat sa visokim iskorišćenjem bakra ali i niskim sadržajem ovog metala. Međutim, sadržaj zlata od 4,7 g/t povrđuje isplativost prerade ove sirovine, jer bi dobijeni kolektivni koncentrat bakra i pirita i pored niskog sadržaja bakra sadržao u sebi značajne količine zlata, kao visoko vrednog metala. Problem metalurške prerade takvog koncentrata bi se mogao rešiti njegovim mešanjem sa koncentratima koji u sebi sadrže veće količine bakra i koji su pogodni za preradu u metalurškim postrojenjima u RTB-u Bor.
- Vrednosti Bondovog radnog indeksa u mlinu sa šipkama i mlinu sa kuglama su nešto niže od uobičajnih, što se može objasniti povišenim sadržajem pirita, kao i glinovitih frakcija, čije su vrednosti ovog parametra niže od vrednosti uobičajnih za rudu bakra. To za posledicu može imati manju potrošnju energije u procesu usitnjavanja, kao i povećanje kapaciteta prerade takve sirovine.

5. ZAKLJUČAK

Ruda bakra iz ležišta „Severni Revir“ se odlikuje heterogenošću u pogledu svojih karakteristika, zbog čega se njenom industrijskom preradom dobijaju rezulatati koji su ispod vrednosti dobijenih preradom ruda iz drugih ležišta u Rudniku bakra Majdanpek. Upravo iz tog razloga je izvršena karakterizacija uzoraka iz ovog ležišta, kako bi se utvrdili problemi i dale sugestije za njihovo rešavanje.

Na osnovu dobijenih rezultata se može videti da je ruda bogata piritom što dovodi do dobijanja koncentrata sa niskim sadržajem bakra, koji nije pogodan za dalju metaluršku preradu. Međutim, zbog visokog sadržaja zlata u njemu postoji ekonomski interes za njegovim mešanjem sa koncentratima bogatijim bakrom. Upravo iz tog razloga dalja istraživanja na ovoj sirovini bi trebalo da idu u pravcu optimizacije parametra procesa flotacije kako bi se postiglo što veće iskorišćenje korisnih komponenti, bakra i zlata.

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MINERALOGICAL, CHEMICAL AND PHYSICAL CHARACTERIZATION OF COPPER ORE FROM THE DEPOSIT "SOUTH MINING DISTRICT" COPPER MINE MAJDANPEK***

Abstract

This paper presents the results of mineralogical, chemical and physical characterization of copper ore samples deposits from the deposit "North Mining District" Majdanpek. Mineralogical analysis of samples showed that the most common minerals are pyrite, chalcopyrite and sphalerite. Based on determined chemical composition, it is seen that copper content in the ore is about 0.6 %, sulphur about 20%, zinc, 0.7-0.85% and gold 4.7 g/t. The following physical properties were determined: grain-size distribution, grindability, bulk density, density and natural pH value.

Analyzing the obtained results, the suggestions were given for optimization of this ore processing in order to obtain the best possible indicators.

Keywords: *copper ore, South Mining District, characterization*

INTRODUCTION

The first copper ore reserves in Majdanpek, about 85 million tons of ore with average copper content of 0.83%, were already identified in the fifties of the last century, and the processing of copper ore from the deposits "South Mining District" started after completion of all preparatory works in 1961.

Mining at the open pit "North Mining District" in the Copper Mine Majdanpek started in 1983. In the beginning, only copper ore was mined and later began with the excavation and mining of zinc and lead ore.

Previous experiences, gained by investigations, and especially in the industrial processing of ore from the deposit "North Mining District" of the Copper Mine Majdanpek, have shown that this deposit is of heterogeneous composition and contains

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various types of ore with very different geomorphological and mineralogical characteristics, what requires the use of various technologies for their processing. As special types of ore are: porphyritic ore, copper-pyrite ire, massive copper-pyrite ore, polymetallic ore and limonite ore. From the viewpoint of processing technology, these types of ores are quite different and represent mineralogically, texturally and technologically more complex mineral resources.

Therefore, the level of technological results, achieved running the processing of some types of ore (porphyritic ore, copper-pyrite ore) in the industrial flotation plant of RBM are below the level of results achieved by long-year processing of porphyritic ore of the "South Mining District".

Taking into consideration such characteristics of ore from the "South Mining District", the laboratory characterization of ore samples "Dolovi", whose mining is predicted in the future period. The aim of these investigations was to define the mineralogical, physical and chemical characteristics of copper ore deposits from the deposit "North Mining District" on which subsequent investigations will select the appropriate technology for processing of this ore.

EXPERIMENTAL PART

A copper ore sample fromt he ore body "Dolovi" was used for testing. A detailed characterization was done on a prepared sample. The mineralogical, chemical and physical characteristics were done.

1. Mineral composition

Based on determined mineral composition and paragenetic relationships, as well as on structural - textural characteristics of minerals, it could be said that the polymetallic mineralization of massive sulphide type is present in the locality "Dolovi".

By review of mineral products, which are made of pieces of sample from the locality "Dolovi" (North Mining District - Majdanpek), the following ore minerals were determined: pyrite, chalcopyrite, sphalerite, Ti-Fe oxides (hematite, magnetite), chalcocite, covelline and tennantite. From non-minerals, quartz and calcite are observed. Minerals are listed based on frequency of occurrence.

Pyrite is the predominant ore mineral (Figure 1). It forms fine grains (rarely below 1.93 μm) and 100.96 μm or shows massive concentrations. The grain forms and fields range from xenomorphic to idomorphic when show the proper sections tesseral habitus (pentagon dodecahedron and hexahedron). Pyrite is formed by crystallization with the generation of copper, iron, zinc and lead minerals. This pyrite shows the crystal forms without inclusions, which are suppressed and affected by younger stages of chalcopyrite, sphalerite, and Fe-Ti oxides, and they are rarely chalcocite and covelline. These crystal forms of pyrite are, due to the subsequent tectonic effects, cataclased. These forms of pyrite usually coalesce with chalcopyrite and Fe-Ti oxides.

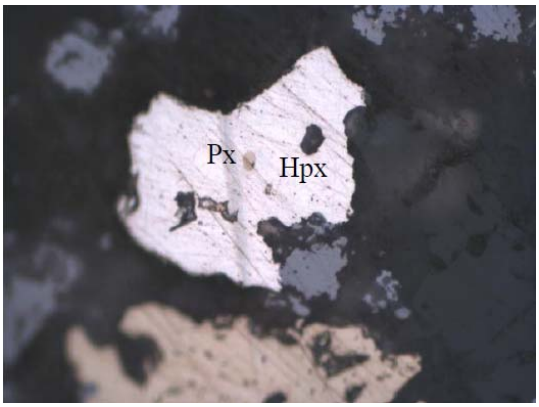

Fig. 1. *Inclusion of chalcopyrite in pyrite (Py), 500 x magnification*

Chalcopyrite forms small to large fields (3.16 to 57.51 μm) of xenomorphic to hyhipidiomorphic development. It most often occurs in the form of embedded aggregates in pyrite as the older stage. It allso often intergrows with pyrite (Figure 2), and pushes it as a younger stage. It rarely occurs in the form of separations along sphalerite, and it is transformed rarely into chalcocite.

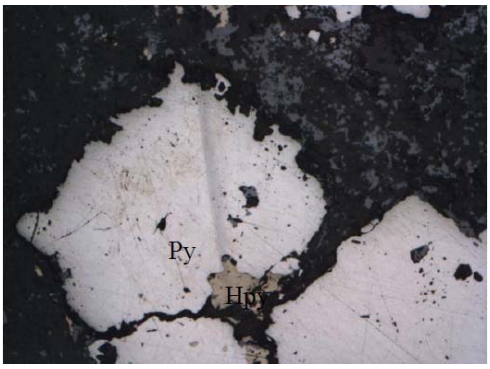

Fig. 2. *Pyrite grown (Py) with chalcopyrite (Hpy), 100 x magnification*

In addition to chalcopyrite, chalcocite, covelline and tennantite occur from copper minerals. They are mostly irregular, fine grains embedded in pyrite. Chalcocite, covelline and tennantite occur rarely. Chalcocite, except as embedded in pyrite, occurs together with chalcopyrite, when they intergrow or when it is replaced by chalcocite.

From Pb-Zn minerals, sphalerite occurs. Sphalerite forms xenomorphic to hypidiomorphic grains and aggregates, size from 2.65 to 25.12 μm. It intergrows most often as younger stage with chalcopyrite and suppresses and embeds pyrite grains. Sphalerite shows emulsion structure during unoriented separation of fine drop-like chalcopyrite. It is rarely embedded in pyrite.

From Ti-Fe oxides, hematite and magnetite are the most common. They show

irregular to hypidiomorphic shapes of different sizes (from 4.46 to 15.23 μm). They are mostly embeded in pyrite or impregnated in the rock mass independently or integrown with chalcopyrite or suppressed pyrite.

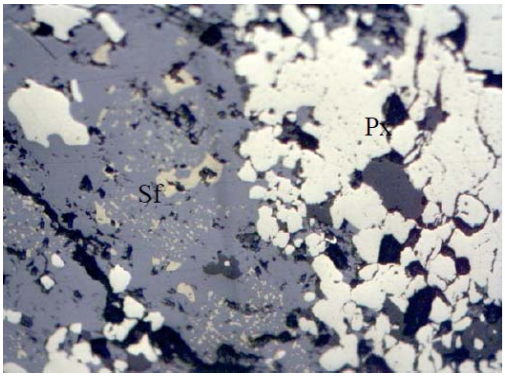

Fig. 3. *Allocations in sphalerite (Sf), pyrite (Py), 100 x magnification*

1) Chemical composition

Chemical composition of samples was determined by two ways: appropriate analytical methods and X-ray fluorescence analysis.

The results of chemical analysis of a composite sample, determined by analytical method, are given in Table 1.

Table 1. *Chemical composition of samples determined by analytical method*

Element / Compound	Content	Method / Device	Method designation
Cu	0.57 %	Atomic absorption spectrophotometry Atomic absorption spectrophotometer PERKIN ELMER 2380	AAS
Cu-ox	0.033 %	Atomic absorption spectrophotometry Atomic absorption spectrophotometer PERKIN ELMER 2380	AAS
Cu-sulf.	0.537 %	Calculating	R
S	21.13 %	Gas volumetry	S
Fe	21.82 %	Volumetry	V
Pb	0.038 %	Atomic absorption spectrophotometry Atomic absorption spectrophotometer PERKIN ELMER 2380	AAS
Zn	0.69 %	Atomic absorption spectrophotometry Atomic absorption spectrophotometer PERKIN ELMER 2380	AAS
SiO_2	31.02 %	Gravimetry	G
Al_2O_3	9.07 %	Atomic absorption spectrophotometry Atomic absorption spectrophotometer PERKIN ELMER 2380	AAS
Fe_3O_4	0.738 %	Magnetite analyzer	A Fe_3O_4

As	0.048 %	Atomic emission spectrometry with inductively coupled plasma Atomic emission spectrometer with inductively coupled plasma	ICP-AES
K_2O	1.70 %	Atomic emission spectrometry PERKIN ELMER 2380	AES
Na_2O	0.36 %	Atomic emission spectrometry PERKIN ELMER 2380	AES
MgO	4.28 %	Atomic absorption spectrophotometry PERKIN ELMER 2380	AAS
Ag	45.0 g/t	Flame analysis of precious metals / cupellation / dokimastic method Cupellation furnace	FA
Au	4.7 g/t	Flame analysis of precious metals / cupellation / dokimastic method Cupellation furnace	FA
Hg	0.4 g/t	Without flame atomic absorption spectrophotometry Mercury analyzer /PERKIN ELMER, FIMS 100	AHg
Cd	0.020 g/t	Atomic absorption spectrophotometry Atomic absorption spectrophotometer PERKIN ELMER 2380	AAS
Pt	<0.025 %	Atomic emission spectrometry with inductively coupled plasma Atomic emission spectrometer with inductively coupled plasma SPECTRO CIROS VISION	ICP-AES
Mo	<0.0010 %	Atomic emission spectrometry with inductively coupled plasma Atomic emission spectrometer with inductively coupled plasma SPECTRO CIROS VISION	ICP-AES

The results of chemical analysis of samples determined by X-ray fluorescence analysis are given in Table 2.

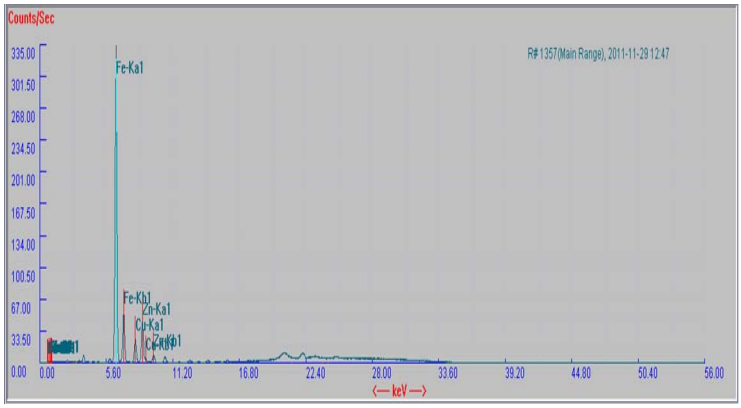

Fig. 4. *X-ray of ore sample*

Table 2. *Chemical content of samples determined by X-ray fluorescence analysis*

Element	Content (%)	Method / Device	Designation
Fe	15.12	X-ray fluorescence analysis ROENTGEN NITON XL3t	XRFA
Mn	0.30		
Cu	0.662		
Zn	0.845		
As	0.073		
Si	21.73		
Al	10.01		
S	8.35		
Ca	3.68		
K	3.67		

2) Physical characteristics

a) Grain-size distribution of sample

Grain-size distribution of sample, crushed to a size of -12.7 +0.0 mm, was determined by wet sieving on a series of standard laboratory sieves. The results of granulometric analysis are given in Figure 5.

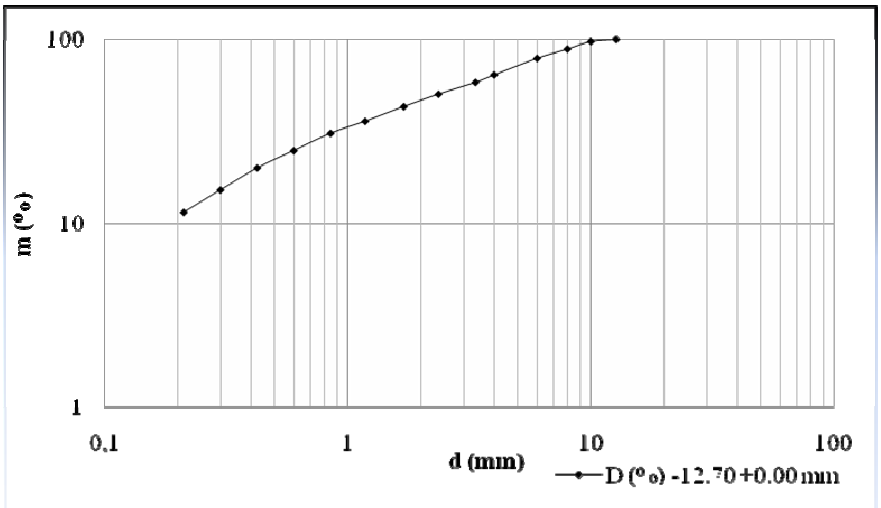

Fig. 5. *Grain-size distrubution of sample "Dolovi -12.7 +0.0 mm"*

Grain-size distribution of sample, crushed to a size of -3.35 +0.0 mm, was determined by wet sieving on a series of standard laboratory sieves. The results of granulometric analysis are given in Figure 6.

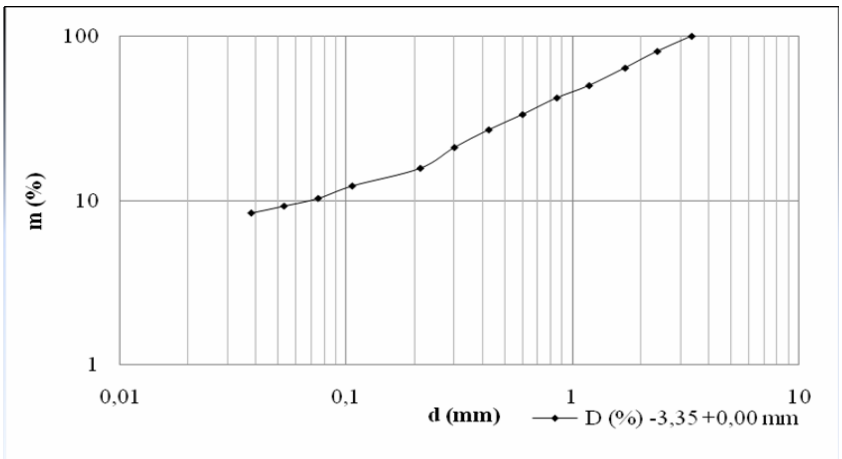

Fig. 6. *Grain-size distrubution of sample "Dolovi -3.35 +0.0 mm"*

b) Ore grindability

Ore grindability is defined the values of Bond working index, determined by the standard Bond test in the Bond rod mill and the Bond ball mill. The following values of working index were obtained:

Wi_{mr} = 12.22 kWh/t

Wi_{mb} = 8.80 kWh/t

c) Density of sample

Density of ore sample is determined by the method of glass picnometers with vacuum. The mean value of density from three measurements is:

ρ=3 246 kg/m^3

d) Bulk density

Bulk density was determined on sa sample size 100 % -12.7 mm and 100 % -3.35 mm. The following results were obtained:

$\Delta_{(-12.7\ mm)}$= 1890.7 kg/m^3

$\Delta_{(-3.35\ mm)}$= 1723.0 kg/m^3

e) Natural pH value of sample

Natural pH-value of ore sample was determined by measuringt the pH value of liquid phase after mixing the dringing water with ore (S:L=1:1) for 30 minuts.

pH-natural = 6.79

Discussion of Results

Characterization of copper ore samples from the Copper Mine Majdanpek, deposit "North Mining District" has showed the following:

- Based on specific mineral composition, it is seen that it is copper-pyrite ore in which the dominant minerals are pyrite and chalcopyrite, as well as sphalerite as the main carrier of zinc. These minerals are rare in a native form, but mainly in the form of integrowth and as inclusion of one mineral into another, what indicates the necessity of grinding tests of such raw minerals in order to achieve the most optimum release.

- The results of chemical analyses have shown that it is medium-rich ore with copper content of about 0.6% and dominant share of sulphide copper, what indicates the suitability of processing such raw minerals by flotation concentration. On the other side, sulfur content of over 20% indicates that the ore has besides the sulphide copper minerals also high percentage of other sulfide minerals such as pyrite, and that it would be difficult to achieve the selection of these minerals in the flotation process and that the application of this method of concentration will give the collective concentrate with high copper recovery, but also low content of this metal. However, gold content of 4.7 g/t confirms the profitability of processing this raw mineral, as the obtained collective concentrate of copper and pyrite will contain, besides low content of copper, also the significant amounts of gold as high valuable metal. Problem of metallurgical treatment of such concentrate could be solved by its mixing with concentrates containing large quantities of copper and that are suitable for treatment into metallurgical plants in RTB Bor.
- Values of the Bond working index in the rod mill and ball mill are somewhat lower than usual, what may be explained by higher pyrite content as well as clay fractions with lower values of this parameter than usual values for copper ore. The results of this may have less energy consumption in the comminution process as well as increase the processing capacity of such raw minerals.

CONCLUSION

Copper ore from the deposit "North Mnign District" is characterized by heterogeneity in terms of its characteristics, why its industrial processing gives the results that are below the values obtained by ore processing from other deposits in the Copper Mine Majdanpek. Due to this reason, the characterization of samples from this deposit was done, in order to identify the problems and give suggestions for their solution.

It can be seen from the obtained results that the ore is rich with pyrite, what leads to obtaining the concentrate with low content of copper, which is not suitable for further metallurgical treatment. However, due to the high content of gold in it, there is an economic interest in its mixing with richer copper concentrates. Precisely from this reason, further investigations on this raw material should go into direction of optimizing the flotation parameters to achieve the highest possible recovery of useful components, copper and gold.

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MOMENTI SAVIJANJA I NAPONSKO STANJE U ZAŠTITNOJ STROPNOJ POLICI EKSPLOATACIONOG POLJA, KOJA SE OSTAVLJA IZMEĐU RAZLIČITIH TEHNOLOGIJA EKSPLOATACIJE***

Izvod

U radu se analizira zaštitna stropna polica kao kontinualno opterećen gredni nosač pravougaonog poprečnog preseka. U ovom slučaju statički neodređene veličine su momenti u osloncima. Oslonački momenti su određeni primenom jednačine „triju momenata" po Klaperjonu. Kontrola napona u grednom nosaču je sprovedena polazeći od diferencijalne jednačine elastične linije koja ima oblik po drugom izvodu.

Ključne reči: *gredni nosač, moment savijanja, reakcija u osloncima, Klaperjon, kritični presek i maksimalni moment savijanja*

1. UVOD

Zaštitna stropna polica se ostavlja u stenskom masivu kada se želi preći sa jedne na drugu tehnologiju eksploatacije mineralne sirovine. U rudniku kamene soli „Tušanj" u Tuzli, BiH, u jednom vremenskom intervalu korišćene su istovremeno dve tehnologije eksploatacije. Do -250 horizonta korišćena je komorno-stubna metoda eksploatacije sa klasičnim miniranjem u komorama, a ispod -250 horizonta korišćena je tehnologija tzv. kontrolisanog izluživanja soli bušotinama sa -250 horizonta.

Da bi se sprečili deformacioni uticaji stenskog masiva izazvani jednom tehnologijom eksploatacije na deo stenskog masiva koji se eksploatiše drugom tehnologijom, nad celim eksploatacionim poljem mora se ostaviti zaštitna sigurnosna stropna polica. Taj princip važi i za prelazak površinske eksploatacije na podzemnu eksploataciju istog rudnog tela.

2. PRORAČUN ZAŠTITNE POLICE EKSPLOATACIONOG POLJA

Zaštitnu policu eksploatacionog polja možemo smatrati i tretirati kao kontinuirano opterećen gredni nosač pravougaonog poprečnog preseka, sl.1. U ovom slučaju sta-

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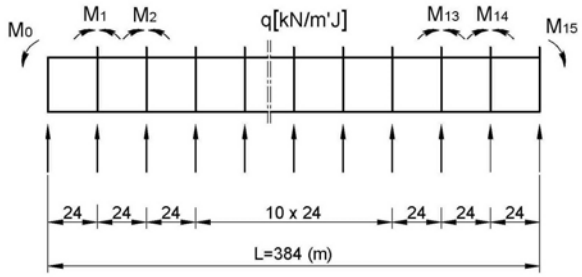
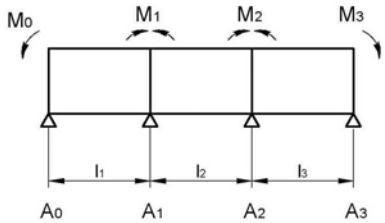
tički neodređene veličine su momenti u osloncima.



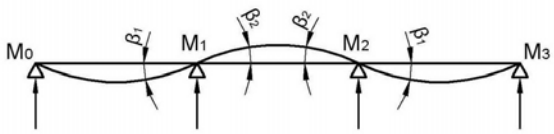
Sl. 1. *Statička šema stropnog nosača eksploatacionog polja*

Pretpostavimo kontinualni nosač sa (*n*) oslonaca, tada je statički neodređen (*n*-2) puta uz pretpostavku da su u krajnjim osloncima pokretni zglobovi. Jedan od načina da se odrede oslonački momenti jeste primena jednačine „triju momenata“ po Klaperjon-u. Obzirom da se radi o nosaču kontinuirano opterećenom i jednakim rasponima, to je očigledno da će momenti M_1 do M_{14} imati istu vrednost. Prema tome, zadatak se može svesti na sledeće jednostavno rešenje, razmatrajući kontinuirani nosač sa četiri oslonca, sl.2, koji će biti u ravnoteži ako se u krajnjim presecima isključe transverzalne sile (*dT*) i (*lT*) i oslonački momenti.



Sl. 2. *Nosač sa četiri oslonca*

Veza u osloncima (1) i (2) je kruta, tj. uslovi pre i posle deformacija ostaju nepromenjeni. U osloncima (1) i (2) moraju se javiti momenti (M_1) i (M_2), a elastična linija nosača mora zadovoljiti uslov ($\beta_1+\beta_2=0$), sl. 3, drugim rečima, uglovni koeficijenti tangente na elastičnu liniju u tri raspona su isti sa različitim predznakom.



Sl. 3. *Oblik elastične linije*

Iz navedenog uslova, a pretpostavljajući da je moment inercije kao i modul elastičnosti isti, to se po Klaperjon-u dolazi do izraza

$$M_0 \cdot l_1 + 2M_1(l_1 + l_2) + M_2 \cdot l_3 + 6R_{01} = 0 \quad (1)$$

$$M_1 \cdot l_1 + 2M_2(l_2 + l_3) + M_3 \cdot l_3 + 6R_{02} = 0 \quad (2)$$

R_{01} i R_{02} - celokupna reakcija u osloncima (1) i (2)

Jednačine (1) i (2) važe za bilo koja dva susedna polja.

Kako je $M_0 = M_3 = 0$, dolazimo do konačnog oblika:

$$2M_1(l_1 + l_2) + M_2 \cdot l_3 + 6R_{01} = 0 \qquad (3)$$

$$M_1 \cdot l_1 + 2M_2(l_2 + l_3) + 6R_{02} = 0 \qquad (4)$$

Obzirom na jednake raspone l = const., tada je vrednost apsolutnog člana celokupne reakcije

$$R_{01} = R_{02}$$

$$6(R_{01} - R_{02}) = \\ = \frac{1}{2}\left(q_n \cdot l_n^3 + q_{(n+1)}\right) \cdot l_{(n+1)}^3 \qquad (5)$$

q – kontinuirano opterećenje

Za q = const. i l = const. izraz (5) poprima sledeći oblik:

$$6(R_{01} - R_{02}) = \frac{1}{2} q l^3 \qquad (6)$$

Reakcija u osloncu (0) je:

$$A_0 = \frac{q_1 l_1}{2} - \frac{M_1}{l_1}$$

Izraz za transverzalne sile u tački (1) je:

$$lT_1 = q_i \cdot l_1 - A_0$$

$$dT_1 = \frac{q_i \cdot l_1}{2} + \frac{M_1 - M_2}{l}$$

Reakcija u osloncu (1) je

$$A_1 = lT_1 + dT_1$$

Transverzalne sile koje se odnose na oslonac (2), imaju vrednost:

$$lT_2 = q_i \cdot l_2 - dT_1$$

$$dT_2 = \frac{q_2 \cdot l_2}{2} + \frac{M_2}{l_2}$$

Reakcija u osloncu (2) je

$$A_2 = lT_2 + dT_2$$

Obzirom na poznatu vrednost desne transverzalne sile u tački oslonca (2), reakcija u osloncu (3) će biti:

$$A_2 = q_3 l_3 - dT_2$$

Vrednost sveukupnih reakcija u osloncima je:

$$\sum q = A_0 + A_1 + A_2 + A_3$$

Kritični presek i maksimalni moment savijanja u I polju određuje se iz sledeće jednačine:

$$x_1 = \frac{A_0}{q_1}; \quad M_{I\,max} = \frac{A_0^2}{2q_1}$$

Kritični presek i maksimalni moment savijanja u II polju:

$$x_{II} = \frac{dT_1}{q_2}; \quad M_{I\,Im\,ax} = \frac{dT^2}{2q_2} - M_1$$

Na osnovu do sada iznetog, stropna polica je kontinuirano opterećen nosač sa 16 oslonaca sa konstantnim rasponom, pri čemu su momenti savijanja M_0 i $M_{15} = 0$, M_1 do M_{14} su jednaki.

Reakcije u osloncima A_1 do A_{14} su jednake $A_0 = A_{15}$.

Transverzalne neparne i parne sile u osloncima su jednake $lT_1 = lT_{13}$, $dT_2 = lT_{14}$, takođe su maksimalni momenti savijanja u sredini raspona jednaki.

3. PROVERA NAPONA U STROPNOJ POLICI EKSPLOATACIONOG POLJA

Polazeći od činjenice da je stropna polica greda prizmatičnog preseka sa kritičnim mestom maksimalnog momenta savijanja, može se napisati $M_{max} = -\frac{ql^2}{8}$, odnosno maksimalni napon savijanja je $\sigma_{max} = \frac{M_{max}}{W}$.

Za bilo koju vrednost x duž raspona stropne grede imamo:

$$M_x = -\frac{ql^2}{8} + \frac{qx^2}{2} \qquad (7)$$

U tom slučaju jednačina elastične linije imaće oblik po drugom izvodu:

$$IEY'' = -M_x + \frac{ql^2}{8} - \frac{qx^2}{2} \qquad (8)$$

Odnosno, integralenjem po x – u

$$IEY' = \frac{ql^2}{8} \cdot x - \frac{qx^3}{6} + c_1 \qquad (9)$$

Konstanta c_1 određuje se iz uslova da u tački (0) za x = 0, tangenta na elastičnu liniju je horizontalna tj. y' = 0, što znači da je i c_1 = 0. Ponovnim integralenjem (9) dobije se:

$$IEY = \frac{ql^2x^2}{16} - \frac{qx^4}{24} + c_2 \qquad (10)$$

Prema kritičnom mestu ugiba za $x = \frac{l}{2}$ i izjednačavanjem (10) sa nulom, dobije se vrednost konstante c_2

$$0 = \frac{ql^2}{16}\left(\frac{l}{2}\right)^2 - \frac{q \cdot \left(\frac{l}{2}\right)^4}{24} \qquad (11)$$

$$c_2 = \frac{5ql^4}{384} \qquad (12)$$

Jednačina elastične linije dobiće konačan oblik

$$IEY = \frac{q}{384E}\left(24l^2x^2 - 16x^4 - 5l^4\right) \qquad (13)$$

Ugib u sredini raspona za $x = \frac{l}{2}$

$$f_{max} = \frac{5ql^4}{384E} \qquad (14)$$

Moment inercije

$$J = \frac{bh^3}{12}$$

h – visina stropne grede

b = 1,0

Otporni moment preseka:

$$W = \frac{bh_3}{6}$$

Odnos izračunatog napona savijanja i granične vrednosti otpornosti stene na savijanje daje koeficijent sigurnosti

$$n = \frac{\sigma_f}{\sigma_{max\,rač.}}$$

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BENDING MOMENTS AND STRESS STATE IN THE PROTECTIVE ROOF SHELF OF EXPLOITATION FIELD, LEFT BETWEEN DIFFERENT MINING TECHNOLOGIES***

Abstract

This paper analyzes the protective roof shelf as a continuous loaded carrier beam of rectangular cross section. In this case, the statically undetermined sizes are moments in the supports. Support moments are determined using the equation of "three moments" by Clapeyron. Stress control in the carrier beam is carried out starting from the differential equation of elastic line that has a form per the second statement.

Keywords: *carrier beam, bending moment, reaction in supports, Claperyon, critical section, maximum bending moment*

1. INTRODUCTION

Protective roof shelf is left in the rock massif in the case of transfer from one technology to another technology of mining the mineral raw materials. In the rock salt mine "Tušanj" in Tuzla, B&H, two mining technologies were simultaneously used in a time. The chamber-pillar mining method was used up to -250 horizon with the classic blasting in chambers, and the technology of so called controlled leaching of salt was use below -250 horizon with drill holes from -250 horizon.

The protective roof shelf must be left over the entire exploitation field to prevent the deformation effects of rock massive, caused by one mining technology of the rock mass that is exploited by the other technology. This principle is also applied to transfer the open pit mining into the underground mining the same ore body.

2. CALCULATION THE PROTECTIVE ROOF SHELF OF EXPLOITATION FIELD

The protective shelf of exploitation field can be considered and treated as a continuous loaded beam carrier of a rec-tangular cross-section, Figure 1. In this case, the

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statically undetermined sizes are the moments in supports.

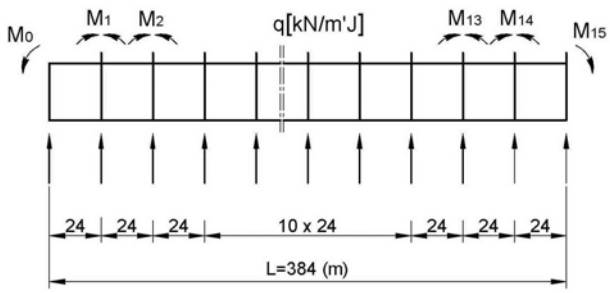

Fig. 1. *Static scheme of roof beam of the exploitation field*

Suppose a continuous carried with *(n)* supports, then it is statically undetermined for (*n*-2) times with an assumption that the movable joints are in the end supports. One way to determine the support moments is to apply the equation of "three moments" by Claperyon. Since it is a carried a continuous loaded carrier and with the same ranges, it is obvious that the moments M_1 to M_{14} will have the same value. Therefore, the task can be reduced to the following simple solution, considering the continuous beam with four supports, Figure 2, which will be in equilibrium if the transverse forces *(dT)* and *(lT)* and support moments are excluded in the final sections.

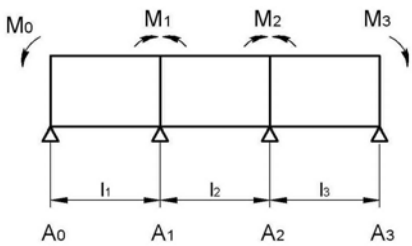

Fig. 2. *Carrier with four supports*

Connection in supports (1) and (2) is rigid, i.e. the conditions before and after deformation remain unchanged. In the supports (1) and (2), the moments (M_1) and (M_2) must appear, and the elastic line of carrier must satisfy the condition ($\beta 1 + \beta 2 = 0$), Figure 3; in the other words, the angular coefficient of tangent on the elastic line in the three ranges are the same with a different sign.

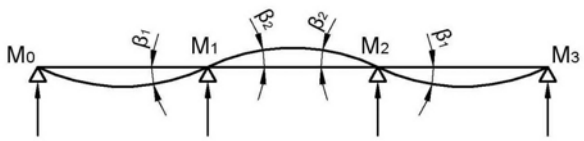

Fig. 3. *Form of the elastic line*

From the specified condition, and assuming that the moments of inertia as well as the elastic modulus are the same, according Claperyon, the expression follows

$$M_0 \cdot l_1 + 2M_1(l_1 + l_2) + M_2 \cdot l_3 + 6R_{01} = 0 \quad (1)$$

$$M_1 \cdot l_1 + 2M_2(l_2 + l_3) + M_3 \cdot l_3 + 6R_{02} = 0 \quad (2)$$

R_{01} and R_{02} – overall reaction in supports (1) and (2)

Equations (1) and (2) are valid for any two adjacent fields.

As $M_0 = M_3 = 0$, it is come to the final form:

$$2M_1(l_1 + l_2) + M_2 \cdot l_3 + 6R_{01} = 0 \quad (3)$$

$$M_1 \cdot l_1 + 2M_2(l_2 + l_3) + 6R_{02} = 0 \quad (4)$$

Regard to the same tanges l = const., then the value of absolute member of the overall reaction

$$R_{01} = R_{02}$$

$$6(R_{01} - R_{02}) = = \frac{1}{2}\left(q_n \cdot l_n^3 + q_{(n+1)}\right) \cdot l_{(n+1)}^3 \quad (5)$$

q – Continuous load

For q = const. and l = const. expression (5) has the following form:

$$6(R_{01} - R_{02}) = \frac{1}{2} q l^3 \quad (6)$$

Reaction in the support (0) is:

$$A_0 = \frac{q_1 l_1}{2} - \frac{M_1}{l_1}$$

Expression for transversal forces at point (1) is

$$lT_1 = q_i \cdot l_1 - A_0$$

$$dT_1 = \frac{q_i \cdot l_1}{2} + \frac{M_1 - M_2}{l}$$

Reaction in the support (1) is $A_1 = lT_1 + dT_1$

Transversal forces relating to the support (2) have value:

$$lT_2 = q_i \cdot l_2 - dT_1$$

$$dT_2 = \frac{q_2 \cdot l_2}{2} + \frac{M_2}{l_2}$$

Reaction in the support (2) is

$$A_2 = lT_2 + dT_2$$

Considering the known value of the right transversal force at the point of support (2), the reaction in support (3) will be:

$$A_2 = q_3 l_3 - dT_2$$

Value of overall reactions in supports is:

$$\sum q = A_0 + A_1 + A_2 + A_3$$

Critical section and maximum bending moment in the field I is determined from the following equation:

$$x_1 = \frac{A_0}{q_1}; \quad M_{Imax} = \frac{A_0^2}{2q_1}$$

Critical section and maximum bending moment in the field II:

$$x_{II} = \frac{dT_1}{q_2}; \quad M_{I\,Imax} = \frac{dT^2}{2q_2} - M_1$$

Based on the above mentioned, the roof shelf is a continuous loaded carrier with 16 supports with a constant range, where the bending moments M_0 and $M_{15} = 0$, M_1 to M_{14} are equal.

Reactions in the supports A_1 to A_{14} are equal $A_0 = A_{15}$.

Unpaired and paired transversal forces in the supports are equal $lT_1 = lT_{13}$, $dT_2 = lT_{14}$, also maximum bending moments in the mid-range are equal.

3. CHECKING THE STRESS IN THE ROOF SHELF OF EXPLOITATION FIELD

Based on the fact that the roof shelf is a beam of prismatic cross-section with critical point of maximum bending moment, the following can be written $M_{max} = -\frac{ql^2}{8}$, i.e. maximum bending stress is $\sigma_{max} = \frac{M_{max}}{W}$.

For any value x along the range of roof beam, the following is:

$$M_x = -\frac{ql^2}{8} + \frac{qx^2}{2} \quad (7)$$

In this case, the equation of elastic line will have the form according to the second statement:

$$IEY'' = -M_x + \frac{ql^2}{8} - \frac{qx^2}{2} \quad (8)$$

That is, using integral per x – u

$$IEY' = \frac{ql^2}{8} \cdot x - \frac{qx^3}{6} + c_1 \quad (9)$$

Constant c_1 is determined from the condition that at point (0) for x = 0, the tangent on elastic line is horizontal, i.e. y' = 0, which means that also c_1 = 0 and using integral (9), the following is obtained:

$$IEY = \frac{ql^2x^2}{16} - \frac{qx^4}{24} + c_2 \quad (10)$$

According to the critical point of deflection for $x = \frac{l}{2}$ and equating (10) to zero, the value of constant c_2 is obtained

$$0 = \frac{ql^2}{16}\left(\frac{l}{2}\right)^2 - \frac{q \cdot \left(\frac{l}{2}\right)^4}{24} \quad (11)$$

$$c_2 = \frac{5ql^4}{384} \quad (12)$$

The equation of elastic line will obtain the final form

$$IEY = \frac{q}{384E}\left(24l^2x^2 - 16x^4 - 5l^4\right) \quad (13)$$

Deflection in the middle of range for $x = \frac{l}{2}$

$$f_{max} = \frac{5ql^4}{384E} \quad (14)$$

Moment of inertia

$$J = \frac{bh^3}{12}$$

h – height of roof beam
b = 1.0

Resistant moment of section

$$W = \frac{bh_3}{6}$$

Ratio of calculated bending stress and limit value of rock strength to bending gives the safety coeficient

$$n = \frac{\sigma_f}{\sigma_{max\,rač.}}$$

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LITOTAMNIJSKI KREČNJAK LEŽIŠTA „DOBRILOVIĆI“ U ODSUMPORAVANJU DIMNIH GASOVA MOKRIM POSTUPKOM[**]

Izvod

U ovom radu su dati rezultati ispitivanja litotamnijskog krečnjaka iz ležišta „Dobrilovići“, za upotrebu u odsumporavanju dimnih gasova mokrim postupkom. Prema uslovima tehnološkog postupka, ODG krečnjak treba da ispuni određene kriterijume da bi mogao da se koristi u tu svrhu. Imajući u vidu te kriterijume, u ovom radu su ispitivani hemijski sastav, nasipna masa, granulometrijski sastav i Bondov radni indeks. Rezultati ovih ispitivanja su pokazali da krečnjak ležišta "Dobrilovići" prema svojim fizičko-hemijskim karakteristikama potpuno odgovara za upotrebu u procesu odsumporavanja dimnih gasova u termoelektranama, kao i za dobijanje praškastog (rasutog) gipsa.

Ključne reči: *odsumporavanje dimnih gasova mokrim postupkom, lithotamnijski krečnjak, fizičko-hemijske karakteristike, praškasti (rasuti) gips*

1. UVOD

U okviru Nacionalnog programa zaštite životne sredine Republike Srbije, koji je donet u skladu sa Zakonom o zaštiti životne sredine, planirane su mere za održivi razvoj i upravljanje životnom sredinom u Republici Srbiji za narednih 10 godina. Jedan od prioritetnih ciljeva zaštite životne sredine u sektoru energetike, u periodu 2005.-2014. godine, je smanjenje emisije sumpornih oksida iz velikih postrojenja za sagorevanje kao što je TE Kostolac B i Termoelektrane Nikola Tesla A i B i novi termo kapacitet na kolubarski lignit približne snage 700 MW[1].

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U cilju zaštite vazduha na blokovima ovih termoelektrana ugradeni su samo uredaji za prečišcavanje dimnih gasova od čestica, elektrofilteri, ali nisu preduzete mere za smanjenje emisija sumpornih oksida, tako da njihove koncentracije u dimnom gasu višestruko premašuju dozvoljene vrednosti, kako domaće, tako i regulative Evropske zajednice. [2]

Sam sistem odsumporavanja se sastoji od postrojenja za prečišćavanje dimnih gasova vlažnim postupkom, takozvano pranje gasova, sa suspenzijom krečnjaka, a što bi se obavljalo u delu postrojenja nazvanim abzorberom. Pranje gasova se vrši tako što se struja dimnog gasa uvodi u abzorber u kojem se u vidu kiše ili kapljica uvodi suspenzija krečnjaka i u tom procesu sumpordioksid reaguje sa kalcijumom u krečnjaku i iz toga nastaje gips u vidu suspenzije, a koja se kasnije suši i odvozi u skladište gipsa, ili na mesto gde će se deponovati i spremiti za kasniju upotrebu. Precišceni gasovi se vode u dimnjak i izbacuju u atmosferu. Jasno je da je za proces odsumporavnja potrebna velika količina krečnjaka koja se dovozi iz rudnika krečnjaka. [3] Krečnjak za odsumporavanje se dobija eksplaoatacijom u rudnicima i preradom u kamenolomima rovnog materijala na zadate uslove kvaliteta. Zatim se kao takav transportuje do skladišta krečnjaka pri postrojenju za odsumporavanje.

Suspenzija gipsa koja nastaje kao nusprodukt procesa odsumporavanja primenom vlažnog krečnjačkog postupka je potencijalna sirovina za dobijanje gipsa. Pri tom kvalitet gipsa zavisi od više faktora, a prvenstveno od kvaliteta ulaznih sirovina (krečnjaka i vode). Da bi se obezbedio zahtevani kvalitet gipsa biće potrebno rekonsturisati i elektrofilter da bi se smanjila koncentracija čestica u dimnom gasu.

U ovom radu su dati rezultati ispitivanja litotamnijskog krečnjaka iz ležišta „Dobrilovići“, za upotrebu u odsumporavanju dimnih gasova mokrim postupkom. Ispitivanja su obuhvatala određivanje vlage, hemijskog sastava, nasipne mase, granulometrijskog sastava i Bondovog radnog indeksa.

2. EKSPERIMENT

2.1. Materijal i uređaji

Polazni uzorak je predstavljao krečnjak litotamnijakog porekla, ležišta Dobrilović kod Loznice. Njegov granulometrijski sastav je prikazan u tabeli 1.

Tabela 1. *Granulometrijski sastav ulaznog krečnjaka*

Klasa krupnoće, mm	M, %
-200 + 100	34,00
-100 + 50	34,00
- 50 + 30	12,00
- 30 + 0	20,00
∑	100,00

Oprema koja je korišćena u eksperimentima: laboratorijska čeljusna drobilica Wedag, 5”x6”; laboratorijska valjkasta drobilica „Denver“; laboratorijsko vibaciono sito „Kefama“; laboratorijska sušara „Heraus“; menzura zapremine 1l; atomski adsorpcioni spektrofotometar „Perkin Elmer 703“.

3. REZULTATI I DISKUSIJA

Polazni uzorak krečnjaka je usitnjen dvostepeno, prvo na čeljusnoj drobilici (Wedag, 5”x6”) i kasnije na valjkastoj drobilici (Denver), sa prosejavanjem na laboratorijskom vibacionom situ (Kefama), do krupnoće 100% -20 mm. Naime, jedan od zahteva za kvalitetom krečnjaka koji se koristi za odsumporavanje dimnih gasova mokrim postupkom jeste da ima krupnoću -19,05+0 mm.

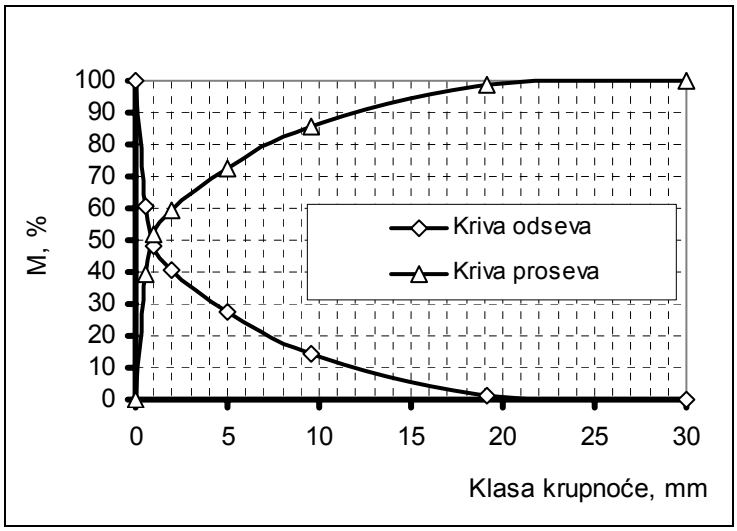
Na slici 1. je dat granulometrijski sastav dobijenog asortimana krečnjaka tj. klase krupnoće -20,0+0 mm.

Na tako pripremljenom materijalu su urađena dalja ispitivanja.

Određivanje sadržaja vlage polaznog uzorka krečnjaka je izvršeno je sušenjem uzoraka u laboratorijskoj sušari na tem-

peraturi od 105°C i merenjem do konstantne mase. Dobijena vrednost za sadržaj vlage u ulaznom uzorku litotamnijskog krečnjaka jeste 6,23%.

Određivanje nasipne mase dobijenog usitnjenog krečnjaka je vršeno merenjem mase uzorka u menzuri zpremine 1l. Dobijena vrednost je iznosila 1,39 t/m^3



Sl. 1. *Dijagram granulometrijskog sastava krečnjaka nakon usitnjavanja na potrebnu krupnoću -20,0+0 mm*

Mineraloškom analizom ispitivanih uzoraka krečnjaka ležišta "Dobrilovići" utvrđeno je prisustvo kalcita, kvarca, minerala glina, limonita. Kalcit je organogenog porekla, uglavnom kriptokristalast. Javljaju se fragmenti fosilnih ostataka. Kvarc je malo zastupljen. Krečnjak je slabo zaglinjen i limonitisan. [4].

Rezultati ispitivanja ***hemijskog sastava*** proizvoda usitnjavanja su prikazani u tabeli 2. [5].

Tabela 2. *Delimični hemijski sastav proizvoda usitnjavanja*

Element, jedinjenje	$CaCO_3$	$MgCO_3$	SiO_2	Fe_2O_3
Sadržaj, %	91,85	0,887	4,80	0,545

3.1. Ocena primenljivosti

Uporedni prikaz dobijenih rezultata ispitivanja krečnjaka ležišta "Dobrilovići" i potrebnog kvaliteta krečnjaka za upotrebu u odsumporavanju dimnih gasova prikazan je u tabeli 3.

Tabela 3. Uporedni prikaz dobijenih rezultata i zahtevanog kvaliteta krečnjaka za ODG

Parametri	Jedinice	Stanje uzorka	Praškasti (rasuti) gips	Gipsane ploče	Krečnjak „Dobrilovići“
Slobodna vlaga	Težinski %	Po prijemu	≤5,0	≤5,0	**6,23**
Ukupni $CaCO_3$	Težinski %	Suv	≥89,0	≥94,0	**91,85**
Ukupni $MgCO_3$	Težinski %	Suv	≤4,0	≤3,0	**0,887**
Nerastvorni ostatak uključujući SiO_2 (kiselinski nerastvorni)	Težinski %	Suv	--------		**--------**
SiO_2	Težinski %	Suv	≤5,0	≤3,0	**4,80**
Fe_2O_3	Težinski %	Suv	---------	≤0,8	**0,545**
Inertne materije (uključujući $MgCO_3$)	Težinski %	Suv	≤11,0	≤6,0	**5,23**
Granulometrijska analiza	milimetri	Suv	-19,05+0	-19,05+0	**20,00+0**
Bondov radni indeks	kWh/T	Po prijemu	≤ 12,0	≤12,0	**8,09**

Iz rezultata datih u tabeli 3 može se videti da krečnjak iz ležišta „Dobrilovići“ zadovoljava uslove kvaliteata za dobijanje praškastog (rasutog) gipsa.

4. ZAKLJUČAK

U ovom radu prikazani su rezultati ispitivanja mogućnosti primene litotamnijskog krečnjaka, ležišta “Dobrilovići”, kod Loznice, u postrojenjima za odsumporavanje dimnih gasova u termoelektranama. Na osnovu poređenja rezultata dobijenih ispitivanjem i potrebnih karakteristika koje krečnjak treba da ispunjava, može se sa sigurnošću reći da uz minimalne korekcije, koje se jedino odnose na vlagu u uzorku (potrebno sušenje), krečnjak litotamnijskog porekla ležišta “Dobrilovići” u potpunosti odgovara za upotrebu u postrojenjima za odsumporavanje dimnih gasova. Primenom ovog krečnjaka u postupku odsumporavanja kao proizvod može se dobiti praškasti (rasuti) gips.

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LITHOTAMNIAN LIMESTONE FROM THE DEPOSIT "DOBRILOVIĆI" IN FLUE GAS DESULPHURIZATION BY WET PROCESS[**]

Abstract

This paper presents the results of investigation lithotamnian limestone from the "Dobrilovići" deposit for the use in flue gas desulphurization by wet process. According to the technological process conditions, FGD limestone should fulfill the certain criteria in order to be used for that purpose. In respect to those criteria, this paper investigates the chemical composition, bulk density, grain-size distribution and Bond work index (kWh/t). The results of these investigations have showed that limestone from "Dobrilovići" deposits, according to its physicochemical properties, is completely suitable for the flue gas desulphurization process in thermal power plants, as well as for disposable gypsum obtaining.

Keywords: *flue gas desulphurization by wet process, lithotamnian limestone, physicochemical properties, disposable gypsum*

1. INTRODUCTION

Within the National Program for Environmental Protection of the Republic of Serbia which was adopted in accordance with the Law on Environmental Protection, the measures for sustainable development and environmental management in the Republic of Serbia are planned for the ten-year period. One of the fundamental goals of environmental protection in the energy sector, in the period from

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2005-2014, is reduction the emission of sulphur oxides from large plants, such as the Thermal Power Plant ''Kostolac B'' and Thermal Power Plant ''Nikola Tesla A'' and ''Nikola Tesla B'', and the new thermal capacity on the Kolubara lignite of approximate power of 700 MW [1].

For the purpose of air protection, only flue gas conditioning devices for removal the particulate matter (electro filters) were installed, but no measures for reduction the sulphur oxides emission were taken. Concentrations in flue gasses exceed the allowed levels of domestic, as well as those of EU legislation several times [2].

The system of desulphurization consists of equipment for flue gas purification by wet process (flue gas cleaning) using the limestone suspension, which is carried out in a part of system called absorber. Flue gas cleaning is carried out by passing the flue gas stream into the absorber, into which the limestone suspension is introduced as spray or drops, facilitating the reaction of sulphur dioxide with calcium from limestone. It produces gypsum as suspension, which is then dewatered and taken to the storage or to the place where it is stored and prepared for future use. Purified flue gas is then discharged into the chimney, and from there into the atmosphere. Desulphurization process evidently requires large amounts of limestone which is brought from limestone mines [3]. Limestone which, used for desulphurization, is exploited and processed in queries of run-of-mine material in order to obtain the required quality. After that, it is transported to the limestone storages in desulphurization plants.

Gypsum suspension as a by-product of wet limestone desulphurization process is a potential raw material for gypsum obtaining. Gypsum quality depends on several factors, above all on the quality of input raw materials (limestone and water). In order to provide the required gypsum quality, it will be necessary to reconstruct the electro filter to reduce the concentration of particulate matter in flue gas.

This paper presents the results of investigation lithotamnian limestone from the "Dobrilovići" deposit for use in flue gas desulphurization by wet process. Investigation of moisture, chemical composition, bulk density, grain-size distribution and Bond work index are conducted.

2. EXPERIMENTAL

2.1. Material and Equipment

Starting sample was lithotamnian limestone from Dobrilović deposit near Loznica. Its grain-size distribution is present in Table 1.

Table 1. *Grain-size distribution of starting limestone*

Size class, mm	M, %
-200 + 100	34.00
-100 + 50	34.00
- 50 + 30	12.00
- 30 + 0	20.00
∑	100.00

The used equipment in the experiments was: laboratory ''Wedag'' jaw crusher, 5"x6"; laboratory ''Denver'' roll crusher, laboratory ''Kefama'' vibrating screen; laboratory ''Heraeus'' heating and drying oven; 1 l gauge glass; ''Perkin Elmer'' 703 atomic absorption spectrophotometer.

3. RESULTS AND DISCUSSION

Limestone starting sample was carefully crushed in the two-phase process, first by jaw crusher and after that by roll crusher. It was screened on the laboratory vibrating screen until size 100% -20mm was obtained. Namely, one of the requirements, regarding the quality of used limestone for flue gas desulphurization by wet process, is the size 19.05+0 mm.

Figure 1 presents the grain-size distribution of the obtained limestone assortment, i.e. size class -20.0+0 mm.

Such prepared material was further analyzed.

Measuring of moisture content. Measuring the starting sample moisture was performed by dewatering sample in a laboratory dryer at temperature of 105°C and measuring until the constant mass was obtained. The obtained value of moisture was 6.23%.

Bulk density of the obtained crushed was determined measuring the ample mass in 1 l gauge glass. The obtained value for bulk density was 1.39 t/m^3.

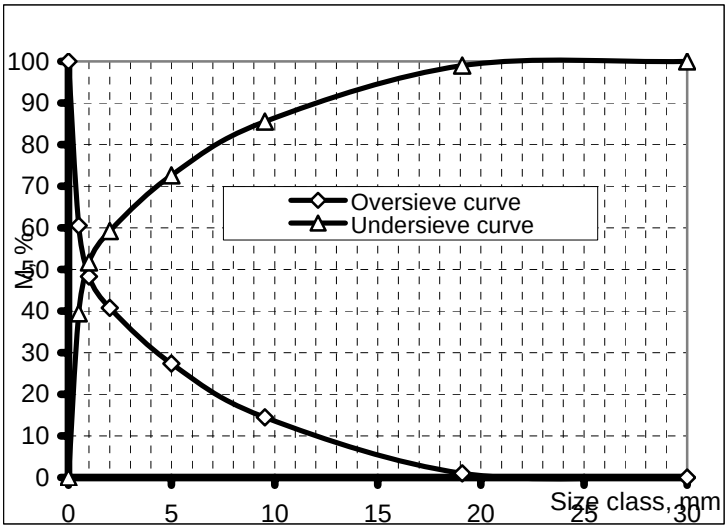

Fig. 1. *Diagram of limestone grain-size distribution after crushing into desired -20.0+0 mm size*

Mineralogical analysis of limestone samples from the ''Dobrilovići'' deposit: Mineralogical analysis showed the presence of calcite, quartz, and clay mineral limonite. Calcite was of organogenic origin, mostly cryptocrystalline. There were fossil residue fragments and minor quantities of quartz. Limestone contained small amounts of clay and limonite [4].

Results of ***chemical composition analysis*** of the crushed sample are present in Table 2 [5].

Table 2. *Partial chemical composition of limestone*

Element, compound	$CaCO_3$	$MgCO_3$	SiO_2	Fe_2O_3
Content, %	91.85	0.887	4.80	0.545

3.1. Applicability evaluation

Comparative overview the obtained results of limestone from the ''Dobrilovići'' deposit analyses and the required lime stone quality for the purpose of flue gas desulphurization are present in Table 3.

Table 3. *Comparative overview of the results and required limestone quality for FDG*

Parameter	Units	Reporting Basis	Disposable Gypsum	Gypsum Wallboards	Limestone "Dobrilovići"
Free Moisture	Weight %	As received	≤5.0	≤5.0	**6.23**
Total $CaCO_3$	Weight %	Dry	≥89.0	≥94.0	**91.85**
Total $MgCO_3$	Weight %	Dry	≤4.0	≤3.0	**0.887**
Insoluble matter including SiO_2 (acid insoluble)	Weight %	Dry	--------		**--------**
SiO_2	Weight %	Dry	≤5.0	≤3.0	**4.80**
Fe_2O_3	Weight %	Dry	---------	≤0.8	**0.545**
Total inert matters (including $MgCO_3$)	Weight %	Dry	≤11,0	≤6.0	**5.23**
Grain-size analysis	millimeters	Dry	-19.05+0	-19.05+0	**20.00+0**
Bond Work Index (BWI)	kWh/T	Ac received	≤12.0	≤12.0	**8.09**

The present results in Table 3 show that limestone from the ''Dobrilovići'' deposit meets the quality requirements for obtaining the disposable gypsum.

4. CONCLUSIONS

This paper presents the results of investigation the possibility of using lithotamnian limestone from the ''Dobrilovići'' deposit near Loznica in flue gas desulphurization systems in thermal power plants. Comparison the investigation results and requirements that limestone should meet, lead to a definite conclusion that lithotamnian limestone from the ''Dobrilovići'' deposit is completely suitable for the use in flue gas desulphurization systems with minimum corrections regarding sample moisture (necessary dewatering). Application of this limestone in desulphurization process can provide disposable gypsum product.

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ISTRAŽIVANJE RANGA UTICAJA PRIRODNO-GEOLOŠKIH USLOVA NA IZBOR SISTEMA PODZEMNOG OTKOPAVANJA UGLJENIH SLOJEVA U SRBIJI

Izvod

Problematika obrađivana u ovom radu posvećena je definisanju ranga-kategorije uticaja prirodno-geoloških uslova u ležištima uglja u Srbiji na izbor sistema otkopavanja podzemnim načinom. Na osnovu razmatranog metodološkog pristupa izvršeno je rangiranje uticajnih uslova pri čemu su izdvojene četiri grupe i dat njihov kvalitativni opis, korišćenjem metoda analize i sinteze.

Na osnovu dobijenih rezultata moguće je za konkretne uslove u ležištu izvršiti optimizaciju sistema otkopavanja (metodu i tehnologiju otkopavanja)

Ključne reči: *ugalj, metoda otkopavanja, prirodno-geološki uslovi eksploatacije*

1. UVOD

Kod izbora racionalnog sistema otkopavanja u aktivnim ležištima uglja u Srbiji odlučujući uticaj imaju prisutni prirodno-geoloških uslovi, koji se znatno razlikuju od ležišta do ležišta. Pitanje ranga uticaja pojedinih uslova predstavlja značajno pitanje u oblasti podzemne eksploatacije ležišta uglja, a poseban značaj ima metodološki postupak kvantifikacije.

Može se istaći da su u aktivnim ležištima uglja u Srbiji relativno otežani uslovi eksploatacije, sa znatnim promenama od ležišta do ležišta, a često i između pojedinih otkopnih polja u istom ležištu. Ove promene posebno dolaze do izražaja spuštanjem eksploatacionih radova po dubini.

Za donošenje odluke o primeni određene metode i tehnologije otkopavanja pored ocene prilagođenosti konkretnim prirodno-geološkim uslovima je i postupak optimizacije glavnih parametara, pri čemu između njih postoji direktna zavisnost.

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Otkopne radove karakteriše zajedničko optimiziranje izbora sistema otkopavanja, načina mehanizovanja, upravljanja krovinom, odnosno određivanja osnovnih parametara otkopa: kapacitivnosti, produktivnosti i proizvodne cene. Postupak optimizacije zasniva se na korišćenju više prikladnih matematičkih metoda:računom varijanti i ekonomsko-matematičkim modeliranjem, dobijanjem složenih rešenja, ispitivanjem ekstrema funkcija, linearnim programiranjem, dinamičkim modeliranjem i metodom grafa, statičkom analizom i dr.

U ovome radu u okviru sprovedenih istraživanja korišćene su metode matematičkog modeliranja, eksperimentalne metode analize i sinteze. Okvir istraživanja predstavljaju aktivna ležišta uglja u Srbiji, predisponirana za sisteme podzemne eksploatacije, sa ciljem da se kvalitativno definiše rang uticaja prirodno-geoloških uslova na izbor sistema otkopavanja debelih ugljenih slojeva. Navedenom problematikom u Srbiji se bavilo niz istraživača koji su dolazili do različitih hipoteza, mahom za konkretne uslove jednog ležišta. Ovde se postavlja osnovni problem definisanja uticajnih faktora kod otkopavanja debelih ugljenih slojeva, dok su slučajevi otkopavanja tankih i srednje debelih ugljenih slojeva na zadovoljavajući način rešeni.

Otkopavanje debelih ugljenih slojeva je najsvestranije i istovremeno i najteže područje u oblasti podzemnog otkopavanja. Kod inače istih uslova i istog načina i metode otkopavanja, varijacije napona, kretanje i zarušavanje u stenama sve do površine terena su veće nego kod otkopavanja tankih i srednje debelih slojeva. Ovo za sobom u praksi povlači niz teškoća, otežano upravljanje krovinom, veća oštećenja na površini, izražena endogena požarna ugroženošt, veći gubici i veće poteškoće kod odvodnjavanja i provetravanja.

2. OSNOVNI PRIRODNO-GEOLOŠKI USLOVI EKSPLOATACIJE U AKTIVNIM RUDNICIMA U SRBIJI

U Srbiji je sada u eksploatacionom smislu aktivno osam ležišta uglja, a planira se aktiviranje i drugih ležišta s obzirom na raspoložive rezerve i zahteve tržišta. U aktivnim ležištima uglja u Srbiji dominantni geološki oblici su slojevite nagnute strukture sa izraženim tektonskim deformacijama čije su posledice nepravilni oblici ograničenih eksploatacionih područja i moguće kratke dužine otkopnih polja i blokova sa čestim promenama pravca pružanja i uslova pada slojeva. Ove pojave su rezultat složene postrudne tektonike u ležištima. Pored navlačenja, postrudna tektonika je izražena i u vertikalnim skokovima sa pomeranjima i do 100 m. Slojevi debljine od nekoliko do 40 m padaju pod uglom do 35°. Ovome treba dodati činjenicu da su osnovna fizičko-mehanička svojstva radne sredine nepovoljna, jer preovlađuju ležišta u kojima su vrednosti čvrstoće na pritisak krovine i podine niža ili znatno niža u odnosu na ugalj, te to u mnogome sužava mogućnosti primene velikih mehanizovanih proizvodnih sistema i koncentracije proizvodnje u istim. Prema dubini zaleganja ugljenih slojeva, većina ležišta pripada grupi rudnika sa srednjom dubinom eksploatacije do 500 m, sa retkim izuzecima.

Hidrološki uslovi u ležištima su relativno povoljni i radi se o malim prilivima vode u rudarske prostorije. Sva ležišta karakteriše opasna ugljena prašina i izražena sklonost uglja ka samozapaljenju, tako da su u jamama česti endogeni oksidacioni procesi i jamski požari. Izdvajanje metana su vezana samo za određena ležišta i to eshalacijom, a u ekstremnim slučajevima izbojem sa materijalom. Aktivne jame otvorene su različitim kombinovanim sistemima otvaranja, pri čemu dominiraju kose i horizontalne prostorije. Izrada rudarskih prostorija vrši se polumehanizovano, primenom bušačko-minerske tehnologije za

iskopavanje, ručnim utovarom u grabuljaste transportere i podgrađivanjem sa drvenom odnosno čeličnom podgradom, pri čemu se postižu niski učinci u dinamici izrade što povremeno dovodi do diskontinuiteta radova otkopavanja zbog međusobne neusklađenosti.

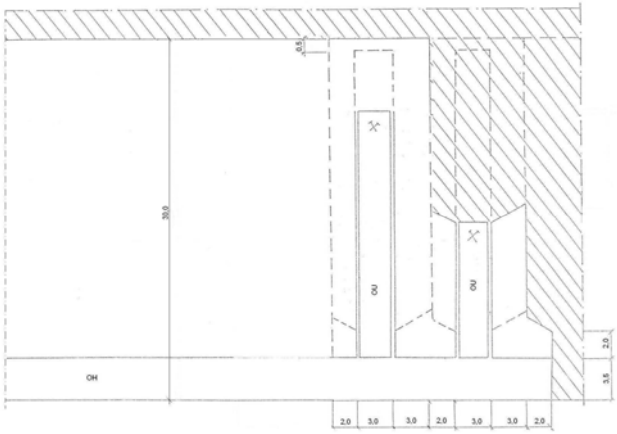
3. PRIMENJENI SISTEMI OTKOPAVANJA

U složenim i različitim uslovima ležišta uglja u Srbiji primenjivana su brojna i specifična rešenja procesa podzemnog otkopavanja slojeva kamenog uglja, mrkog uglja i lignita. Raznolikost mineološko-petrografskih karakteristika, širok dijapazon vrednosti fizičko-mehaničkih svojstava uglja i pratećih stena, izražena tektonika, variranje debljine ugljenih slojeva i dr, doprineli su u mnogome da se kao osnovni sistemi otkopavanja koriste stubne i komorno stubne metoda sa tehnologijom miniranja, a koje karakteriše:

- široka primena zbog velike mogućnosti prilagođavanja geometrije radne fronte otkopa i taktike otkopavanja složenim uslovima eksploatacije,
- niska proizvodnost i produktivnost u odnosu na širokočelne mehanizovane otkope, te potreba rada većeg broja otkopnih jedinica,
- dekoncentrisanost otkopnih i pripremnih radova,
- nizak stepen mehanizovanosti (izuzev transporta) na otkopnim jedinicama,
- visoko učešće izrade rudarskih prostorija pripreme za otkopavanje

U određenim ležištima (rudnicima) u Srbiji primenjivana je i metoda mehanizovanih širokih čela sa tehnologijom rezanja i natkopnog dobivanja sobzirom da su ovim sistemom otkopavani debeli ugljeni slojevi. Postignuti kapaciteti proizvodnje, učinci i ekonomičnost su bili različiti, od slučaja do slučaja, ali u svakom slučaju povoljniji nego što se postižu stubnim metodama otkopavanja. Treba istaći da je u primeni bila i metoda širokog čela sa kratkim radnim frontom i kompleksnom mehanizacijom. Ovaj tip otkopa poznat kao »slepo čelo«, sa jednom transportno-ventilacionom prostorijom i separatnim provetravanjem, primenjen je u sistemu vertikalne koncentracije za otkopavanje sloja uglja debljine do 12 m. Stubne metode otkopavanja primenjuju se sa tehnologijom kratkobušotinskog miniranja za slojeve debljine 2-6 m, a sa primenom dubokobušotinskog miniranja i do debljine od 10m.

Osnovni princip stubne metode otkopavanja sastoji se u otkopavanju pripremljenih stubova, i to povlačenjem otkopnih uskopa na obe strane. Osnovna priprema za primenu ove metode otkopavanja sastoji se u izradi prostorija po pružanju ugljenog sloja-osnovica za otkopavanje kojima se otkopno polje deli po padu sloja na nagnute stubove dužine 30-50 m. Osnovice za otkopavanje izrađuju se u podinskom delu ugljenog sloja i u toku otkopavanja se međusobno povezuju spojnim vezama radi bolje organizacije transporta i provetravanja. Izrada otkopnih osnovica vrši se bušačko-minerskim radovima, sa osiguranjem podgradnim okvirima (slika 1.).



Sl. 1. *Dispozicija otkopa u jednom otkopnom stubu*

4. DEFINISANJE RANGA UTICAJA NA IZBOR SISTEMA OTKOPAVANJA

Otkopavanje je osnovna faza procesa eksploatacije uglja koja najvećim delom utiče i na ostale faze procesa. Uspešno odabran skup tehnoloških operacija u procesu otkopavanja za određenu radnu sredinu i određene prirodno-geološke uslove, koja se definiše kao metoda otkopavanja, obezbeđivanjem visokog stepena koncentracije tehnike i tehnoloških rešenja treba da postigne:

- što veći smenski, odnosno dnevni kapacitet otkopa,
- što veću produktivnost po zaposlenom u otkopu,
- što manje gubitke uglja,
- što veću sigurnost rada u svim tehnološkim operacijama na dobijanju uglja,
- zadovoljavajuću ekonomičnost.

Osnovni pravac razvoja sistema otkopavanja ležišta uglja podzemnim sistemom usmeren je ka unapređenju metoda širokih čela sa kompleksnom mehanizacijom, sa različitim dužinama otkopa i visinama otkopavanja. U složenim i različitim uslovima ležišta uglja u Srbiji primenjivana su brojna i specifična tehničko-tehnološka rešenja procesa podzemnog otkopavanja uz stalna nastojanja da se što više prilagode uslovima svakog ležišta.

Za efikasno i racionalno otkopavanje ugljenih slojeva podzemnim sistemima moraju se detaljno istražiti i utvrditi uslovi radne sredine, te na osnovu rezultata istih izvršiti izbor sistema otkopavanja i odgovarajuće mehanizacije. Bitno je istaći da se samo na osnovu kompleksno sprovedenih istraživanja i ispitivanja mogu definisati uslovi otkopavanja i utvrditi način ispoljavanja izabranog tehnološkog procesa na radnu sredinu. Pitanje ranga uticaja pojedinih faktora predstavlja značajno pitanje u oblasti podzemne eksploatacije ležišta uglja, a poseban značaj ima metodološki postupak kvalitativne i kvantitativne ocene. Na osnovu analize prirodno-geoloških uslova eksploatacije u aktivnim ležištima i pregleda primenjenih sistema otkopavanja

sa relevantnim parametrima, određena su ograničenja u primeni pojedinih sistema otkopavanja i određen rang uticaja, a što je prikazano u tabeli 1.

Tabela 1. *Kategorizacija ranga uticaja prirodno-geoloških uslova na izbor sistema otkopavanja ugljenih slojeva u Srbiji*

SISTEM OTKOPAVANJA		KATEGORIJA -RANG UTICAJA PRIRODNO-GEOLOŠKOH USLOVA			
		I OPREDELJUJUĆI	II DOPUNSKI	III OGRANIČAVAJUĆI	IV ISKLJUČIVI
Princip konc. otkop.	Horizontalna koncentracija	1. debljina sloja od 5 m	1. nagib sloja	1. gorski udar 2. ekspanzije gasa	
	Vertikalna koncentracija	1. debljina sloja preko 5 m	1. nagib sloja	1. sklonost uglja ka samozapaljivanju	1. debljina sloja manja od 5 m
METODA OTKOPAVANJA	2.1 Široko čelo (HK)	1. debljina sloja do 5 m 2. racionalna dužina otkop. polja po pružanju i padu	1. nagib sloja 2. fizičko-mehaniča svojstva sloja i pratečih stena 3. izmene debljine sloja	1. visoka metanonosnost 2. veličina rezervi uglja 3.fizičko-mehanička svojstva podine	1. neracionala dužina otkopnog polja po pružanju i padu
	2.2 Široko čelo (VK)	1. debljina sloja do 5 m 2. racionalna dužina otkop. polja po pružanju i padu	1. nagib sloja 2. fizičko-mehaniča svojstva sloja i pratečih stena	1. vodoobilnost 2. sklonost uglja ka samozapaljenju 3.visoka metanonosnost 4. veličina rezervi uglja	1. neracionala dužina otkopnog polja po pružanju i padu
	2.3 Komorna metoda	1. debljina slojapreko 5 m 2. čvrstoča i kompaktnost neposredne krovine	1. Izmene nagiba debljine sloja	1. nagib sloja 2. visoka metanonosnost 3. sklonost uglja ka samozapaljenju	1. nepovoljne veličine čvrstoče i kompaktnosti krovine 2. gorski udar
	2.4 Stubna metoda	1. debljina sloja do 5 m 2. racionalna dužina otkop. polja po pružanju i padu	1. nagib sloja 2. fizičko-mehaniča svojstva sloja i pratečih stena	1. nagib sloja 2. visoka metanonosnost 3. sklonost uglja ka samozapaljenju 4. gorski udar	
TEHNOLOGIJA OTKOPAVANJA	3.1 Miniranje	1. fizičko-mehanička svojstva ugljenog sloja	1. debljina ugljenog sloja	1. svojstva ugljene prašine 2. metanonosnost 3. struktura ugljenog sloja	prema izabranom principu i metodi otkopavanja i opredeljujućim faktorima izabira se odgovarajuća tehnologija otkopavanja (alternativna kombinacija dve ili više tehnologija).
	3.2 Podsecanje	1. fizičko-mehanička svojstva ugljenog sloja	1. debljina ugljenog sloja	1. struktura ugljenog sloja	
	3.3 Struganje	1. fizičko-mehanička svojstva ugljenog sloja 2. debljina sloja	1. fizičko mehanička svojstva podine	1. struktura ugljenog sloja	
	3.4 Rezanje	1. fizičko-mehanička svojstva ugljenog sloja	1. nagib sloja 2. fizičko-mehaniča svojstva podine	1. nagib sloja preko 25 2. struktura ugljenog sloja	
	3.5 Hidrorazaranje	1. fizičko-mehanička svojstva ugljenog sloja		1. izražena sklonost uglja ka samozapaljenju	

ZAKLJUČAK

Na izbor racionalnih sistema podzemnog otkopavanja u ležištima uglja u Srbiji, odlučujući uticaj imaju prisutni prirodno-geološki uslovi eksploatacije. S obzirom da se na prirodno-geološke uslove nemože direktno uticati to tehničko-tehnološka rešenja sistema otkopavanja moraju biti prilagođena prirodno-geološkim uslovima. U složenim uslovima eksploatacije u konkretnim ležištima vrši se otkopavanje ugljenih slojeva uglavnom velike debljine, nahom metodom stubnog otkopavanja sa tehnologijom miniranja, sa promenljivim rezultatima rada. Očigledno je da se u cilju sigurnijeg i ekonomičnijeg rada mora vršiti modernizovanje i osavremenjivanje sistema otkopavanja.

Jedna od bitnih faza u istraživanju uvođenja racionalnog sistema otkopavanja je određivanje ranga uticaja prirodno-geoloških uslova, i ona služi za dalju razradu metodološkog postupka optimizacije glavnih parametara otkopa.

U ovome radu metodološki postupak kvalitativne procene uticaja prirodno-geoloških uslova na izbor rešenja sistema otkopavanja dat je preko kategorizacije-ranga uticaja, dok je za kvantitativnu procenu korišćena analitička metoda po kriteriju adaptacije sistema i radne sredine.

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STUDY OF RANK IMPACT THE NATURAL-GEOLOGICAL CONDITIONS ON A SELECTION THE UNDERGROUND MINING SYSTEM OF COAL SEAMS IN SERBIA

Abstract

The covered issues in this paper are dedicated to defining the rank-impact of natural-geological conditions on a selection the underground mining method and system for coal deposits in Serbia. Based on the observed methodological approach, the ranking of influential conditions were made in which four groups were selected and given their qualitative description, using the methods of analysis and synthesis.

Based on the obtained results of the study, it is possible to make the optimization of mining systems (mining methods and technology) for the specific conditions in coal deposit.

Keywords: *coal, mining methods, natural-geological conditions of excavation.*

1. INTRODUCTION

In a selection of rational system of mining in the active coal deposits in Serbia, the natural and geological conditions have a decisive influence. These conditions differ greatly from deposit to deposit. The impact of these conditions is a significant issue in the underground exploitation of coal, and the most significant is the methodological process of quantification.

It may be noted that in the active coal deposits in Serbia there are relatively difficult conditions of exploitation, which change significantly from deposit to deposit, and often between mining sections of the same deposit. These changes are manifested in particular in steeper parts of deposits.

The main parameters for optimization should be considered in a decision making to use a specific method and technology of excavation. In addition, the specific natural geological conditions should be studied since there is a direct dependence between them.

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Excavation works are characterized by joint optimization for a selection of mining system, system of mechanization, overlying strata management, and determination the main parameters of excavation: output, productivity and production rates. The optimization procedure is based on the use of more appropriate mathematical methods: variations calculus and economic-mathematical modeling, obtaining complex solutions, examining the extremes of functions, linear programming, dynamic modeling and graph methods, static analysis and others.

Mathematical modeling methods and experimental methods of analysis and synthesis were used in the research, conducted for this study. The research framework involved the active coal deposits in Serbia, predisposed for underground mining systems. This was done in order to define the qualitative impact that natural-geological conditions had on a range of choices for systems of coal excavation in thick seams. A number of researchers in Serbia were dealing with this issue and came up with different hypothesis, mostly for the specific conditions of deposit. This is the basic problem in defining the set of influential factors in the excavation of thick coal seams, while the cases of mining thin and medium thick coal seams were satisfactorily resolved.

Excavation of thick coal seams is the most versatile but also the most difficult area in the underground mining. In otherwise, the same conditions and the same ways and methods of excavation, variations of stress, roof caving and rock movement to the ground surface are larger than in mining of thin and medium thick seams. In practice, this entails a number of difficulties e.g. difficulties in the management of overlaying strata (roof), greater damage on the surface, expressed endogenous fire treat, higher losses of ore and greater difficulty in drainage and ventilation.

2. GENERAL NATURAL-GEOLOGY CONDITIONS OF MINING IN THE ACTIVE MINES IN SERBIA

In Serbia, there are currently eight active coal deposits, in exploitation terms with plans to activate other deposits dependant upon demand for reserves. In the active coal deposits of Serbia, the dominant geological forms are stratified inclined structures with strong tectonic deformation effects. These geologic forms are irregular and have limited areas of exploitation with possible short lengths of mining fields and blocks. Also, frequent changes of direction and fall angles of seams exist in geological form. This phenomena is the result of complex tectonics in deposits. In addition to retention, tectonics is expressed in vertical jumps with shifts up to 100 m. Seams range in thickness from a few to 40 m dipping up to 35°. It should be mentioned that the basic physical and mechanical properties of surrounding rocks are unfavorable because the values of compressive strength of the seams floor and roof are lower or much lower when compared to coal. This greatly narrows the possibilities to use large mechanized production systems with concentrated production in one area. Reviewing the depth of coal seams, the most of deposits have mines with medium depth of exploitation up to 500 m, with rare exceptions.

Hydrological conditions in deposits are relatively favorable with small water inflow in mining areas. All deposits are characterized with dangerous coal dust and a noticeable tendency towards spontaneous coal combustion. The endogenous oxidative processes and fires are common in mines. Extraction of methane is related

only to the certain deposits by exhalation, and in extreme cases discharges with material. The active mines are open by different combined opening systems, with domination of inclined and horizontal galleries. Development of mining facilities shall be semi-mechanized, using the drilling-mining technology for excavation, manual loading on chain conveyors and supporting with wooden or steel support. This achieves low effects in dynamics of development and it occasionally leads to a discontinuity of excavation due to the mutual disharmony.

3. THE APPLIED SYSTEMS OF EXCAVATION

In the complex and varying conditions of Serbian coal deposits, a number of specific solutions have been applied in the underground mining the seams of stone coal, brown coal and lignite. The diversity of mineralogy and petrography characteristics, a wide range in physical and mechanical property values of coal and associated rocks, expressed tectonics, varying thickness of coal layers, etc., have greatly contributed to the use of basic mining systems i.e. pillar and chamber mining methods with blasting technology, which are characterized by the following:

- Widely use due to a great adaptability in geometry working front excavated and excavation tactics in the complex condition of exploitation
- Low productivity and efficiency in relation to the mechanized face, and the need to operate a greater number of mining units,
- De-concentration of excavation and development work
- Low level of mechanization (except transportation) of excavation units
- High proportion of development work for excavation.

Mechanized face with technology of cutting and getting immediately the upper coal seams has been applied in some thick coal seams (mines) in Serbia. The achieved production capacity, performance and economy were different from case to case, but in any case better than in the use of pillar mining methods. It should be noted that some mines used mechanized face technology with a short working front. This type of excavation is known as a “blind shortwall system” with only one transportation-ventilation drift. Coal seams with thickness up to 12 m used auxiliary ventilation in the vertical concentration of the excavation. Pillar mining methods with short borehole mining technology was applied for seam thicknesses of 2 – 6 m, and the application of long borehole blasting methods was used for seam thicknesses up to 10 m.

The basic principle of the pillar mining method consists of excavation the prepared pillars by retreat the rise heading on both sides. The basic preparation for implementing this mining method consists of development the mining facilities along the strike of coal seam. This divides the excavation field decline on the inclined pillars, 30-50 m long (Figure 1). The main tunnels for mining are made in the floor of coal seam and connected during excavation for better organization for transportation and ventilation. Development of main tunnels is carried out using the borehole blasting methods and supported by frame support [1].

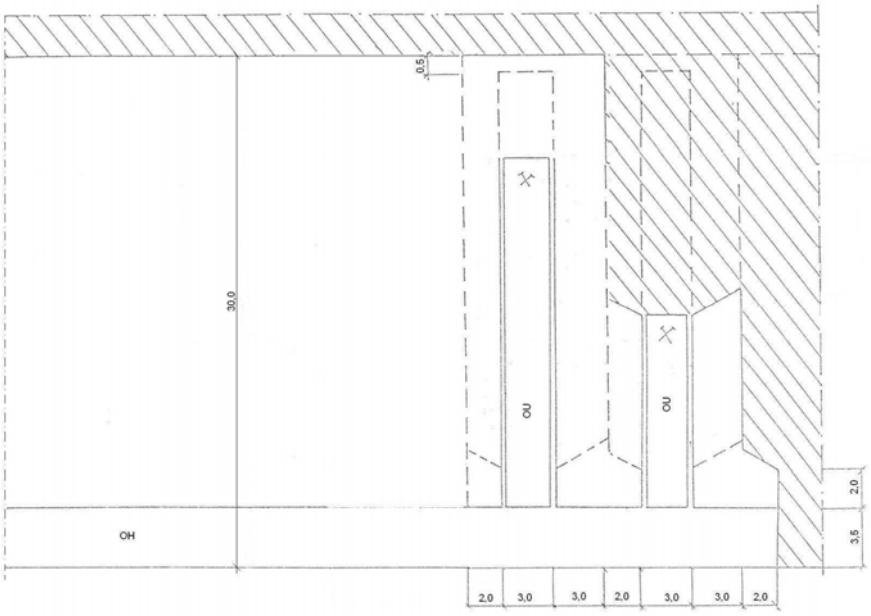

Fig. 1. *Disposition of excavation in one excavated pillar*

4. DEFINITION OF IMPACT RANK ON A SELECTION OF EXCAVATION SYSTEM

Excavation is the main phase of coal exploitation and mainly affects the other phases of the process. Successful selection of a set of technological operations in the process of excavation for the particular work environment and particular natural and geological condition defines the mining method, providing a high level of concentration techniques and technological solutions to achieve:

- Maximum shifts and daily capacity of face,
- Maximum productivity per employee on the face,
- Minimum losses of coal,
- Optimized safety of all technological operations on exploitation,
- Satisfactory efficiency.

The main direction in development of underground coal mining systems is in improvement the long wall methods with complex machinery mining different face excavation lengths and heights. In the complex and varying conditions of Serbian coal deposits, numerous and specific technical and technological solutions are applied for the underground mining processes with continuous efforts to adapt to the conditions of each deposits [2], [3].

For efficient and rational excavation of coal seams by underground systems, the conditions of working environment must be thoroughly investigated. Based on these results, a selection of excavation system and appropriate mining machinery must be made. It is important to point out

that only on the basis of complex research and conducted tests these mining conditions can be defined and determination on how selected technological processes affect the working environment. The issue of impact the individual-level factors is significant in the underground exploitation of coal, and very significant is the methodological procedure of qualitative and quantitative assessments. Based on the analysis of natural and geological conditions in the active exploitation of deposits and a review the applied mining systems to the relevant parameters, the certain limitations were determined in the application of systems and influence rank, shown in Table 1.

Table 1. *Categorization of impact rank the natural and geological conditions on a selection of mining systems the coal deposits in Serbia*

SYSTEM OF EXCAVATION		CATEGORY-RANK -affected by natural and geological conditions			
		I CHOOSING	II ADDITIONAL	III LIMITED	IV EXCLUSIVE
The principle of concentration of face excavated	Horizontal conc.	1. thickness of layer up to 5 m	1.subsidence slope of layer	1. rock burst 2. gas explosion	
	The vertical conc.	1. thickness of layer over 5 m	1.subsidence slope of layer	1. propensity of coal to self ignition	1. thickness of layer less than 5 m
METHOD MINING	2.1 longwall face (HK)	1. thickness of layer up to 5 m 2.rational length of mining field in direction of full dip	1.subsidence slope of layer 2.physical-mechanical properties of layer and adjoining rock 3. changes in thickness of layer	1. high coal -seam methane content 2. size of coal reserves 3. physical and mechanical properties of immediate floor	1.irrational length of mining field in direction of full dip
	2.2 longwall face (VK)	1. thickness of layer up to 5 m 2.rational length of mining field in direction of full dip	1.subsidence slope of layer 2.physical-mechanical properties of layer and adjoining rock	1. abundant in water 2. propensity of coal to self ignition 3. high coal-seam methane content 4. size of coal reserves	1.irrational length of mining field in direction of full dip
	2.3 Chamber Method	1. thickness of layer over 5 m 2. strength and compactness of immediate roof	1. changes of slope and thickness of layer	1.subsidence slope of layer 2. high coal -seam methane content 3. pensity of coal to self ignition	1. unfavorable strength and compactness of immediate roof
	2.4 Pillar Method	1. thickness of layer up to 5 m 2.rational length of mining field in direction of full dip	1.subsidence slope of layer 2.physical-mechanical properties of layer and adjoining rock	1.subsidence slope of layer 2. high coal -seam methane content 3.propensity of coal to self ignition 4. rock burst	
OF EXCAVATION TECHNOLOGY	3.1 Blasting	1. physical and mechanical properties of coal seam	1. thickness of coal seam	1. properties of coal dust 2. coal-seam methane content 3. structure of coal seam	according to selected principle and mining method and decisive factors
	3.2 Undercutting	1. physical and mechanical properties of coal seam	1. thickness of coal seam	1. structure of coal seam	appropriate mining technologies are
	3.3 Ploughing	1. physical and mechanical properties of coal seam 2. thickness of coal seam	1.physical-mechanical properties of immediate floor	1. structure of coal seam	chosen (alternative combinations of two or more technologies)
	3.4 Cutting	1. physical and mechanical properties of coal seam	1.subsidence slope of layer 2.physical-mechanical properties of immediate floor	1.subsidence slope of layer over 25° 2. structure of coal seam	
	3.5 Hydro fracture	1. physical and mechanical properties of coal seam		1. pronounced tendency towards spontaneous combustion of coal	

5. CONCLUSION

On a choice of rational systems in the underground coal mining in Serbia, the decisive factors are the present natural and geological conditions of mining. Since natural and geological conditions cannot be directly affected, the technical and technological solutions of the excavation system must be adapted to these conditions. Due to the complex conditions of exploitation in specific coal deposits, the

excavation is carried out mainly in thicker seams using the pillar mining method with blasting technology, yielding varying results. It is obvious that in order to have secure and economical operations the modernization and upgrading of mining systems must be carried out.

One of the important phases in the study of introducing a rational system of mining is to determine the rank impact of natural and geological conditions. It also serves to further elaborate in the methodological procedure for optimization the main parameters of excavated face.

In this paper, methodological quality assessment of impact the natural and geological conditions on a choice of excavation system is given by categorization-rank effects, while for the quantitative evaluation, the analytical methods are used by criterion of adoption the system and working environment.

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NASTAVAK RUDARSKIH AKTIVNOSTI RTB-a BOR NA LOKALITETU KRAKU BUGARESKU CEMENTACIJA SA ANALIZOM OSETLJIVOSTI IRR IZBORA VARIJANTI OTKOPAVANJA***

Izvod

Radom su opisane aktivnosti na nastavku eksploatacije na lokalitetu Kraku bugaresku Cementacija 1 i 2, sa kratkim prikazom istorijata dosadašnjih izvedenih i sadašnjim stanjem rudarskih radova, kao i koncepcijom buduće eksploatacije.

Zbog planiranih izmena u koncepciji buduće eksploatacije sa aspekta prelaska na veći kapacitet (5,5 Mt godišnje) u odnosu na projektovani od 2,5 Mt kao i smanjenja broja faza (push backs) u razvoju kopa Cementacija 2 u odnosu na projektovano rešenje od strane Investitora, prikazana je i analiza osetljivosti Interne stope rentabilnosti (IRR) na promenu flotacijskog iskorišćenja, kao implicitne posledice smanjenja broja aktivnih radilišta na rudi u istovremenom radu. Drugim rečima – eksploatacija sa manjim brojem faza u otkopavanju smanjuje mogućnost blendinga prema flotaciji čime utiče na koherentnost sadržaja metala u rudi koja se dozira flotaciji, odnosno iskorišćenje u flotaciji. Smanjenjem iskorišćenja, smanjuje se i prihod, a time se utiče i na IRR kao jednan od pokazatelja ekonomske ocene projekta .

***Ključne reči**: eksploatacija, stanje rudarskih radova, push backs, flotacijsko iskorišćenje, interna stopa rentabilnosti, investiciona ulaganja, povraćaj ulaganja.*

1. UVOD

Ležište rude bakra Kraku bugaresku - Cerovo nalazi se u Istočnoj Srbiji, oko 20 km severno od Bora (sl.1.).

Na ovom kompleksu rudnih ležišta (Cerovo Cementacija 1, Cerovo 2, Cerovo 3, Cerovo 4, Cerovo primarno i Drenova) eksploatacija je započeta kopom Cerovo Cementacija 1 koji je otvoren 1993. godine, a radovi na investicionom raskri-vanju započeli su još 1990. godine. Tokom investicionog raskri-vanja koje je trajalo od 1990. do 1993. godine, koliko je zapravo trajala izgradnja objekata prerade na lokaciji Cerova i hidrotransportnog sistema transpor-

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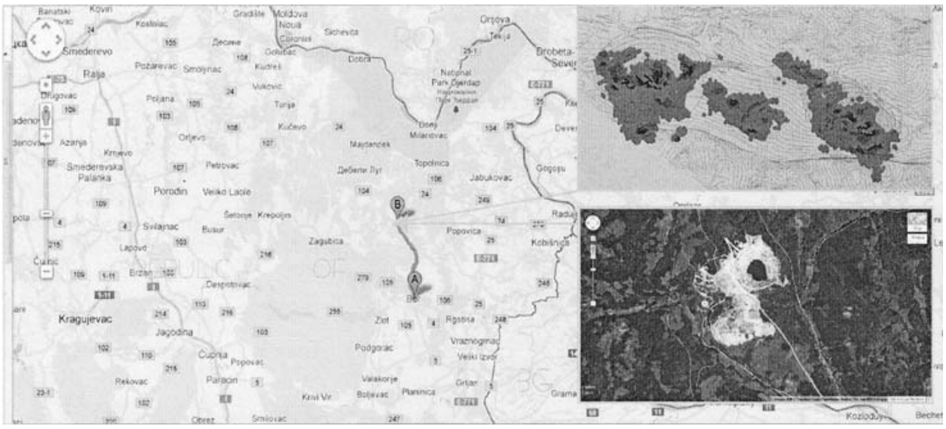
tovanja pulpe do borske flotacije, bilo je raskriveno oko 10 miliona tona jalovine (skoro polovina od ukupne količine u zahvatu kopa), čime su stvoreni uslovi za vrlo povoljnu kasniju eksploataciju sa malim koeficijentom raskrivke. To je svakako imalo svoju cenu, ali okolnosti su bile takve da je to je zapravo i omogućilo da se na ovom rudniku odvija eksploatacija i u vrlo teškim, skoro nemogućim uslovima, pri vrlo nepovoljnim tržišnim uslovima kada je cena bakra u jednom momentu (2002.) iznosila čak neverovatnih 1300 US$ po toni katodnog bakra.

Glavnim rudarskim projektom otkopavanja ležišta "Cerovo Cementacija" [1], definisane su sledeće eksploatacione reserve u konturi 0,3 % Cu kopa Cerovo Cementacija 1:

- Ruda ------------------17.479.165 t
- Jalovina----------------23.674.605 t
- Iskopine ---------------41.153.770 t
- Srednji sadržaj Cu u rudi ---------------------0,713 % Cu,
- Srednji koeficijent raskrivke --------------1,35 t/t.



Sl. 1. *Položaj rudnog ležišta bakra "KB-Cementacija"RTB Bor (Google map)*

2. DOSADAŠNJE AKTIVNOSTI NA EKSPLOATACIJI RUDNOG LEŽIŠTA KRAKU BUGARESKU - CEROVO

Koncepcija eksploatacije se sastojala u klasičnom otkopavanju bušačko minerskim radovima sa diskontinuiranim – kamionskim transportom rude i raskrivke. Projektovana visina etaže bila je 15 m, putevi spiralni sa početkom na severozapadnoj strani kopa, sa kote 515, na lokaciji gde kop prelazi iz brdskog u dubinski tip. Širina puteva 20 m, sa nagibom do 10%.

Ruda je transportovana do primarnog drobljenja nakon čega je deponovana na zatvoreno skladište. Sledeća tehnološka faza je sekundarno i tercijalno drobljenje. Izdrobljena ruda je odatle je dozirana u sledeću fazu prerade - dva stadijuma mlevenja, sa šipkama i kuglama. Proces flotacijske prerade je na Cerovu išao do dobijanja pulpe koja se nakon zgušnjavanja, hidrauličnim putem transpor-

tovala do flotacije Bor gde je vršeno flotiranje. Odlaganje flotacijske jalovine je bilo na flotacijskom jalovištu RTH u Boru.

Problem vezan za dinamiku zamene opreme i kvalitet samog elektromašinskog održavanja zbog nedostatka rezervnih delova, koji je u rudarstvu nastao tokom devedesetih godina, a zbog poznatih limitiranih uslova privređivanja, kulminirao je tokom 2003/2004. godine, kada je *kop* prestao sa radom. Namera je bila da se izvrši konzerviranje preostale opreme i instalacija i to je u nekoj meri i učinjeno. Ostatak rudarske mehanizacije sa Cerova je vraćen u Veliki Krivelj kako bi se tamo održala kakva - takva proizvodnja.

Rudarski radovi na kopu Cerovo Cementacija 1 zaustavljeni na k +395 m (etaža 395), sa neznatnim otkopavanjem i na etaži 380. Odvodnjavanje kopa je nastavljeno još izvesno vreme, da bi se i sa tim prestalo. U sadašnjem trenutku, dno kopa je pod vodom (sl. 1), i tehničkim projektom odvodnjavanja biće definisani uslovi i način ispumpavanja akumuliranih količina vode sa dna kopa, sa ciljem stvaranja uslova za nastavak proizvodnje.

Tokom 2011/12. godine krenulo se sa revitalizacijom i nastavkom proizvodnje, ali sa nešto izmenjenom koncepcijom u odnosu na ranije definisanu, kako sa aspekta godišnjeg kapaciteta otkopavanja i prerade rude, tako i sa aspekta koncepta otkopavanja Cerova 2, odnosno celokupne dinamike.

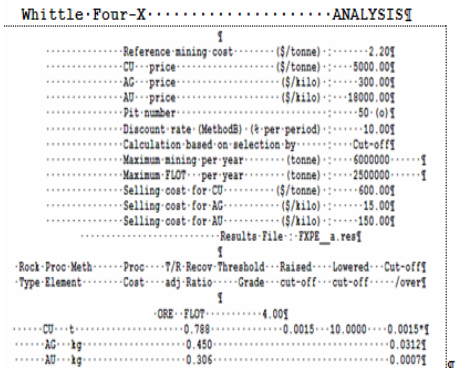
3. KONCEPCIJA PONOVNOG POKRETANJA RUDNIKA

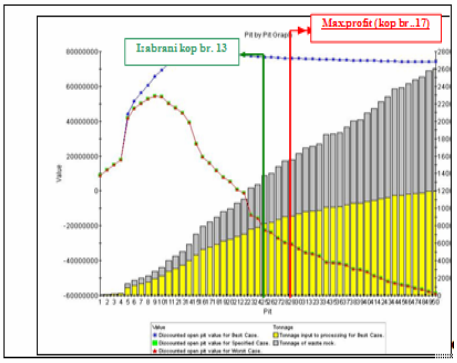
Zbog toga što su se poslednjih godina uslovi na tržištu bakra poboljšali tako da je cena bakra u jednom momentu dostigla i cifru od 9 000 US$, čak i relativno siromašna ležišta su postala atraktivna i ekonomski isplativa za eksploataciju.

Strategija ponovnog aktiviranja eksploatacije rude bakra na lokaciji Cerovo – Kraku Bugaresku projektovana je *Dopunskim rudarskim projektom otkopavanja 2008. godine*, [2] i sastoji se u proširenju i produbljenju površinskog kopa Cerovo Cementacija 1, i otvaranju i eksploataciji rudnog ležišta Cementacija 2.

Optimizacijom je izvršen izbor kontura kopova, takođe i optimalne dugoročne dinamike otkopavanja po kriterijumu profita i diskontovanog profita za budući period eksploatacije, softverom Whittle Fx.

U tehničkom projektu otkopavanja (DRP 2008.) je detaljno obrađen navedeni postupak, s tim što je kapacitet rudnika bio ograničen (po zahtevu investitora) postojećim kapacitetom flotacijske prerade od 2,5 x 10^6 t rude.





Grafik 1. *Ulazni parametri optimizacije i grafik sa prikazom profita i diskontovanog profita, i mogućim konturama kopa (50) za različite cene Cu*

Polazni parametri korišćeni u optimizaciji i grafik optimizacije u Whittle Fx:

Sa grafika 1 se vidi da krive profita i diskontovanog profita jako divergiraju sa povećanjem kapaciteta proizvodnje, što upućuje na fazno otkopavanje – push backs.

Spisak planirane opreme u rudarskom delu za kapacitet od 2,5Mt prikazan je u tabeli 1:

Tabela 1. *Planirana oprema DRP-om otkopavanja kompleksa rudnih tela Cerovo Kraku bugaresku*

No.	Naziv opreme	Karakteristike	Tip i oznaka	Kom.
1	Bušilica prečnika 250 mm	Rb=250 mm	Atlas Copco	1
2	Bušilica prečnika 89 - 130 mm	R89 do 130 mm	Atlas Copco	1
3	Hidraulični bager sa elektro pogonom	V_K= 10 m^3	Terex -OK	1
4	Utovarivač L-950	V_K=13 m^3	Leturnoau	1
5	Kamion-damper	nosivosti 90 Mt	HD785-7Komatsu	6
6	Bulldozer guseničar	CAT 249 KW)	CAT	2
7	Grjder	249 KW	CAT 16H	1
8	Cisterna za vodu FAP1823	V=9 m^3		1
9	Servisno vozilo FAP1318/42	Nosivost 8 t		2
10	Servisno terensko vozilo		Lada Niva	2
11	Muljne potapajuće pumpe	Flyght	BS 25.00	4
12	Utovarivač točkaš	V = 2.5 – 3		1

Koncepcija budućeg rada jeste da se u *prvoj godini* pokretanja proizvodnje na kompleksu, sa radovima raskrivanja započne na kopu Cementacija 1, odnosno postojećem kopu. U prvoj godini treba raskrivanjem stvoriti uslove da se pun kapacitet na rudi od 2.5 miliona tona rude, dostigne u *drugoj godini*. U prvoj godini je planirano i otkopavanje investicione raskrivke do momenta stvaranja uslova za pokrivanje troškova raskrivanja vrednošću rude.To praktično omogućava da se u delu prerade mineralne sirovine završe radovi na revitalizaciji i pogon pripremi za normalnu proizvodnju.

Tabela 2. *Dinamika otkopavanja po godinama (periodima) prema DRP iz 2008. godine*

God	Iskopine (t)	Jalovina	Ruda	Cu uk(t)	Ag	Au	Cu uk (%)	Ag (g/t)	Cu uk (%)	Au (g/t)
1.	6,012,750	4,330,190	1,682,560	4,552.20	1,871.50	194.20	0.27	1.11	0.27	0.12
2	4,211,527	1,713,040	2,498,487	5,831.80	3,062.70	307.20	0.23	1.23	0.23	0.12
3.	5,547,786	3,049,922	2,497,865	5,948.40	2,410.90	248.90	0.24	0.97	0.24	0.10
4.	5,085,516	2,589,466	2,496,050	6,817.00	4,249.70	334.90	0.27	1.70	0.27	0.13
5.	5,888,154	3,389,624	2,498,531	7,458.50	3,284.70	229.50	0.30	1.32	0.30	0.09
6.	5,957,158	3,463,180	2,493,977	7,573.30	3,194.80	182.10	0.30	1.28	0.30	0.07
7.	4,059,750	1,427,516	2,632,234	8,136.80	3,447.10	164.80	0.31	1.31	0.31	0.06
8.	2,966,965	475,,116.0	2,491,849	8,833.90	2,280.80	162.00	0.36	0.92	0.36	0.07
9.	3,060,615	567,411	2,493,204	9,725.30	3,032.10	196.80	0.39	1.22	0.39	0.08
10	3,085,217	590,779	2,494,438	9,166.20	2,881.50	223.00	0.37	1.16	0.37	0.09
11.	2,974,106	478,970	2,495,136	7,824.00	3,107.00	155.40	0.31	1.25	0.31	0.06
12.	2,583,542	82,816	2,500,727	7,791.30	2,628.60	207.50	0.31	1.05	0.31	0.08
13.	1,657,514	8	1,657,506	5,095.80	1,768.60	166.80	0.31	1.07	0.31	0.10
SUMA	53,090,601	22,158,038	30,932,564	94,754.40	37,220.00	2,773.10	0.31	1.20	0.31	0.09

Obzirom na to da postrojenja prerade – infrastruktura u delu prerade, zahteva znatan obim radova na reparaciji i dovođenju u funkcionalno stanje, sa navedenim aktivnostima treba započeti znatno pre početka otkopavanja.

Koncepcija eksploatacije je izmenjena i promenom lokacije flotiranja u odnosu na prvobitnu. Umesto ranijeg rešenja da se flotiranje odvija u flotaciji Bor, flotiranje je sada planirano u flotaciji Veliki Krivelj što podrazumeva i promenu trase cevovoda za hidraulični transport pulpe.

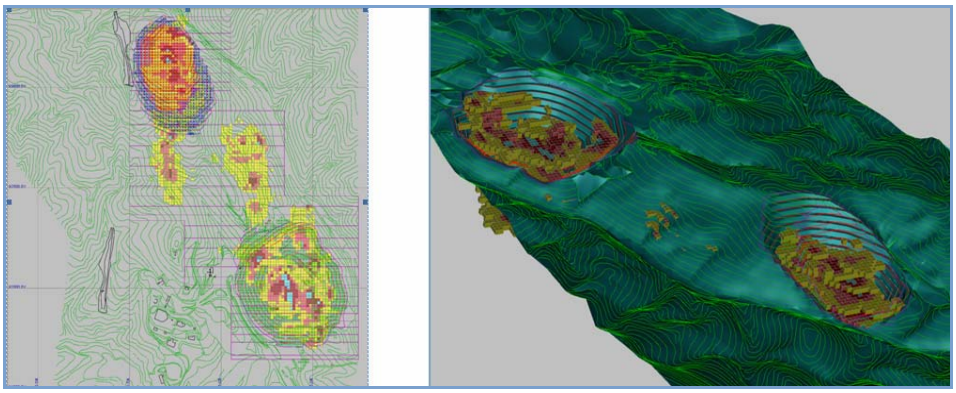
U rudarskom delu ovim projektom nije predviđena promena dosadašnje tehnologije otkopavanja, osim modifikacija u bušačko minerskim radovima u severozapadnom delu kopa C2 zbog blizine železničke pruge i to u smislu minimiziranja uticaja eksploatacije na objekte železnice.

4. VARIJANTE PRELASKA NA KAPACITET OD 5.5 Mt GODIŠNJE

Nova strategija razvoja RTB –a je svojim biznis planom kao stratešim dokumentom definisala povećanje kapaciteta sa lokacije Kraku bugaresku Cementacija, i to na 5.5 milona tona, nakon stvaranja odgovarajućih potrebnih uslova kako na kopu tako i u delu PMS. Potrebno vreme za te aktivnosti je procenjeno na 2 godine. Dakle, povećanje godišnjeg kapaciteta sa 2.5 Mt na 5.5 Mt će uslediti dve godine nakon ponovnog aktiviranja rudarskih radova na kopu (kopovima) i u flotaciji.

Postoje dve mogućnosti za nastavak otkopavanja sa povećanim kapacitetom otkopavanja.

1. *Otkopavanje Cementacije 2 u jednom zahvatu (varijanta 2F), i*
2. *Fazno otkopavanje Cementacije 2 sa dve faze C2-1 i C2-2 (varijanta 3F).*



Sl. 2. *Kopovi Cerovo Cementacija 1 i Cerovo 2, sa faznim otkopavanjem Cerova 2 (push backs C21 i C22)*
(U pozadini je geološki blok model ležišta Kraku Bugaresku, Gemcom)

Za ostvarenje prve varijante otkopavanja sa podizanjem kapaciteta otkopavanja na 5.5 miliona tona godišnje, potrebni su veći kapaciteti utovara i transporta jer je ostvarljiva intenzivnijim raskrivanjem ležišta, tj. povećanjem obima iskopa na početku otkopavanja.

U obe varijante potrebno je postrojenje za pripremu i koncentraciju osposobiti za navedeni kapacitet, što će zahtevati ulaganja koja će biti navedena u narednim tabelama. (*izvor* [6] *Biznis plan RTB Bor*).

4.1. Dinamika otkopavanja za varijantu 2F

U tabeli 3. Prikazana je dinamika otkopavanja sa radom na kopu Cementacija 1 (postojeći kop na kome je bila obustavljena eksploatacija 2004. godine) i na kopu Cementacija 2 gde se planira otkopavanje bez faznog rada.

Tabela 3. *Dinamika otkopavanja u varijanti prelaska na kapacitet 5.5 Mt godišnje bez faznog otkopavanja na Cerovu2*

Period	Tonne in place	Waste tonne	Tonne input	Grade CU	Grade AG	Grade	Units to process	Units to process	Units to process
				input	input	input	FLOT	FLOT	FLOT
				%	g/t	AU'g/t	CU t	AU kg	AG kg
1	7 000 000	4 943 885	2 056 115	0. 27	01.1	0.0001	5 579	219	2 262
2	7 000 000	4 512 181	2 487 819	0. 23	1.3	0.0001	5 692	322	3 113
3	12 000 000	6 502 351	5 497 649	0. 26	1.3	0.0001	14 197	571	7 110
4	10 106 771	4 606 771	5 500 000	0. 28	1.2	0.0001	15 132	399	6 628
5	6 502 574	1 002 574	5 500 000	0. 33	1.2	0.0001	18 243	421	6 755
6	5 803 845	303 845	5 500 000	0. 38	1.1	0.0001	20 892	416	6 212
7	5 554 089	54 089	5 500 000	0. 31	1.2	0.0001	16 778	510	6 549
8	352 807	0	352 807	0.00	1.2	0.0001	1 060	34	413
Total	**54 320 086**	**21 925 696**	**32 394 390**	**0.30**	**1.2**	**0.0893**	**97 573**	**2 892**	**39 042**

Tabela 3.1. *Dinamika otkopavanja u varijanti prelaska na kapacitet 5.5 Mt godišnje bez faznog otkopavanja na Cerovu 2*

tonne in place PUSH1	*tonne to waste PUSH1*	*tonne processed PUSH1*	*Units to process PUSH1 CU*	*tonne in place PUSH2*	*tonne to waste PUSH2*	*tonne processed PUSH2*	*Units to process PUSH2 CU*
C1				C22			
6 751 924	4 695 809	2 056 115	5 579	248 076	248 076		
4 250 772	1 762 953	2 487 819	5 692	2 749 228	2 749 228		
6 370 434	1 401 145	4 969 289	13 213	5 629 565	5 101 206	528 360	984
				10 106 771	4 606 771	5 500 000	15 132
2 103 259	168 921	1 934 337	6 044	4 399 315	833 653	3 565 663	12 199
876 247	68 861	807 387	2 433	4 927 598	234 985	4 692 613	18 459
2 378 379	33 623	2 344 756	6 651	3 175 710	20 466	3 155 244	10 127
				352 807		352 807	1 060
22 731 015	8 131 312	14 599 703	39 612	31 589 070	13 794 385	17 794 687	57 961

4.2. Dinamika otkopavanja za varijantu 3F

Tabela 4. *Dinamika otkopavanja u varijanti prelaska na kapacitet 5.5 Mt godišnje sa faznim otkopavanja na Cerovu 2*

				Grade	Grade	Grade	Units to process	Units to process	Units to process
Period	*tonne*	*Waste*	*tonne*	*input*	*input*	*input*	*FLOT*	*FLOT*	*FLOT*
	in place	*tonne*	*input*	*CU %*	*AG g/t*	*AU g/t*	*CU t*	*AU kg*	*AG kg*
1	7 000 000	4 846 958	2 153 042	0.271	1.11	0.110	5 829	233	2 399
2	7 000 000	4 502 294	2 497 706	0.228	1.25	0.130	5 686	320	3 114
3	12 000 000	6 500 582	5 499 418	0.249	1.17	0.100	13 703	538	6 420
4	10 921 136	5 421 136	5 500 000	0.289	1.22	0.070	15 903	364	6 727
5	6 180 653	680 653	5 499 999	0.328	1.34	0.090	18 023	494	7 378
6	5 842 773	342 773	5 500 000	0.378	1.13	0.080	20 808	414	6 239
7	5 557 354	57 354	5 500 000	0.305	1.19	0.090	16 796	508	6 518
8	542 594	0	542 594	0.300	1.17	0.090	1 629	51	637
TOTAL	**55 044 510**	**22 351 750**	**32 692 759**	**0.305**	**1.21**	**0.089**	**98 377**	**2 922**	**39 432**

Tabela 4.1. *Dinamika otkopavanja u varijanti prelaska na kapacitet 5.5 Mt godišnje sa faznim otkopavanja na Cerovu 2*

tonne	*tonne to*	*tonne*	*Units to process*	*tonne*	*tonne to*	*tonne*	*Units to process*	*tonne*	*tonne to*	*tonne*	*Units to process*
in place	*waste*	*processed*	*PUSH1*	*in place*	*waste*	*processed*	*PUSH2*	*in place*	*waste*	*processed*	*PUSH3*
PUSH1	*PUSH1*	*PUSH1*	*CU*	*PUSH2*	*PUSH2*	*PUSH2*	*CU*	*PUSH3*	*PUSH3*	*PUSH3*	*CU*
Cementacija 1				Cementacija 2-1				Cementacija 2 -2			
7 000 000	4 846 958	2 153 042	5 829	0	0	0	0	0	0	0	0
4 242 056	1 778 759	2 463 297	5 627	2 757 944	2 723 535	34 409	59	0	0	0	0
4 913 450	1 341 299	3 572 151	8 678	4 643 248	2 715 982	1 927 267	5 025	2 443 302	2 443 302	0	0
11 851	1 705	10 147	26	2 361 651	737 786	1 623 865	5 954	8 547 633	4 681 645	3 865 988	9 923
3 699 558	321 875	3 377 683	10 695	1 142 548	42 910	1 099 638	4 406	1 338 547	315 868	1 022 679	2 922
970 228	77 976	892 252	2 670	1 678 595	0	1 678 595	8 656	3 193 950	264 797	2 929 153	9 482
2 369 424	32 738	2 336 687	6 614	470 602	0	470 602	1 924	2 717 328	24 617	2 692 712	8 259
0	0	0	0	0	0	0	0	542 594	0	542 594	1 629
23 206 567	**8 401 310**	**14 805 259**	**40 139**	**13 054 588**	**6 220 213**	**6 834 376**	**26 024**	**18 783 354**	**7 730 229**	**11 053 126**	**32 215**

4.3. Investiciona ulaganja u opremu i objekte na kopu i na postrojenju PMS-a

Za kapacitet rudnika od 2.5 Mt u prve dve godine i povećanja na 5,5 Mt do kraja veka eksploatacije, po varijantama, potrebna su sledeća investiciona ulaganja:

a) Varijanta 2F

Tabela 5. *Investiciona ulaganja za pokretanje proizvodnje sa 2.5 Mt i prelazak na kapacitet 5.5 Mt godišnje na kopu Kraku bugaresku C1 i C2 (Izvor:Biznis plan RTB Bor)*

No.	Naziv	Jedinična cena US$	2011		2012		2013		2014	
			količina	vrednost	količina	vrednost	količina	vrednost	količina	vrednost
1.	**Nabavka nove opreme**			**5,554,000**		**8,184,000**		**14,877,000**		**13,331,000**
	- Postrojenja pripreme i prerade					3,530,000		6,189,000		10,331,000
	- Drobilično postrojenje za rudu									1,000,000
	- Bušilica D=200mm	650,000	1	650,000	1	650,000	1	650,000		
	- Hudraulični bager V=10m^3	2,000,000	1	2,000,000		0	1	2,000,000	1	2,000,000
	- Kamion Nosivosti 150 t	1,452,000	2	2,904,000	2	2,904,000	4	5,808,000		
	- Buldozer 375 KS	893,750		0	1	893,000		0		
	- Grejder 16 G	500,000		0	1	500,000		0		
	- Pomoćna mehanizacija			0		0		230,000		
2.	**Sanacija, rekonstrukcija i dogradnja**			**5,350,000**		**3,300,000**		**1,485,500**		**0**
	- Revitalizacija post.pripreme i prerade			2,650,000		0		0		
	- Sanacija postojećeg hidrotransporta			2,700,000		3,300,000		0		
3.	Izrada postr. za prečiš.otpadnih voda			0		1,570,000		0		
4.	Ostala investiciona ulaganja			0		0		1,485,000		
5.	Eksproprijacija			0		0		0		750,000
	Ukupno kop Cerovo po godinama			**10,904,000**		**13,287,000**		**16,362,000**		**14,081,000**
	UKUPNO	**54,634,000.00 US$**								

b. Varijanta 3F

Tabela 5.1. *Investiciona ulaganja za pokretanje proizvodnje 2.5 Mt i prelazak na kapacitet 5.5 Mt godišnje na kopu Kraku bugaresku C1 i C 2 sa ukupno 3 faze*

No.	Naziv	Jedinična cena US$	2011		2012		2013		2014	
			količina	vrednost	količina	vrednost	količina	vrednost	količina	vrednost
1.	**Nabavka nove opreme**			**5,554,000**		**10,477,000**		**11,973,000**		**11,331,000**
	- Postrojenja pripreme i prerade					3,530,000		6,189,000		10,331,000
	- Drobilično postrojenje za rudu									1,000,000
	- Bušilica D=200mm	650,000	1	650,000	1	650,000	1	650,000		
	- Hudraulični bager V=10m^3	2,000,000	1	2,000,000	1	2,000,000	1	2,000,000		
	- Kamion Nosivosti 150 t	1,452,000	2	2,904,000	2	2,904,000	2	2,904,000		
	- Buldozer 375 KS	893,750		0	1	893,000		0		
	- Grejder 16 G	500,000		0	1	500,000		0		
	- Pomoćna mehanizacija			0		0		230,000		
2.	**Sanacija, rekonstrukcija i dogradnja**			**5,350,000**		**3,300,000**		**0**		**0**
	- Revitalizacija post.pripreme i prerade			2,650,000		0		0		
	- Sanacija postojećeg hidrotransporta			2,700,000		3,300,000		**0**		
3.	Izrada postr. za prečiš.otpadnih voda			**0**		**1,570,000**		**0**		
4.	Ostala investiciona ulaganja			**0**		**0**		**1,485,000**		
5.	Eksproprijacija			**0**		**0**		**0**		**750,000**
	Ukupno kop Cerovo po godinama			**10,904,000**		**15,347,000**		**13,458,000**		**12,081,000**
	UKUPNO					**51,790,000.00**				

5. OSVRT NA TEORIJSKE OSNOVE METODE „ANALIZA OSETLJIVOSTI INTERNE STOPE RENTABILNOSTI PROJEKTA“

Analiza osjetljivosti projekta ima cilj da proceni prihvatljivost projekta ako vrednosti kritičnih parametara projekta budu drugačije nego što je planirano pri projektovanju.

Metoda interne stope rentabilnosti (profitabilnosti) (*engl. internal rate of return method, njem. interne Zinssatzmethode*) je metoda za ocjenu prihvatljivosti investicionog ulaganja, koristi internu stopu rentabilnosti kao meru delotvornosti projekta. Interna stopa rentabilnosti definiše se kao ona diskontna stopa koja neto sadašnju vrednost svodi na nulu, a određuje se prema matematičkom obrascu. Pri izračunavanju interne stope rentabilnosti analitičari se služe iterativnim postupkom, grafičkim postupkom ili interpolacijom. U ovom slučaju IRR je na osnovu ulaganja sračunata i analizirana u softveru za ekonomsku optimizaciju i strateško planiranje na ležištima mineralnih sirovina - *Whittle Fx*.

Tumačenje interne stope rentabilnosti zavisi od kombinacije izvora finansiranja. Ako u finansiranju investicija učestvuje samo vlastiti kapital, tada je to stopa po kojoj on odbacuje prosečnu akumulaciju. Ako se koriste i krediti, tada će i vlastiti i tuđi izvori finansiranja stvarati povrat po toj stopi u odnosu na svoju veličinu.

Kada se investicioni projekt finansira samo iz kredita, tada tuđi kapital po internoj stopi rentabilnosti odbacuje prosečnu godišnju akumulaciju, pa je to ujedno i maksimalno prihvatljiva kamatna stopa na kredite. Interna stopa rentabilnosti ima značenje maksimalno prihvatljive kamatne stope na kredite, nezavisno od toga da li u finansiranju učestvuje vlastiti kapital ili ne. Nezavisno dakle od strukture izvora finansiranja, internu stopu rentabilnosti treba tumačiti kao maksimalno prihvatljivu kamatnu stopu na kredite. Prednost metode je u tome što pruža informaciju o maksimalno prihvatljivoj prosečnoj godišnjoj kamatnoj stopi na ukupne izvore finansiranja, i to pod uslovom da se finansijske obveze na osnovu njih otplaćuju tokom celog veka projekta. Ako je reč o kreditu, to znači da interna stopa rentabilnosti daje informaciju o maksimalno prihvatljivoj kamatnoj stopi na kredite, čija otplata traje do kraja veka projekta. Ako je reč o vlastitom kapitalu, to je prosečna godišnja stopa njegovog povraćaja tokom celog veka projekta, što znači da ta

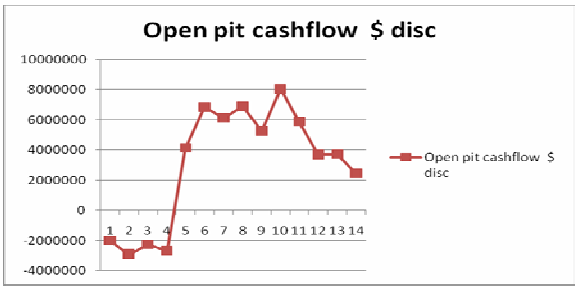
stopa određuje i maksimalni iznos **dobiti** koja se može podeliti vlasnicima.

U ovom slučaju, kritični parametar čiji se uticaj na efektivnost investicije analizira (odnosno IRR), jeste *koeficijent iskorišćenja Cu iz rude u flotaciji*. tj. konkretnije, uticaj broja faza otkopavanja na kopu na koeficijent iskorišćenja Cu iz rude u flotaciji, podrazumevajući da se doziranje rude sa kopa vrši usrednjavanjem sadržaja Cu ili pravljenjem kompozita odnosno *blendingom.*

6. PRIKAZ FINALNIH EKONOM SKIH REZULTATA ZA POJEDINE VARIJANTE OTKOPAVANJA KB CEMENTACIJA 1 I 2

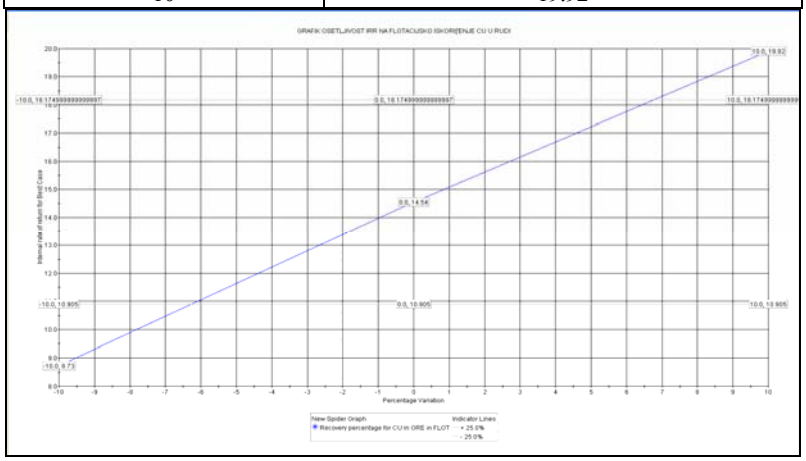
a) Varijanta iz DRP-a sa konstantnim godišnjim kapacitetom 2.5 Mt
b) Varijanta 2F sa kapacitetom 2.5 /5.5 Mt godišnje,
c) Varijanta 3F sa kapacitetom 2.5 /5.5 Mt godišnje.

A) *Varijanta prema DRP za 2.5 Mt godišnje i otkopavanjem na C1, C2-1 i C2-2*



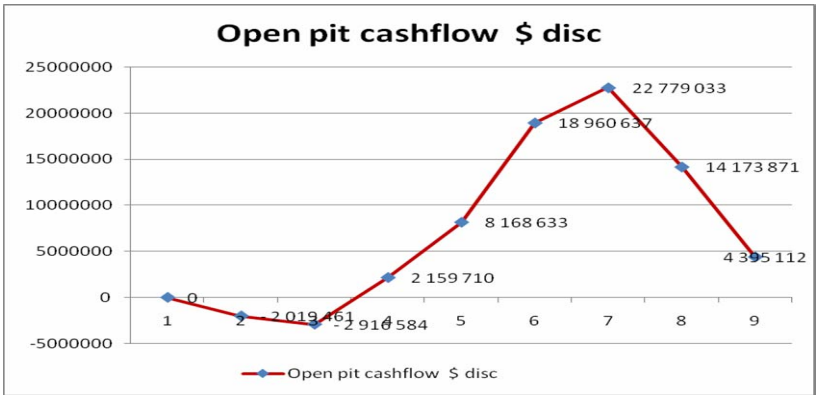
Grafik 2. *Grafik NPV diskontovan za varijantu 2.5 mt sa 3 faze, vek eksploatacije 15 godina, Df=10%*

% Variation	Recovery percentage for Cu in ORE in FLOT
-10	8.73
0	14.54
10	19.92



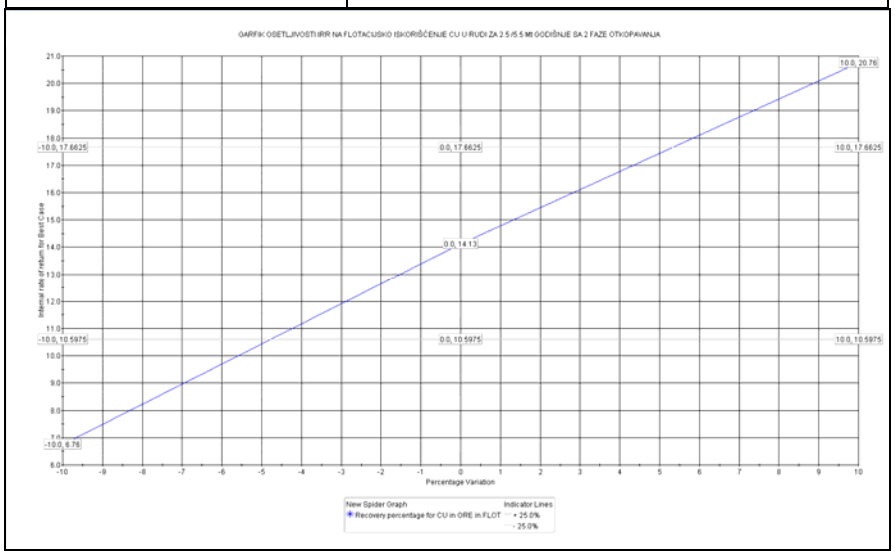
Grafik 3. *Osetljivost IRR na flotacijsko iskorišćenje u slučaju varijante 3 F i kapacitetom 2.5 Mt godišnje*

B) ***Varijanta 3F sa kapacitetom 2.5/5.5 Mt godišnje i otkopavanjem na C1 i C2-2***



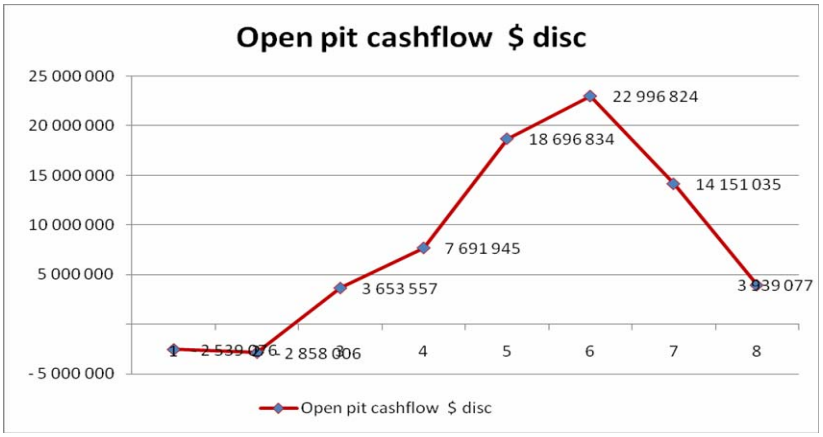
Grafik 4. *Diskontovana vrednost kopa (NPV) za varijantu 3F (fazno otkopavanje C2), Df=10%*

% Variation	Recovery percentage for Cu in ORE in FLOT
-10	6.67
0	14.13
10	20.76



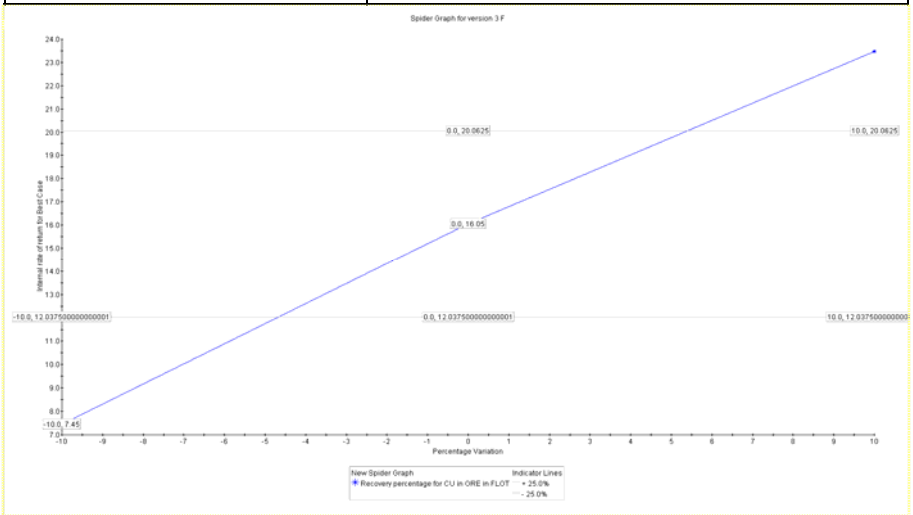
Grafik 5. *Grafik osetljivosti IRR projekta Cerovo na flotacijsko iskorišćenje u slučaju otkopavanja sa 2 faze (push backs) i kapacitetom 2.5/5.5 Mt godišnje*

C) ***Varijanta 3F sa kapacitetom 2.5 /5.5 Mt godišnje i otkopavanjem na C1, C2-1 i C2-2***



Grafik 6. *Diskontovana vrednost kopa (NPV) za varijantu 3F (fazno otkopavanje C2), Df=10%*

% Variation	Recovery percentage for Cu in ORE in FLOT
-10	7.45
0	16.05
10	23.48



Grafik 7. *Grafik osetljivosti IRR projekta Cerovo na flotacijsko iskorišćenje u slučaju otkopavanja sa 3 faze sa kapacitetom 2.5/5.5 Mt godišnje*

7. ZAKLJUČAK

U varijanti otkopavanja „3F“ smanjenjem koeficijenta iskorišćenja za 10%, IRR se smanjuje 8.6, dok promenom istog koeficijenta za +10%, IRR se povećava za 7.45, tj. vrednost promene je $\Delta \pm$ IRR = 0.15;

U varijanti „2F“, smanjenjem koeficijenta iskorišćenja u flotaciji za 10 %, IRR se smanjuje za 7.46, dok povećanjem $I_{f\,z}$ za 10%, IRR se povećava za 6.63. i vrednost promene iznosi $\Delta \pm$ IRR = 0.23.

Ovako posmatrajući, varijanta 2F je osetljivija na promene flotacijskog iskorišćenja.

Bez obzira na prikazane rezultate analize, otkopavanje sa više faza omogućava kvalitetno stvaranje kompozita rude prema flotaciji zbog mogućnosti istovremenog rada na više otkopnih čela.

Obzirom da program Whittle prilikom klasične optimizacije bez korišćenja *stockpila* ne prepoznaje prevelike razlike prilikom otkopavanja u ovakvim slučajevima, potrebno je detaljno obraditi dinamiku otkopavanja sa opcijom „*Extractiv Blend Scenario*“ koji omogućava optimizaciju flotacijskog iskorišćenja metala ili korišćenjem stockpile ili stvaranjem mogućnosti da postoji više aktivnih otkopnih čela na rudi (sa različitim sadržajima metala).

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CONTINUATION THE MINING ACTIVITIES OF RTB BOR ON LOCATION KRAKU BUGARESKU CEMENTATION WITH THE SENSITIVITY ANALYSIS OF IRR SELECTION THE MINING VARIANTS***

Abstract

This paper describes the activities on exploitation resumption at Kraku Bugaresku Cementation 1 and 2 site, with a short review of the history of previously realized and current state of mining activities, as well as the concept of the future exploitation.

The investor plans changes in the concept of future exploitation in terms of annual productivity increase (5.5 Mt) compared to the designed 2.5 Mt as well as reduction of the number of stages (push backs) in the development of the open pit Cementation 2. The article presents the sensitivity analysis of the IRR and the consequences of the reduction in the number of working sites in simultaneous operation. In other words, the exploitation with smaller number of push backs reduces the possibility of ore blending, affecting the coherence of metal grade in the ore fed to flotation, i.e. the recovery in the flotation. Reduction the efficiency reduces the income and thus affects the IRR as one of the indicators of economic evaluation of the project.

Keywords*: exploitation, state of mining operations, push backs, flotation recovery, IRR, investments, return on investments*

INTRODUCTION

Copper ore deposit Kraku Bugaresku - Cerovo is located in the East Serbia, some 20 km north of Bor (Figure 1).

Mining operations in the complex of Cerovo ore deposits (Cerovo Cementation 1, Cerovo 2, Cerovo 3, Cerovo 4, Cerovo Primary and Drenova), started in 1990 with the open pit Cerovo Cementation 1. During investment stripping, which lasted from 1990 to 1993 and covered the construction of processing facilities at the site and the hydro-transport system to the Bor flotation

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plant, nearly 10 Mt of overburden was stripped (nearly half of total amount of overburden in the pit outline). That created very favorable conditions for subsequent exploitation with a low striping ratio. This obviously had its price, but the circumstances were such that it actually made Cerovo to operate in very difficult and almost impossible conditions, with very unfavorable market conditions, when the price of copper was even incredible 1300 US$ per ton of cathode copper (2002).

The Main Mine Design of "Cerovo Cementation 1" [1] defined the following recoverable reserves within the 0.3% Cu contour of Cerovo Cementation 1 open pit:

- Ore ----------17,479,165 t,
- Waste ----------23,674,605 t,
- Excavations ----------41,153,770 t,
- Mean Cu content in the ore ----------0.713 % Cu,
- Mean overburden coefficient ----------1.35 t/t.

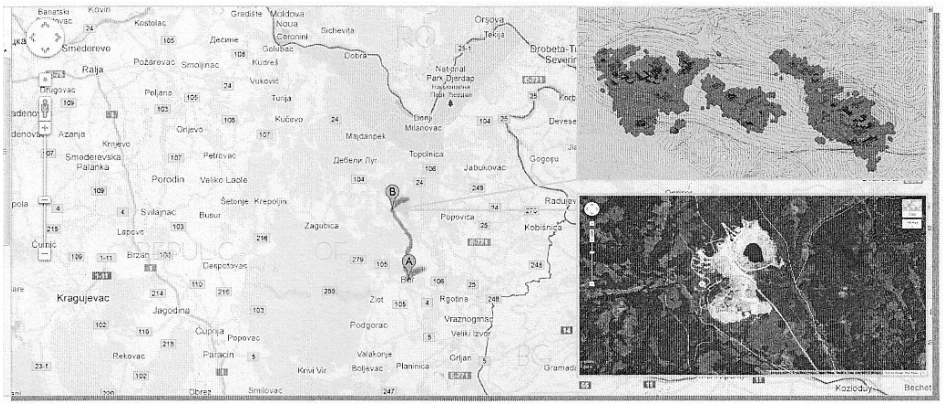

Fig. 1. *Position of the copper ore deposit "KB-Cementation" RTB Bor (Google map)*

1. PREVIOUS MINING ACTIVITIES AT KRAKU BUGARESKU – CEROVO DEPOSIT

The concept of mining considered drilling and blasting and cyclic haul-truck haulage of ore and waste. Designed bench height was 15 m, the spiral roads starting at the northwest side of the pit, at elevation of K+515 m, at the location where pit passes from the mountain into deep type. Road width was 20 m, and ramp slope 10%.

The ore was hauled to primary crusher and then stocked in a closed depot. The next technological phase was secondary and tertiary crushing. Crushed ore was fed to the next phase, two stages of milling. Cerovo did not have fully developed flotation. The process ended with the pulp which was, after thickening, hydraulically transported to the Bor Flotation Plant, where flotation was carried out. The tailings were dumped at the flotation tailing dump RTH in Bor.

The problem of equipment replacement dynamics and maintenance quality due to a lack of spare parts arose in the mining industry during the ninety-nineties because of known limited economic conditions and culminated during 2003 and 2004, when all mining operations at Cerovo were terminated. The intention was to carry out conservation of remaining equipment and installations and to some extent it has been done. The rest of mining mechanization from Cerovo was transferred to Veliki Krivelj in an attempt to maintain even minimum possible production.

Mining works at the open pit Cerovo Cementation 1 stopped at elevation of K+395 m (bench 395). Dewatering continued for some time but eventually it came to a caese. Presently the pit floor is flooded Fig. 1), and technical design of dewatering will define the terms and method for the removal of the water accumulated at the pit floor, with the aim of creating conditions for production resumption.

Revitalization and resumption of production started during 2011/2012, but with a slightly different concept than previously defined, both from the aspect annual capacity of ore extraction and processing, and from the aspect of mining concept of the Cerovo 2, that is the overall dynamics.

2. THE CONCEPT OF MINE REVIVAL

Since, during the last several years, copper market recovered and copper price at one point reached 9 000 US$, even relatively low-grade deposits became more at tractive and economically viable for mining. Strategy of reactivation of the copper ore mining at Cerovo - Kraku Bugaresku is degned by the *Supplementary Mining Design of Excavation in 2008,* [2] , and it considers expansion and deepening of the Cerovo Cementation 1 open pit, and opening and mining operations start at Cementation 2 deposit.

Optimization resulted in selection of pit contours and the optimum long-term dynamics of excavation according to the criterion of profit and discounted profit for future mining period using the software Whittle Fx. The technical design of mining (SMD 2008), discussed the above procedure in detail, with the exception of mine capacity limited (at the request of the Investor) by the existing flotation processing capacity of 2.5 x 10^6 t of ore.

Starting parameters used in the optimization and resulting graph as output of optimization process in Whittle Fx are given in figure 2.

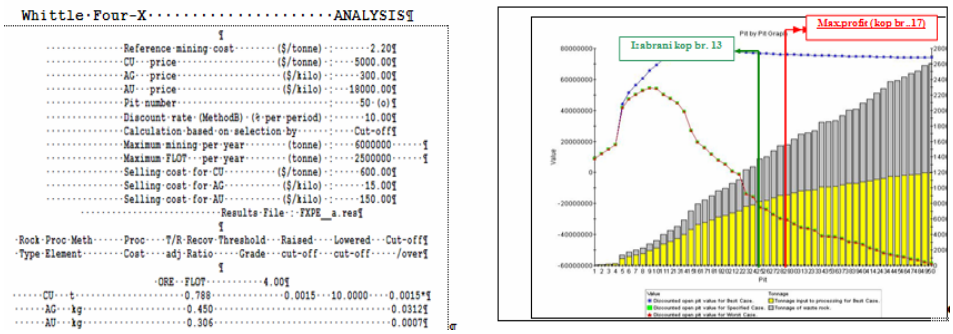

Fig. 2. *Input parameters of optimization and graph with a review of profit and discounted profit, and possible pit contours (50) for different prices of Cu*

As it can be seen from the graph given in Fig. 2 curves of profit and discounted profit heavily diverge with increase in production, indicating excavation with push backs.

List of planned mining equipment for the achievement of annual capacity of 2.5 Mt is shown in Table 1:

Table 1. *Mining equipment planned by the SMD for the complex of Cerovo Kraku Bugaresku ore bodies*

No	Name of equipment	Characteristics	Type and designation	Pcs.
1	Drill, diameter 250 mm	Rb=250 mm	Atlas Copco	1
2	Drill, diameter 89 - 130 mm	R89 do 130 mm	Atlas Copco	1
3	Hydraulic excavator with electric drive	V_K= 10 m^3	Terex -OK	1
4	Loader L-950	V_K=13 m^3	Leturnoau	1
5	Truck - dumper	Capacity 90 Mt	HD785-7 Komatsu	6
6	Bulldozer crawler	CAT 249 KW)	CAT	2
7	Loader	249 KW	CAT 16H	1
8	Water cistern FAP1823	V=9 m^3		1
9	Service vehicle FAP1318/42	Capacity 8 t		2
10	Service-terrain vehicle		Lada Niva	2
11	Submersible slurry pumps	Flyght	BS 25.00	4
12	Wheel loader	V = 2.5 – 3		1

The concept of future work is to start stripping operations at Cementation 1 open pit in *the first year* creating the necessary conditions for achievement of full designed annual productivity of 2.5 Mt of ore as early as the second year. Investment stripping should carry on until the moment the necessary conditions to cover stripping operations by extracted ore are met. This would allow finalization of the works on revitalization in a part of mineral processing and preparation plant for normal production.

Table 2. *Dynamics of excavation per years (periods) according to SMD from 2008*

Year	Excavations (t)	Waste	Ore	Cu Total(t)	Ag	Au	Cu Total (%)	Ag (g/t)	Cu Total (%)	Au (g/t)
1.	6,012,750	4,330,190	1,682,560	4,552.20	1,871.50	194.20	0.27	1.11	0.27	0.12
2	4,211,527	1,713,040	2,498,487	5,831.80	3,062.70	307.20	0.23	1.23	0.23	0.12
3.	5,547,786	3,049,922	2,497,865	5,948.40	2,410.90	248.90	0.24	0.97	0.24	0.10
4.	5,085,516	2,589,466	2,496,050	6,817.00	4,249.70	334.90	0.27	1.70	0.27	0.13
5.	5,888,154	3,389,624	2,498,531	7,458.50	3,284.70	229.50	0.30	1.32	0.30	0.09
6.	5,957,158	3,463,180	2,493,977	7,573.30	3,194.80	182.10	0.30	1.28	0.30	0.07
7.	4,059,750	1,427,516	2,632,234	8,136.80	3,447.10	164.80	0.31	1.31	0.31	0.06
8.	2,966,965	475,116.0	2,491,849	8,833.90	2,280.80	162.00	0.36	0.92	0.36	0.07
9.	3,060,615	567,411	2,493,204	9,725.30	3,032.10	196.80	0.39	1.22	0.39	0.08
10	3,085,217	590,779	2,494,438	9,166.20	2,881.50	223.00	0.37	1.16	0.37	0.09
11.	2,974,106	478,970	2,495,136	7,824.00	3,107.00	155.40	0.31	1.25	0.31	0.06
12.	2,583,542	82,816	2,500,727	7,791.30	2,628.60	207.50	0.31	1.05	0.31	0.08
13.	1,657,514	8	1,657,506	5,095.80	1,768.60	166.80	0.31	1.07	0.31	0.10
TOTAL	53,090,601	22,158,038	30,932,564	94,754.40	37,220.00	2,773.10	0.31	1.20	0.31	0.09

Since the processing plant i.e. the ore processing infrastructure, requires a considerable amount of works on reconstruction and revitalization to operational state, these ac-

tivities should begin before the start of mining operations.

Mining concept is also modified in a way to change the location of ore flotation. Instead of previous operations when ore was processed in the Bor Flotation Plant, the ore will now be processed in the Veliki Krivelj Flotation Plant which requires the construction of new pipeline route for hydraulic transport of pulp.

Changes in current mining technology are not anticipated, except modifications in drill and blast operations in the N-W of the C2 open pit. The proximity of railroad requires minimization the adverse effects of blasting operations in terms of ground vibrations and flyrock.

3. VARIANTS OF TRANSITION TO ANNUAL PRODUCTIVITY OF 5.5 Mt

The new strategy of RTB development, with its business plan as a strategic document, defined the capacity increase at Kraku Bugaresku Cementation to 5.5 million t, after creating the appropriate necessary conditions at both the open pit and in a part of mineral processing. The required time for these activities is estimated to two years. Thus, increasing the annual capacity from 2.5 Mt to 5.5 Mt will follow two years after reactivation of the mining activities at the open pit and Flotation Plant.

There are two possibilities for resumption of mining with the increased capacity.

1. ***Variant 2F*** *- Mining of Cementation 2 in one phase which includes two open pits: Cerovo cementation 1 (abbr. C_1) and Cerovo cementation 2 or (abbr.C_2) and*
2. ***Variant 3F*** *- Mining of Cementation 2 in two phases, this means that there are total of three phases – the first push back is C_1 and another two push backs are at Cementation 2 (C_{2-1} and C_{2-2})*

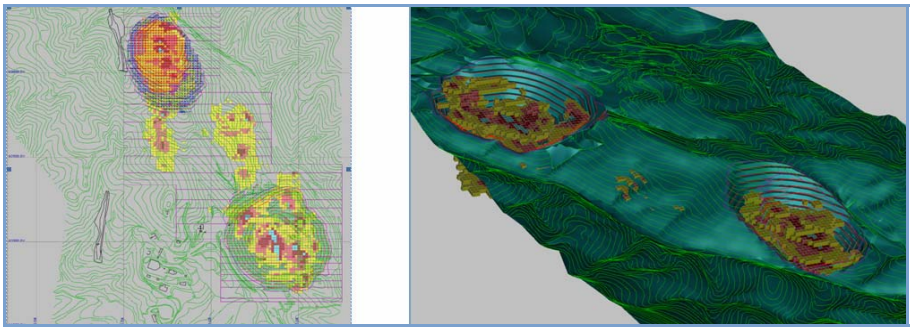

Fig. 3. *Open pits Cerovo Cementation 1and Cerovo 2, with stage mining of Cerovo 2 (pushbacks C21 and C22)*

Realization of the first variant of mining with annual productivity increased to 5.5 million t requires higher capacities of loading and hauling because it is only viable by more intensive stripping operations, i.e. increased volume of excavation at the start of mining operations.

In both variants, it is necessary to provide an ore processing plant for the listed capacity, which will require significant investments (Tables 5 and 5.1). *(Source Business Plan of RTB Bor, [6]).*

3.1. Dynamics of mining for variant 2F

Table 3 shows the dynamics of mining with operations at the Cementation 1 open pit (the existing open pit where mining was suspended in 2004) and the Cementation 2 open pit where mining is planned without the stage (phase or push backs) mining.

Table 3. *Mining dynamics at Cerovo 2 – single phase mining*

Period	Tonne in place	Waste tonne	Tonne input	Grade CU input %	Grade AG input g/t	Grade input AU'g/t	Units to process FLOT CU t	Units to process FLOT AU kg	Units to process FLOT AG kg
1	7 000 000	4 943 885	2 056 115	0. 27	01.1	0.0001	5 579	219	2 262
2	7 000 000	4 512 181	2 487 819	0. 23	1.3	0.0001	5 692	322	3 113
3	12 000 000	6 502 351	5 497 649	0. 26	1.3	0.0001	14 197	571	7 110
4	10 106 771	4 606 771	5 500 000	0. 28	1.2	0.0001	15 132	399	6 628
5	6 502 574	1 002 574	5 500 000	0. 33	1.2	0.0001	18 243	421	6 755
6	5 803 845	303 845	5 500 000	0. 38	1.1	0.0001	20 892	416	6 212
7	5 554 089	54 089	5 500 000	0. 31	1.2	0.0001	16 778	510	6 549
8	352 807	0	352 807	0.00	1.2	0.0001	1 060	34	413
	54 320 086	**21 925 696**	**32 394 390**	**0.30**	**1.2**	**0.0893**	**97 573**	**2 892**	**39 042**

Table 3.1. *Mining dynamics at Cerovo 2 – single phase mining, details*

tonne in place PUSH1	tonne to waste PUSH1	tonne processed PUSH1	Units to process PUSH1 CU	tonne in place PUSH2	tonne to waste PUSH2	tonne processed PUSH2	Units to process PUSH2 CU
C1				C22			
6 751 924	4 695 809	2 056 115	5 579	248 076	248 076		
4 250 772	1 762 953	2 487 819	5 692	2 749 228	2 749 228		
6 370 434	1 401 145	4 969 289	13 213	5 629 565	5 101 206	528 360	984
				10 106 771	4 606 771	5 500 000	15 132
2 103 259	168 921	1 934 337	6 044	4 399 315	833 653	3 565 663	12 199
876 247	68 861	807 387	2 433	4 927 598	234 985	4 692 613	18 459
2 378 379	33 623	2 344 756	6 651	3 175 710	20 466	3 155 244	10 127
				352 807		352 807	1 060
22 731 015	8 131 312	14 599 703	39 612	31 589 070	13 794 385	17 794 687	57 961

3.2. Dynamics of mining for variant 3F

Table 4. *Table 4 Mining dynamics at Cerovo 2 – phase mining*

Period	tonne in place	Waste tonne	tonne input	Grade input CU %	Grade input AG g/t	Grade input AU g/t	Units to process FLOT CU t	Units to process FLOT AU kg	Units to process FLOT AG kg
1	7 000 000	4 846 958	2 153 042	0.271	1.11	0.110	5 829	233	2 399
2	7 000 000	4 502 294	2 497 706	0.228	1.25	0.130	5 686	320	3 114
3	12 000 000	6 500 582	5 499 418	0.249	1.17	0.100	13 703	538	6 420
4	10 921 136	5 421 136	5 500 000	0.289	1.22	0.070	15 903	364	6 727
5	6 180 653	680 653	5 499 999	0.328	1.34	0.090	18 023	494	7 378
6	5 842 773	342 773	5 500 000	0.378	1.13	0.080	20 808	414	6 239
7	5 557 354	57 354	5 500 000	0.305	1.19	0.090	16 796	508	6 518
8	542 594	0	542 594	0.300	1.17	0.090	1 629	51	637
TOTAL	**55 044 510**	**22 351 750**	**32 692 759**	**0.305**	**1.21**	**0.089**	**98 377**	**2 922**	**39 432**

Table 4.1. *Table 4 Mining dynamics at Cerovo 2 – phase mining, details*

tonne	*tonne to*	*tonne*	*Units to process*	*tonne*	*tonne to*	*tonne*	*Units to process*	*tonne*	*tonne to*	*tonne*	*Units to process*
in place	*waste*	*processed*	*PUSH1*	*in place*	*waste*	*processed*	*PUSH2*	*in place*	*waste*	*processed*	*PUSH3*
PUSH1	*PUSH1*	*PUSH1*	*CU*	*PUSH2*	*PUSH2*	*PUSH2*	*CU*	*PUSH3*	*PUSH3*	*PUSH3*	*CU*
Cementacija 1				Cementacija 2-1				Cementacija 2 -2			
7 000 000	4 846 958	2 153 042	5 829	0	0	0	0	0	0	0	0
4 242 056	1 778 759	2 463 297	5 627	2 757 944	2 723 535	34 409	59	0	0	0	0
4 913 450	1 341 299	3 572 151	8 678	4 643 248	2 715 982	1 927 267	5 025	2 443 302	2 443 302	0	0
11 851	1 705	10 147	26	2 361 651	737 786	1 623 865	5 954	8 547 633	4 681 645	3 865 988	9 923
3 699 558	321 875	3 377 683	10 695	1 142 548	42 910	1 099 638	4 406	1 338 547	315 868	1 022 679	2 922
970 228	77 976	892 252	2 670	1 678 595	0	1 678 595	8 656	3 193 950	264 797	2 929 153	9 482
2 369 424	32 738	2 336 687	6 614	470 602	0	470 602	1 924	2 717 328	24 617	2 692 712	8 259
0	0	0	0	0	0	0	0	542 594	0	542 594	1 629
23 206 567	**8 401 310**	**14 805 259**	**40 139**	**13 054 588**	**6 220 213**	**6 834 376**	**26 024**	**18 783 354**	**7 730 229**	**11 053 126**	**32 215**

3.3. Investments in equipment and facilities at the open pit and mineral processing plant

Necessary investments required to achieve annual productivity of 2.5 Mt during first two years, increase the productivity to 5.5 Mt and maintain it during mine lifespan are given in tables 5 and 5.1.

a) Variant 2F

Table 5. *Investments required for variant 2F*

No.	Naziv	Jedinična cena US$	2011		2012		2013		2014	
			količina	vrednost	količina	vrednost	količina	vrednost	količina	vrednost
1.	**Nabavka nove opreme**			**5,554,000**		**8,184,000**		**14,877,000**		**13,331,000**
	- Postrojenja pripreme i prerade					3,530,000		6,189,000		10,331,000
	- Drobilično postrojenje za rudu									1,000,000
	- Bušilica D=200mm	650,000	1	650,000	1	650,000	1	650,000		
	- Hudraulični bager V=10m^3	2,000,000	1	2,000,000		0	1	2,000,000	1	2,000,000
	- Kamion Nosivosti 150 t	1,452,000	2	2,904,000	2	2,904,000	4	5,808,000		
	- Buldozer 375 KS	893,750		0	1	893,000		0		
	- Grejder 16 G	500,000		0	1	500,000		0		
	- Pomoćna mehanizacija			0		0		230,000		
2.	**Sanacija, rekonstrukcija i dogradnja**			**5,350,000**		**3,300,000**		**1,485,500**		**0**
	- Revitalizacija post.pripreme i prerade			2,650,000		0		0		
	- Sanacija postojećeg hidrotransporta			2,700,000		3,300,000		0		
3.	Izrada postr. za prečiš.otpadnih voda			0		1,570,000		0		
4.	Ostala investiciona ulaganja			0		0		1,485,000		
5.	Eksproprijacija			0		0		0		750,000
	Ukupno kop Cerovo po godinama			**10,904,000**		**13,287,000**		**16,362,000**		**14,081,000**
	UKUPNO	**54,634,000.00 US$**								

b) Variant 3F

Table 5.1. *Investments for variant 3F*

No.	Naziv	Jedinična cena US$	2011		2012		2013		2014	
			količina	vrednost	količina	vrednost	količina	vrednost	količina	vrednost
1.	**Nabavka nove opreme**			**5,554,000**		**10,477,000**		**11,973,000**		**11,331,000**
	- Postrojenja pripreme i prerade					3,530,000		6,189,000		10,331,000
	- Drobilično postrojenje za rudu									1,000,000
	- Bušilica D=200mm	650,000	1	650,000	1	650,000	1	650,000		
	- Hudraulični bager V=10m^3	2,000,000	1	2,000,000	1	2,000,000	1	2,000,000		
	- Kamion Nosivosti 150 t	1,452,000	2	2,904,000	2	2,904,000	2	2,904,000		
	- Buldozer 375 KS	893,750		0	1	893,000		0		
	- Grejder 16 G	500,000		0	1	500,000		0		
	- Pomoćna mehanizacija			0		0		230,000		
2.	**Sanacija, rekonstrukcija i dogradnja**			**5,350,000**		**3,300,000**		**0**		**0**
	- Revitalizacija post.pripreme i prerade			2,650,000		0		0		
	- Sanacija postojećeg hidrotransporta			2,700,000		3,300,000		**0**		
3.	Izrada postr. za prečiš.otpadnih voda			**0**		**1,570,000**		**0**		
4.	Ostala investiciona ulaganja			**0**		**0**		**1,485,000**		
5.	Eksproprijacija			**0**		**0**		**0**		**750,000**
	Ukupno kop Cerovo po godinama			**10,904,000**		**15,347,000**		**13,458,000**		**12,081,000**
	UKUPNO					**51,790,000.00**				

4. REVIEW OF THE THEORETICAL BASIS OF THE "SENSITIVITY ANALYSIS OF THE IRR OF THE PROJECT"

Sensitivity analysis of the Project is aimed to evaluate the acceptability of the Project if the values of critical parameters of the Project are different than planned in the design.

Internal rate of return (profitability) method is a method for assessing the acceptability of the investments, and it is used for internal rate of return as a measure of the project effectiveness. Internal rate of return is defined as discount rate that reduces the net present value to zero, and it is determined by mathematical form. When calculating the IRR, analysts use an iterative procedure, graphical method or interpo-lation. In this case, the IRR is calculated and analyzed on the basis of investments using software for economic optimization and strategic planning - *Whittle Fx.*

Interpretation of the IRR depends on a combination of funding sources. If only own capital participates in funding the investments, then this is the rate at which it rejects the average accumulation. If the loans are used, then own and other sources of funding will create the return per that rate in relation to its size.

When the investment project is financed only from the loan, then other capital per internal rate of return rejects the average annual accumulation, and this is also the maximum acceptable interest rate on loans. Internal rate of return has the meaning of maximum acceptable interest rate on loans, regardless of whether the own capital participates in funding or not. Therefore, independently of the structure of funding sources, the internal rate of return should be interpreted as maximum acceptable interest rate on loans. The advantage of this method is that it provides information on maximum acceptable average annual interest rate on total sources of financing, and under a condition that financial obligations are paid, during the entire life of the project. If it is a loan, this means that the internal rate of return provides information on maximum acceptable interest rate on loans, whose payment lasts until the end of life of the project. If it is own capital, it is an average annual rate of its return throughout the entire life of the project, what means that this rate determines the maximum amount of **profit** that can be distributed to the owners.

In this case, the critical parameter, whose influence on the effectiveness of the investments is analyzed (i.e. IRR), is the *coefficient of Cu recovery from the ore in the flotation,* that is specifically, the impact of the number of mining stages at the open pit on Cu recovery coefficient from the ore in the flotation, including the ore feeding from the open pit is done by averaging the content of Cu or making a composite or *blending*.

I - REVIEW OF THE FINAL ECONOMIC RESULTS FOR SOME MINING VARIANTS FOR KB CEMENTATION 1 AND 2

a) Variant from SMD with constant annual productivity of 2.5 Mt,
b) Variant 2F with annual productivity of 2.5 /5.5,
c) Variant 3F with annual productivity of 2.5 /5.5 Mt.

A. *Variant according to the SMD for 2.5 Mt annually and mining at C1, C2-1 and C2-2*

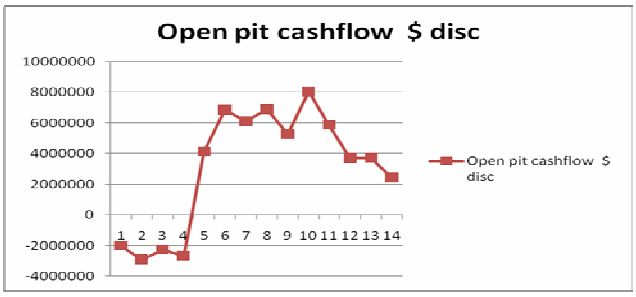

Fig. 4. *Discounted NPV for variant 2.5 Mt with 3 phase mining, mine life of 15 years, and Df=10% (SMD)*

% Variaant	*Recovery percentage for Cu in ORE in FLOT*
-10	*8.73*
0	*14.54*
10	*19.92*

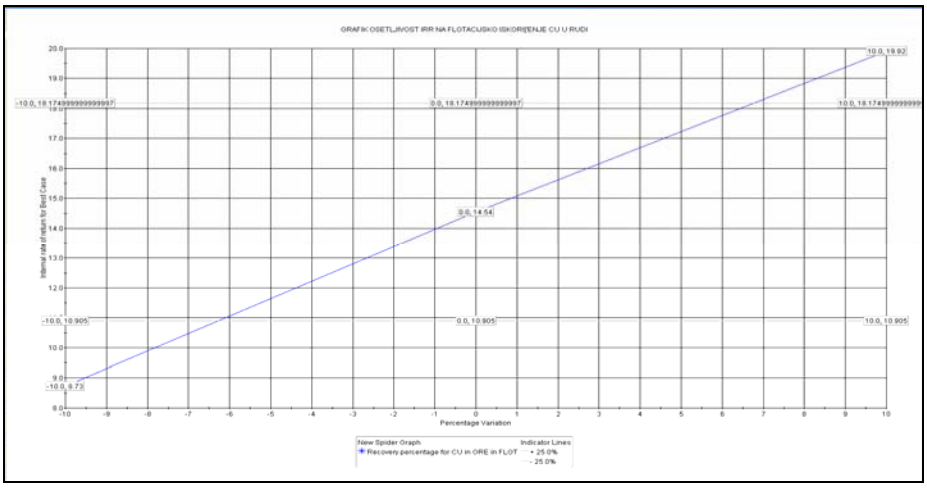

Fig. 5. *Sensitivity of IRR on flotation recovery for variant 3 F and annual productivity of 2.5 Mt*

B. *Variant 2F according to the Bussines Plann of RTB Bor, with annual productivity of 2.5 /5.5 Mt and mining at C1 and C2-2*

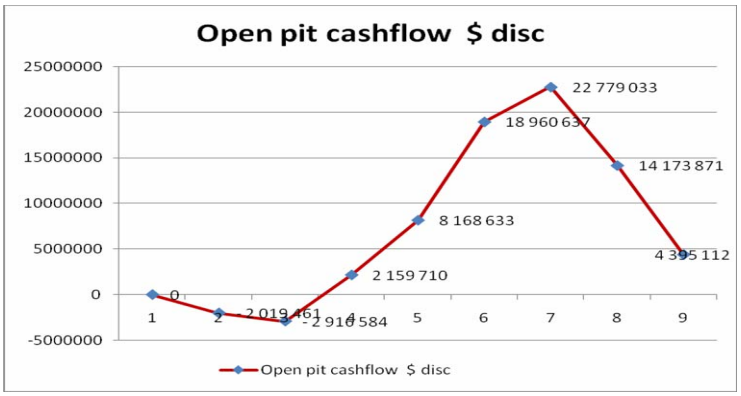

Fig. 6. *Discounted NPV for variant 2F ,Df=10%*

% Variaant	*Recovery percentage for Cu in ORE in FLOT*
-10	*6.67*
0	*14.13*
10	*20.76*

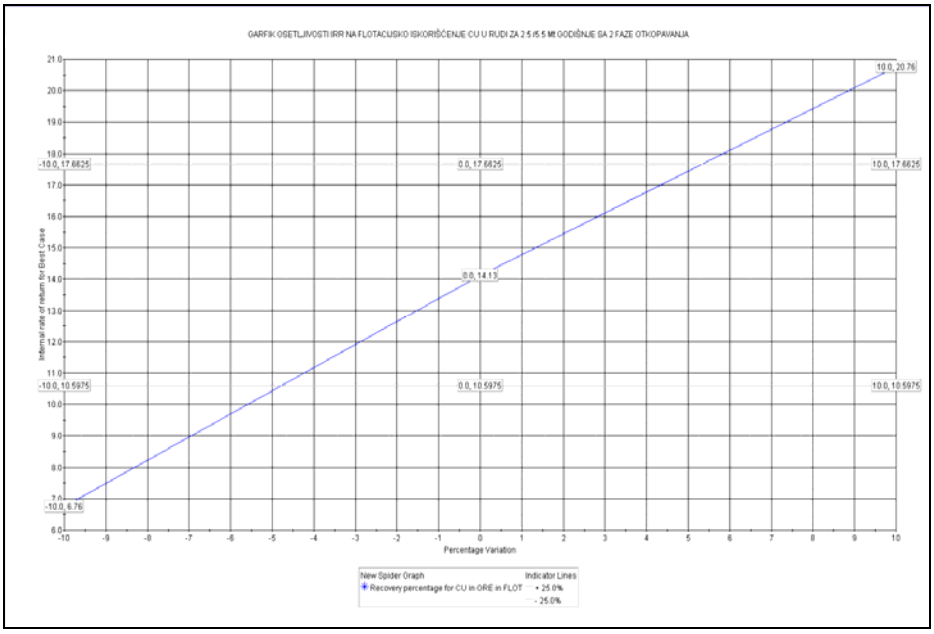

Fig. 7. *Sensitivity of IRR of the Project Cerovo on flotation recovery in the case of mining with 2 phases (push backs) and annual productivity of 2.5/5.5 Mt*

C. *Variant 3F with capacity 2.5 /5.5 Mt annually and mining at C1, C2-1 and C2-2*

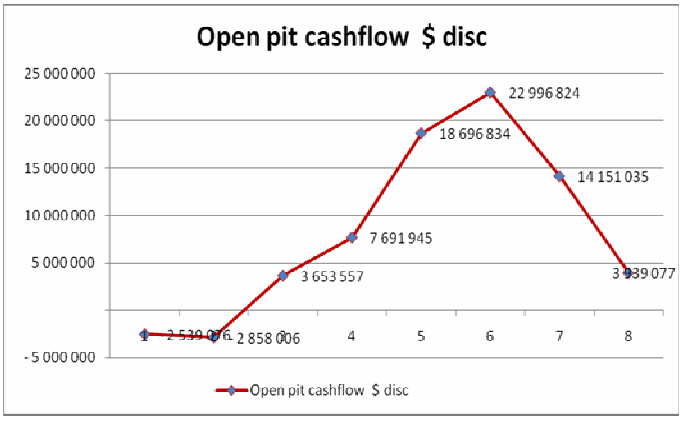

Fig. 8. *Discounted NPV for variant 3F, Df=10%*

% Variant	*Recovery percentage for Cu in ORE in FLOT*
-10	*7.45*
0	*16.05*
10	*23.48*

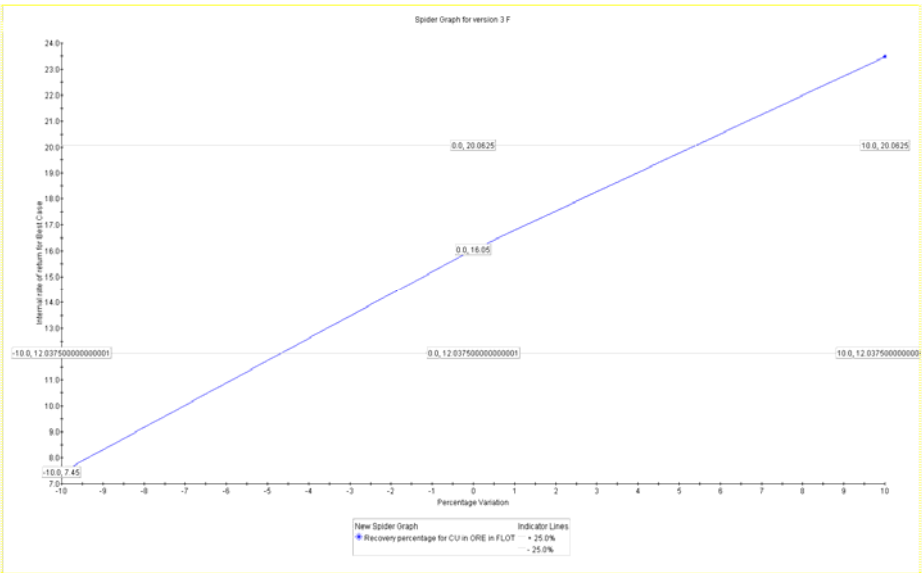

Fig. 9. *Sensitivity of IRR of the Project Cerovo on flotation recovery in the case of mining with 3 stages with capacity of 2.5/5.5 Mt annually*

CONCLUSION

Flotation recovery factor decrease of 10 %, in the mining variant "3F", results in IRR reduction to 8.6, while the change of the same factor for +10%, increases IRR 7.45, i.e. the value of change is $\Delta \pm$ IRR = 0.15;

For the variant "2F", reduction of the flotation recovery factor for 10%, reduces IRR to 7.46, while 10 % increase results in IRR increase to 6.63 ($\Delta \pm$ IRR = 0.23) meaning that the variant 2F is more sensitive to the changes in flotation recovery.

Regardless to the presented results of analysis phase mining enables higher recovery of the ore in the flotation due to the possibility of simultaneous work on several working sites faces and the possibility to provide ore composite with appropriate grade as an input to processing.

If stockpiling is not used during optimization Whittle software does not recognize significant differences in presented cases. Thus, it is necessary to perform detailed mining dynamics analysis using "*Extractive Blend Scenario*" option. This will allow the optimization of flotation metal recovery by either using stockpile or simultaneous operation of several working sites with different Cu content in ore.

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PRIMENA SOFTVERSKIH PAKETA ZA PROJEKTOVANJE U RUDARSTVU GEMCOM I WHITTLE U CILJU RACIONALNOG I EKONOMIČNOG ISKORIŠĆENJA LEŽIŠTA BAKRA VELIKI KRIVELJ KOD BORA, SRBIJA**

Izvod

Ležište bakra Veliki Krivelj nalazi se na oko 3 km vazdušnom linijom, severno od grada Bora i pripada porfirskim ležištima velikih razmera. Ukupne geološke rezerve bakra, u konturi graničnog sadržaja 0,15 %, iznose 621.921.288 t. Po svom značaju, ovo ležište ima vodeću ulogu u proizvodnji bakra u kompaniji RTB Bor, s obzirom da mu pripada 75% ukupne proizvodnje.

Svetske rudarske kompanije kod procene finansijske održivosti i definisanja optimalne strategije za razvoj rudnika u cilju racionalnog i ekonomičnog iskorišćenja ležišta mineralnih sirovina, koriste neke od softvera za optimizaciju i projektovanje, a među vodećim su Whittle i Gemcom, koje poseduje i Institut za rudarstvo i metalurgiju u Boru.

U radu je prikazan način definisanja optimalne konture ležišta bakra Veliki Krivelj primenom softvera Whittle i Gemcom, čime se postiže optimalno iskorišćenje ležišta, što je nužan preduslov odgovornog upravljanja mineralnim sirovinama.

***Ključne reči**: Gemcom, Whittle, ležište bakra Veliki Krivelj, racionalno, optimalno, ekonomično iskorišćenje ležišta.*

UVOD

Prirodna rudna bogatstva jedne zemlje predstavljaju osnovu njenog ekonomskog i društvenog prosperiteta. Po ekonomskoj vrednosti rudnih bogatstava kojim raspolaže, Srbija ne pripada bogatim zemljama. Zato postoji obaveza da se rudarska delatnost obavlja po principima racionalnog upravljanja mineralnim resursima.

Ležište bakra Veliki Krivelj nalazi se na oko 3 km vazdušnom linijom, severno od grada Bora i pripada porfirskim ležištima velikih razmera. Ukupne geološke rezerve bakra, u konturi graničnog sadržaja 0,15 %, iznose 621.921.288 t. Značaj ovog ležišta za kompaniju RTB Bor ogleda se u tome što mu pripada 75%

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** *Rad je proizašao iz projekta broj 33038 „Usavršavanje tehnologija eksploatacije i prerade rude bakra sa monitoringom životne i radne sredine u RTB Bor Grupa“, koji je finansiran sredstvima Ministarstva za prosvetu, nauku i tehnološki razvoj Republike Srbije*

ukupne proizvodnje bakra, u koju su uključeni i jama Bor i Rudnik bakra Majdanpek. Pored ovih ležišta, od izuzetnog značaja je i kompleks ležišta Cerovo, na kome su u ovoj godini nastavljeni radovi na eksploataciji rude bakra, koja je prekinuta 2003. godine.

S obzirom da ležište bakra Veliki Krivelj pripada ležištima sa niskim sadržajem metala u rudi koji u ukupnim geološkim rezervama iznosi 0,318 %, to je primena savremenog softverskog alata za strateško planiranje i optimizaciju ležišta Whittle i softvera za konstrukciju površinskih kopova Gemcom od izuzetnog značaja za racionalno iskorišćenje ležišta i postizanje maksimalnog profita u eksploataciji.

RUDNE REZERVE LEŽIŠTA

Proračun rudnih rezervi u ležištu bakra Veliki Krivelj, urađen je primenom računarskog softvera Gemcom, pri čemu je primenjena metoda mini blokova, koja je potvrđena u fazi eksploatacije ležišta poslednjih deset godina (od 2000. godine).

U slučaju ležišta bakra Veliki Krivelj i sličnih ležišta, sa velikim brojem podataka koji se koriste za proračun rezervi, neosporna je prednost proračuna rezervi korišćenjem računarske tehnike, u odnosu na proračun drugim („manuelnim") metodama:

- Zbog veličine ležišta, stanja budućeg površinskog kopa i kapaciteta proizvodnje (velike količine iskopina), jako su složena projektovanja i izmene projekata sa optimalnim radnim i završnim konturama površinskog kopa, a digitalni model, sa proračunatim rezervama po mini-blokovima, olakšava i ubrzava taj proces, jer je moguće u kratkom vremenskom periodu sagledati veliki broj varijanti i iznaći najbolja rešenja
- Rezultati koji su dobijeni projektovanjem i ekonomskim sagledavanjem, na bazi formiranog blok-modela ležišta i proračuna rezervi ovom metodom, na ležištima bakra porfirskog tipa, zadovoljavajućeg su kvaliteta, odnosno u svetu su prihvaćeni kao zadovoljavajući
- Potencijalni koncesionari zahtevaju da ležište bude prikazano u digitalnom obliku.

U tabelama koje slede dat je pregled rezervi ležišta bakra Veliki Krivelj sa srednjim sadržajem i količinama korisnih komponenti, za ukupne geološke rezerve (tabela 1), bilansne rezerve (tabela 2) i vanbilansne rezerve (tabela 3), u konturi graničnog sadržaja 0,15% Cu.

Tabela 1. *Geološke rezerve ležišta bakra Veliki Krivelj, u konturi graničnog sadržaja 0,15% Cu*

Kategorija	Količina rude (t)	Srednji sadržaj Cu (%)	Količina Cu (t)	Srednji sadržaj Au (g/t)	Količina Au (kg)	Srednji sadržaj Ag (g/t)	Količina Ag (kg)
B	430 049 240	0,344	1 477 700	0,062	26 469	0,264	113 544
C1	191 872 047	0,261	500 814	0,043	8 250	0,198	37 972
B+C1	621 921 288	0,318	1 978 514	0,056	34 719	0,244	151 516

Tabela 2. *Bilansne rezerve ležišta bakra Veliki Krivelj, u konturi graničnog sadržaja 0,15% Cu*

Kategorija	Količina rude (t)	Srednji sadržaj Cu (%)	Količina Cu (t)	Srednji sadržaj Au (g/t)	Količina Au (kg)	Srednji sadržaj Ag (g/t)	Količina Ag (kg)
B	364 663 299	0,347	1 266 014	0,061	22 073	0,266	97 090
C1	109 627 786	0,244	267 807	0,039	4 270	0,188	20 631
B+C1	474 291 085	0,323	1 533 821	0,056	26 343	0,248	117 721

Tabela 3. Vanbilansne rezerve ležišta bakra Veliki Krivelj, u konturi graničnog sadržaja 0,15% Cu

Kategorija	Količina rude (t)	Srednji sadržaj Cu (%)	Količina Cu (t)	Srednji sadržaj Au (g/t)	Količina Au (kg)	Srednji sadržaj Ag (g/t)	Količina Ag (kg)
B	65 385 941	0,324	211 685	0,067	4 397	0,252	16 454
C1	82 244 2616	0,283	233 008	0,048	3 980	0,211	17 340
B+C1	147 630 202	0,301	444 693	0,057	8 376	0,229	33 794

PRIMENA SOFTVERA WHITTLE I GEMCOM U PROJEKTOVANJU EKSPLOATACIJE RUDE BAKRA U LEŽIŠTU VELIKI KRIVELJ

Primena softvera za projektovanje u rudarstvu predstavlja danas standard u Svetu, pre svega što omogućavaju brzo i sa velikom tačnošću sagledavanje najpovoljnijih varijanti eksploatacije mineralnih sirovina, sa aspekta njihovog racionalnog iskorišćenja iz ležišta uz postizanje maksimalnog profita.

Projektovanje eksploatacije rude bakra u ležištu Veliki Krivelj izvršeno je primenom softvera Whittle i Gemcom, koji predstavljaju jedne od najsavremenijih softverskih alata za projektovanje u rudarstvu u Svetu.

Na osnovu blok modela ležišta i definisanih ulaznih tehno-ekonomskih parametara, u programu za ekonomsku optimizaciju Whittle 4.1.3, izvršena je optimizacija ležišta i definisan fazni razvoj površinskog kopa u granicama optimalnih kontura.

Izbor završne – optimalne konture kopa izvršen je za baznu cenu bakra od 6.000 $. U slučaju nestabilnosti na tržištu metala, eksploatacija rude u projektovanoj konturi kopa biće rentabilno do granične cene bakra od 3.480 $. Veća cena od planirane znači da će i ekonomski efekti poslovanja biti bolji od planiranih, tj. ostvariće se veći profit. Ekonomski efekti eksploatacije rude bakra obračunati su za granični sadržaj metala bakra u rudi GS = 0,15 %.

Primenom ovog graničnog sadržaja, obračunati su osnovni pokazatelji u dobijenim granicama kopova, prikazani u tabeli 4. U ovoj tabeli, pored fizičkih pokazatelja, odnosno ukupnih količina iskopina (rude i jalovine), za 91 varijantu granice kopa, prikazan je novčani tok (cashflow) i diskontovani novčani tok (discounted cashflow) za tri varijante analize – „*best case*“, „*worst case*“ i „*specified case*“ koje definišu način prostornog razvoja kopa.

Nakon izvršene analize dobijenih rezultata ekonomskih efekata eksploatacije rude bakra iz ležišta Veliki Krivelj (tabela 4), kao optimalan izabran je kop broj 45, sa 419.610.060 t rude.

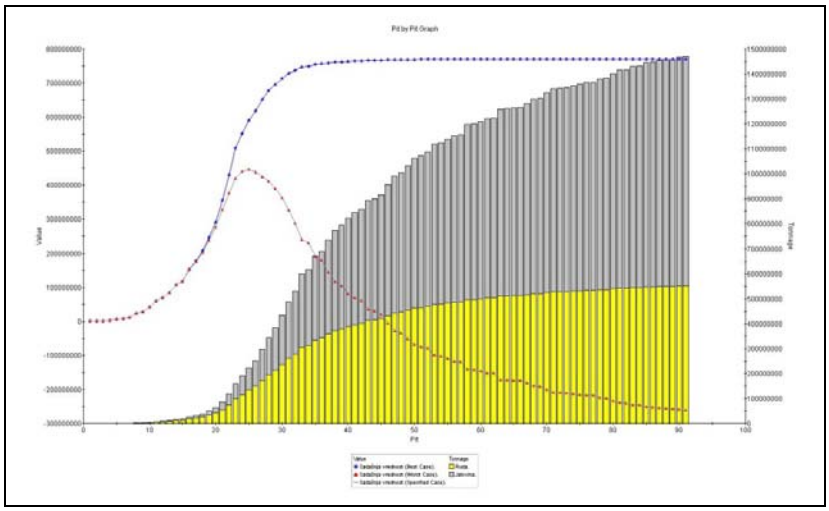
Tabela 4. Osnovni pokazatelji u granicama kopova za GS=0,15 % Cu

Kop	Iskopine (t)	Ruda (t)	Novčani tok (cashflow best) $	Novčani tok (cashflow best) $ disc	Novčani tok (cashflow worst) $	Novčani tok (cashflow worst) $ disc
1	29 910	29 582	490 904	490 775	490 904	490 775
2	67 356	66 886	985 521	984 934	985 521	984 934
3	109 928	107 534	1 574 076	1 572 569	1 574 076	1 572 569
4	274 424	262 930	3 555 604	3 547 286	3 555 604	3 547 286
5	426 857	412 355	5 404 891	5 385 075	5 404 891	5 385 075
6	627 023	595 630	7 664 789	7 624 231	7 664 789	7 624 231
7	1 027 505	958 359	11 535 955	11 437 897	11 535 955	11 437 897

8	2 313 114	2 155 619	23 690 594	23 240 047	23 690 594	23 240 047
9	2 958 650	2 658 544	28 972 205	28 294 175	28 972 205	28 294 175
10	4 949 120	4 417 189	45 293 800	43 546 271	45 293 800	43 546 271
11	7 321 384	6 406 354	63 131 626	59 629 910	63 131 626	59 629 910
12	9 029 763	7 659 288	74 251 463	69 354 597	74 251 463	69 354 597
13	11 730 621	9 616 086	91 164 693	83 681 043	91 164 693	83 681 043
14	15 892 438	12 663 158	119 468 873	108 223 901	119 565 161	108 238 394
15	17 920 191	13 965 699	131 360 892	118 470 820	131 573 394	118 405 792
16	25 174 088	18 682 288	173 142 266	152 502 056	173 771 762	151 201 869
17	31 021 328	22 420 726	205 879 646	177 908 043	206 674 729	175 328 925
18	38 638 100	27 175 624	244 901 278	208 010 726	245 910 715	203 318 340
19	49 547 011	33 642 790	297 951 548	245 842 303	299 193 226	236 949 549
20	63 259 170	42 112 004	366 459 724	291 451 918	369 619 910	277 436 583
21	85 797 798	55 079 842	470 297 062	355 201 325	477 385 285	329 346 507
22	118 287 028	74 005 879	616 811 197	430 937 206	631 640 208	377 940 954
23	159 667 669	98 825 552	800 747 296	509 580 857	818 614 350	421 267 096
24	189 577 442	115 793 415	924 303 475	552 775 158	943 171 862	439 794 899
25	222 256 514	133 016 248	1 046 937 309	590 091 947	1 067 017 556	446 734 583
26	252 430 580	148 999 425	1 157 996 594	618 463 228	1 179 550 911	438 729 903
27	296 922 791	171 856 092	1 311 651 507	652 103 359	1 334 496 612	424 878 477
28	342 589 322	194 922 116	1 459 213 954	678 129 140	1 481 827 291	412 851 160
29	382 823 379	213 458 494	1 580 555 317	695 730 321	1 605 079 229	390 864 550
30	432 551 682	236 472 055	1 726 701 205	713 479 157	1 752 878 929	364 320 532
31	486 933 216	260 089 622	1 877 698 519	727 737 746	1 905 426 130	326 902 636
32	530 507 671	276 968 140	1 985 459 151	736 251 653	2 014 068 545	289 352 065
33	599 048 234	305 235 290	2 158 811 899	746 641 246	2 188 192 897	241 181 739
34	617 598 990	313 607 458	2 205 291 711	749 120 696	2 234 697 022	230 810 522
35	671 991 222	334 363 117	2 328 033 827	754 458 155	2 357 900 315	191 169 250
36	690 450 640	342 456 306	2 371 069 072	756 129 120	2 400 973 132	181 133 588
37	735 659 231	358 212 735	2 459 548 052	759 095 762	2 489 928 400	144 752 173
38	773 786 426	371 650 802	2 531 684 666	761 369 135	2 562 406 007	117 321 434
39	793 434 978	378 825 077	2 567 951 741	762 357 707	2 598 749 124	104 617 047
40	824 250 908	388 914 953	2 620 333 608	763 764 548	2 651 440 275	81 296 094
41	843 083 911	395 633 986	2 650 924 905	764 518 435	2 682 129 055	68 733 300
42	857 665 379	400 987 294	2 674 351 990	765 047 823	2 705 603 015	61 636 371
43	894 466 018	412 275 607	2 725 847 668	766 156 415	2 757 398 355	35 836 121
44	901 522 365	414 652 982	2 735 662 866	766 355 940	2 767 236 913	31 133 205
45	916 413 694	419 610 060	2 754 619 445	766 713 771	2 786 297 656	21 015 616
46	957 712 821	431 985 896	2 805 266 684	767 581 472	2 837 221 492	- 5 201 934
47	991 112 469	441 908 484	2 841 504 231	768 157 072	2 873 689 960	- 26 343 365
48	1 005 354 875	446 292 295	2 856 783 235	768 391 144	2 889 045 502	- 34 341 121
49	1 031 434 676	453 593 026	2 881 860 067	768 731 804	2 914 240 747	- 49 594 157
50	1 060 999 692	461 880 115	2 910 051 367	769 082 881	2 942 575 361	- 67 047 681
51	1 073 260 491	465 294 430	2 920 480 753	769 214 137	2 953 054 680	- 74 022 242
52	1 085 921 499	469 315 733	2 931 692 956	769 344 756	2 964 271 053	- 79 099 597
53	1 118 356 519	477 299 327	2 955 300 322	769 595 814	2 988 041 139	- 99 041 430
54	1 125 951 338	479 609 259	2 960 870 334	769 649 269	2 993 614 294	- 102 377 486
55	1 138 323 890	482 922 408	2 969 037 392	769 734 674	3 001 795 916	- 108 604 825
56	1 153 382 960	486 564 343	2 978 283 956	769 826 921	3 011 090 358	- 116 401 898
57	1 158 205 998	487 651 866	2 980 833 559	769 851 021	3 013 665 898	- 119 410 476
58	1 198 236 683	497 228 807	3 001 419 826	770 020 723	3 034 387 252	- 140 778 988
59	1 200 769 104	497 962 252	3 002 729 275	770 030 518	3 035 696 736	- 141 527 219
60	1 208 817 105	499 800 081	3 006 279 213	770 060 837	3 039 256 992	- 144 812 585
61	1 221 273 828	502 691 710	3 010 827 280	770 098 424	3 043 847 315	- 151 744 512
62	1 223 942 696	503 534 750	3 011 875 600	770 106 518	3 044 895 636	- 152 543 932
63	1 258 918 125	510 810 191	3 021 468 022	770 156 418	3 054 624 753	- 171 073 241
64	1 261 198 182	511 324 445	3 022 039 559	770 159 327	3 055 198 311	- 172 218 022
65	1 263 747 676	512 041 030	3 022 661 372	770 161 943	3 055 821 802	- 172 988 938
66	1 265 750 880	512 538 424	3 023 090 238	770 163 709	3 056 250 668	- 173 582 796
67	1 281 737 858	515 851 573	3 025 296 826	770 173 410	3 058 469 252	- 180 618 353
68	1 301 153 009	520 100 498	3 027 356 274	770 183 761	3 060 542 505	- 189 320 186
69	1 302 834 907	520 471 436	3 027 502 684	770 184 261	3 060 688 915	- 189 873 773

70	1 324 574 470	524 846 816	3 028 399 272	770 179 162	3 061 608 418	- 199 842 101
71	1 341 793 178	527 898 623	3 028 623 827	770 175 947	3 061 848 565	- 208 818 505
72	1 343 006 690	528 227 409	3 028 588 143	770 175 209	3 061 812 881	- 209 119 253
73	1 345 644 541	528 817 537	3 028 456 524	770 173 449	3 061 681 262	- 209 839 866
74	1 353 464 473	530 807 113	3 027 783 340	770 166 028	3 061 008 077	- 211 985 751
75	1 360 189 098	532 139 117	3 027 079 131	770 160 605	3 060 304 399	- 214 475 322
76	1 365 916 793	533 353 096	3 026 275 992	770 155 399	3 059 502 101	- 216 384 984
77	1 366 748 775	533 530 134	3 026 138 338	770 154 524	3 059 364 518	- 216 656 213
78	1 380 246 008	535 696 749	3 023 913 120	770 140 886	3 057 156 344	- 223 870 892
79	1 383 338 502	536 362 751	3 023 232 513	770 136 873	3 056 475 738	- 224 816 611
80	1 402 617 243	540 088 990	3 018 541 928	770 107 672	3 051 798 604	- 232 606 033
81	1 415 067 370	541 876 236	3 015 643 733	770 090 296	3 048 920 148	- 239 098 493
82	1 417 006 216	542 280 895	3 015 054 935	770 086 848	3 048 331 691	- 239 728 297
83	1 430 237 956	544 447 510	3 011 063 202	770 064 321	3 044 343 281	- 244 579 954
84	1 431 634 414	544 759 435	3 010 605 015	770 061 885	3 043 885 136	- 245 078 948
85	1 446 170 838	547 415 013	3 005 401 308	770 035 448	3 038 689 252	- 250 679 145
86	1 447 764 097	547 710 077	3 004 763 557	770 032 327	3 038 051 717	- 251 201 593
87	1 454 915 498	548 772 308	3 001 920 345	770 018 730	3 035 211 599	- 254 027 244
88	1 458 510 817	549 294 993	3 000 563 411	770 012 440	3 033 860 236	- 255 821 526
89	1 460 264 394	549 657 501	2 999 700 708	770 008 429	3 032 997 996	- 256 294 791
90	1 467 141 196	550 938 922	2 996 541 212	769 994 131	3 029 838 500	- 258 486 697
91	1 469 621 413	551 394 164	2 995 315 867	769 988 395	3 028 613 626	- 259 331 679

Određeni karakteristični pokazatelji iz tabele 4 prikazani su i grafički na slici 1.



Sl. 1. *Grafički prikaz podataka za kopove*

Vrlo važan pokazatelj racionalnog korišćenja mineralnih sirovina je iskorišćenje bilansnih rezervi ležišta. Na osnovu količina bilansnih rezervi rude i količina rude u optimalnoj konturi kopa (ekspoloatacione rezerve) dobija se stepen iskorišćenja bilansnih rezervi ležišta Veliki Krivelj i on iznosi:

$$I = R_e / R_b \cdot 100,\% \qquad (1)$$

gde su:

R_e – eksploatacione rezerve, (t)

R_b – bilansne rezerve, (t).

$I = 88{,}47\%$

ZAKLJUČAK

Ležište bakra Veliki Krivelj, koje se nalazi na oko 3 km vazdušnom linijom,

severno od grada Bora, ima primarnu ulogu u proizvodnji bakra u kompaniji RTB Bor, s obzirom da mu pripada 75% ukupne proizvodnje, u koju su sada uključeni i jama Bor, površinski kop Cerovo Cementacija 1 i Rudnik bakra Majdanpek u kome se eksploatacija rude odvija na površinskom kopu Severni revir, a od 2013. godine planiran je početak eksploatacije i na površinskom kopu Južni revir.

S obzirom da se radi o ležištu sa niskim sadržajem metala u rudi koji u ukupnim geološkim rezervama iznosi 0,318 %, to je primena savremenog softverskog alata za strateško planiranje i optimizaciju ležišta Whittle i softvera za konstrukciju površinskih kopova Gemcom od izuzetnog značaja za racionalno iskorišćenje ležišta i postizanje maksimalnog profita u eksploataciji.

Proračun rudnih rezervi u ležištu bakra Veliki Krivelj, urađen je primenom računarskog softvera Gemcom, pri čemu je primenjena metoda mini blokova, koja je potvrđena u fazi eksploatacije ležišta poslednjih deset godina (od 2000. godine).

U konturi graničnog sadržaja 0,15% Cu, ukupne geološke rezerve u ležištu iznose 621.921.288 t, a bilansne rezerve 474.291.085 t.

Izbor završne - optimalne konture kopa izvršen je za baznu cenu bakra od 6.000 $, u softveru za ekonomsku optimizaciju ležišta Whittle.

Na osnovu ulaznih tehno - ekonomskih parametara u pomenutom softveru generisana je 91 granica kopa. Nakon izvršene analize dobijenih rezultata ekonomskih efekata eksploatacije rude bakra iz ležišta Veliki Krivelj, kao optimalan izabran je kop broj 45, sa 419.610.060 t rude.

Vrlo važan pokazatelj racionalnog korišćenja mineralnih sirovina je iskorišćenje bilansnih rezervi ležišta. Na osnovu količina bilansnih rezervi rude i količina rude u optimalnoj konturi kopa (eksploatacione rezerve) dobija se stepen iskorišćenja bilansnih rezervi ležišta Veliki Krivelj i on iznosi 88,47 %.

Na primeru ležišta Veliki Krivelj, dobijena vrednost iskorišćenja bilansnih rezervi, u potpunosti potvrđuje značaj korišćenja softvera za projektovanje u rudarskoj struci u cilju racionalnog i ekonomičnog iskorišćenja ležišta.

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APPLICATION OF SOFTWARE PACKAGES GEMCOM AND WHITTLE FOR DESIGN IN MINING AIMED TO RATIONAL AND COST-EFFECTIVE UTILIZATION THE COPPER DEPOSIT VELIKI KRIVELJ NEAR BOR, SERBIA**

Abstract

The copper deposit Veliki Krivelj is located about 3 km by the air, north of the town of Bor and belongs to the porphyritic large-scale deposits. Total geological reserves of copper, in a contour of limit content 0.15% amount to 621 921 288 t. For its importance, this deposit has a leading role in the production of copper in the company RTB Bor, as it has 75% of total production.

The World mining companies in assessment the financial viability and defining the optimum strategy for development the mine and rational and economical utilization of mineral deposits, use some software for optimization and design, and among the leading ones are Whittle and Gemcom, which the Mining and Metallurgy Institute Bor also owns.

This work presents a method of defining the optimum contour of the copper deposit Veliki Krivelj using the software Whittle and Gemcom, which ensure the optimum utilization of deposit, which is a necessary prerequisite for responsible management of mineral resources.

***Keywords**: Gemcom, Whittle, copper deposit Veliki Krivelj, rational, optimum, economical utilization of deposit*

INTRODUCTION

Natural mineral resources of one country are the basis of its economic and social prosperity. According to the economic value of mineral resources at its disposal, Serbia does not belong to the rich countries. Therefore, there is an obligation to perform the mining activity by the principles of rational management of mineral resources.

The copper deposit Veliki Krivelj is located about 3 km by the air, north of the town of Bor and belongs to the porphyritic large-scale deposits. Total geological reserves of copper, in a contour of limit content 0.15% amount to 621 921 288 t.

The significance of this deposit for the company RTB Bor is reflected in the fact

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that it has 75% of total copper production, which also involves the underground mine Jama Bor and Copper Mine Majdanpek. In addition to these deposits, the complex of the deposit Cerovo is of exceptional importance, in which the operations are continued this on mining the copper ore, which was interrupted in 2003.

Since the copper deposit Veliki Krivelj belongs to the deposits with low metal content in the ore, which in total geological reserves amounts to 0.318%, the use of modern software tools Whittle for strategic planning and optimization of deposit and software Gemcom for design of the open pits is essential for rational utilization of deposit and obtaining maximum profits in mining.

ORE RESERVES OF DEPOSIT

Calculation of ore reserves in the copper deposit Veliki Krivelj was performed using the computer software Gemcom where the method of mini blocks was used, which was confirmed in the stage of deposit mining in the last ten years (since 2000).

In the case of the copper deposit Veliki Krivelj and similar deposits, with a large number of data used for the calculation of reserves, the advantage of calculation the budget reserves using the computer technology is indisputable, as compared to the calculation using the other ("manually") methods:

- Due to the size of deposit, states of the future open pit and production capacity (large amounts of excavation), project desings and changes are very complex with optimum working and final contours of the open pit, and the digital model with calculated reserves by mini-blocks, facilitates and accelerates the process, since it is possible in a short period of time to see a large number of variants and find the best solutions,
- The obtained results in design and economic consideration, on the basis of formed block-model of deposit and calculation of reserves by this method, on the copper deposits of porphyritic type, have the satisfactory quality, or they are accepted as satisfactory in the world,
- Potential concessionaires require the deposit to be displayed in a digital form.

The following Tables give an overview of reserves of the copper deposit Veliki Krivelj with the medium content and amounts of useful components for total geological reserves (Table 1), balance reserves (Table 2) and off-balance reserve (Table 3), in a contour of limit content 0.15 % Cu.

Table 1. *Geological reserves of the copper deposit Veliki Krivelj in a contour of limit content, 0.15% Cu*

Category	Amount of ore (t)	Medium content Cu (%)	Amount Cu (t)	Medium content Au (g/t)	Amount Au (kg)	Medium content Ag (g/t)	Amount Ag (kg)
B	430 049 240	0.344	1 477 700	0.062	26 469	0.264	113 544
C1	191 872 047	0.261	500 814	0.043	8 250	0.198	37 972
B+C1	621 921 288	0.318	1 978 514	0.056	34 719	0.244	151 516

Table 2. *Balance reserves of the copper deposit Veliki Krivelj in a contour of limit content, 0.15% Cu*

Category	Amount of ore (t)	Medium content Cu (%)	Amount Cu (t)	Medium content Au (g/t)	Amount Au (kg)	Medium content Ag (g/t)	Amount Ag (kg)
B	364 663 299	0.347	1 266 014	0.061	22 073	0.266	97 090
C1	109 627 786	0.244	267 807	0.039	4 270	0.188	20 631
B+C1	474 291 085	0.323	1 533 821	0.056	26 343	0.248	117 721

Table 3. *Off-balance reserves of the copper deposit Veliki Krivelj in a contour of limit content, 0.15% Cu*

Category	Amount of ore (t)	Medium content Cu (%)	Amount Cu (t)	Medium content Au (g/t)	Amount Au (kg)	Medium content Ag (g/t)	Amount Ag (kg)
B	65 385 941	0.324	211 685	0.067	4 397	0.252	16 454
C1	82 244 2616	0.283	233 008	0.048	3 980	0.211	17 340
B+C1	147 630 202	0.301	444 693	0.057	8 376	0.229	33 794

APPLICATION OF SOFTWARE WHITTLE AND GEMCOM IN DESIGN THE COPPER ORE MINING IN THE DEPOSIT VELIKI KRIVELJ

Application of software for design of mining is nowadays a standard in the world, primarily by enabling fast and accurately understanding the most appropriate variants of mining the mineral resources from the aspect of their rational utilization from deposits with attaining maximum profits.

Design the copper ore mining in the deposit Veliki Krivelj was made using the software Whittle and Gemcom, which represents one of the most advanced software tools for design in mining industry in the world.

Based on the block model of deposit and defined input techno-economic parameters in the program Whittle 4.1.3 for economic optimization, the optimization of deposit was made and the stage development of open pit was defined within the limits of optimum contours.

Selection of the final - optimum contour of open pit was made for the base copper price of 6 000 $. In the case of instability on the metal market, the ore mining in designed contour of open pit will be profitable to the marginal copper price of 3 480 $. Higher price than the planned one also means that the economic effects of business will be better than expected, i.e. a higher profit will be achieved. The economic effects of copper ore mining were calculated for the limit metal content of copper in the ore GS = 0.15%.

The basic indicators were calculated using this limit content in the obtained open pit limits, shown in Table 4. In this Table, in addition to the physical indicators, i.e. total amount of excavations (ore and waste), for the 91 variant of the open pi limit, the cash flow and discounted cash flow are present for three variantsof analysis - the "*best case", "worst case* and *"specified case"* that define the spatial development of the open pit.

After carried out analysis of the obtained results of economic effects the mining of copper ore from the deposit

Veliki Krivelj (Table 4), the open pit No. 45, with 419 610 060 t of ore, was selected as the optimum one.

Table 4. *Basic indicators within the limits of open pits for GS=0.15 % Cu*

Open pit	Excavations (t)	Ore (t)	Cashflow best $	Cashflow best $ disc	Cashflow worst $	Cashflow worst $ disc
1	29 910	29 582	490 904	490 775	490 904	490 775
2	67 356	66 886	985 521	984 934	985 521	984 934
3	109 928	107 534	1 574 076	1 572 569	1 574 076	1 572 569
4	274 424	262 930	3 555 604	3 547 286	3 555 604	3 547 286
5	426 857	412 355	5 404 891	5 385 075	5 404 891	5 385 075
6	627 023	595 630	7 664 789	7 624 231	7 664 789	7 624 231
7	1 027 505	958 359	11 535 955	11 437 897	11 535 955	11 437 897
8	2 313 114	2 155 619	23 690 594	23 240 047	23 690 594	23 240 047
9	2 958 650	2 658 544	28 972 205	28 294 175	28 972 205	28 294 175
10	4 949 120	4 417 189	45 293 800	43 546 271	45 293 800	43 546 271
11	7 321 384	6 406 354	63 131 626	59 629 910	63 131 626	59 629 910
12	9 029 763	7 659 288	74 251 463	69 354 597	74 251 463	69 354 597
13	11 730 621	9 616 086	91 164 693	83 681 043	91 164 693	83 681 043
14	15 892 438	12 663 158	119 468 873	108 223 901	119 565 161	108 238 394
15	17 920 191	13 965 699	131 360 892	118 470 820	131 573 394	118 405 792
16	25 174 088	18 682 288	173 142 266	152 502 056	173 771 762	151 201 869
17	31 021 328	22 420 726	205 879 646	177 908 043	206 674 729	175 328 925
18	38 638 100	27 175 624	244 901 278	208 010 726	245 910 715	203 318 340
19	49 547 011	33 642 790	297 951 548	245 842 303	299 193 226	236 949 549
20	63 259 170	42 112 004	366 459 724	291 451 918	369 619 910	277 436 583
21	85 797 798	55 079 842	470 297 062	355 201 325	477 385 285	329 346 507
22	118 287 028	74 005 879	616 811 197	430 937 206	631 640 208	377 940 954
23	159 667 669	98 825 552	800 747 296	509 580 857	818 614 350	421 267 096
24	189 577 442	115 793 415	924 303 475	552 775 158	943 171 862	439 794 899
25	222 256 514	133 016 248	1 046 937 309	590 091 947	1 067 017 556	446 734 583
26	252 430 580	148 999 425	1 157 996 594	618 463 228	1 179 550 911	438 729 903
27	296 922 791	171 856 092	1 311 651 507	652 103 359	1 334 496 612	424 878 477
28	342 589 322	194 922 116	1 459 213 954	678 129 140	1 481 827 291	412 851 160
29	382 823 379	213 458 494	1 580 555 317	695 730 321	1 605 079 229	390 864 550
30	432 551 682	236 472 055	1 726 701 205	713 479 157	1 752 878 929	364 320 532
31	486 933 216	260 089 622	1 877 698 519	727 737 746	1 905 426 130	326 902 636
32	530 507 671	276 968 140	1 985 459 151	736 251 653	2 014 068 545	289 352 065
33	599 048 234	305 235 290	2 158 811 899	746 641 246	2 188 192 897	241 181 739

34	617 598 990	313 607 458	2 205 291 711	749 120 696	2 234 697 022	230 810 522
35	671 991 222	334 363 117	2 328 033 827	754 458 155	2 357 900 315	191 169 250
36	690 450 640	342 456 306	2 371 069 072	756 129 120	2 400 973 132	181 133 588
37	735 659 231	358 212 735	2 459 548 052	759 095 762	2 489 928 400	144 752 173
38	773 786 426	371 650 802	2 531 684 666	761 369 135	2 562 406 007	117 321 434
39	793 434 978	378 825 077	2 567 951 741	762 357 707	2 598 749 124	104 617 047
40	824 250 908	388 914 953	2 620 333 608	763 764 548	2 651 440 275	81 296 094
41	843 083 911	395 633 986	2 650 924 905	764 518 435	2 682 129 055	68 733 300
42	857 665 379	400 987 294	2 674 351 990	765 047 823	2 705 603 015	61 636 371
43	894 466 018	412 275 607	2 725 847 668	766 156 415	2 757 398 355	35 836 121
44	901 522 365	414 652 982	2 735 662 866	766 355 940	2 767 236 913	31 133 205
45	916 413 694	419 610 060	2 754 619 445	766 713 771	2 786 297 656	21 015 616
46	957 712 821	431 985 896	2 805 266 684	767 581 472	2 837 221 492	- 5 201 934
47	991 112 469	441 908 484	2 841 504 231	768 157 072	2 873 689 960	- 26 343 365
48	1 005 354 875	446 292 295	2 856 783 235	768 391 144	2 889 045 502	- 34 341 121
49	1 031 434 676	453 593 026	2 881 860 067	768 731 804	2 914 240 747	- 49 594 157
50	1 060 999 692	461 880 115	2 910 051 367	769 082 881	2 942 575 361	- 67 047 681
51	1 073 260 491	465 294 430	2 920 480 753	769 214 137	2 953 054 680	- 74 022 242
52	1 085 921 499	469 315 733	2 931 692 956	769 344 756	2 964 271 053	- 79 099 597
53	1 118 356 519	477 299 327	2 955 300 322	769 595 814	2 988 041 139	- 99 041 430
54	1 125 951 338	479 609 259	2 960 870 334	769 649 269	2 993 614 294	- 102 377 486
55	1 138 323 890	482 922 408	2 969 037 392	769 734 674	3 001 795 916	- 108 604 825
56	1 153 382 960	486 564 343	2 978 283 956	769 826 921	3 011 090 358	- 116 401 898
57	1 158 205 998	487 651 866	2 980 833 559	769 851 021	3 013 665 898	- 119 410 476
58	1 198 236 683	497 228 807	3 001 419 826	770 020 723	3 034 387 252	- 140 778 988
59	1 200 769 104	497 962 252	3 002 729 275	770 030 518	3 035 696 736	- 141 527 219
60	1 208 817 105	499 800 081	3 006 279 213	770 060 837	3 039 256 992	- 144 812 585
61	1 221 273 828	502 691 710	3 010 827 280	770 098 424	3 043 847 315	- 151 744 512
62	1 223 942 696	503 534 750	3 011 875 600	770 106 518	3 044 895 636	- 152 543 932
63	1 258 918 125	510 810 191	3 021 468 022	770 156 418	3 054 624 753	- 171 073 241
64	1 261 198 182	511 324 445	3 022 039 559	770 159 327	3 055 198 311	- 172 218 022
65	1 263 747 676	512 041 030	3 022 661 372	770 161 943	3 055 821 802	- 172 988 938
66	1 265 750 880	512 538 424	3 023 090 238	770 163 709	3 056 250 668	- 173 582 796
67	1 281 737 858	515 851 573	3 025 296 826	770 173 410	3 058 469 252	- 180 618 353
68	1 301 153 009	520 100 498	3 027 356 274	770 183 761	3 060 542 505	- 189 320 186
69	1 302 834 907	520 471 436	3 027 502 684	770 184 261	3 060 688 915	- 189 873 773
70	1 324 574 470	524 846 816	3 028 399 272	770 179 162	3 061 608 418	- 199 842 101
71	1 341 793 178	527 898 623	3 028 623 827	770 175 947	3 061 848 565	- 208 818 505

72	1 343 006 690	528 227 409	3 028 588 143	770 175 209	3 061 812 881	- 209 119 253
73	1 345 644 541	528 817 537	3 028 456 524	770 173 449	3 061 681 262	- 209 839 866
74	1 353 464 473	530 807 113	3 027 783 340	770 166 028	3 061 008 077	- 211 985 751
75	1 360 189 098	532 139 117	3 027 079 131	770 160 605	3 060 304 399	- 214 475 322
76	1 365 916 793	533 353 096	3 026 275 992	770 155 399	3 059 502 101	- 216 384 984
77	1 366 748 775	533 530 134	3 026 138 338	770 154 524	3 059 364 518	- 216 656 213
78	1 380 246 008	535 696 749	3 023 913 120	770 140 886	3 057 156 344	- 223 870 892
79	1 383 338 502	536 362 751	3 023 232 513	770 136 873	3 056 475 738	- 224 816 611
80	1 402 617 243	540 088 990	3 018 541 928	770 107 672	3 051 798 604	- 232 606 033
81	1 415 067 370	541 876 236	3 015 643 733	770 090 296	3 048 920 148	- 239 098 493
82	1 417 006 216	542 280 895	3 015 054 935	770 086 848	3 048 331 691	- 239 728 297
83	1 430 237 956	544 447 510	3 011 063 202	770 064 321	3 044 343 281	- 244 579 954
84	1 431 634 414	544 759 435	3 010 605 015	770 061 885	3 043 885 136	- 245 078 948
85	1 446 170 838	547 415 013	3 005 401 308	770 035 448	3 038 689 252	- 250 679 145
86	1 447 764 097	547 710 077	3 004 763 557	770 032 327	3 038 051 717	- 251 201 593
87	1 454 915 498	548 772 308	3 001 920 345	770 018 730	3 035 211 599	- 254 027 244
88	1 458 510 817	549 294 993	3 000 563 411	770 012 440	3 033 860 236	- 255 821 526
89	1 460 264 394	549 657 501	2 999 700 708	770 008 429	3 032 997 996	- 256 294 791
90	1 467 141 196	550 938 922	2 996 541 212	769 994 131	3 029 838 500	- 258 486 697
91	1 469 621 413	551 394 164	2 995 315 867	769 988 395	3 028 613 626	- 259 331 679

The certain characteristic indicators from Table 4 are shown graphically in Figure 1.

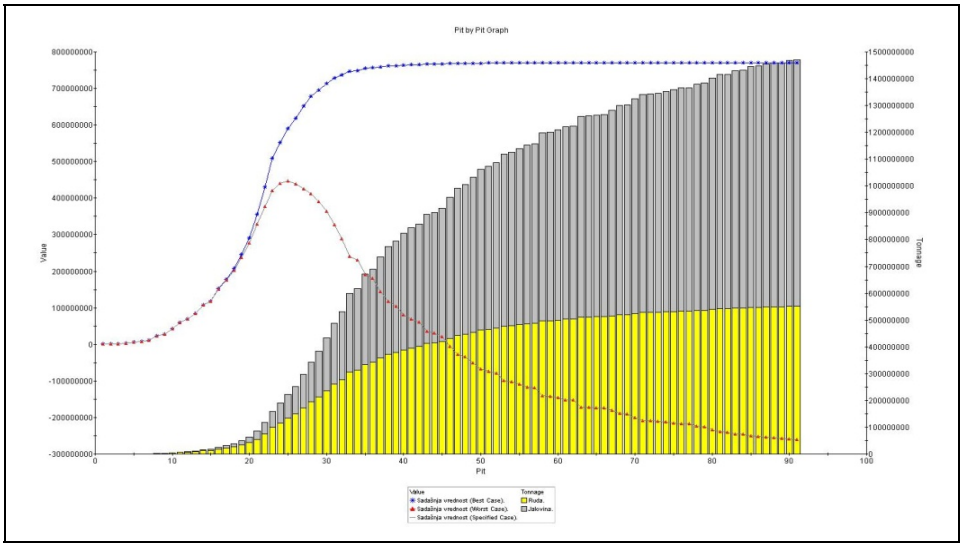

Fig. 1. *Graphical view of data for open pits*

An important indicator of rational use the mineral resources is utilization the balance reserves of deposit. Based on the amount of balance ore reserves and the amount of ore in the optimum contour of open pit (mineable reserves), the utilization degree of balance reserves of the open pit Veliki Krivelj is obtained and amounts:

$$I = R_e / R_b \cdot 100,\% \qquad (1)$$

where:

R_e – mineable reserves, (t)

R_b – balace reserves, (t).

$I = 88{,}47\%$

CONCLUSION

The copper deposit Veliki Krivelj, located about 3 miles by the air, north of the town of Bor, has a primary role in the production of copper in the company RTB Bor as it has 75% of total production, which now involves the underground mine Jama Bor, open pit Cerovo Cementacija 1 and Copper Mine Majdanpek, where ore mining takes place at the open pit North Mining District, and from 2013 the start of mining operations is planned in the South Mining District.

Since it is a deposit with low metal content in the ore, which in total geological reserves is 0.318%, the use of modern software tools Whittle for strategic planning and optimization of deposit and software Gemcom for design of open pits is essential for rational use of deposit and attaining the maximum profits in mining.

Calculation of ore reserves in the copper deposit Veliki Krivelj was made using the computer software Gemcom with the use of mini blocks method, confirmed during the operation stage of deposit mining in the last ten years (since 2000).

In a contour of limit content 0.15% Cu, total geological reserves in the deposit amount 621 921 288 t, and the balance reserves amount 474 291 085 t.

Selection of the final – optimum contour of the open pit was made for the basic copper price of 6 000 $ using the software Whittle for economic optimization of the deposit.

Based on the input of techno - economic parameters in the given software, the 91 copper limit was generated. After carried out analysis of the obtained results of economic effects the copper ore mining from the deposit Veliki Krivelj, the open pit No. 45, with 419 610 060 t of ore, was selected as the optimum one.

An important indicator of rational use the mineral resources is utilization the balance reserves of deposit. Based on the amount of balance ore reserves and the amount of ore in the optimum contour of open pit (mineable reserves), the degree of utilization the balance reserves of the deposit Veliki Krivelj is obtained and it is 88.47%.

In the example of the deposit Veliki Krivelj, the obtained value of utilization the balance reserves, fully confirms the importance of using the software for design in the mining profession aimed to a rational and economical utilization of the deposit.

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UZROCI NASTAJANJA UDESA NA FLOTACIJSKIM JALOVIŠTIMA U SRBIJI***

Izvod

Flotacijska jalovišta sa aspekta tehnologije predstavljaju neophodan rudarski objekat, a u pogledu životne sredine realnu opasnost po ekološke faktore životne sredine bilo da su u funkciji ili je završen proces odlaganja. U Srbiji i u svetu, dogodili su se brojni udesi na flotacijskim jalovištima usled havarija. Pojave udesa zaslužuju da budu predmet istraživanja u cilju otkrivanja mehanizma njihovog nastajanja, obima i dometa ugrožavanja životne sredine kako bi se inicirali zahtevi za projektovanje i ugradnju zaštitnih sistema čija pouzdanosti treba da bude veća od ukupne verovatnoće opasnosti. Sve vrste sistema za suzbijanje, otkrivanje i alarmiranje opasnosti imaju svoju cenu nabavke, ugradnje i korišćenja koja je u principu srazmerna verovatnoći pouzdanosti i sigurnosti rada. Na taj način se uspostavlja funkcionalna veza između troškova ugradnje sistema sigurnosti i verovatnoće sigurnosti od nastajanja udesa (havarija). U radu su dati uzroci nastajanja udesa svrstani po uzroku nastajanja.

Ključne reči: *flotacijsko jalovište, havarija, životna sredina.*

1. UVOD

Flotacijska jalovišta predstavljaju prirodne ili veštački pregrađene prostore za akumuliranje hidromešavine (usitnjenog materijala i hemijski zagađene vode). Prema gradnji, flotacijska jalovišta svrstavaju se u: brdsko - dolinski, ravničarski, dubinski, podvodni i kombinovani tip odlaganja. Brdski (dolinski) i ravničarski tip u suštini imaju iste konstruktivne karakteristike i sličan način građenja. Kod ovih vrsta odlagališta grade se osnovne brane (inicijalne ili startne), čija visina zavisi od zapremine akumulacionog prostora i načina gradnje brana. Flotacijska jalovišta su najčešće locirana u blizini flotacija i grade se prema topografiji terena. Formiranje flotacijskih odlagališta može da se vrši u dolinama reka i potoka, na ravnom terenu i u prirodnim depresijama i otkopanim prostorima površinskog kopa. Prostor flotacijaskih odlagališta koristi se za:

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deponovanje flotacijske jalovine, potpuno izbistravanje vode, i akumuliranje tehnološke vode potrebne u procesu flotacijske koncentracije.

Flotacijska jalovišta su važni objekti u procesu rudarske proizvodnje. Bezbednost flotacijskih jalovišta se ne odnosi samo na proces rudarske proizvodnje i izgradnju, već se odnosi i na bezbednost ljude koji žive nizvodno od jalovišta i okoline [1].

Potencijalni proboj brane i izlivanje jalovine je katastrofalan pri čemu nastaje poplavni talas velike energije koji se kreće nizvodno [2].

2. KRITERIJUMI ZA IZBOR LOKACIJE FLOTACIJSKIH ODLAGALIŠTA

Za formiranje flotacijskih jalovišta postoje kriterijumi koji utiču na izbor lokacije i oni su ekonomske, tehničko–tehnološke i ekološke prirode.

Ekonomski kriterijum podrazumeva da na lokaciji ne treba da nema rezerve korisnih mineralnih sirovina, kulturnih, arheoloških spomenika i spomenika prirode, da je rastojanje lokacije jalovišta od flotacije najmanje.

Tehnički kriterijumi uključuju topografske, hidrološke i geološke karakteristike terena.

Za **Tehnološki kriterijum** važan je kapacitet odlagališta, način transporta flotacijske jalovine i mogućnost korišćenja povratne vode.

Ekološki kriterijum podrazumeva da se ne ugrožava staništa retkih biljaka i životinjskih vrsta, površinskih, podzemnih voda i zemljišta uzvodno i nizvodno od jalovišta.

3. NAJVEĆA FLOTACIJSKA JALOVIŠTA U EVROPI I SRBIJI

U tabeli 1. date su lokacije najvećih flotacijskih jalovišta u Evropi.

Tabela 1. *Najveća flotacijska jalovišta u Evropi i Srbiji*

Država	mesto	Količina jalovine m^3	Površina jalovišta m^2
Nemačka	Culmitzsch	90 000 000,00	2 280 000,00
	Helmsdorf	50 000 000,00	2 500 000.00
	Trunzig	19 000 000,00	1 080 000,00
Francuska	Escapiere	12 000 000,00	820 000,00
Mađarska	Pecs	16 000 000,00	1 540 000,00
Bugarska	Elesnitza	8 000 000,00	500 000,00
	Buhovo	11 000 000,00	700 000,00
Češka republika	Straz	33 000 000,00	1 360 000,00
	Rozna	15 000 000,00	400 000,00
	Mydlovary	15 000 000,00	2 600 000,00
Estonia	Sillamae	8 000 000,00	330 000,00
Srbija	Bor (odlagalište Bor)	12 436 160,00	600 000,00
	Bor(RT-H)	17 903 019,00	500 000,00
	Krivelj Polje 1	94 000 000,00	810 000,00
	Krivelj Polje 2	89 000 000,00	1 270 000,00
	Majdanpek	187 879 000,00	

U "World Register of Mine and Industrial Tailings Dams" su navedene osam flotacijskih brana višljih od 150 m, 22 višljih od 100 m i 115 višljih od 50 m.

Za šest zatvorenih se zna da zauzimaju površinu veću od 100 km^2 a zapremine su preko 50 000 000 m^3. [3].

3.1. Udesi na flotacijskim jalovištima u svetu

Poznati katastrofalni događaji u vezi sa izlivanjem flotacijske jalovine i vode koji su ugrozili životnu sredinu u svetu su:

1. Bivša ČSSR,
2. Čile (1967. god, poginulo više od 200 ljudi),
3. SAD,
4. Nemačka (Saksonija 1960 - tih god., izliveno 250 000 t jalovine u rečno korito),
5. Rumunija (Baia Mare 30. januara 2000. godine, zatrovane reke cijanidima: Mura, Tisa i Dunav).
6. Makedonija

Najveća slatkovodna ekološka katastrofa pogodila je države u slivu Dunava na dužini od 2000 kilometara kada je 30. januara 2000. godine, došlo do proboja brane na taložnim jezerima za jalovinu na postrojenjima fabrike i rudnika zlata Aurul SA Company, u mestu Baia Mare na severozapadu Rumunije.

Tom prilikom iscurelo je oko 100 000 kubnih metara odložene jalovine koja je sadržala u sebi između 50 i 100 tona cijanida kao i teške metale, uključujući i bakar.

Do pucanja brane došlo je kombinacijom propusta učinjenih još u izgradnji brane i nepovoljnim vremenskim uslovima brzog otapanja snega. Poplavni otrovni talas je putovao rekama Lapoš, Samoš, Tisom i Dunavom oko četiri nedelje pre nego što je stigao do Crnog Mora.

Tokom proteklih godina došlo je do tri proboja brana koje su izazvale katastrofe u Republici Makedoniji. Svi su prouzrukovali značajne štete posebno na vazduh, vode i zemljišta. Takve nesreće su se desile u rudniku olova i cinka Zletovo u Probišipu, rudniku bakra Bučim i poslednja u rudniku olova i cinka Sasa (Septembar 2003). [4].

Kolpas na flotacijskoj brani u Sasi napravio je krater od 120-160 m na dubine od 30-40 m. Posle katastrofe preko 1 000 000 tona jalovine sa teškim metalima izlilo se u Reku Kamenica, i dalje u jezero Kalimanci, reku Bragalnicu i okolni prostor. [4].

4. UZROCI NASTAJANJA HAVARIJA NA FLOTACIJSKIM JALOVIŠTIMA

Havarije ili udesi na flotacijskim jalovištima nastaju usled prirodnih nepogoda, tehničkih nedostataka i kombinacijom ova dva uzroka. Tom prilikom dovode do pojave opasnih rizika po životnu sredinu gde se zagađuju vode, zemljište, biljke, uništava se stanište životinja i plave kuće ljudima. U cilju predviđanja obima pojedinih udesa potrebno je odmah pri projektovanju flotacijskih jalovišta izvršiti procenu verovatnoće nastajanja havarija i štete na terenu. To se vrši na osnovu matematičke statistike i korelacije sa zbivanjima na sličnim jalovištima i primenom teorema iz teorije verovatnoće i pouzdanosti flotacijskih odlagališta pri radu u uslovima delovanja tehničko - tehnoloških nedostataka i prirodnih nepogoda (atmosferskih padavina, poplava, oluja, zemljotresa) i ratnih dejstava .

Istraživanjem je zaključeno da najčešći uzroci havarija kod nas i u bivšoj Jugoslaviji prouzrokovani su uslovima delovanja tehničkih nedostataka i nepoštovanjem projektnih rešenja. Od šesnaest zabeleženih havarija na flotacijskim odlagalištima na prostoru bivše Jugoslavije, devet slučajeva se odnosi na oštećenje betonske obloge kolektora i prodor flotacijske jalovine kroz **betonsku** oblogu kolektora (neotporan na kiselu sredinu). Jedan slučaj se odnosi na **oštećenje**

obloge tunela i jedan slučaj kroz betonsku cev za vodu, dok se dva slučaja odnosi na prelivanje poplavnog talasa atmosferske vode preko istaložene flotacijske jalovine u jalovištu i brane, dva slučaja isticanja vode ispod tela brane i jedan slučaj kroz "odžak" karstnog terena i pećinu. Zabeleženi primeri proboja flotacijskog odlagališta dati su u tabeli 2.

Havarije nastaju usled istovremene pojave opasnih stanja izazvanih tehničkim nedostacima i prirodnim pojavama na odlagalištima usled kojih dolazi do proboja flotacijskog mulja i njegovog oticanja u obliku poplavnog talasa u slivu područja.

Opasna stanja mogu da dovedu do iznenadnih klizanja podloge i kvarova na drenažnom sistemu i prelivnom organu na flotacijskim odlagalištima, pojave pukotina na kolektoru usled pritisaka sedimentovane jalovine, propadanja obloge kolektora usled dejstva kisele sredine i destabilizacije čitavog jalovišnog sistema.

Tabela 2. *Poznati uzroci havarija do sada kod nas i u bivšoj Jugoslaviji*

Prodor flotacijske jalovine kroz beton oblogu cevi za vodu	**Prodor flotacijske jalovine kroz oblogu kolektora**	**Isticanje flotacijske jalovine i vode ispod tela brane**	**Prelivanje poplavnog talasa atmosferske vode preko brana**	**Prodor flotacijske jalovine kroz betonsku oblogu tunela**	**Prodor flotacijske jalovine kroz pećinu**
1.Probištip	1. Kriva Feja – Besna Kobila	1. Rudnica – Leposavić	1. Šaški Potok Majdanpek	1. Sasa - Makedonska Kamenica	1. Valja Fundata Majdanpek
	2. Trepča	2. Rudnik – Rudnik	2. Kišnica – Priština		
	3. Leposavić				
	4. Probištip				
	5. Toranica – Kriva Palanka				
	6. Staro Borsko jalovište				
	7 .Jalovište V. Krivelj				
	8. Sasa- Makedonska Kamenica				
	9. Bučim – Radoviš Makedonija				

Kod nas i u svetu, dogodile su se havarije flotacijskih odlagališta sa vrlo velikim posledicama po životnu sredinu u području rudnika i u slivovima reka. Poznata je ugroženost sliva reke Timoka iz Borskog flotacijskog odlagališta preko Borske reke, reke Peka i Šaške iz flotacijskih odlagališta u Majdanpeku, zatim Kriveljske reke iz flotacijskog odlagališta u Velikom Krivelju. Slične ekološke katastrofe su nastajale i kod susednih zemalja (Mađarske, Rumunije, Bugarske, Makedonije).

5. IZVORI NASTAJANJA HAVARIJA NA FLOTACIJSKIM ODLAGALIŠTIMA

Analizom je utvrđeno da nastanak havarija na flotacijskim jalovištima najčešće je usled: tehničkih nedostataka (propusta) i prirodnih katastrofa. Često ova dva uslova se kombinuju i tada štete od nastalih udesa su većih razmera.

Pojava havarija na flotacijskim odlagalištima izazvanim **tehničkim nedostacima** su:

1. Neadekvatna projektna rešenja (loša procena),
2. Nepoštovanja projektnih rešenja (nepouzdana gradnja: brana, kolektora ispod jalovišta i brana, drenažnih sistema i prelivnog organa),
3. Odsustva kontrole i ne poštovanja propisa,

Izvori havarija na flotacijskim odlagalištima izazvanim **prirodniim katastrofama** (nepogodama) mogu biti usled:

1. Klizanja podloga, odnosno promene fizičkih i geoloških procesa koji dovode do klizanja obala u akumulacioni prostor i stvaranja poplavnog

talasa koji može ugroziti branu i dovesti do njenog rušenja, takođe dovodi do zatrpavanja prelivnog organa,
2. Pojava pukotina i kaverni u kraškom terenu,
3. Dugotrajnih kiša i naglog otapanja snega u vidu velikih voda koje dovode do erozije brana i obodnih nasipa jalovišta,
4. Zemljotresi (tektonski, vulkanski, urvinski i veštački usled miniranja),
5. Vetrovi orkanske jačine koji izazivaju peščane oluje i eroziju brane - premeštanje ciklonskog peska sa brana u okolinu i
6. Ratnih dejstva na prostoru flotacijskih odlagališta, koja bombardovanjem dovode do oštećenje kolektora i flotaciskih brana.

5.1. Neadekvatna projektna rešenja

Najčešći vid neadekvatnih projektnih rešenja su:

- loše procene pri izboru i pripremi lokacije za gradnju brana i flotacijskog jalovišta,
- loše određivanje dozvoljenih napona za betonsku konstrukciju kolektora i prelivnog organa,
- greška u dimenzionisanju kolektora i izboru oblika
- izbor vrste i količine cementa za spravljanje betona,
- način spravljanja i ugrađivanja betona i
- kvalitet primenjene armature (kompaktna i homogena struktura).

Zbog velike cene izgradnje obloge kolektora od kiselo otpornog betona po m', pribegava se uštedi u materijalu primenom portland cementa za spravljanje betona, umesto cementa otpornog na hemijske uticaje, takozvani "pucolan" za gradnju obloge kolektora otpornog na agresivne vode iz flotacijskog odlagališta.

Primer kako može doći do greške u dimenzionisanju ili nepouzdanosti gradnje kolektora je kolektor ispod Polja 2 i brane 3A u Velikom Krivelju. Prema projektnom rešenju, visina brane iznad kolektora trebala je da iznosi 100 m, a već pri dostizanju visine od 56 metara pojavile su se pukotine na oblozi kolektora. Da bi se dostigla visina brane od 100m unutar kolektora je ugrađena dodatna obloga debljine 40 cm. Drugi primer havarija na kolektoru i tunelu usled agresivnog dejstva kisele sredine dogodio se u rudniku bakra Bučim i olovo-cinkanom rudniku Sasa u Makedoniji.

5.2. Nepoštovanje projektnih rešenja

Verovatnoća pojave havarije pri normalnim uslovima rada sitema na flotacijskim odlagalištima i ugrožavanje životne sredine može nastati usled nepoštovanja projektnih rešenja, odnosno odstupanja radnih parametara od projektovanih pri čemu dolazi do:

1. Kvarova na hidrauličnom i gravitacionom transportu pulpe (pucanja cevi i pojave pukotina na betonskim kanalima, zapušenja i prelivi).
2. Pojave kvarova na drenažnom sistemu na brani (odsustva poroznog drenirajućeg sloja iznad kolektora ili smanjenja poroznosti usled sabijanja),
3. Kvarova na sistemu za povratnu vodu iz taložnog jezera (plovećoj pumpnoj stanici),
4. Nefunkcionisanja prelivnog (ispusnog) organa,
5. Pojave pukotina i oštećenja na kolektoru ispod jalovišta ili njegovog rušenja celom dužinom ili samo na pojedinim delovima zbog uštede u materijalu i nesolidne gradnje i dejstva hemijske erozije i
6. Nefunkcionisanja sistema za orošavanje suvih površina brana.

U zavisnosti od ispoljavanja potencijalne opasnosti od nepoštovanja tehničkih uslova i verovatnoće da do pojave havarije pri normalnim uslovima rada na flotacijskim odlagalištima dođe, ugrađuju se sistemi za otkrivanje opasnosti radi sprečavanja havarija. Verovatnoća efikasnosti sistema za otkrivanje opasnosti i suzbijanja havarija je u vezi sa pouzdanošću predviđenog sistema i primenjenog načina primene sistema u otklanjanju havarija.

Na flotacijskim odlagalištima zbog prirode poslova, sistemi za otkrivanje ispoljavanja potencijalne opasnosti i otklanjanje havarija su kombinovani. Sastoje se od ugrađenih uređaja na brani (piezometri) koji služe za merenje vode unutar brane i flotacijskog odlagališta (pokazuju položaj linije provirnih voda, koje utiču na stabilnost brane) i postupaka zaposlenih radnika određenih za otkrivanje pojava opasnosti na odlagalištu (kontrolu ispoljavanja opasnosti vrše svojim čulima). Ovakav vid zaštite od nastajanja havarija, koji uglavnom zavisi od ljudskog faktora ne može biti visok. Veličina verovatnoće sigurnosti od nastajanja havarija primenom kombinovanog sistema za otkrivanje i spre-čavanje havarija se kreće od 0,2 do 0,8. Verovatnoća efikasnosti (sigurnosti) ovakvog načina otkrivanja opasnosti i suzbijanja nezgoda bliža je nuli, a opasnost od nastanka havarije bliža jedinici. Efikasnost sistema za otkrivanje opasnosti je u zavisnosti od verovatnoće **apriori**:

Odsustva kontrole i nepoštovanja propisa

Havarije izazvane tehničkim nedostacima (ljudskim faktorom) u normalnim (projektovanim) uslovima rada na flotacijskimodlagalištima, smatraju se kao havarije grešaka ili havarije usled odsustva kontrole i ne poštovanja propisa. One nastaju zbog nepoštovanja tehnologije odlaganja flotacijske jalovine predviđene projektom, nepažljivog rada i upravljanja nivoom vode taložnog jezera unutar jalovišta, nepravilnog dimenzionisanja ili nepozdanosti gradnje kolektora (primenom betona neotpornog na kiselu sredinu) ispod polja i brane jalovišta i sistema odlaganja u celini.

Veličina štete na ekosistemima i ekološkim faktorima životne sredine izazvane odsustvom kontrole i nepoštovanja propisa

Veličina štete na ekosistemima i ekološkim faktorima životne sredine izazvane odsustvom kontrole i nepoštovanjem propisa zavise od: veličine havarije (udesa), veličine odlagališnog prostora (zapremine), vrste odlaganog materijala, agregatnog stanja štetnih materija, količine štetnih materija koje mogu dospeti u životnoj sredini, pravca i dometa štetnih materija i osetljivosti eko sistema na štetne materije iz flotacijskih jalovišta.

Oštećenje okosistema prodorom flotacijske jalovine može biti lokalnog, regionalnog i međunarodnog karaktera. Lokalna i regionalna oštećenja ekosistema su mala u prostoru i vremenu (prodor flotacijske jalovine u Šašku reku i Pek na području Majdanpeka). Međunarodna oštećenja ekosistema su velika u prostoru, a mala u vremenu (prodor flotacijske jalovine i cijanida iz rudnika Baja Mare u Rumuniji u reku Tisu, Dunav sve do Crnog Mora). I lokalna i međunarodna oštećenja ekosistema posle nastajanja vremenom se smanjuju jer se štetne materije razgrađuju ili se oštećene površine raščišćavaju, a zatim rekultiviraju što dovodi do regeneracije ekosistema.

Verovatnoća ekoloških katastrofa usled havarija (udesa) grešaka na lokalnom ili međunarodnom nivou se određuje na osnovu odnosa ukupnih i mogućih površina na ugroženom području, vremena trajanja ugrožavanja i prisustva osetljivih članova ekološkog sistema na ispoljavanje povećanje koncentracije štetnosti u okolinu.

6. AGRESIVNO DEJSTVO VODE IZ FLOTACIJSKOG JALOVIŠTA NA BETONSKU OBLOGU KOLEKTORA I TUNELA

Flotacijsko odlagalište sa svojim pratećim objektima kao što su: peščani nasip, akumulacioni prostor, drenaže, tuneli i kolektori, predstavlja specifičan rudarski objekat. Hidrohemijski procesi kako u samoj akumulaciji, tako i peščanim nasipima su prisutni i veoma složeni. Tome doprinosi usitnjenost minerala sadržanih u flotacijskoj jalovini, zatim prisustvo vode, vazduha, temperature i pritiska. Pojedini procesi imaju štetno dejstvo na betonske obloge od kojih su izgrađeni prateći objekti.

Hemijski zagađene vode na flotacijskim odlagalištima agresivno deluju na betonsku oblogu kolektora. Ta agresivnost se ogleda u sposobnosti hemijski zagađene vode da izoluje iz betona sastavne delove, odnosno da uz pomoć rastvorenih soli i gasova ruši beton. Vezivni sastojak betona je cement, koji u prvom redu predstavlja smešu silikata kalcijuma. Kvalitet cementa se određuje hidrauličkim modelom koji predstavlja odnos bazne komponente CaO prema kiselijim:

$-SiO_2$, Al_2O_3, Fe_2O_3

$$\left(-\frac{\%CaO}{\%(SiO_2 + Al_2O_3 + Fe_2O_3)} \geq 2\right) \quad ....(1)$$

Agresivnost vode u flotacijskom jalovištu na betonski kolektor se ispoljava na nekoliko načina u zavisnosti od hemijskog sastava vode:

1. agresivnost ugljene kiseline, agresivnost izlučivanja kreča, kiselinska agresivnost:

Ugljokiselinska aktivnost sastoji se u rastvaranju $CaCO_3$ pod dejstvom agresivne ugljene kiseline po formuli:

$$CaCO_3 + H_2CO_3 \leftrightarrow CO^{++} + 2HCO_3^{+} \quad (2)$$

Agresivnost izlučivanja teče na račun rastvaranja $CaCO_3$ i izdvajanja $Ca(OH)_2$ iz betona.

Opšta kiselinska agresivnost je vezana za sadržaj slobodnih jona vodonika. Voda je agresivnija ako je pH = 5 ÷ 6,8.

2. Sulfatna i magnezijumova agresivnost:

Sulfatna i magnezijska agresivnost prisutna je kod voda koje imaju visok sadržaj jona SO_4^{--} Pri prolasku vode kroz beton dolazi do kristalizacije i obrazovanja soli $CaSO_4\,2H_2O$, koje ruše beton.

Magnezijska agresivnost, se pojavljuje pri visokom sadržaju jona Mg^{+++} i u vezi je sa sadržajem $SO_4^{--} \geq +50$ mg/l. Sve ove vrste agresivnosti su prisutne u manjoj ili većoj meri na svim flotacijskim jalovištima kod nas.

Redovna pojava je **sulfatno razgrađivanje** betona naime prelaz iz bazne u kiselu vodu u donjim slojevima odloženog mulja na flotacijskim jalovištima je posledica oksidacije pirita FeS_2 i drugih sulfidnih minerala. Pri dejstvu kiseonika i kontaktu sa vlagom, sulfidi reaguju u smislu stvaranja sumporne kiseline H_2SO_4 i ferosulfata $FeSO_4$. Fero sulfat se dalje oksidiše do trovalentnog feri sulfata, koji potom hidrolizira dok se ne stvori kiseliji. Sledeći pojednostavljenim jednačinama ilustruje se mehanizam piritne oksidacije.

$$2FeS_2+7O_2+H_2O \rightarrow 2FeSO_4+2H_2SO_4 \quad .. (3)$$

Proces je u tesnoj vezi sa vremenskim uslovima, količinom pirita, stepenom njegove usitnjenosti i kvalitetom izrade betonske obloge sulfatno razgrađivanje je efikasnije u delu gde je ugrađen "posan beton". Naime usled segregacije šljunka na pojedinim delovima obloge stvaraju se uslovi za brže reagovanje kiselih voda te i iznošenje komponente betona.

Sadržaj jona SO_4^{--} u vodama flotacijskog jalovišta u Majdanpeku prema istraživanjima je sledeći:

lokalitet istraživanja	SO_4^{--}	pH vrednost
• Drenažna voda	534 mg/l	6-7,8
• Jezerska voda	368 mg/l	11,4-11,8
• Voda koja ističe kroz oblogu kolektora	317 mg/l	6-8,28

Na jalovištima olovo cinkanih rudnika bivše Jugoslavije joni SO_4 se kreću iznad 1000 mg/l, a pH vrednost od 4,5-9,5.

7. ZAKLJUČAK

Uzroci nastajanja havarija na flotacijskim jalovištima su tehnički nedostaci i prirodne katastrofalne nepogode. Mere koje treba preduzeti u borbi protiv tehničkog nedostatka je izrada kolektora ispod flotacijskih jalovišta od kiselootpornog betona ili primena plastičnih cevovoda. Nažalost na prostorima bivše Jugoslavije, svi tuneli i kolektori za devijaciju reka ispod flotacijskih odlagališta izgrađeni su od betona neotpornog na kiselu sredinu. Zbog toga su svi tuneli i kolektori pretrpeli manja ili veća oštećenja usled sulfatnog razgrađivanja betona. Pri izgradnji flotacijskih odlagališta (jalovišta) treba sprovesti da havarije grešaka budu minimalne pooštravanjem kontrole i predviđenih propisa.

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CAUSES OF ACCIDENTS ON THE FLOTATION TAILING DUMPS IN SERBIA**

Abstract

Flotation tailing dumps from the aspect of technology are necessary mining facility, and in terms of environmental present a real threat to the ecological environmental factors that are either in operation or the process of disposal is completed. In Serbia and in the world, numerous accidents occurred on the flotation tailing dumps due to the accidents. Occurrences of accidents deserve to be the subject of research in order to identify the mechanism of their formation, extent and scope of threats to the environment in order to trigger the requirements for design and installation of security systems, whose reliability should be greater than total probability of danger. All types of systems for prevention, detection and alarming shave their price of procurement, installation and use, which is generally proportional to the probability of reliability and operational safety. In this way, a functional link is established between the cost of installing the security and probability system on occurrence the accidents. This paper gives the causes of accidents classified by the cause of formation.

Keywords: *flotation tailing dump, accident, environment*

1. INTRODUCTION

Flotation tailing dumps are natural or artificially dammed spaces for accumulation of hydro mixtures (ground material and chemically contaminated water). By construction, the flotation tailing dumps are classified as: hilly - valleys, plains, deep, deep and combined type. Hilly (valley) and plain type have essentially the same design characteristics and a similar way of construction. In these types of landfills, the primary dams are built (initial or starting), with the height which depends on the volume of accumulation space and dam construction methods. Flotation tailing dumps are usually located near the flotation plants and they are built

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according to the terrain topography. Formation of flotation tailing dumps can be done in the valleys of the rivers and streams, on the flat terrain and in natural depressions and excavated areas of the open pit. The space of flotation tailing dumps is used for: disposal of flotation tailings, full clarification of water, and accumulation of industrial water, needed in the process of flotation concentration.

Flotation tailing dumps are important facilities in the process of mining production. Safety of flotation tailing dumps is not only for the process of mining production and construction, but also it is applied to the safety of people living downstream of the tailing dumps and environment [1].

A potential breakthrough of a dam and spills of tailings is disastrous where the flood wave of high-energy is formed moving downstream. [2].

2. CRITERIA FOR SELECTION OF A SITE OF FLOTATION TAILING DUMPS

There are criteria for formation the flotation tailing dumps that influence the selection of a site and they are of economic, technical, technological and environmental nature.

Economic criterion implies that there is no reserve of valuable mineral resources, cultural, archeological monuments and monuments of nature, and that a distance from the site of flotation tailing dump to the flotation plant is minimum.

Technical criteria include topographic, hydrologic and geologic characteristics of the terrain.

Capacity of landfill, transport way of flotation tailings and possibility of use the feedback water are important for **technological criterion.**

Ecological criterion means that there is no threatening the habitats of rare plants and animal species, surface water, groundwater and soil, upstream and downstream of tailing dumps.

3. THE LARGEST FLOTATION TAILING DUMPS IN EUROPE AND SERBIA

Table 1 gives the locations of the largest flotation tailing dumps in Europe.

Table 1. *The largest flotation tailing dumps in Europe and Serbia*

Country	Place	Amount of tailings, m^3	Surface of tailing dump, m^2
Germany	Culmitzsch	90 000 000.00	2 280 000.00
	Helmsdorf	50 000 000.00	2 500 000.00
	Trunzig	19 000 000.00	1 080 000.00
France	Escapiere	12 000 000.00	820 000.00
Hungary	Pecs	16 000 000.00	1 540 000.00
Bulgaria	Elesnitza	8 000 000.00	500 000.00
	Buhovo	11 000 000.00	700 000.00
Czech Republic	Straz	33 000 000.00	1 360 000.00
	Rozna	15 000 000.00	400 000.00
	Mydlovary	15 000 000.00	2 600 000.00
Estonia	Sillamae	8 000 000.00	330 000.00
Serbia	Bor (Tailing dump Bor)	12 436 160.00	600 000.00
	Bor(RT-H)	17 903 019.00	500 000.00
	Krivelj Polje 1	94 000 000.00	810 000.00
	Krivelj Polje 2	89 000 000.00	1 270 000.00
	Majdanpek	187 879 000.00	

"The World Register of Mine and Industrial Tailings Dams" specifies the eight flotation dams higher than 150 m, 22 higher than 100 m and 115 higher than 50 m. It is known for the six closed that they have the surface area higher than 100 km^2, with volumes over 50 000 000 m^3 [3].

3.1. Accidents on the flotation tailing dumps in the world

The known disastrous events concerning the spills of flotation tailings and water, which threatened the environment in the world, are:

1. The former CSSR,
2. Chile (1967, killed more than 200 people),
3. USA,
4. Germany (Saxony, in the sixties, 250 000 t of tailings spilled in the river bed),
5. Romania (Baia Mare 30 January 2000, the rivers Mura, Tisza and Danube poisoned with cyanide),
6. Macedonia.

The biggest freshwater ecological disaster affected the countries in the basin of the Danube in the length of 2000 km when on 30 January 2000, the breakthrough of dam occurred at the sediment lakes for tailings in the factory plants and gold mine Aurul SA Company, in Baia Mare in the north-west of Romania.

On that occasion, about 100 000 m^3 of disposed tailings spilled containing between 50 and 100 tons of cyanide as well as heavy metals, including copper.

Breaking of the dam occurred by a combination of failures incurred in the construction of dam and adverse weather conditions due to the rapid melting of snow. Toxic flood wave traveled down the rivers Lapos, Samos, Tisza and Danube about four weeks before it came to the Black Sea.

Over the past year, there have been three breakthroughs of dams that caused the disasters in the Republic of Macedonia. All have caused the significant damages to air, water and soil. Such accidents have occurred in the lead and zinc mine in Zletovo in Probištip, the copper mine Bučim and copper mine and the last one in the lead and zinc mine Sasa (September 2003) [4].

Breaking of the flotation dam in Sasa made a crater of 120-160 m at depth of 30-40 m. After the disaster over 1 000 000 tons of tailings with heavy metals spilled into the River Kamenica, and further into Kalimanci lake, river Bregalnica and surrounding area [4].

4. CAUSES OF ACCIDENTS ON THE FLOTATION TAILING DUMPS

Accidents or incidents on the flotation tailing dumps are caused by natural disasters, technical failures, and the combination of both. On this occasion they result into ocurrence of dangerous threats to the environment where they pollute the water, soil, plants, destroy the habitat of animals and flood the houses of people. In order to forecast the volume of individual incidents, it is necessary to assess the probability of accidents and damage on the site immediately in design of flotation tailing dumps. It is done on the basis of mathematical statistics and correlation with events on similar tailing dumps using the theorems of probability theory and reliability of flotation landfills at work in the conditions of action the technical-technological defects and natural disasters (atmospheric precipitation, floods, storms, earthquakes) and war activities.

It was concluded by research that the most common causes of accidents in our country and former Yugoslavia were caused by the conditions of technical deficiencies and disrespectance the design solutions. Of the sixteen recorded accidents on tailing dumps in the former Yugoslavia, the nine cases relate to a damage of concrete lining of collector

and flotation tailings penetration through the **concrete** lining of collector (not resistant to the acidic environment). One case relates to a **damage** of tunnel lining and one case through a concrete pipe for water, while two cases relate to the overflow of storm water flood wave through deposited tailings in the tailing dump and dam, two cases of water spilling under the dam body and one case through the "chimney" of the karst terrain and cave. The recorded examples of breakthroughs are given in Table 2.

Accidents are caused by simultaneous occurrence of hazardous conditions, caused by technical defects and natural phenomena on landfills that are the subject for breaking the flotation slime and its outflow in the form of flood into the basin areas.

Hazardous conditions can lead to sudden slippage of surface and failures on drainage system and overflow body on flotation tailing dumps, appearance of cracks on collector due to the pressure of sedimented tailings, deterioration of collector lining due to the effects of acidic environment and destabilization the entire system of tailing dump.

Table 2. *The known causes of accidents until now in our country and in the former Yugoslavia*

Breakthrough of flotation tailings through a concrete lining of pipe water	**Breakthrough of flotation tailings through a collector lining**	**Leaking of flotation tailings and water under dam body**	**Overflow the flood wave of atmospheric water over dam**	**Breakthrough of flotation tailings through a concrete lining of tunnel**	**Breakthrough of flotation tailings through a cave**
1. Probištip	1. Kriva Feja – Besna Kobila	1. Rudnica – Leposavić	1. Šaški Potok Majdanpek	1. Sasa - Makedonska Kamenica	1. Valja Fundata Majdanpek
	2. Trepča	2. Rudnik – Rudnik	2. Kišnica – Priština		
	3. Leposavić				
	4. Probištip				
	5. Toranica – Kriva Palanka				
	6. Staro Borsko jalovište				
	7 .Jalovište V. Krivelj				
	8. Sasa- Makedonska Kamenica				
	9. Bučim – Radoviš Makedonija				

There have been accidents of flotation tailing dumps in our country and in the world with very large consequences for the environment in the mine area and river basins. It is known a threat to the Timok River Basin from the Bor flotation tailing dump through the Bor River, river Pek and Saska River and the flotation tailing dumps in Majdanpek, then the Krivelj River from the flotation tailing dump in Veliki Krivelj. Similar environmental disasters were also created in the neighboring countries (Hungary, Romania, Bulgaria, Macedonia).

5. SOURCES OF ACCIDENTS ON THE FLOTATION TAILING DUMPS

Analysis determined that the occurrence of accidents on the flotation tailing dumps is usually due to the: technical problems (failures) and natural disasters. Often these two conditions are combined and then the damages, caused lby accidents, are large-scale.

The appearance of accidents on tailing dumps, caused by **technical deficiencies**, is:

1. Inadequate design solutions (bad assessment)
2. Failure to comply with design solutions (unreliable construction of: dams, collectors below the tailing dumps and dams, drainage systems and overflow body),
3. Lack of control and breaching the rules.

Sources of accidents on tailing dumps, caused by **natural disasters**, may be due to:

1. Sliping of surfaces, i.e. a change of physical and geological processes that lead to sliping of coasts into the accumulation space and creation of flood wave that could endanger a dam and lead to its demolition, also leading to backfilling of overflow body,
2. Appearance of cracks and caverns in the karst terrain,
3. Long rains and rapid melting of snow in the form of floods which lead to the erosion of dams and peripheral dikes of tailing dumps,
4. Earthquakes (tectonic, volcanic, and artificial due to blasting),
5. Hurricane force winds causing dust storms and erosion of the dam - moving cyclone sand from dams in the environment, and
6. Effects of war actions on the territory of flotation tailing dumps, which leads to a damage of collector and flotation dams by bombing.

5.1. Inadequate design solutions

The most common form of inadequate design solutions are:

- inadequate assessments in the selection and preparation of location for construction of dams and flotation tailing dumps,
- bad determining the allowable stresses for concrete construction of collector and overflow body,
- error in the collector sizing and selection of forms,
- selection of the type and quantity of cement for concrete making,
- method of preparation and insertion of concrete, and
- quality of applied fitting (compact and homogeneous structure).

Due to the high cost of construction the collector lining of acid resistant concrete per m', it is resorted to savings in materials using the portland cement for concrete making instead of cement resistant to the chemical impacts, called "pozzolan" for building the collector lining resistant to aggressive water from the flotation tailing dump.

An example of how error can occur in sizing or unreliability of collector building is a collector below the Field 2 and dam 3A in Veliki Krivelj. According to the design solution, the height of dam above the collector is supposed to be 100 m, but on reaching the height of 56 m, the cracks appeared in the lining of collector. To reach the dam height of 100 m within the collector, an additional coating thickness of 40 cm was built. Another example of accident on collector and tunnel, due to the aggressive effect of acidic medium, occurred in the copper mine Bučim and lead-zinc mine Sasa in Macedonia.

5.2. Failure to comply with design solutions

Probability of occurrence the accident under normal operation conditions on the flotation tailing dumps and endangering the environment can result due to the failure to comply with design solutions, i.e. deviations from designed operating parameters, which cause:

1. Breakdowns in hydraulic and gravitational transport of pulp

(cracking of pipes and appearance cracks in concrete channels, clogging and overflows),

2. Occurrence of breakdowns in drainage system at the dam (the absence of a porous drainage layer over the collector or porosity reduction due to compaction),
3. System failures to return water from settling lake (floating pump station),
4. Dysfunction the overflow (discharge) body,
5. Appearance of cracks and damages on collectoe below the tailing dump and its collapse along the entire length or only in the certain parts due to the savings in material and non-solid construction and effects of chemical erosion, and
6. Dysfunctional spraying system for dry surfaces of dams.

Depending on the expression of potential risks of failure to comply the technical requirements and probability of accident occurrence in normal operation conditions on the flotation tailing dumps, the systems are installed to detect hazards to prevent accidents. Probability of the system efficiency for detection the hazards and disaster prevention is connected to the reliability of predicted system and applied method of system use in the elimination of accidents.

On tailing dumps, due to the nature of work, the systems for detecting a potential hazard and elimination the accident are combined. They consist of installed devices at dam (piezometers) that are used for water measurement inside dam and flotation tailing dumps (indicating the lines of protruding water that affect the dam stability) and actions of responsible employees for detection the occurrences of hazards at the landfill (control of danger manifesting is done by their senses). This kind of protection from accidents, which mainly depends on the human factor, can be high. A size of safety probability on accidents using the combined system for detecting and preventing the accidents ranges from 0.2 to 0.8. Probability of efficiency (safety) of this type of hazard detection and prevention of accidents is closer to zero, and the risk of accidents is close to one. The efficiency of the system to detect the danger depends on the **priori** probabily:

Absence of control and non-compliance the rules

Damages caused by technical deficiencies (human factor) in normal (designed) conditions of operation the flotation tailing dumps, are considered as the accidents of errors or accidents due to the absence of control and non-compliance the rules. Those resulting from non-compliance the technology of disposal the flotation tailings, proposed by the design, careless operation and management of water level in the sedimentary lake inside the tailing dump, improper sizing or unreliable construction of collector (using the resistless concrete to acidic media) below the field and dam of tailing dump and disposal system as a whole.

Size of damage to ecosystems and ecological factors of the environment caused by the absence of control and non-compliance the rules

Size of damage to ecosystems and ecological factors of the environment, caused by the absence of control and non-compliance the rules depend on: the size of accident, size of landfill space (volume), type of delayed material, aggregate state of harmful substances, amount of harmful substances that may enter the environment, direction and range of harmful substances and sensitivity of ecosystem to harmful substances from the flotation tailing dumps.

Damage to ecosystems by breakthrough of flotation tailing can be of local,

regional or international character. Local and regional damages of ecosystem are small in space and time (breakthrough of flotation tailings into the Saska River and Pek in Majdanpek). International damages of ecosystem are large in space and small in time (penetration the flotation tailings and cyanide s from the mine Baia Mare in Romania in the river Tisza, the Danube to the Black Sea). Both local and international damages to ecosystem after the formation decreased with time due to degradation of harmful substances or damaged areasare cleared, and then remediated what leading to the regeneration of ecosystem.

Probabailityof environmental disasters due to the accident errors at the local or international level is determined on the basis of the ratio of total and potential surfaces at the endangered area, duration of endangerous and presence the sensitive members of the environment system on the expression of increasing the concentrations of harmful effects to the environment.

6. AGGRESSIVE EFFECT OF WATER FROM THE FLOTATION TAILING DUMP ON CONCRETE LINING OF COLLECTOR AND TUNNEL

Tailing dump with its supporting facilities such as: sand dike, accumulation space, drainage, tunnels and collectors, is a specific mining facility. Hydrochemical processes, both in the accumulation itself and sand dikes, are present and very complex. This is helped by the fragmentation of minerals, contained in the flotation tailings, then the presence of water, air, temperature and pressure. Some processes have a harmful effect on the concrete lining of which the supporting facilities are built.

Chemically contaminated water at the flotation tailing dumps, act aggressively on concrete lining of collector. This aggressiveness is reflected in the ability of chemically contaminated water to isolate the components of concrete, or with the help of dissolved salts and gases destroy the concrete. Bonding ingredient of concrete is cement, which primarily represents the mixture of calcium silicates. The quality of cement is determined by the hydraulic model that represents the ratio of base component CaO to acidic ones:

$-SiO_2$, Al_2O_3, Fe_2O_3

$$\left(-\frac{\%CaO}{\%(SiO_2 + Al_2O_3 + Fe_2O_3)} \geq 2\right) \quad (1)$$

Aggressiveness of water in the flotation tailing dump on concrete collector is manifested in several ways, depending on the chemical composition of water:

1. Aggressiveness of carbonic acid, aggressiveness of lime leaching, acid aggressiveness:

Carbonic acid activity consists in dissolution $CaCO_3$ under the influence of aggressive carbonic acid by the formula:

$$CaCO_3 + H_2CO_3 \leftrightarrow CO^{++} + 2HCO_3^{+} \quad (2)$$

Aggressiveness of leaching flows at the expense of $CaCO_3$ dissolution and separation of $Ca(OH)_2$ iz from concrete.

General acid aggressiveness is related to the content of free hydrogen ions. Water is more aggressive if pH = 5 ÷ 6,8.

2. Sulphate and magnesium aggressiveness:

Sulphate and magnesium aggressiveness is present in water with igh content of SO_4^{--} ions. In the water passage through concrete, the salt crystallization and formation of $CaSO_4$ $2H_2O$ salt is developed, which demolish the concrete.

Magnesium aggressiveness appears at high content of Mg^{+++} ion and it is associated with the content of $SO_4^{--} \geq +50$ mg/l. All these types of aggressiveness are present in a greater or lesser extent in all flotation tailing dumps in our country.

The regular appearance is the **sulfate degradation** of concrete, namely the transition from base into acid water in the

lower layers of deposited slime on the flotation tailing dumps is the result of pyrite oxidation FeS_2 and other sulphide minerals. At the effect of oxygen and in contact with moisture, sulfides react in terms of creating the sulfuric acid H_2SO_4 and ferrous sulfate $FeSO_4$. Ferrous sulfate is further oxidized to the trivalent ferric sulfate, which is then hydrolyzed until it becomes more acidic. The following simplified equations illustrate the mechanism of pyrite oxidation.

$$2FeS_2+7O_2+H_2O \rightarrow 2FeSO_4+2H_2SO_4 \quad ...(3)$$

The process is closely related to the weather conditions, amount of pyrite, degree of its fragmentation, and quality concrete lining construction. Sulphate degradation is more effective in a part where the "fast concrete" is built. Namely, due to segregation of gravel in some parts of the lining, the conditions for faster reaction of acid water are created and out of concrete components.

Content SO_4^{--} ions in the water of the flotation tailing dump in Majdanpek is, according to the research, the following:

Research site	**SO_4^{--}**	**pH value**
1.Drainage water	534 mg/l	6-7.8
2.Lake water	368 mg/l	11.4-11.8
3.Spilling water through collector lining	317 mg/l	6-8.28

On the tailing dumps of the lead zinc mines of the former Yugoslavia, SO_4 ions move above 1000 mg/l, and pH value of 4.5 to 9.5.

CONCLUSION

Causes of accidents in the flotation tailing dumps are technical defects and natural catastrophic ndisasters. Measures to be taken to combat the technical absencence are construction a collector of acid resistant concrete or the use of plastic pipelines below the flotation tailing dumps. Unfortunately, in the former Yugoslavia, all tunnels and collectors for deviation of rivers below the flotation tailing dumps were built of concrete not resistant to acidic media. Therefore, all tunnels and collectors suffered minor or major damages due to sulfate degradation of concrete. In building the flotation landfills (tailing dumps), the measures have to be applied that the accident errors would be minimum by tightening the controls and anticipated regulations.

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PRIMENA SOFTVERSKOG PAKETA WHITTLE ZA ODREĐIVANJE EKSPLOATACIONIH REZERVI LEŽIŠTA BAKRA SEVERNI REVIR – MAJDANPEK, SRBIJA

Izvod

Ležište bakra Severni revir nalazi se neposredno uz grad Majdanpek. Ukupne geološke rezerve bakra, u konturi graničnog sadržaja 0,10 %, iznose 193.983.489 t.

Svetske rudarske kompanije kod procene finansijske održivosti i definisanja optimalne strategije za razvoj rudnika u cilju racionalnog i ekonomičnog iskorišćenja ležišta mineralnih sirovina, koriste neke od softvera za optimizaciju i projektovanje, a među vodećim je i Whittle, koga poseduje Institut za rudarstvo i metalurgiju Bor.

U radu je prikazan način definisanja eksploatacionih rezervi ležišta bakra Severni revir primenom softvera Whittle, čime se postiže optimalno iskorišćenje ležišta, što je nužan preduslov odgovornog upravljanja mineralnim sirovinama.

***Ključne reči**: Whittle, ležište bakra Severni revir, eksploatacione rezerve*

UVOD

Prirodna rudna bogatstva jedne zemlje predstavljaju osnovu njenog ekonomskog i društvenog prosperiteta. Po ekonomskoj vrednosti rudnih bogatstava kojim raspolaže, Srbija ne pripada bogatim zemljama. Zato postoji obaveza da se rudarska delatnost obavlja po principima racionalnog upravljanja mineralnim resursima.

Ležište bakra Severni revir [1, 3] nalazi se neposredno uz grad Majdanpek i sastoji ce od četiri rudna tela: Centralno rudno telo, Dolovi 1, Dolovi 2, i rudno telo Stari Dušan. Ukupne geološke rezerve bakra, u konturi graničnog sadržaja 0,10 %, iznose 193.983.489 t. Po značaju, ovo ležište ima veliku ulogu u proizvodnji bakra u kompaniji RTB Bor, u koju su sada uključeni i Rudnik bakra Veliki Krivelj i Jama Bor. Pored ovih ležišta, od izuzetnog značaja je ikompleks ležišta Cerovo, na kome se u ovoj godini planira nastavak radova na eksploataciji rude bakra, koja je prekinuta 2003. godine [3].

S obzirom da ležište bakra Severni revir pripada ležištima sa niskim sadržajem metala u rudi koji u ukupnim geološkim rezervama iznosi 0,298 %, to je primena savremenog softverskog alata za strateško planiranje i optimizaciju ležišta Whittle [2, 4, 5] od izuzetnog značaja za racionalno iskorišćenje ležišta i postizanje maksimalnog profita u eksploataciji.

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RUDNE REZERVE LEŽIŠTA

Proračun rudnih rezervi u ležištu bakra Severni revir, urađen je primenom računarskog softvera Gemcom [2, 4, 5, 8, 9], pri čemu je primenjena metoda mini blokova, koja je potvrđena u fazi eksploatacije ležišta.

U slučaju ležišta bakra Severni revir i sličnih ležišta, sa velikim brojem podataka koji se koriste za proračun rezervi, neosporna je prednost proračuna rezervi korišćenjem računarske tehnike, u odnosu na proračun drugim metodama:

- Zbog veličine ležišta, stanja budućeg površinskog kopa i kapaciteta proizvodnje (velike količine iskopina), jako su složena projektovanja i izmene projekata sa optimalnim radnim i završnim konturama površinskog kopa, a digitalni model, sa proračunatim rezervama po mini-blokovima, olakšava i ubrzava taj proces, jer je moguće u kratkom vremenskom periodu sagledati veliki broj varijanti i iznaći najbolja rešenja
- Rezultati koji su dobijeni projektovanjem i ekonomskim sagledavanjem, na bazi formiranog blok-modela ležišta i proračuna rezervi ovom metodom, na ležištima bakra porfirskog tipa, zadovoljavajućeg su kvaliteta, odnosno u svetu su prihvaćeni kao zadovoljavajući
- Potencijalni koncesionari zahtevaju da ležište bude prikazano u digitalnom obliku.

U tabelama 1 i 2 prikazane su geološke, a u tabelama 3 i 4 i bilansne rezerve ležišta bakra Severni revir određene u program Gemcom 6.2 [1].

Tabela 1. *Geološke rezerve ležišta bakra Severni revir – Centralno rudno telo, Dolovi 1, Dolovi 2, i rudno telo Stari Dušan*

Rudno telo	Kategorija rezervi	Količina rude (t)	Srednji sadržaj Cu (%)	Količina Cu (t)	Srednji sadržaj Au (g/t)	Količina Au (kg)	Srednji sadržaj Ag (g/t)	Količina Ag (kg)	Srednji sadržaj S (%)	Količina S (t)
A	B	C	D	E	F	G	H	I	J	K
Centralno rudno telo	B	63.574.104	0,307	195.392	0,234	14.864	1,796	114.199	2,330	1.480.999
	C_1	84.086.776	0,323	271.616	0,266	22.341	1,755	147.608	2,871	2.414.432
	$B+C_1$	147.660.880	0,316	467.007	0,252	37.205	1,773	261.807	2,638	3.895.432
Dolovi 1	B	27.388.741	0,199	54.551	0,132	3.618	1,317	36.075	2,109	577.675
Dolovi 2	B	920.691	0,251	2.310	0,745	686	4,177	3.846	13,453	123.864
Stari Dušan	B	386.321	0,238	921	1,085	419	8,524	3.293	11,448	44.227
Ležište bakra „Severni revir“ (Centralno rudno telo+ Dolovi 1 + Dolovi 2+ Stari Dušan)	**Σ B**	**92.269.857**	**0,274**	**253.173**	**0,212**	**19.587**	**1,706**	**157.413**	**2,413**	**2.226.766**
	Σ C_1	**84.086.776**	**0,323**	**271.616**	**0,266**	**22.341**	**1,755**	**147.608**	**2,871**	**2.414.432**
	Σ $B+C_1$	**176.356.633**	**0,298**	**524.789**	**0,238**	**41.928**	**1,730**	**305.021**	**2,632**	**4.641.198**

Tabela 2. *Geološke rezerve ležišta bakra Severni revir – rudna tela, Tenka 1, Tenka 2, i Tenka 3*

Rudno telo	Kategorija rezervi	Količina rude (t)	Srednji sadržaj Zn (%)	Količina Zn (t)	Srednji sadržaj Pb (%)	Količina Pb (t)	Srednji sadržaj Au (g/t)	Količina Au (kg)	Srednji sadržaj Ag (g/t)	Količina Ag (kg)	Srednji sadržaj Cu (%)	Količina Cu (t)	Srednji sadržaj S (%)	Količina S (t)
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Proračunate geološke rezerve polimetalične rude (Zn-Pb) u rudnim telima Tenka 1 i Tenka 2, u konturi graničnog sadržaja 0,5% Zn														
Tenka 1	B	750.213	1,679	12.595	0,575	4.310	0,531	398	10,112	7.586	0,179	1.342	8,226	61.714
	C_1	208.008	1,424	2.961	0,393	818	0,630	131	9,093	1.892	0,203	423	9,423	19.601
	$B+C_1$	958.221	1,623	15.556	0,535	5.128	0,552	529	9,891	9.478	0,184	1.765	8,486	81.315
Tenka 2	B	358.638	1,478	5.865	0,270	1.089	0,708	270	6,844	2.546	0,284	1.058	8,871	31.945
	C_1	119.071	1,681	2.001	0,192	228	0,911	109	8,102	965	0,297	353	15,993	19.044
	$B+C_1$	477.709	1,647	7.866	0,276	1.317	0,793	379	7,349	3.511	0,295	1.411	10,674	50.989
Tenka 1 +Tenka 2	**Σ B**	**1.108.851**	**1,665**	**18.460**	**0,487**	**5.399**	**0,603**	**668**	**9,138**	**10.132**	**0,216**	**2.400**	**8,447**	**93.659**
	Σ C_1	**327.079**	**1,517**	**4.962**	**0,320**	**1.046**	**0,732**	**240**	**8,732**	**2.856**	**0,237**	**776**	**11,815**	**38.645**
	Σ $B+C_1$	**1.435.930**	**1,631**	**23.422**	**0,449**	**6.445**	**0,632**	**908**	**9,045**	**12.988**	**0,221**	**3.176**	**9,214**	**132.304**
Proračunate geološke rezerve u rudnom telu Tenka 3, u konturi graničnog sadržaja 0,10% Cu														
Tenka 3	C_1	**17.626.856**	**0,000**	**0,0**	**0,000**	**0,0**	**0,188**	**3.307**	**1,655**	**29.175**	**0,278**	**48.966**	**5,827**	**1.027.091**

Tabela 3. *Bilansne rezerve ležišta bakra Severni revir revir – Centralno rudno telo, Dolovi 1, Dolovi 2, i rudno telo Stari Dušan*

Rudno telo	Kategorija rezervi	Količina rude (t)	Srednji sadržaj Cu (%)	Količina Cu (t)	Srednji sadržaj Au (g/t)	Količina Au (kg)	Srednji sadržaj Ag (g/t)	Količina Ag (kg)	Srednji sadržaj S (%)	Količina S (t)
A	B	C	D	E	F	G	H	I	J	K
Centralno rudno telo	B	53.673.819	0,311	166.895	0,241	12.950	1,861	99.871	2,397	1.286.571
	C_1	62.593.481	0,337	210.826	0,295	18.468	1,872	117.184	3,108	1.945.171
	$B+C_1$	116.267.300	0,325	377.721	0,270	31.418	1,867	217.055	2,780	3.231.742
Dolovi 1	B	20.857.431	0,204	42.646	0,135	2.810	1,357	28.294	2,199	458.674
Dolovi 2	B	920.691	0,251	2.310	0,745	686	4,177	3.846	13,453	123.864
Stari Dušan	B	386.321	0,238	921	1,085	419	8,524	3.293	11,448	44.227
Ležište bakra „Severni revir“	**Σ B**	**75.838.262**	**0,281**	**212.771**	**0,222**	**16.864**	**1,784**	**135.304**	**2,523**	**1.913.337**
(Centralno rudno telo+ Dolovi 1	**Σ C_1**	**62.593.481**	**0,337**	**210.826**	**0,295**	**18.468**	**1,872**	**117.184**	**3,108**	**1.945.171**
+ Dolovi 2+ Stari Dušan)	**Σ $B+C_1$**	**138.431.743**	**0,308**	**423.597**	**0,259**	**35.332**	**1,828**	**252.488**	**2,816**	**3.858.508**

Tabela 4. *Bilansne rezerve ležišta bakra Severni revir – rudna tela, Tenka 1, Tenka 2, i Tenka 3*

Rudno telo	Kategorija rezervi	Količina rude (t)	Srednji sadržaj Zn (%)	Količina Zn (t)	Srednji sadržaj Pb (%)	Količina Pb (t)	Srednji sadržaj Au (g/t)	Količina Au (kg)	Srednji sadržaj Ag (g/t)	Količina Ag (kg)	Srednji sadržaj Cu (%)	Količina Cu (t)	Srednji sadržaj S (%)	Količina S (t)
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Predložene bilansne rezerve polimetalične rude (Zn-Pb) u rudnim telima Tenka 1 i Tenka 2, u konturi graničnog sadržaja 1,0% Zn+Pb														
Tenka 1	B	522.437	1,805	9.429	0,624	3.261	0,544	285	10,623	5.550	0,193	1.010	8,395	43.861
Tenka 2	B	336.631	1,714	5.769	0,322	1.084	0,765	257	7,264	2.445	0,295	992	9,019	30.362
	C_1	59.330	1,910	1.133	0,218	129	0,976	58	8,464	502	0,292	173	16,132	9.571
	$B+C_1$	395.961	1,743	6.902	0,305	1.214	0,823	315	7,594	2.947	0,294	1.165	9,997	39.933
Tenka 1 +Tenka 2	**Σ B**	**859.068**	**1,769**	**15.198**	**0,506**	**4.345**	**0,631**	**542**	**9,301**	**7.995**	**0,233**	**2.002**	**8,640**	**74.223**
	Σ C_1	**59.330**	**1,910**	**1.133**	**0,218**	**129**	**0,976**	**58**	**8,464**	**502**	**0,292**	**173**	**16,132**	**9.571**
	Σ $B+C_1$	**918.398**	**1,778**	**16.331**	**0,487**	**4.474**	**0,653**	**600**	**9,252**	**8.497**	**0,237**	**2.175**	**9,124**	**83.794**
Predložene bilansne rezerve u rudnom telu Tenka 3, u konturi graničnog sadržaja 0,10% Cu														
Tenka 3	C_1	**8.073.532**	**0,000**	**0,0**	**0,000**	**0,0**	**0,223**	**1.798**	**1,599**	**12.910**	**0,335**	**27.085**	**7,335**	**592.153**

ODREĐIVANJE EKSPLOATACIONIH REZERVI LEŽIŠTA BAKRA SEVERNI REVIR – MAJDANPEK

Primena softvera za projektovanje u rudarstvu [2, 4 – 11] predstavlja danas standard u svetu, pre svega što omogućavaju brzo i sa velikom tačnošću sagledavanje najpovoljnijih varijanti eksploatacije mineralnih sirovina, sa aspekta njihovog racionalnog iskorišćenja iz ležišta uz postizanje maksimalnog profita. Određivanje eksploatacionih rezervi rude bakra u ležištu Severni revir izvršeno je primenom softvera Whittle [12], koji predstavlja jedan od najsavremenijih softverskih alata za projektovanje u rudarstvu u svetu.

Na osnovu blok modela ležišta iz programa Gemcom 6.2 i definisanih ulaznih tehno-ekonomskih parametara, u programu za ekonomsku optimizaciju Whittle 4.1.3, izvršena je optimizacija ležišta. Navedeni programski paket određuje granicu kopa po „Lersh-Grossman“ algoritmu [12]. Pri tome je primenjen postupak bez zadavanja fiksnog graničnog sadržaja, već softver za svaki mineralizovani blok izračunava mogući prihod od metala i potrebne troškove za njegovo dobijanje, i na osnovu razlike zaključuje dali se taj blok uključuje u granicu kopa.

Za jednu kombinaciju tehno-ekonomskih parametara dobija se jedan granični kop, a promenom nekih od ulaznih parametara menja se kontura graničnog kopa. Softver ima mogućnost da primenom promenljivog koeficijenta na obračunati prihod, generiše

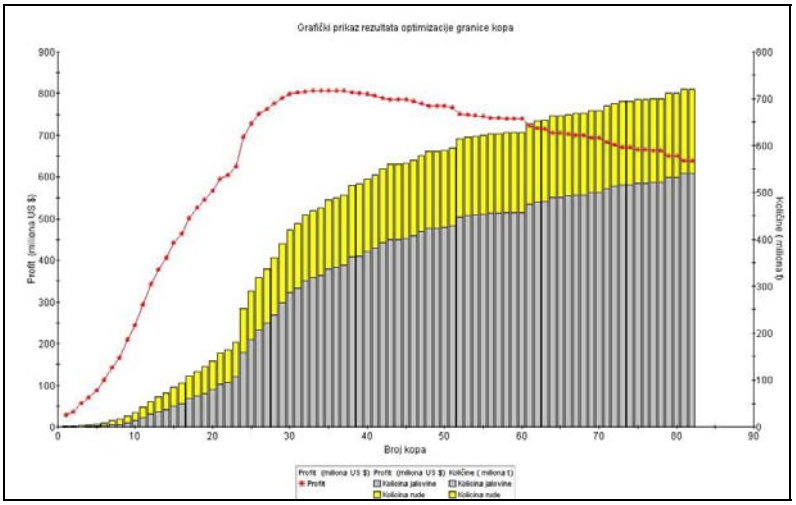
više mogućih kontura kopova pogodnih za detaljniju analizu [12].

Dobijeni rezultati za određivanje graničnog kopa prikazani su u tabeli 5 i na slici 1. Zaključak je da kop br. 36 ima faktor prihoda jednak 1,00, što znači da je to granični kop za definisane tehno-ekonomske parametre. Površina tog kopa je izdvojena i grafički dalje detaljnije obrađena u programu Gemcom 6.2, slika 2.

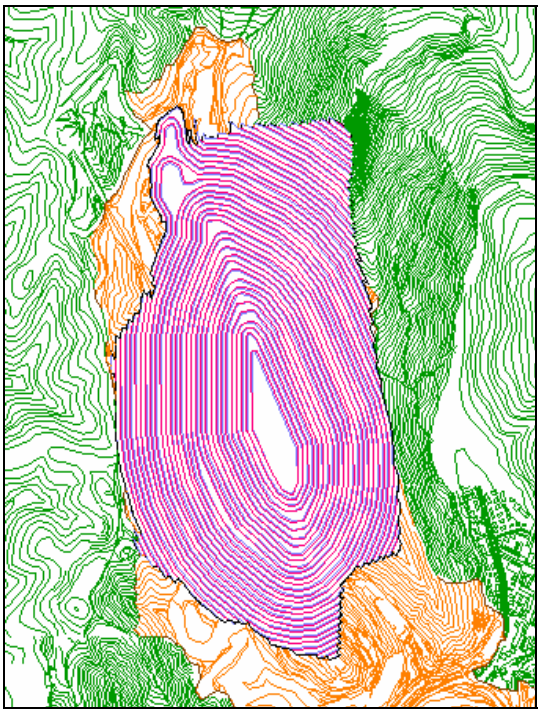
Tabela 5. *Rezultati optimizacije ležišta bakra Severni revir u programu Whittle 4.1.3.*

Broj kopa	Faktor prihoda	Iskopine	Jalovina	Ruda	Koeficijent raskrivke	Obačunat profit
		t	t	t	t/t	US $
A	B	C	D	E	F	G
1	0.30	1473922	238985	1236916	0.19	29321457
2	0.32	1970876	340231	1633258	0.21	37058546
3	0.34	3597933	792322	2810107	0.28	58132331
4	0.36	4845384	1198145	3653084	0.33	71405395
5	0.38	6560604	1791982	4776264	0.38	88655170
6	0.40	9190571	2682368	6518633	0.41	112535211
7	0.42	13153679	4346847	8820946	0.49	142461016
8	0.44	16598181	5809225	10806247	0.54	165566157
9	0.46	23826113	8958141	14891800	0.60	209577652
10	0.48	31282483	13363028	17948173	0.75	244908937
11	0.50	42369663	19527908	22878362	0.85	294519824
12	0.52	54620490	26755649	27909498	0.96	343520460
13	0.54	63999915	32298655	31752065	1.02	378031953
14	0.56	72944616	37942654	35058057	1.08	406170865
15	0.58	84303806	44533956	39833586	1.12	441562758
16	0.60	92488321	49932841	42623680	1.17	462867547
17	0.62	108465385	60283109	48259494	1.25	501177788
18	0.64	118672691	65680487	53077131	1.24	526654973
19	0.66	127880658	71574042	56396854	1.27	544562744
20	0.68	141003470	80070056	61031067	1.31	567143428
21	0.70	158357104	91502179	66962068	1.37	594583857
22	0.72	164740512	95477222	69374293	1.38	603822425
23	0.74	181603597	107217546	74505264	1.44	624546850
24	0.76	252682527	158982191	93850502	1.70	696177337
25	0.78	289587601	186147953	103605423	1.80	728680696
26	0.80	318387131	207401234	111163766	1.87	750977770
27	0.82	337364603	222209274	115339880	1.93	762463380
28	0.84	361197338	239793476	121598427	1.98	775732786
29	0.86	392073194	263992869	128285590	2.06	789597828
30	0.88	420341443	286627310	133928426	2.14	798974286
31	0.90	433217903	296561519	136875393	2.17	802552884
32	0.92	451638084	311230904	140632200	2.22	805554682
33	0.94	461161763	318451951	142938522	2.23	806885510
34	0.96	467711447	323541828	144400669	2.24	807051431
35	0.98	483756603	336742738	147249473	2.29	806960792
36	**1.00**	**488706557**	**340642282**	**148301566**	**2.30**	**806548756**

37	1.02	494876447	345809086	149306260	2.32	805765970
38	1.04	515631272	362972146	152903781	2.38	801973956
39	1.06	517607935	364549673	153303557	2.38	801432867
40	1.08	529012211	374453403	154806508	2.42	798090372
41	1.10	537573815	381411543	156412541	2.44	795161178
42	1.12	551159835	392969108	158444247	2.48	790228046
43	1.14	560435424	400325615	160366405	2.50	785956354
44	1.16	560609109	400454792	160410984	2.50	785856946
45	1.18	561793763	401429952	160620814	2.50	785230353
46	1.20	569376740	407672978	161962912	2.52	781012916
47	1.22	579646453	416787817	163119637	2.56	775583014
48	1.24	588232499	424228802	164266533	2.59	770519726
49	1.26	588385637	424345871	164302660	2.59	770394688
50	1.28	588967994	424760015	164471143	2.59	769911322
51	1.30	594179811	429190329	165253898	2.60	766237817
52	1.32	614419448	446820000	167868047	2.67	751534610
53	1.34	618267600	450072888	168464265	2.68	748556705
54	1.36	620707072	452134741	168842489	2.68	746565714
55	1.38	622554180	453634107	169190788	2.69	744926857
56	1.40	625435601	456148661	169558243	2.69	742552000
57	1.42	625643604	456317576	169597394	2.69	742337883
58	1.44	627799506	458326456	169744651	2.70	740589203
59	1.46	627818038	458342849	169746794	2.70	740568801
60	1.48	627877153	458387093	169761689	2.70	740503355
61	1.50	646391456	474550541	172116311	2.76	723050003
62	1.54	651828901	479217857	172887674	2.78	717614789
63	1.56	654163218	481265297	173175011	2.78	715264365
64	1.58	663536433	489858537	173956236	2.82	706231881
65	1.60	664045009	490294757	174028708	2.82	705678648
66	1.64	666663672	492564450	174378237	2.83	702837961
67	1.66	668729849	494355745	174653560	2.84	700530652
68	1.70	669335209	494880983	174733810	2.84	699840599
69	1.72	674616379	499501584	175395438	2.85	693716403
70	1.74	674863953	499715293	175429357	2.85	693422422
71	1.76	684852263	508835075	176299277	2.89	682248739
72	1.78	689349301	512748095	176884231	2.90	676818705
73	1.80	694382086	517233397	177432592	2.92	670873992
74	1.82	694418538	517260750	177441705	2.92	670819971
75	1.86	698240159	520589002	177935865	2.93	666036998
76	1.88	698550662	520858426	177977010	2.93	665635751
77	1.90	699438287	521599083	178124213	2.93	664419374
78	1.92	700283219	522338181	178230217	2.94	663320236
79	1.94	710748606	531976880	179058230	2.98	650577822
80	1.96	711067649	532244268	179109968	2.98	650123634
81	1.98	720370784	540560312	180098640	3.01	637979119
82	2.00	720424544	540604253	180108475	3.01	637899612



Sl. 1. *Grafik kopova dobijenih optimizacijom u programu Whittle 4.1.3.*



Sl. 2. *Izgled optimalnog kopa bez transportnih puteva u programu Gemcom 6.2.*

U konturi kopa graničnog sadržaja 0,10% Cu definisane su eksploatacione rezerve i prognozna dinamika otkopavanja, tabela 6.

Tabela 6. *Eksploatacione rezerve i dinamika otkopavanja u programu Whittle 4.1.3*

Godina	Iskopine	Jalovina	Ruda	Koef.ras.	Cu u rudi	Ag u rudi	Au u rudi
	t	t	t	t/t	%	g/t	g/t
A	B	C	D	E	F	G	H
1	15000000	12032876	2971879	4.06	0.340	1.800	0.260
2	15000000	11002253	4004153	2.75	0.362	2.290	0.370
3	15000000	11010504	3995890	2.76	0.312	3.490	0.490
4	15000000	10986764	4019667	2.74	0.302	2.830	0.430
5	15000000	10926671	4079857	2.68	0.321	2.420	0.370
6	15000000	10899180	4107393	2.66	0.395	2.170	0.340
7	15000000	10414148	4593201	2.27	0.337	2.710	0.310
8	15000000	10928949	4077575	2.68	0.435	2.220	0.360
9	15000000	10936956	4069556	2.69	0.272	1.890	0.260
10	15000000	11010651	3995743	2.76	0.269	1.610	0.230
11	15000000	11008930	3997466	2.76	0.258	1.650	0.240
12	15000000	11008679	3997718	2.76	0.244	1.850	0.280
13	15000000	11008681	3997716	2.76	0.248	2.200	0.380
14	15000000	11006813	3999586	2.76	0.252	2.320	0.350
15	20000000	15948316	4058177	3.94	0.287	2.150	0.300
16	20000000	15811144	4195569	3.77	0.314	2.110	0.270
17	20000000	15882066	4124534	3.86	0.337	2.290	0.290
18	20000000	16047152	3959182	4.06	0.342	1.890	0.260
19	19973227	15973227	4006410	3.99	0.322	1.610	0.230
20	20000000	16012338	3994053	4.02	0.288	1.350	0.190
21	20000000	16019665	3986714	4.02	0.271	1.380	0.180
22	20000000	15993590	4006410	3.59	0.252	1.680	0.230
23	20000000	15993590	4006410	3.33	0.250	1.780	0.260
24	20000000	15993590	4006410	3.03	0.250	1.850	0.270
25	20000000	15993590	4006410	2.61	0.254	2.000	0.300
26	16074282	12067872	4006410	1.89	0.268	1.910	0.290
27	9470204	5463794	4006410	1.37	0.278	1.710	0.250
28	8047168	4040758	4006410	1.01	0.280	1.570	0.210
29	6706174	2699763	4006411	0.68	0.283	1.440	0.160
30	5993390	1986980	4006410	0.50	0.283	1.460	0.150
31	5479195	1472785	4006410	0.37	0.291	1.470	0.140
32	4984140	977729	4006411	0.25	0.319	1.450	0.140
33	4607667	601257	4006410	0.15	0.335	1.380	0.130
34	4391315	384905	4006410	0.10	0.349	1.320	0.130
35	4197431	191021	4006410	0.05	0.370	1.270	0.130
36	4079737	73327	4006410	0.02	0.398	1.290	0.150
37	2967623	13486	2954137	0.01	0.455	1.620	0.200
Ukupno:	506971553	359824000	147282328				

Vrlo važan pokazatelj racionalnog korišćenja mineralnih sirovina je iskorišćenje bilansnih rezervi ležišta. Na osnovu količina bilansnih rezervi rude i količina rude u optimalnoj konturi kopa (ekspoloatacione rezerve) dobija se stepen iskorišćenja bilansnih rezervi ležišta Severni revir i on iznosi:

$$I = 100 \cdot R_e / R_b$$

gde su:

- R_e – eksploatacione rezerve, t
- R_b – bilansne rezerve, t

$I = 99{,}90\%$

ZAKLJUČAK

Proračun rudnih rezervi u ležištu bakra Severni revir, urađen je primenom računarskog softvera Whittle 4.1.3 u konturi graničnog sadržaja 0,10% Cu. Izbor završne – optimalne konture kopa izvršen je za baznu

cenu bakra od 6 000 $. Na osnovu ulaznih tehno - ekonomskih parametara u pomenutom softveru generisana su 82 granice kopa. Ukupne bilansne rezerve u ležištu iznose 147.423.286 t a eksploatacione rezerve 147.282.328 t, odnosno skoro 100%.

Na primeru ležišta Severni revir, dobijena vrednost iskorišćenja bilansnih rezervi, u potpunosti potvrđuje značaj korišćenja softvera za projektovanje u rudarskoj struci u cilju racionalnog i ekonomičnog iskorišćenja ležišta.

Prema planovima rudnika, otkopavanje ležišta Severni revir odvijaće se paralelno sa otkopavanjem na kopu Južni revir. Polimetalična ruda odnosno olovno cinkana ruda se nalazi u severnom delu kopa, na površinskim etažama. Pošto se radi o maloj količini rude, ona treba da bude otkopana u kontinuitetu da bi se obezbedilo bolje iskorišćenje i manje mešanje sa rudom bakra prilikom transporta.

Da bi se uprostila ekonomska ocena ovog ležišta, softverom je urađena prognozna dinamika otkopavanja samo rude bakra, dok obračun vrednosti polimetalične rude treba naknadno dodati. U prvoj godini ne može biti obezbeđen pun kapacitet na rudi bakra za izbalansirane količine iskopina, pa je najjednostavnije pretpostaviti da će polimetalična ruda biti otkopana u prvoj godini.

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APPLICATION THE SOFTWARE PACKAGE WHITTLE FOR DETERMINING THE MINEABLE RESERVES OF THE COPPER DEPOSIT SOUTH MINING DISTRICT MAJDANPEK, SERBIA

Abstract

The copper deposit North Mining District is located close to the town of Majdanpek. Total geological reserves of copper, in the contour of limit content 0.10%, amount 193 983 489 t.

The world mining company, in assessment the financial viability and defining the optimum strategy for development of the mine in order to the rational and economical utilization of mineral deposits, use some of the software for optimization and design, and among the leading is Whittle, owned by the Mining and Metallurgy Institute Bor.

This work presents a method of defining the mineable reserves of the copper deposit North Mining District using Whittle software, which enables optimum utilization of the deposit, which is a necessary prerequisite for responsible management of mineral resources.

***Keywords**: Whittle, copper deposit North Mining District, mineable reserves*

INTRODUCTION

Natural mineral resources of a country are the basis of its economic and social prosperity. According to the economic value of mineral resources at disposal of Serbia, it does not belong to the rich countries. Therefore, there is an obligation to perform the mining activities by the principles of rational management of mineral resources.

The copper deposit North Mining District [1, 3] is located close to the town of Majdanpek and it consists of four ore bodies: Central ore body, Dolovi 1, Dolovi 2 and the ore body Old Dusan. Total geological reserves of copper, in the contour of limit content 0.10%, amount 193 983 489 t. In significance, this deposit has a large role in the production of copper in the company RTB Bor, which now also involves the Copper Mine Veliki Krivelj and Jama Bor. In addition to these deposits, the complex of the deposit Cerovo is of exceptional importance, at which a continuation of operation on mining the copper ore is planned this year, which is interrupted in 2003 [3].

Since the copper deposit North Mining District belongs to the deposits with low metal content in the ore, which in total geological reserves amounts to 0.298%, the use of modern software tools for strategic planning and optimization of reservoir Whittle [2, 4, 5] is of great importance for rational utilization of deposit and attaining maximum profits in mining.

* *Mining and Metallurgy Institute Bor*

ORE RESERVES OF THE DEPOSIT

Calculation of ore reserves in the North Mining District was done using the computer software Gemcom [2, 4, 5, 8, 9], where the method of mini blocks was used, which was confirmed during the mining phase of deposit.

In the case of copper deposit North Mining District and similar deposits, with a large number of data, used for the calculation of reserves, is indisputable the advantage of calculation the budget reserves, using the computer technology, is indisputable, compared to other methods of calculation:

- Due to the size of deposit, the state of future of open pit and production capacity (large amount of excavation), designs and alterations of designs are very complex with optimum working and final contours of the open pit, and the digital model with calculated reserves by mini-blocks, facilitates and accelerates this process, since it is possible in a short period of time to see a large number of variants and find the best solutions.
- The obtained results in designing and economic consideration, on the basis of formed block-model and calculations of reserves and deposits using this method, on the copper deposits of porphyritic type, have satisfactory quality, or in the world they are accepted as satisfactory.
- Potential concessionaires require the deposit to be displayed in a digital form.

Tables 1 and 2 show the geological reserves and Tables 3 and 4 show the balance reserves of the copper deposit North Mining District, determined in the program Gemcom 6.2 [1].

Table 1. *Geological reserves of the copper deposit North Mining District - Central ore body, Dolovi 1, Dolovi 2 and the ore body Old Dusan*

Rudno telo	Kategorija rezervi	Količina rude (t)	Srednji sadržaj Cu (%)	Količina Cu (t)	Srednji sadržaj Au (g/t)	Količina Au (kg)	Srednji sadržaj Ag (g/t)	Količina Ag (kg)	Srednji sadržaj S (%)	Količina S (t)
A	B	C	D	E	F	G	H	I	J	K
Centralno rudno telo	B	63.574.104	0,307	195.392	0,234	14.864	1,796	114.199	2,330	1.480.999
	C_1	84.086.776	0,323	271.616	0,266	22.341	1,755	147.608	2,871	2.414.432
	$B+C_1$	147.660.880	0,316	467.007	0,252	37.205	1,773	261.807	2,638	3.895.432
Dolovi 1	B	27.388.741	0,199	54.551	0,132	3.618	1,317	36.075	2,109	577.675
Dolovi 2	B	920.691	0,251	2.310	0,745	686	4,177	3.846	13,453	123.864
Stari Dušan	B	386.321	0,238	921	1,085	419	8,524	3.293	11,448	44.227
Ležište bakra „Severni revir“ (Centralno rudno telo+ Dolovi 1 + Dolovi 2+ Stari Dušan)	**Σ B**	**92.269.857**	**0,274**	**253.173**	**0,212**	**19.587**	**1,706**	**157.413**	**2,413**	**2.226.766**
	Σ C_1	**84.086.776**	**0,323**	**271.616**	**0,266**	**22.341**	**1,755**	**147.608**	**2,871**	**2.414.432**
	Σ $B+C_1$	**176.356.633**	**0,298**	**524.789**	**0,238**	**41.928**	**1,730**	**305.021**	**2,632**	**4.641.198**

Table 2. *Geological reserves of the copper deposit North Mining District – ore bodies Tenka 1, Tenka 2 and Tenka 3*

Rudno telo	Kategorija rezervi	Količina rude (t)	Srednji sadržaj Zn (%)	Količina Zn (t)	Srednji sadržaj Pb (%)	Količina Pb (t)	Srednji sadržaj Au (g/t)	Količina Au (kg)	Srednji sadržaj Ag (g/t)	Količina Ag (kg)	Srednji sadržaj Cu (%)	Količina Cu (t)	Srednji sadržaj S (%)	Količina S (t)
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Proračunate geološke rezerve polimetalične rude (Zn-Pb) u rudnim telima Tenka 1 i Tenka 2, u konturi graničnog sadržaja 0,5% Zn														
Tenka 1	B	750.213	1,679	12.595	0,575	4.310	0,531	398	10,112	7.586	0,179	1.342	8,226	61.714
	C_1	208.008	1,424	2.961	0,393	818	0,630	131	9,093	1.892	0,203	423	9,423	19.601
	$B+C_1$	958.221	1,623	15.556	0,535	5.128	0,552	529	9,891	9.478	0,184	1.765	8,486	81.315
Tenka 2	B	358.638	1,478	5.865	0,270	1.089	0,708	270	6,844	2.546	0,284	1.058	8,871	31.945
	C_1	119.071	1,681	2.001	0,192	228	0,911	109	8,102	965	0,297	353	15,993	19.044
	$B+C_1$	477.709	1,647	7.866	0,276	1.317	0,793	379	7,349	3.511	0,295	1.411	10,674	50.989
Tenka 1 +Tenka 2	**Σ B**	**1.108.851**	**1,665**	**18.460**	**0,487**	**5.399**	**0,603**	**668**	**9,138**	**10.132**	**0,216**	**2.400**	**8,447**	**93.659**
	Σ C_1	**327.079**	**1,517**	**4.962**	**0,320**	**1.046**	**0,732**	**240**	**8,732**	**2.856**	**0,237**	**776**	**11,815**	**38.645**
	Σ $B+C_1$	**1.435.930**	**1,631**	**23.422**	**0,449**	**6.445**	**0,632**	**908**	**9,045**	**12.988**	**0,221**	**3.176**	**9,214**	**132.304**
Proračunate geološke rezerve u rudnom telu Tenka 3, u konturi graničnog sadržaja 0,10% Cu														
Tenka 3	C_1	17.626.856	0,000	0,0	0,000	0,0	0,188	3.307	1,655	29.175	0,278	48.966	5,827	1.027.091

Table 3. *Balance reserves of the copper deposit North Mining District - Central ore body, Dolovi 1, Dolovi 2 and the ore body Old Dusan*

Rudno telo	Kategorija rezervi	Količina rude (t)	Srednji sadržaj Cu (%)	Količina Cu (t)	Srednji sadržaj Au (g/t)	Količina Au (kg)	Srednji sadržaj Ag (g/t)	Količina Ag (kg)	Srednji sadržaj S (%)	Količina S (t)
A	B	C	D	E	F	G	H	I	J	K
Centralno rudno telo	B	53.673.819	0,311	166.895	0,241	12.950	1,861	99.871	2,397	1.286.571
	C_1	62.593.481	0,337	210.826	0,295	18.468	1,872	117.184	3,108	1.945.171
	$B+C_1$	116.267.300	0,325	377.721	0,270	31.418	1,867	217.055	2,780	3.231.742
Dolovi 1	B	20.857.431	0,204	42.646	0,135	2.810	1,357	28.294	2,199	458.674
Dolovi 2	B	920.691	0,251	2.310	0,745	686	4,177	3.846	13,453	123.864
Stari Dušan	B	386.321	0,238	921	1,085	419	8,524	3.293	11,448	44.227
Ležište bakra „Severni revir“ (Centralno rudno telo+ Dolovi 1 + Dolovi 2+ Stari Dušan)	**Σ B**	**75.838.262**	**0,281**	**212.771**	**0,222**	**16.864**	**1,784**	**135.304**	**2,523**	**1.913.337**
	Σ C_1	**62.593.481**	**0,337**	**210.826**	**0,295**	**18.468**	**1,872**	**117.184**	**3,108**	**1.945.171**
	Σ $B+C_1$	**138.431.743**	**0,308**	**423.597**	**0,259**	**35.332**	**1,828**	**252.488**	**2,816**	**3.858.508**

Table 4. *Balance reserves of the copper deposit North Mining District – ore bodies Tenka 1, Tenka 2 and Tenka 3*

Rudno telo	Kategorija rezervi	Količina rude (t)	Srednji sadržaj Zn (%)	Količina Zn (t)	Srednji sadržaj Pb (%)	Količina Pb (t)	Srednji sadržaj Au (g/t)	Količina Au (kg)	Srednji sadržaj Ag (g/t)	Količina Ag (kg)	Srednji sadržaj Cu (%)	Količina Cu (t)	Srednji sadržaj S (%)	Količina S (t)
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Predložene bilansne rezerve polimetalične rude (Zn-Pb) u rudnim telima Tenka 1 i Tenka 2, u konturi graničnog sadržaja 1,0% Zn+Pb														
Tenka 1	B	522.437	1,805	9.429	0,624	3.261	0,544	285	10,623	5.550	0,193	1.010	8,395	43.861
Tenka 2	B	336.631	1,714	5.769	0,322	1.084	0,765	257	7,264	2.445	0,295	992	9,019	30.362
	C_1	59.330	1,910	1.133	0,218	129	0,976	58	8,464	502	0,292	173	16,132	9.571
	$B+C_1$	395.961	1,743	6.902	0,305	1.214	0,823	315	7,594	2.947	0,294	1.165	9,997	39.933
Tenka 1 +Tenka 2	**Σ B**	**859.068**	**1,769**	**15.198**	**0,506**	**4.345**	**0,631**	**542**	**9,301**	**7.995**	**0,233**	**2.002**	**8,640**	**74.223**
	Σ C_1	**59.330**	**1,910**	**1.133**	**0,218**	**129**	**0,976**	**58**	**8,464**	**502**	**0,292**	**173**	**16,132**	**9.571**
	Σ $B+C_1$	**918.398**	**1,778**	**16.331**	**0,487**	**4.474**	**0,653**	**600**	**9,252**	**8.497**	**0,237**	**2.175**	**9,124**	**83.794**
Predložene bilansne rezerve u rudnom telu Tenka 3, u konturi graničnog sadržaja 0,10% Cu														
Tenka 3	C_1	**8.073.532**	**0,000**	**0,0**	**0,000**	**0,0**	**0,223**	**1.798**	**1,599**	**12.910**	**0,335**	**27.085**	**7,335**	**592.153**

DETERMINING THE MINEABLE RESERVES OF THE COPPER DEPOSIT NORTH MINING DISTRICT – MAJDANPEK

Application the software for design of mining [2, 4 - 11] is now a standard in the world, primarily by enabling fast and high accurately understanding the most appropriate variants of mining the mineral resources, in terms of their rational utilization from the deposit with attaining maximum profits. Determining the mineable reserves of copper ore in the deposit North Mining District was carried out using Whittle software [12], which is one of the most advanced software tools for design in mining in the world.

Based on a block model of the deposit from the program Gemcom 6.2 and defined input techno-economic parameters in the program for economic optimization Whittle 4.1.3, optimization of the deposit was done. Specified software package determines the limit of open pit per the "Lersh-Grossman" algorithm [12]. In this, the procedure was applied without assigning the fixed boundary content of the material, but the software for each mineralized block calculates the potential revenue of metal and the involved costs for its production process, and on the basis of difference it is concluded whether this block is included in the border of the mine. For a combination of technical-economic parameters, one limit open pit is obtained, and changing some of the input parameters, a contour of border open pit is changed. Software has the ability to generate by a variable coefficient to the calculated revenue using a number of possible contours of open pits, suitable for more detailed analysis [12].

The obtained results for determination the border open pit are shown in Table 5 and Figure 1. Conclusion is that open pit No. 36 has a factor of revenue equals to 1.00, which means that it is the border open pit for de-

fined the techno-economic parameters. Surface of this open pit is extracted and processed graphically in details further in the program Gemcom 6.2, Figure 2.

Table 5. *Results of optimization the copper deposit North Mining District in the program Whittle 4.1.3.*

Open pit No.	Revenue factor	Excavation	Waste	Ore	Overburden coefficient	Calculated profit
		t	t	t	t/t	US $
A	B	C	D	E	F	G
1	0.30	1473922	238985	1236916	0.19	29321457
2	0.32	1970876	340231	1633258	0.21	37058546
3	0.34	3597933	792322	2810107	0.28	58132331
4	0.36	4845384	1198145	3653084	0.33	71405395
5	0.38	6560604	1791982	4776264	0.38	88655170
6	0.40	9190571	2682368	6518633	0.41	112535211
7	0.42	13153679	4346847	8820946	0.49	142461016
8	0.44	16598181	5809225	10806247	0.54	165566157
9	0.46	23826113	8958141	14891800	0.60	209577652
10	0.48	31282483	13363028	17948173	0.75	244908937
11	0.50	42369663	19527908	22878362	0.85	294519824
12	0.52	54620490	26755649	27909498	0.96	343520460
13	0.54	63999915	32298655	31752065	1.02	378031953
14	0.56	72944616	37942654	35058057	1.08	406170865
15	0.58	84303806	44533956	39833586	1.12	441562758
16	0.60	92488321	49932841	42623680	1.17	462867547
17	0.62	108465385	60283109	48259494	1.25	501177788
18	0.64	118672691	65680487	53077131	1.24	526654973
19	0.66	127880658	71574042	56396854	1.27	544562744
20	0.68	141003470	80070056	61031067	1.31	567143428
21	0.70	158357104	91502179	66962068	1.37	594583857
22	0.72	164740512	95477222	69374293	1.38	603822425
23	0.74	181603597	107217546	74505264	1.44	624546850
24	0.76	252682527	158982191	93850502	1.70	696177337
25	0.78	289587601	186147953	103605423	1.80	728680696
26	0.80	318387131	207401234	111163766	1.87	750977770
27	0.82	337364603	222209274	115339880	1.93	762463380
28	0.84	361197338	239793476	121598427	1.98	775732786
29	0.86	392073194	263992869	128285590	2.06	789597828
30	0.88	420341443	286627310	133928426	2.14	798974286
31	0.90	433217903	296561519	136875393	2.17	802552884
32	0.92	451638084	311230904	140632200	2.22	805554682
33	0.94	461161763	318451951	142938522	2.23	806885510
34	0.96	467711447	323541828	144400669	2.24	807051431
35	0.98	483756603	336742738	147249473	2.29	806960792
36	**1.00**	**488706557**	**340642282**	**148301566**	**2.30**	**806548756**
37	1.02	494876447	345809086	149306260	2.32	805765970
38	1.04	515631272	362972146	152903781	2.38	801973956
39	1.06	517607935	364549673	153303557	2.38	801432867
40	1.08	529012211	374453403	154806508	2.42	798090372
41	1.10	537573815	381411543	156412541	2.44	795161178
42	1.12	551159835	392969108	158444247	2.48	790228046
43	1.14	560435424	400325615	160366405	2.50	785956354
44	1.16	560609109	400454792	160410984	2.50	785856946
45	1.18	561793763	401429952	160620814	2.50	785230353
46	1.20	569376740	407672978	161962912	2.52	781012916
47	1.22	579646453	416787817	163119637	2.56	775583014

48	1.24	588232499	424228802	164266533	2.59	770519726
49	1.26	588385637	424345871	164302660	2.59	770394688
50	1.28	588967994	424760015	164471143	2.59	769911322
51	1.30	594179811	429190329	165253898	2.60	766237817
52	1.32	614419448	446820000	167868047	2.67	751534610
53	1.34	618267600	450072888	168464265	2.68	748556705
54	1.36	620707072	452134741	168842489	2.68	746565714
55	1.38	622554180	453634107	169190788	2.69	744926857
56	1.40	625435601	456148661	169558243	2.69	742552000
57	1.42	625643604	456317576	169597394	2.69	742337883
58	1.44	627799506	458326456	169744651	2.70	740589203
59	1.46	627818038	458342849	169746794	2.70	740568801
60	1.48	627877153	458387093	169761689	2.70	740503355
61	1.50	646391456	474550541	172116311	2.76	723050003
62	1.54	651828901	479217857	172887674	2.78	717614789
63	1.56	654163218	481265297	173175011	2.78	715264365
64	1.58	663536433	489858537	173956236	2.82	706231881
65	1.60	664045009	490294757	174028708	2.82	705678648
66	1.64	666663672	492564450	174378237	2.83	702837961
67	1.66	668729849	494355745	174653560	2.84	700530652
68	1.70	669335209	494880983	174733810	2.84	699840599
69	1.72	674616379	499501584	175395438	2.85	693716403
70	1.74	674863953	499715293	175429357	2.85	693422422
71	1.76	684852263	508835075	176299277	2.89	682248739
72	1.78	689349301	512748095	176884231	2.90	676818705
73	1.80	694382086	517233397	177432592	2.92	670873992
74	1.82	694418538	517260750	177441705	2.92	670819971
75	1.86	698240159	520589002	177935865	2.93	666036998
76	1.88	698550662	520858426	177977010	2.93	665635751
77	1.90	699438287	521599083	178124213	2.93	664419374
78	1.92	700283219	522338181	178230217	2.94	663320236
79	1.94	710748606	531976880	179058230	2.98	650577822
80	1.96	711067649	532244268	179109968	2.98	650123634
81	1.98	720370784	540560312	180098640	3.01	637979119
82	2.00	720424544	540604253	180108475	3.01	637899612

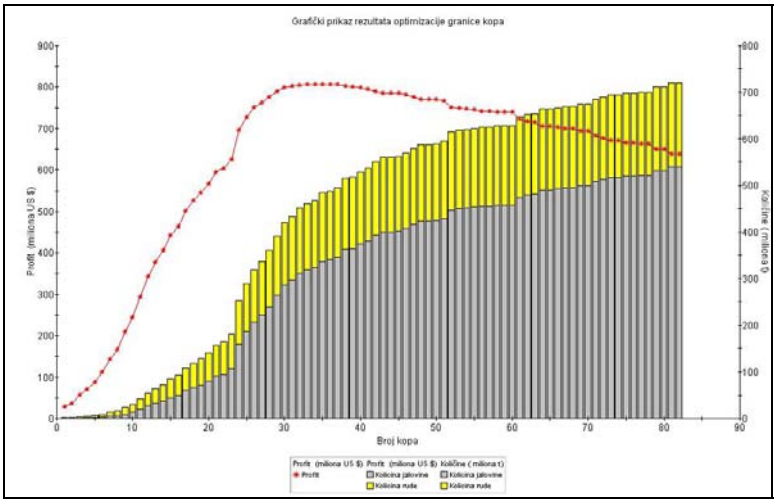

Fig. 1. *Graph of the open pits obtained by optimization in the program Whittle 4.1.3.*

Fig. 2. *View of the optimum open pit without transport roads in the program Gemcom 6.2.*

Mineable reserves and prognostic dynamics of mining are defined in the boundary contour of open pit, content 0.10% Cu, Table 6.

Table 6. *Mineable reserves and prognostic dynamics of mining in the program Whittle 4.1.3.*

Year	Excavation	Waste	Ore	Overburden coefficient	Cu in ore	Ag in ore	Au in ore
	t	t	t	t/t	%	g/t	g/t
A	B	C	D	E	F	G	H
1	15000000	12032876	2971879	4.06	0.340	1.800	0.260
2	15000000	11002253	4004153	2.75	0.362	2.290	0.370
3	15000000	11010504	3995890	2.76	0.312	3.490	0.490
4	15000000	10986764	4019667	2.74	0.302	2.830	0.430
5	15000000	10926671	4079857	2.68	0.321	2.420	0.370
6	15000000	10899180	4107393	2.66	0.395	2.170	0.340
7	15000000	10414148	4593201	2.27	0.337	2.710	0.310
8	15000000	10928949	4077575	2.68	0.435	2.220	0.360
9	15000000	10936956	4069556	2.69	0.272	1.890	0.260
10	15000000	11010651	3995743	2.76	0.269	1.610	0.230

11	15000000	11008930	3997466	2.76	0.258	1.650	0.240
12	15000000	11008679	3997718	2.76	0.244	1.850	0.280
13	15000000	11008681	3997716	2.76	0.248	2.200	0.380
14	15000000	11006813	3999586	2.76	0.252	2.320	0.350
15	20000000	15948316	4058177	3.94	0.287	2.150	0.300
16	20000000	15811144	4195569	3.77	0.314	2.110	0.270
17	20000000	15882066	4124534	3.86	0.337	2.290	0.290
18	20000000	16047152	3959182	4.06	0.342	1.890	0.260
19	19973227	15973227	4006410	3.99	0.322	1.610	0.230
20	20000000	16012338	3994053	4.02	0.288	1.350	0.190
21	20000000	16019665	3986714	4.02	0.271	1.380	0.180
22	20000000	15993590	4006410	3.59	0.252	1.680	0.230
23	20000000	15993590	4006410	3.33	0.250	1.780	0.260
24	20000000	15993590	4006410	3.03	0.250	1.850	0.270
25	20000000	15993590	4006410	2.61	0.254	2.000	0.300
26	16074282	12067872	4006410	1.89	0.268	1.910	0.290
27	9470204	5463794	4006410	1.37	0.278	1.710	0.250
28	8047168	4040758	4006410	1.01	0.280	1.570	0.210
29	6706174	2699763	4006411	0.68	0.283	1.440	0.160
30	5993390	1986980	4006410	0.50	0.283	1.460	0.150
31	5479195	1472785	4006410	0.37	0.291	1.470	0.140
32	4984140	977729	4006411	0.25	0.319	1.450	0.140
33	4607667	601257	4006410	0.15	0.335	1.380	0.130
34	4391315	384905	4006410	0.10	0.349	1.320	0.130
35	4197431	191021	4006410	0.05	0.370	1.270	0.130
36	4079737	73327	4006410	0.02	0.398	1.290	0.150
37	2967623	13486	2954137	0.01	0.455	1.620	0.200
Total:	506971553	359824000	147282328				

An important indicator of rational use the mineral resources is utilization the balance reserves of deposits.

A degree of utilization the balance reserves in the North Mining District is obtained on the basis of the amounts of balance reserves of the ore, and the amount of ore in the optimum open pit contour (mineable reserves), and it is:

$$I = 100 \cdot R_e / R_b$$

where:

- R_e – mineable reserves, t
- R_b – balance reserves, t

$$I = 99.90\%$$

CONCLUSION

Calculation of ore reserves in the copper deposit North Mining District was done using the software Whittle 4.1.3 in a contour of limit content 0.10% Cu. Selection of final – optimum open pit contour was made for the base copper price of 6 000 $. Based on the input techno - economic parameters in the above software, 82 open pit boundaries were generated. Total balance reserves in the deposit amount to 147 423 286 t, and mineable reserves amount 147 282 328 t, or nearly 100%.

The obtained value of utilization the balance reserves, on the example of the North Mining District deposit, fully confirms the importance of using the software for design in the mining profession to rational and economical utilization of the deposit.

According to the plans of the mine, mining the North Mining District will be developed simultaneously with the mining at the open pit South Mining District. Po-

ymetallic ore, or lead-zinc ore, is situated in the northern part of the open pit, on surface benches. Because it is a small amount of ore, it needs to be continually excavated to ensure better utilization and less interference with the copper ore during transport.

In order to simplify the economic evaluation of this deposit, prognostic of mining dynamics of copper ore was done using the software, until the calculation of polymetallic ore value has to be added later. In the first year, the full capacity cannot be provided for copper ore for balanced amounts of excavation, and it is the simplest to assume that the polymetallic ore will be mined in the first year.

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ISPITIVANJA ZAPALJIVIH I EKSPLOZIVNIH SVOJSTAVA UGLJENE PRAŠINE U JAMAMA RMU „REMBAS“ – RESAVICA

Izvod

Ugljena prašina u rudnicima sa podzemnom eksploatacijom zavisno od specifičnih uslova predstavlja složen problem sa stanovištva sigurnosti podzemnih rudarskih objekata s obzirom da može iskazivati eksplozivna, zapaljiva i agresivna svojstva.

Eksplozije ugljene prašine imaju daleko veće i teže posledice nego što je to slučaj kod eksplozije gasnih smeša. Saglasno opasnostima problematici zaštite od opasnih svojstava ugljene prašine u svim podzemnim rudnicima uglja u Srbiji mora se dati adekvatan značaj.

U ovom radu obrađuju se rezultati istraživanja zapaljivih i eksplozivnih svojstava ugljene prašine u jamama RMU „Rembas“ i daje rešenje izmene metodologije kontrole zaprašenosti i ocene ugroženosti.

Ključne reči: *ugalj, ugljena prašina, eksplozivnost prašine.*

1. UVOD

Po svojoj prirodi ugljena prašina u podzemnim rudnicima može iskazivati zapaljiva, eksplozivna i agresivna svojstva. Agresivnim svojstvima prašine danas se može veoma uspešno suprostaviti dok eksplozivna i zapaljiva svojstva traže poseban tretman, od nastanka do eliminisanja opasnosti i sprečavanja širenja udarnog talasa. Ugljena prašina nastaje u svim fazama tehnološkog procesa i nošena vazdušnom strujom taloži se duž rudarskih prostorija. Do eksplozije ugljene prašine, koja po svojoj prirodi poseduje eksplozivna svojstva dolazi u slučajevima kada se u određenom vremenu podudari više faktora:

- uskovitlano stanje prašine sa odgovarajućim disperznim sastavom i sadržajem sagorljivih materija,
- smeša prašine i vazduha u odgovarajućoj razmeri,
- izvor paljenja smeše prašina- vazduh, odnosno prašina-vazduh-metan.

U procesa paljenja i eksplozije ugljene prašine razvijaju se visoke temperature i velike količine toplote, a to izaziva visoke pritiske u delu podzemne rudničke atmosfere koju je zahvatila eksplozija. Razvijeni pritisci prouzrokuju snažne i razarajuće vazdušne udare koji uz ostala svojstva, izazivaju snažno uskovitlavanje

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prašine, te nastaju udari koji daju lanac paljenja i eksplodiranja ugljene prašine u podzemnim prostorijama.

Sve se ovo odigrava izuzetno velikom brzinom, što nastali lanac paljenja pretvara u jedinstveni proces upale i eksplozije ugljene prašine u zahvaćenom prostoru. Ovo iziskuje i obaveznu meru ograničavanja eventualno nastale eksplozije u određenom delu jame.

Slučajevi eksplozije ugljene prašine sa katastrofalnim posledicama koje su se dogodile u nekim rudnicima sa prostora bivše Jugoslavije uticali su da se problematici borbe sa ugljenom prašinom i istraživanja u ovoj oblasti posveti posebna pažnja.

Prema standardima polazni element za istraživanje zapaljivih svojstava je sadržaj isparljivih materija u ugljenom sloju. Ovaj sadržaj se različito tretira u propisima niza zemalja. Neki postavljaju granicu na 10, 12 ili 14%, a po našim propisima ta granica je 14%. Nataložena prašina iz sloja koji je ugrožen eksplozivnom ugljenom prašinom je bezopasna ako sadrži:

a. nesagorive supstance u količini većoj od 70% u nemetanskim prostorijama, odnosno 80% u metanskim prostorijama,
b. grubu vlagu u količini koja onemogućava prenošenje eksplozije i koja u potpunosti sprečava uzvitlavanje ugljene prašine. Minimalni sadržaj grube vlage određuje se po obrascu:

$$W = \frac{70 \times d + 2440}{d + 70} - 0{,}63 \times n \ (\%)$$

gde je:

W- gruba vlaga koja obezbeđuje da ugljena prašina ne može lebdeti (%)

d – sadržaj frakcije prašine ispod 70 μm

n – sadržaj nesagorivih čestica u ugljenoj prašini (%)

Grulometriski sastav utiče na eksplozivna svojstva smeše prašina – vazduh, pri čemu je najbitnije učešće čestica ispod 75 mikrometra i manje. One prve prihvataju plamen, upale se, razvijaju toplotu, koja poprima i ostala ugljena prašina, te tako dolazi do pune eksplozije.

U jamama Strmosten, Senjski rudnik, Jelovac i Ravna reka RMU „Rembas“ – Resavica otkopavaju se slojevi kvalitetnog mrkog uglja u kojima je sadržaj isparljivih materija znatno iznad granice od 14% tako da su vršena propisana istraživanja i ispitivanja kojima je utvrđeno da je ugalj sklon procesu samozapaljenja, a ugljena prašina u određenim uslovima iskazuje eksplozivna i zapaljiva svojstva.

Shodno navedenoj opasnosti propisane su i sprovode se određene mere zaštite od ove potencijalne ugroženosti.

2. UTVRĐIVANJE SKLONOSTI UGLJA KA SAMOZAPALJENJU

Ugalj je hemiski vrlo složena materija, pri čemu ugljevi iz raznih ležišta mogu biti vrlo različitog sastava. Ovo utiče da se proces endogenih oksidacionih procesa intezivno izučava i istražuje. U nizu teoretskih razmatranja procesa samozapaljenja izdvajaju se piritno-sulfidna, bakteriska, fenolna i oksidaciona teorija.

Danas se u rudarskoj nauci prioritetan značaj daje oksidacionoj teoriji, koja samozapaljenje tumači kao proces sorpcije O_2 u više karakterističnih faza, odnosno perioda.

Za ispitivanje prirodne sklonosti ugljeva ka samozapaljenju razvijeno je u svetu oko 20-tak postupaka, pri čemu su opšte prihvaćeni sledeći: Makni, Skočinski, Olpinski i Halupe-Drebeka.

U Srbiji se ispitivanje samozapaljivosti ugljeva vrši po metodi Olpinskog, po kojoj osnovno značenja za samozapaljenje ima sposobnost uglja da sorbira kiseonik

uz izdvajanje toplote. Sorpciona svojstva uglja, kao i higroskopna vlaga, nesumljivo ubrzavaju proces oksidacije. Takođe je vrlo verovatan uticaj elektrohemiskih procesa na proticanje procesa oksidacije uglja.

Pod pokazateljem samozapaljivosti Szb podrazumeva se brzina porasta temperature uglja u ograničenom vremenu i određenim uslovima merenja.

U svojstvu karakteristika samozapaljivosti uglja u sloju primenjuje se pokazatelj samozapaljivosti uglja koji odgovara pokazatelju Szb, preračunatim na gorivu masu. Po ovoj metodologiji ugljevi su razvrstani u četiri kategorije – grupe:

Tabela 1. *Tabela kategorija sklonosti ugljeva ka samozapaljenju po metodi Olpinskog*

Samozapaljenje	Kategorija grupa	SZ	Szb (°C/min)
Veoma skloni	I	iznad	120
Skloni	II		100-120
Umereno skloni	III		80-100
Nisu skloni	IV	ispod	80

Uzroci uglja u sve 4 jame uzimani su na otkopima i pripremnim radilištima i u laboratoriji je određivan prirodni indeks samozapaljenja, pri čemu su dobijeni rezultati dati u tabeli 2.

Tabela 2. *Rezultati ispitivanja prirodnog indeksa samozapaljivosti uglja iz jama RMU „Rembas“*

Rudnik	Prirodni indeks Szb(°C/min)	Grupa
Senjski rudnik	118-140	Veoma sklon
Jelovac	108-111	Sklon –II
Strmosten	110-120	Sklon – II
Ravna Reka	80-100	Umereno sklon III

Opasnost od razvijanja požara nastalog usled zapaljenja ugljene prašine na vrućim površinama u rudnicima je realna opasnost. Sam proces samozapaljenja nastaje tako što se nataložena prašina u toplotnim uslovima javlja kao delimično toplotni izolator, sprečavajući odvođenje toplote akumulirane na vrućim površinama, te nastaje pojačanje oksidacije.

Pokazatelj tinjanja dobija se kada se odredi najniža temperatura, pri kojoj određena visina nataložene prašine može da se užari.

Određivanje temperature tinjanja vrši se pomoću grejnog tela koje ima mogućnost promene temperature i mernu opremu. Na grejno telo počev od 200^0C postavlja se uzorak ugljene prašine visine 5mm i meri se vreme do pojave užarenog jezgra, tako što se temperatura povećava za 10^0C, a ogled se sukcesivno ponavlja sve do pojave užarenja. Ako se užareno jezgro ne pojavi ni na temperaturi od 450^0C za 120 minuta nataložena prašina se smatra bezopasnom.

Ispitivanjem uzetih uzoraka određena je temperatura paljenja nataložene prašine pod dejstvom konstantnog izvora, a rezultati su predstavljeni u tabeli 3.

Tabela 3. *Rezultati ispitivanja karakteristika ugljene prašine iz jama RMU „Rembas“*

Karakteristika	Vrednosti za rudnike			
	S. Rudnik	Jelovac	Strmosten	Ravna reka
Temperatura paljenja pod dejstvom konstantnog izvora toplote (°C)	250-290	270-280	280-290	-
Temperatura paljenja oblaka prašine (°C)	500-620	505-610	550-610	490-510
Donja granica eksplozivnosti prašine (g/m^3) u sistemu:				
• prašina – vazduh	200	300	330	-
• prašina – vazduh-2% CH_4	125	200	200	100

3. ODREĐIVANJE TEMPERATURE PALJENJA UGLJENE PRAŠINE

Temperatura paljenja predstavlja minimalnu temperaturu izvora paljenja, koja je u stanju da kod momentalnog dodira upali smešu prašina-vazduh. Ovaj parametar određuje se po takozvanoj metodi Godberg-Grenwald čiji je princip da se odredi najniža temperatura pri kojoj uz trenutan dodir prašina-vazduh se zapali.

Aparatura za ovo ispitivanje se sastoji od komore (tkz. Godberg-Grenwald-ova peć) u kojoj se stvara oblak prašine i izaziva njegovo paljenje, pomoću generatora varnice određene energije i učestalosti..

Pre početka ispitivanja vrši se priprema uzoraka prašine i određivanje granulacije i vlažnosti prašine. Prašina se uniformno raspršuje u komori pod određenom temperaturom i pritiskom a zatim se stvara varnica na elektrodama pražnjenjem kondenzatora.

Pri ispitivanjima količina prašine varira od 0,2 – 1g, a pritisak vazduha od 1,1 – 1,6 bara. Prašina čija je temperatura paljenja iznad 850^0C, smatra se bezopasnom u pogledu zapaljivosti.

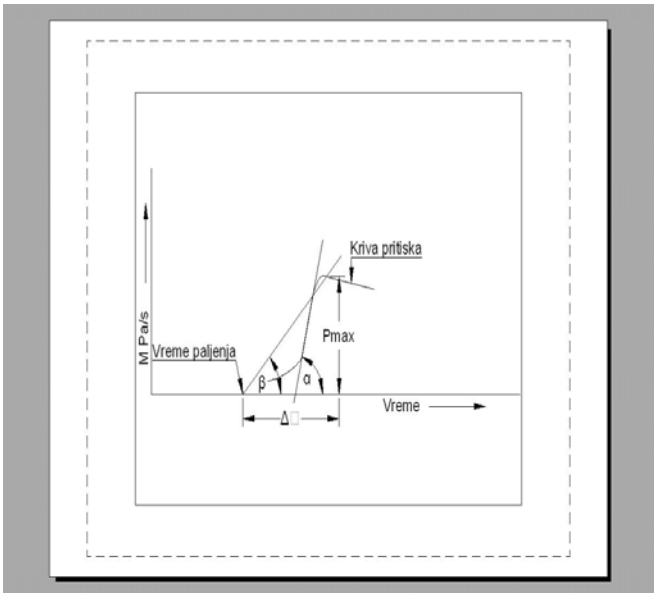
U jamama RMU „Rembas“ uzeti su uzorci prašine i izvršeni opiti paljenja u laboratoriji u cilju određivanja temperature paljenja, a dobijeni rezultati predstavljeni su u tabeli br. 4.

4. ISPITIVANJE EKSPLOZIVNOSTI UGLJENE PRAŠINE

Faktori koji utiču na eksplozivnost ugljene prašine su: hemiski sastav prašine, izvor paljenja, gustina oblaka prašine, sadržaj volatila, stepen disperznosti, vlaga i sadržaj pepela.

Uzorci ugljene prašine za ispitivanje pripremaju se ili iz ugljenog sloja u laboratoriji ili uzimanjem uzoraka nataložene prašine u rudarskim prostorijama. Nakon laboratorijskih ispitivanja fizičkih i hemiskih svojstava vrši se ispitivanje toka eksplozije u laboratorijskim uslovima, a često i u ispitnom rovu, pri čemu se ispituje sposobnost eksplozije smeša prašina-vazduh i prašina – vazduh -2% CH_4.

Područje ispitivanja u posebnoj komori sa upaljačem je obično od 70 – 1500 g/ m^3. Pomoću kvarcnog prijemnika pritiska i elektronskog uređaja vrši se snimanje toka eksplozije. Za obračun parametara eksplozije koristi se kriva eksplozivnog pritiska, (slika 1.).



Sl. 1. *Kriva eksplozivnog pritiska*

Eksplozivna karakteristika (E_k) definiše se kvadratnim korenom iz proizvoda srednjeg i maksimalnog vremenskog porasta pritiska i računa se po obrascu:

$$E_k = \sqrt{\left(\frac{d_p}{d\tau}\right) max \cdot \frac{P_{max}}{\Delta\tau}} \quad \text{(MPa/s)}$$

$\left(\frac{d_p}{d\tau}\right)_{max} = tg\alpha$ - maksimalni vremenski porast pritiska (MPa/s)

$\frac{P\,max}{\Delta\tau} = tg\beta$ - srednji vremenski porast pritiska (MPa/s)

P_{max} - maksimalni eksplozivni nadpritisak (MPa)

Na osnovu ovako dobijenih podataka konstruiše se E_k – q dijagram važan za određivanje donje granice eksplozivnosti, koja predstavlja minimalnu koncentraciju ugljene prašine u vazduhu q (g/m^3) pri kojoj počinje opasnost od procesa eksplozije.

Dobijeni rezultati ispitivanja donje granice eksplozivnosti uzoraka nataložene ugljene prašine uzetih iz rudarskih prostorija u jamama RMU "Rembas" dati su u tabeli 3.

5. ZAKLJUČAK

Predmet istraživanja obrađen u ovom radu je ugroženost jama RMU "Rembas" eksplozivnom i zapaljivom prašinom i obuhvatio je rezultate ispitivanja u laboratorijskim uslovima. Rezultatima ispitivanja je potvrđeno da je ugljena prašina u sve četiri jame pod određenim uslovima eksplozivna i zapaljiva i da je neophodno preduzimanje aktivnih mera zaštite od ovih opasnosti Nesumljivo je potvrđeno da se kontroli nastajanja i merenja koncentracije nataložene prašine mora dati adekvatan značaj, i dati prednost nad metodologijom merenja koncentracija lebdeće prašine u vazduhu rudarskih prostorija.

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TESTING THE FLAMMABLE AND EXPLOSIVE OF COAL DUST IN THE PITS OF THE BROWN COAL MINE "REMBAS" RESAVICA

Abstract

Coal dust in the underground mines, depending on specific conditions is a complex problem with the security of the population of underground mining facilities as it can express the explosive, flammable and aggressive properties.

Explosions of coal dust have much larger and more serious consequences than it is the case with the explosion of gas mixtures. According to risks, an adequate importance has to be paid to the issue of protection on dangerous properties of the coal dust in the all underground coal mines in Serbia.

This paper deals with the results of flammable and explosive properties of coal dust in the pits of BCM "Rembas" and it gives a solution of the modified methodology of dust control and danger evaluation.

***Keywords**: coal, coal dust, explosive dust*

1. INTRODUCTION

By its nature, the coal dust in the underground mines can express flammable, explosive and aggressive properties. Aggressive properties of dust can still be very successful stand up while explosive and flammable properties of seeking special treatment from the beginning to eliminate hazards and prevent the spread of the shock wave. Coal dust occurs in all stages of technological process and, carried by the air stream, is deposited along the mine rooms. The explosion of coal dust, which has explosive properties by its nature, comes to coincide at given time with number of factors:

- Swirling state of dust with suitable dispersive composition and content of combustible substances,
- Mixtures of dust and air in proper proportions,
- A source of ignition dust-air mixtures or dust-air-methane.

In the process of coal dust ignition and explosion, high temperature and large amounts of heat are developed, what causes high pressure in the part of underground mine atmosphere, affected by explosion. Developed pressures cause strong and devastating air strikes, which among other properties cause a strong swirling of

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dust, and the shocks occur giving the ignition chain and explosion of coal dust in the underground rooms.

All of this takes place very rapidly and transforms the ignition chain into a single process of ignition and explosion of coal dust in the affected area. This requires the necessary restricting measure of eventually caused explosion in the certain part of the pit.

Cases of coal dust explosions with disastrous consequences that occurred in some mines in former Yugoslavia led to a special attention in struggle with the problem of coal dust and research in this area.

According to the standards, the starting point of investigation the inflammable properties is the combustible volatile matter content of the coal seam. This content is treated variously in the regulations of many countries. Some set the limits at 10, 12 or 14%, according to our regulations, the limit is 14%. Deposited dust that is endangered by explosive coal dust is harmless, if it contains:

a. incombustible substances in quantity higher than 70% of non-methane facilities, and 80% of methane facilities,
b. free moisture in a quantity that prevents transmission of the explosion that completely prevents swirling the coal dust. Minimum free moisture content is determined by the formula:

$$W = \frac{70 \times d + 2440}{d + 70} - 0.63 \times n(\%)$$

W - free moisture, which ensures that coal dust cannot float (%)

d - dust content of the fraction below 70

n - content of combustible particles in coal dust (%)

Grain size distribution affects the properties of explosive mixtures of dust - air, with the most important part of particles below 75 micrometers or less. They first accept the flame, inflammation, develop heat, which takes on coal and other dust, and thus comes to full blast.

In the pits Strmosten, Senjski Mine, Jelovac and Ravna Reka BCM "Rembas" - Resavica the seams of quality blown coal are mined in which the volatile matter content is significantly above the limit of 14% so that the prescribed done research and studies which showed that the coal tends the process of combustion, and coal dust in the certain circumstances shows explosive and flammable properties.

According to the above hazards, the certain protective measures are prescribed and implemented against this potential threat.

2. DETERMINATION THE COAL TENDENCY TO SELF-IGNITION

Coal is chemically very complex matter where coals from various deposits can have very different composition. This affects that the process of endogenous oxidative processes is intensively studied and researched. In a series of theoretical considerations the self-ignition, the pyrite-sulfide, bacterial and phenol oxidation theory are distinguished.

Today, in the mining science, the priority importance is given to the oxidation theory, which interprets the self-ignition as the sorption process of O_2 in a number of characteristic phases or periods.

For testing the natural tendencies of coals to spontaneous combustion, about 20 procedures have been developed in the world, with generally accepted as follows: the Makni, Skočinski, Olpinski and Halupova-Drebeka procedure.

In Serbia, the test of coal self-ignition is carried out using the Olpinski method, by which the basic meaning of self-ignition is the coal ability to sorb oxygen with heat extraction. Sorption properties of coal, and hygroscopic moisture undoubtly accelerate the oxidation process.

It is also likely to influence the process of electrochemical oxidation of coal flow process.

Under the indicator of coal self-ignition (Szb) means the rate of temperature rise of coal in the limited time and specific measurement conditions.

In the capacity of the auto ignition of the coal layer is applied to the indicator corresponding to the ignition of coal Szb indicator, recalculated to the fuel mass. Under this methodology, coals are classified into four categories - groups:

Table 1. *Categories of coal tendency to the selg-ignition per the Olpinski method*

SELF-IGNITION	CATEGORY-GROUP	SZ	Szb (°C/min)
Very prone	I	above	120
PRONE	II		100-120
Moderately prone	III		80-100
Not prone	IV	below	80

Coal samples in all four pits were taken at the excavation sites and preparation sites and the natural index of self-ignition was determined in the laboratory, with the results given in Table 2.

Table 2. *Test results of natural self-ignition index of coal from the pits of BCM "Rembas"*

MINE	NATURAL INDEX Szb (°C/min)	GROUP
Senjski Mine	118-140	Very prone
Jelovac	108-111	Prone –II
Strmosten	110-120	Prone – II
Ravna Reka	80-100	Moderately prone III

The risk of fire development, resulted due to the ignition of coal dust on hot surfaces in the mines, is a real danger. Self-ignition process generated by the deposition of dust in the thermal conditions occurring as a partial thermal insulator, preventing heat dissipation accumulated on hot surfaces, and the resulting enhancement of oxidation.

The smolder indicator is obtained the lowest temperature is determined at which the certain height of accumulated dust can ignite.

Determination smolder temperature is done by heating body that has the ability to change temperature and measuring equipment. A sample of coal dust, height 5 mm is positioned on a heating body starting from 200°C and the time to the appearance of red-hot core is measured such as the temperature increases for 10°C, and the experiment is repeated successively until the appearance of re-hot. If the red-hot core does not appear at temperature of 450°C for 120 min, the deposited dust is considered as harmless.

Ignition temperature of deposited dust under the influence of constant source was determined by testing the taken samples, and the results are present in Table 3.

Table 3. *Testing results of coal dust characteristics from the pits of BCM "Rembas"*

CHARACTERISTICS	VALUES FOR MINES			
	Senjski Mine	**Jelovac**	**Strmosten**	**Ravna Reka**
Ignition temperature under the influence of constant heat source (^oC)	250-290	270-280	280-290	-
Ignition temperature of dust cloud (^oC)	500-620	505-610	550-610	490-510
Lower explosion limit of dust (g/m^3) in the system:				
• dust – air	200	300	330	-
• dust – air - 2% CH_4	125	200	200	100

3. DETERMINATION THE IGNITION TEMPERATURES OF COAL DUST

Ignition temperature is the minimum temperature of ignition source, which is capable of immediate contact with the fallen dust-air mixture. This parameter defines the so-called method Godberg-Grenwald whose principle to determine the lowest temperature at which the current touch-air dust ignited.

Apparatus for this test consists of a chamber (tkz. Godberg-Grenwald's patch), which creates a cloud of dust and causes it to ignition, spark generator with a certain energy and frequency.

Before the start of the test is performed sample preparation and determination of the dust grain of dust and moisture. Dust is uniformly dispersed in the chamber under a certain temperature and pressure and then creates a spark discharge on the electrodes of capacitors.

During the testing the amount of dust varies from 0.2 - 1 g, while the air pressure of 1.1 to 1.6 bar. Dust with a flash point above 850° C, it is considered harmless in terms of flammability.

In the pits RMU "Rembas" samples of dust and ignition experiments performed in the laboratory to determine the ignition temperature, and the results are presented in Table. 3.

4. TESTING THE EXPLOSIVNESS OF COAL DUST

Factors that affect the explosiveness of coal dust are: chemical composition of dust, ignition source, density of dust cloud, content of volatiles, dispersion degree, moisture and ash content.

Coal dust samples for testing are prepared both from coal seams in the laboratory or sampling of deposited dust in the mining areas. After laboratory testing of physical and chemical properties, the explosion flow is tested in laboratory conditions, and often in a test trench, with testing the capability of explosion the mixtures dust-air and dust - air 2% CH_4.

Testing area in a special chamber with a lighter is usually 70 - 1500 g/m^3. Recording of explosion flow is done using the quartz pressure transducer and electronic device. Curve of explosive pressure is used for calculation the explosion parameters (Figure 1).

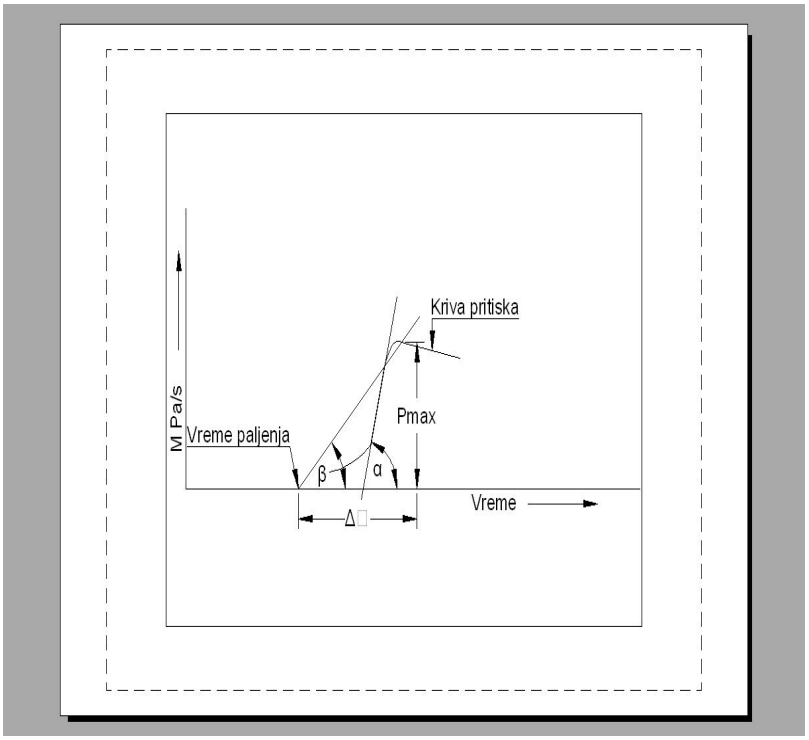

Fig. 1. *Explosive pressure curve*

The explosive characteristic (Ek) is defined by the square root of product of medium and maximum pressure time rise and it is calculated by the formula:

$$E_k = \sqrt{\left(\frac{d_p}{d\tau}\right) max \cdot \frac{P_{max}}{\Delta\tau}} \text{ (MPa/s)}$$

$\left(\frac{d_p}{d\tau}\right)_{max} = tg\alpha$ maximum amount of pressure time rise (MPa/s)

$\frac{P\,max}{\Delta\tau} = tg\beta$ intermediate pressure time rise (MPa/s)

P_{max} maximum explosive overpressure (MPa)

Based on the obtained data, a diagram Ek - q is constructed, relevant to determination the lower explosion limit, which represents the minimum concentration of coal dust in the air q (g/m^3) at which the process begins with a risk of explosion.

The obtained results of the lower explosion limit of deposited coal dust samples, taken from the mining facilities in the pits of BCM "Rembas" are given in Table 3.

5. CONCLUSION

The case study discussed in this paper is a threat in pits of BCM "Rembas" by explosive and flammable dust and it included the results of tests under laboratory conditions. Test results confirmed that the coal dust in all four pits under certain conditions, explosive and lammable and it is necessary to

take active measures against these dangers. Undoubtedly, it was confirmed that the control of generation and measurement of accumulated dust must be given adequate importance, and an advantage over methodology of measuring the concentration of airborne dust in the air of mining facilities.

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PROSTORNI REFERENTNI SISTEMI

Izvod

Geoprostorni podaci dobijeni iz različitih izvora moraju biti referencirani na isti geodetski datum i koordinatni sistem. Usvajanje zajedničkog prostornog referentnog sistema olakšava ažuriranje i geometrijsko uskladjivanje, pristup, razmenu i korišćenje geoprostornih podataka. Horizontalni i vertikalni položaji tačaka danas nisu više dve nezavisne komponente. Razvoj GPS tehnologija omogućio je njihovu integraciju u jedinstveni 3D datum. Geodetski datum predstavlja osnovu za definisanje prostornog referentnog sistema. Referentni sistem je skup fundamentalnih tačaka na površini Zemlje sa poznatim koordinatama. Internacionalni Terestički Referentni Sistem (ITRS) je najprecizniji globalni referentni sistem širom Evrope. Ovaj referentni sistem predstavlja kičmu svih geografskih i geodinamičkih projekata na teritoriji Evrope, i na nacionalnom i na međunarodnom nivou.

Keywords: *GIS, geoinformatika, geodetski datum, prostorni referentni sistemi, geoprostorni podaci*

1. UVOD

Osnovno svojsto geopodataka predstavlja njihova prostorna referenca. Prostorni položaj definisan je u odnosu na fizičku površ Zemlje. Prvi problem koji se pri tome javlja predstavlja aproksimacija. Naime, Zemlja kao nebesko telo može se posmatrati sa dva aspekta: fizičkog i matematičkog. Sa aspekta fizičkog modela Zemlja se može posmatrati kao ***geoid***-nulta ekvipotencionalna površ, pogodna za definisanje visinskog datuma. Matematički modeli koji mogu biti korišćeni za aproksimaciju geoida su sfera (lopta) i sferoid (rotacioni elipsoid) i ovakva interpretacija omogućuje definisanje prostornog položaja tačaka. Medjutim, danas u svetu vlada veliko šarenilo u izboru elipsoida, fundamentalnih tačaka i početnog meridijana. Definisano je nekoliko stotina elipsoida u zavisnosti od raspoložive tehnologije merenja, područja na planeti (npr. Severna i Južna Amerika, Evropa, Afrika), opsega kartiranja (država, kontinent ili ceo svet) i političkih pitanja (npr. Varšavski pakt vs. NATO). Pored toga, početni geopodaci zamenjuju se novoodredjenim, menjaju se fundamentalne tačke, vrše se naknadna ili potpuno nova izravnanja geodetskih mreža.

2. GEODETSKI DATUM

Geoprostorni podaci dobijeni iz različitih izvora moraju biti referencirani na isti geodetski datum i koordinatni sistem. Geodetski datum predstavlja skup parametara

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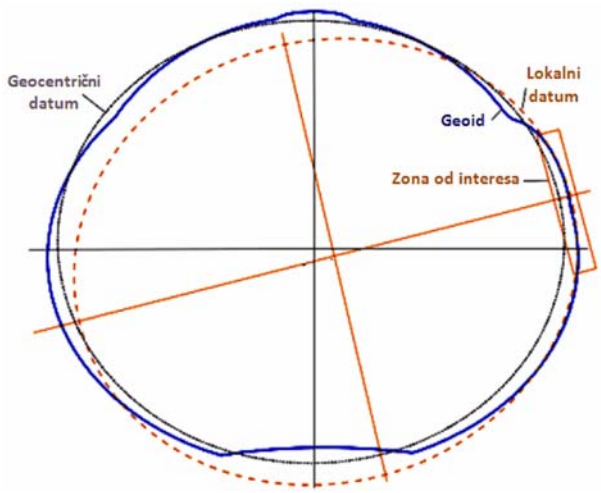
koji definišu koordinatni sistem, uključujući elipsoid i položaj centra elipsoida u odnosu na centar Zemlje i orijentacija u odnosu na Zemljinu osu rotacije. Geodetski datum je bilo koja numerička ili geometrijska vrednost, ili skup takvih vrednosti, koje se koriste kao osnova za računanje drugih vrednosti. Termini elipsoid i datum koriste kao sinonimi. Sve horizontalne i vertikalne pozicije tačaka su relativne u odnosu na odredjeni geodetski datum.

Horizontalni datum čini obrtni elipsoid koji aproksimira Zemljin oblik i skup konstanti i uslova koje odredjuju njegovu veličinu, položaj i orijentaciju. Ukoliko se geodetskim datumom aproksimira deo Zemljine površi on se naziva lokalni datum ili regionalni datum, a ukoliko se predstavlja čitava Zemlja onda se on naziva globalni datum ili geocentrični datum. *Lokalni geodetski datum* bira se tako da najbolje aproksimira neku konkretnu lokalnu fizičku površ Zemlje i obično se definiše sa sedam parametara:

- dva elementa definišu geometriju elipsoida;
- geografskom širinom i dužinom ishodišne tačke;
- referentnim azimutom orijentacije;
- geoidnom visinom ishodišne tačke (obično se uzima srednja vrednost nivoa mora);
- pretpostavkom o paralelnosti male poluose elipsoida i ose Zemljine rotacije.

Tokom istorije mnoge države usvajale su i koristile lokalne elipsoide koji su najbolje odgovarali obliku Zemlje u tim oblastima. Na taj način je obezbedjena visoka lokalna tačnost, ali su praktični problemi nastajali kada je trebalo integrisati ili razmenjivati geoprostorne informacije izmedju različitih oblasti. Sve do 1950. god. u Evropi je vladalo veliko šarenilo u smislu uspostavljenih geodetskih sistema. Praktično, svaka država imala je vlastitu fundamentalnu tačku i orijentaciju sistema uz korišćenje različitih elipsoida. Prvi zvaničan pokušaj objedinjavanja nacionalnih geodetskih datuma na tlu Evrope vezan je za uspostavljanje European Datum 1950-ED50, na Hejfordovom elipsoidu. Nakon ED50 usledili su Evropski datumi iz 1979. god. (ED79) i 1987. godine (ED87) i European Terrestrial Reference System 1989-ETRS89. Usvajanje zajedničkog referentnog sistema olakšava ažuriranje i geometrijsko uskladjivanje, pristup, razmenu i korišćenje geoprostornih podataka. GPS tehnologija (eng. Global Positioning System) obezbedjuje geodetske položaje tačaka u prostornom geocentričnom sistemu WGS84. Veštački sateliti u svom radu „prepoznaju“ Zemlju kao monolitno telo. S obzirom da se sateliti kreću po putanjama oko centra mase Zemlje, položaj zasnovan na takvim tehnologijama logično počiva na vektorima sa ishodištem u geocentru. Zato je bilo neophodno definisati koordinatni sistem u kojem će se takvi vektori opisati.

Iz tih razloga definisan je elipsoid Geodetic Reference System-GRS80, koji bi najpribližnije opisao Zemlju kao celinu, i kao takav bio osnova za formiranje geocentričnog datuma. Iako generalno, niti GRS80, niti WGS84 (eng. World Geodetic System 1984), nisu najpogodniji ni za jednu konkretnu oblast, potreba za idealnim poklapanjem nestaje u situaciji kada globalna merenja u kombinaciji sa računarima, bazama podataka i softverima lako regulišu rezultate za lokalne uslove. Svaki datum se popravlja tokom vremena kako merenja postaju preciznija.

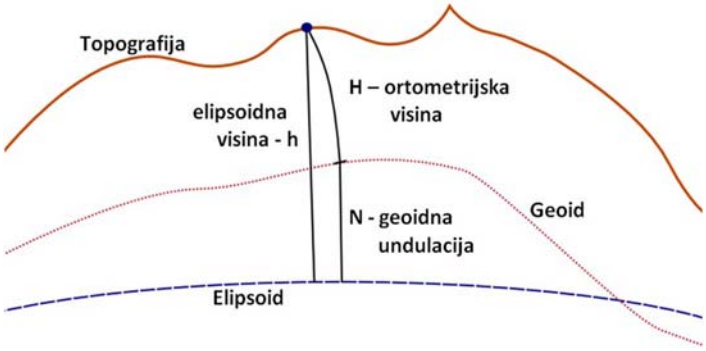


Sl. 1. *Lokalni i geocentrični datum*

Vertikalni datum se definiše kao referentna površ u odnosu na koju se odnosi usvojeni sistem visina. Tradicionalne geodetske metode koriste nivelman za merenje visina u odnosu na srednji nivo mora (različit je u zavisnosti od države ili lokacije). Nivelman prati geoid, tako da su visine izražene u odnosu na geoid. Referentna površ (datum) visina dobijenih geometrijskim nivelmanom jeste površ geoida. Visina definisana u odnosu na nultu nivosku površ odnosno geoid naziva se nadmorska ili *ortometrijska visina* (H). Za računanje ortometrijskih visina, pored visinskih razlika duž putanje nivelanja, meri se i ubrzanje sile Zemljine teže.

Korišćenjem veštačkih Zemljinih satelita dobijen je veliki broj informacija o obliku Zemlje i njenom gravitacionom polju, što je značajno uticalo na definisanje površi geoida. Kada se želi uprostiti opis geoida često se kaže da se poklapa sa idealnom površi mora i okeana (idealna površ u smislu zanemarivanja uticaja, osim uticaja gravitacije, kao što su: morske struje, plimatski poremećaji, promene temperature i sl.). Takvu definiciju geoida prvi je dao J. B. Listing još 1872. godine. Medjutim, navedene pojave realno utiču na srednji nivo mora u odnosu na koju površ geoida varira od 1 do 2 m (Sickle, 2001), tako da jedna takva definicija više nije realno održiva. Gravitaciona sila nije konzistentna duž topografske Zemljine površi. U svakoj tački Zemljine površi ona ima svoj pravac i intenzitet, tj. može se vektorski opisati, a njene vrednosti na različitim mestima topografske površi su različite. Površ jednakog gravitacionog potencijala može se samo zamisliti. Jedna takva ekvipotencijalna površ bila bi u pravom smislu nivoska površ. Iako srednji nivo mora ne može definisati takvu površ, ona nije čisto imaginarna kategorija. Površ geoida nije matematički regularna kao što nije ni topografska Zemljina površ. Ona je negde izdignuta a negde ulegnuta. Uzroci takvog oblika geoida su različiti, a jedan od najznačajnijih je svakako i neravnomeran raspored Zemljinih masa u njenoj unutrašnjosti. Da nije tako, njegov oblik bi bio vrlo blizak elipsoidnom. Medjutim, kao i sama Zemljina površ, fizička površ geoida odstupa od elipsoidne na nekim mestima i do 100 m. Visine koje se dobijaju GPS merenjima odnose se na površ elipsoida Geodetic

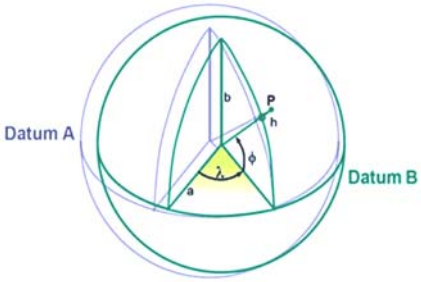
Reference System, GRS80 nazivaju se *elipsoidnim visinama* (h). Razlog za teškoće u prelazu iz geometrijskih-elipsoidnih u ortometrijske visine leži u neregularnom obliku geoida. Razlike ortometrijskih i elipsoidnih visina koje se odnose na geocentrični elipsoid GRS80 iznose od +85 m do -106 m. U Republici Srbiji, ova razlika iznosi oko + 40 m (razlike su pozitivne ukoliko je geoid iznad elipsoida). Razlika površi elipsoida i geoida naziva se *geoidna undulacija* (N) ili geoidalna visina (eng. geoidal height).



Sl. 2. *Odredjivanje ortometrijskih visina.*

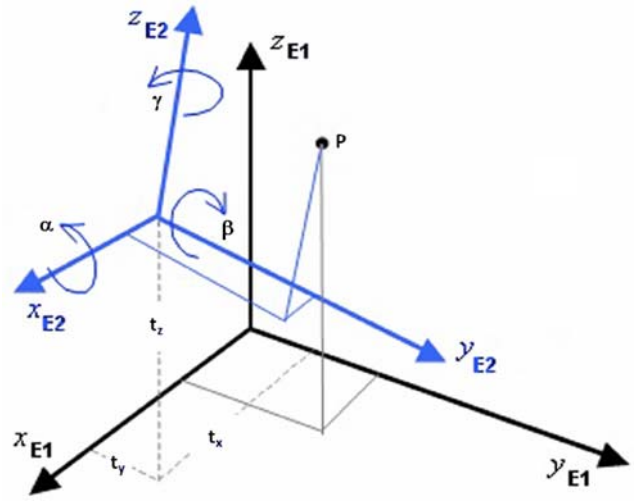
3. DATUMSKA TRANSFORMACIJA

Jedna od osnovnih karakteristika prostornih podataka jeste prostorna veza (eng. spatial reference). Ukoliko su za prostorne entitete vezani ovi podaci, moguće je kombinovati ih čak iako su u različitim koordinatnim sistemima ili projekcijama. Najčešće korišćene koordinate tačaka su one koje se odnose na neki lokalni (referenc) elipsoid, koji definiše datum lokalnog (negeocentričnog) sistema npr. državni koordinatni sistem ili dvodimenzionalne koordinate u ravni kartografske projekcije. Ukoliko je potrebno tačku iz jednog koordinatnog sistema prikazati u drugom koordinatnom sistemu potrebno je izvršiti datumsku transformaciju. Datumska transformacija (eng. datum transformations) konvertuje koordinate tačke date u koordinatnom sistemu Datuma A u koordinate u koordinatnom sistemu Datuma B (slika 3).



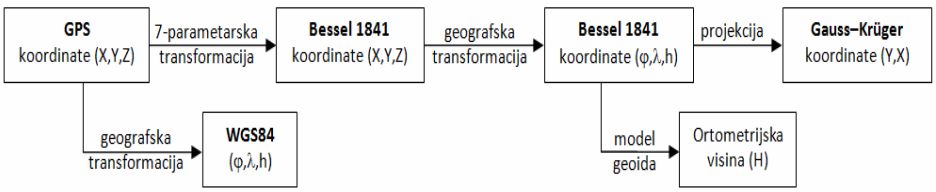
Sl. 3. *Datumska transformacija.*

Da bi se ova dva koordinatna sistema (E1 i E2) poklopila potrebno je jedan od njih (E2) rotirati oko sve tri ose, promeniti mu razmeru i pomeriti ga u prostoru (slika 4). Skup parametara koji definišu datumsku transformaciju nazivaju se transformacioni parametri. Za transformaciju je potrebno poznavati sedam parametara (3 translacije, 3 rotacije i parametar razmere), pa se naziva sedmo-parametarska datumska transformacija (eng. seven-parameter transformation), ili Helmertova transformacija (eng. Helmert transformation).



Sl. 4. *Sedmo-parametarska datumska transformacija.*

Ako dve tačke iz dva različita koordinatna sistema imaju pridruženu prostornu referencu, odnosno ako su poznati projekcija sa svojim parametrima, elipsoid na koji se projektuje, kao i odnos prema referentnom koordinatnom sistemu, moguće je zajedničko korišćenje podataka. U Gauss-Krigerovoj projekciji koordinate tačke se dobijaju projekcijom sekućeg poprečnog cilindra na Bessel 1841 elipsoid, dok se koordinate merene GPS-om odnose na WGS84 elipsoid. Pored toga što se za Bessel 1841 elipsoid i WGS84 razlikuju parametri elipsoida (velika i mala poluosa i spljoštenost), razlikuju se i koordinatni sistemi u koji su ova dva elipsoida smešten. Na teritoriji Republike Srbije koristi se WGS84 elipsoid uz odgovarajuće parametre za transformaciju. Parametri za transformaciju omogućuju direktan prelaz sa WGS84 na Beselov elipsoid. Datumska transformacija omogućava da se koordinate tačke date u WGS84 konvertuju u koordinate na Bessel 1841 elipsoid (Gaus-Krüger-ov koordinatni sistem):



Za potrebe prikazivanja tačaka na kartama koje su u nekoj projekciji ili upoređivanja podataka sa podacima koji su dati u drugom koordinatnom sistemu, potrebno

je definisati: parametre datumske transformacije (ukoliko datum koordinatnog sistema karte nije WGS84), parametre projekcije i model geoida.

Za precizno odredjivanje nadmorske visine potrebno je poznavanje modela lokalnog geoida, koji za Republiku Srbiju nije definisan, pa se koristi globalni EGM96 (eng. Earth Gravitational Model 1996).

4. PROSTORNI REFERENTNI KOORDINATNI SISTEMI

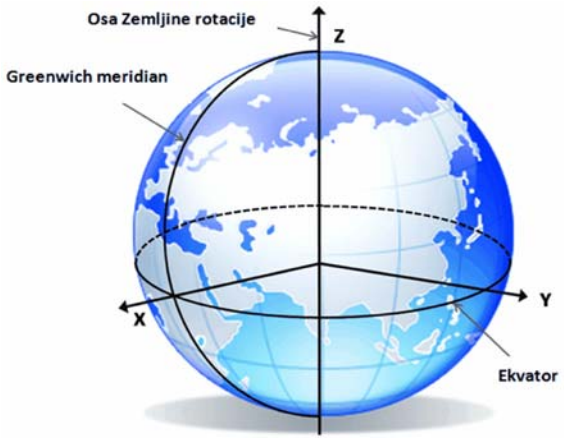
4.1. International Terrestrial Reference System - ITRS

Koordinatni sistem je uvek definisan u odnosu na neki geodetski datum. Kako GPS odredjuje koordinate tačaka na Zemlji, to znači da se za njihov prikaz mora koristiti koordinatni sistem vezan za Zemlju. Takav sistem poznat pod nazivom Conventional Terrestrail Reference System-CTRS), nadgledan je od strane International Earth Rotation and Reference Systems Service-IERS). CTRS se naziva International Terrestrial Reference System - ITRS.

ITRS obrazuje set pravila i konvencija koja su, zajedno sa modelovanjem, potrebna za definisanje početne tačke, razmere, orijentacije i vremenske evolucije CTRS. Prema Rezoluciji broj 2. International Union of Geodesy and Geophysics-IUGG, usvojenoj u Beču 1991. godine, ITRS predstavlja skup tačaka sa njihovim 3D koordinatama koje realizuju idealan referentni sistem. ITRS je realizovan korišćenjem International Terrestrial Reference Frame ITRF97, baziranog na prognoznim koordinatama i brzinama grupe stanica koje su opažane korišćenjem različitih metoda: GPS Global Positioning System), VLBI (Very Long Baseline Radio Interferometry), LLR (Lunar Laser Ranging), SLR (Satellite Laser Ranging) i DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite). ITRS se može povezati na International Celestial Reference System-ICRS, korišćenjem IERS Zemaljskih orijentacionih parametara EOP (eng. Earth Orientation Parameters).

Osnovne karakteristike ITRS su:

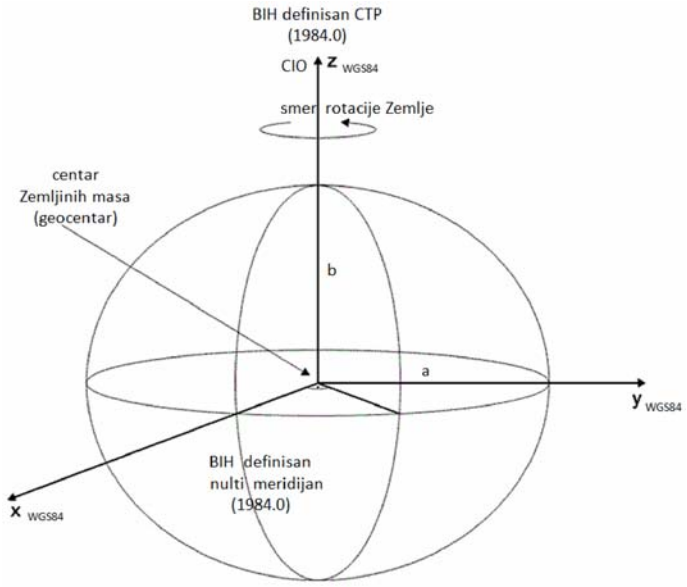
- Koordinatni početak ITRS poklapa se sa centrom masa Zemlje (geocentar);
- X-osa, polazi od geocentra i prolazi kroz tačku preseka početnog Griničkog meridijana i ekvatora;
- Y-osa, polazi od geocentra i leži u ravni srednjeg položaja ekvatora i upravna je na X-osu;
- Z-osa, je usmerena u pravcu srednjeg položaja ose rotacije Zemlje definisane u periodu od 1900. do 1905. godine.



Sl. 5. *International Terrestrial Reference System – ITRS*

4.2. Svetski geodetski sistem 1984 WGS84)

Globalni geocentrični sistem zasnovan je na elipsoidu koji je 1979. prihvaćen je od strane IUGG i nazvan Geodetski referentni sistem GRS80 (eng. Geodetic Reference System 1980). Uz neznatne korekcije GRS80 je 1984. godine preinačen u Svetski geodetski sistem WGS84 (eng. World Geodetic System 1984). WGS84 je naziv elipsoida koji se koristi kao referentni koordinatni sistem. Nastao je modifikovanjem Navy Navigation Satellite System-NNSS) ili TRANSIT, Doppler Reference Frame (NSWC 9Z-2), tj. njegovog koordinatnog početka i razmere, kao i rotacijom kako bi se referentni meridijan složio sa BIH (eng. Bureau International de l'Heure) nultim meridijanom.



Sl. 6. *World Geodetic System 1984 - WGS84*

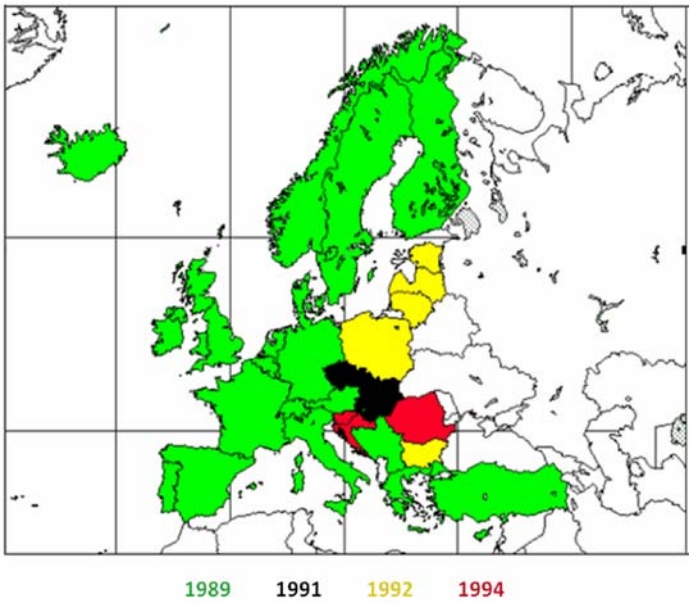
WGS84 je geocentrični koordinatni sistem čiji je centar u središtu Zemljanih masa, dok su koordinatne ose definisane tako da je:

- ZWGS84 osa usmerena prema srednjem položaju Severnog pola CTP (eng. Conventional Terrestrial Pole) od 1900. do 1905. za polarno kretanje, što je definisano od strane Internacionalnog biroa za vreme BIH (eng. International Time Bureau) na osnovu koordinata usvojenih za BIH stanice.
- XWGS84 osa u preseku ravni nultog referentnog meridijana koordinatnog sistema WGS84 i ravni ekvatora, definisane od strane Internacionalnog biroa za vreme, na osnovu koordinata usvojenih za BIH stanice;
- YWGS84 osa 90° istočno od X ose, formira desno orijentisan, geocentričan i geofiksiran ortogonalni koordinatni sistem ECEF (eng. Earth Centered, Earth Fixed), meren u ravni ekvatora.

4.3. Evropski referentni terestički sistem 1989 (ETRS89)

Godine 1987. International Association of Geodesy-IAG i CERCO (fran. Comite Européen des Responsables de la Cartographie Officielle) odlučili su da razviju novi EUropean REference Frame-EUREF, baziran na GPS tehnologiji. To je trebao da bude precizan i moderan sistem, kao WGS84 sistem, koji će omogućiti da se za medjunarodne digitalne kartografske podatke kao izvor ne koriste brojni nacionalni datumi širom Evrope. Pošto je krajem 80-tih godina prošlog veka ITRS (eng. International Terrestrial Reference System) bio najprecizniji globalni referentni sistem koji je bio dostupan, EUREF je odlučio da bazira svoj referentni sistem na ITRS-u, kojeg održava Medjunarodni servis za Zemljinu rotaciju i referentne sisteme IERS (eng. International Earth Rotation and Reference Systems Service).

Medjutim, u globalnom ITRS-u, tektonski pokreti kontinentalnih ploča uzrokuju pomeranja evropskih stanica, reda veličine oko 2,5 cm godišnje. Zbog toga je, na simpozijumu u Firenci 1989. godine EUREF oformila Evropski referentni terestički sistem ETRS89 (eng. European Terrestrial Reference System 1989).[2][3] ETRS89 je geocentrični terestrički referentni sistem sa početkom u centru mase Zemlje sa orijentacijom odnosno razmerom koordinatnih osa koji se podudaraju sa ITRS za epohu 1989. godine. ETRS89 je regionalni sistem koji pokriva područje Evrope i po definiciji je čvrsto vezan za Evropsku kontinentalnu masu sa kojom učestvuje u litosfernoj tektonici. Iz tog razloga su koordinate tačaka u odnosu na ETRS89 principijelno vremenski nepromenljive. ETRS89 je uveden zbog potreba objedinjavanja nacionalnih referentnih sistema za premer, kartiranje, razvoj GIS tehnologija i navigaciju u Evropi. ETRS89 je definisan sa tačnošću od 1cm. Zbog svoje geocentričnosti i poznate vremenske evolucije u odnosu na ITRS, sistem ETRS89 je pogodan za geodetsko korišćenje satelitskih tehnologija i sistema kao što su američki NAVSTAR, ruski GLONASS i budući evropski GALILEO. Koordinate u ETRS89 sistemu se izraža-vaju kao trodimenzionalne Kartezijeve koordinate (X, Y, Z), dok je za predstavljanje ETRS89 prostornih položaja tačaka i objekata u sistemu geografskih koordinata (φ, λ i h-elipsoidna visina), pridružuje elipsoid GRS80 (eng. Geodetic Reference System 1980) sa važnijim osnovnim i izvedenim geometrijskim parametrima.



Sl. 7. *Status ETRF-89/EUREF-01 Jan.1995. Izvor: Seeger (IfAG, Frankfurt)*

GRS80 elipsoid je po definiciji geocentričan i njegova mala poluosa podudara se sa trećom koordinatnom osom ETRS89 sistema, odnosno sa srednjom osom rotacije Zemlje. Prihvatanje sistema ETRS89 od strane različitih institucija (civilna avijacija, industrija, nacionalne i regionalne agencije) kao podstrek za georeferenciranje u Evropi je kontinuirani proces. Strukturu ETRF89 mreže čine: permanentne GPS stanice, operativni centri, lokalni i regionalni centri za obradu podataka, lokalni i regionalni centri za analizu i koordinator mreže (http://itrf.ensg.ign.fr/GIS/).

U Evropi postoje dve vrste permanentnih stanica, i to:

- IGS stanice uključene u IGS (eng. International GPS Geodynamics Service) mrežu;
- EUREF stanice (eng. EUREF Permanent Tracking Network) su GPS tačke koje su deo Evropskog IGS (eng. International GNSS Service), obuhvataju oko 200 GPS stalnih stanica, oko 16 centara za analizu kao i Centralni Biro EPN (eng. EUREF Permanent Network).

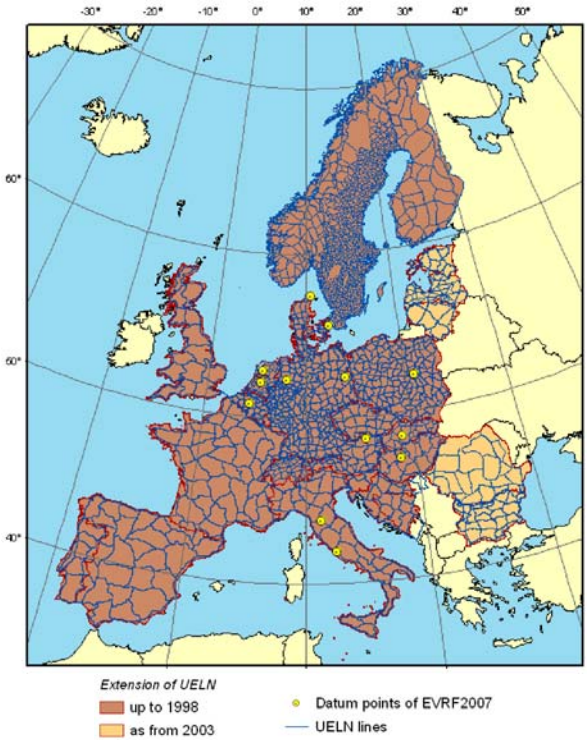
4.4. Evropski vertikalni referentni sistem (EVRS)

Referentni sistemi koji su do danas korišćeni u Evropi definisani su na sledeći način:

- za vertikalni datum usvojen je srednji nivo mora MSL (eng. Mean Sea Level);
- visina neke tačke definisana je geopotencijalnom kotom ili geopotencijalnom jedinicom, a na osnovu geopotencijalnih kota izvodile su se dinamičke, ortometrijske, normalne i sferoidne visine.

Nivelmanske mreže kreirane su na osnovu sledećih osnovnih postavki: srednji nivo mora (MSL) odredjen je korišćenjem mareografa, tačke mreže (reperi) stabilizovani su u geološki stabilnom terenu na medjusobnom rastojanju od 0,5 do 2 km, razlika potencijala odredjena je korišće-

njem rezultata merenja visinskih razlika i rezultata merenja ubrzanja Zemljine teže, reperi su povezani u nivelmanske linije, a povezivanjem više nivelmanskih linija formirani su poligoni. Navedene postavke su primenjene u svim državama Evrope a načini uspostavljanja i dizajn mreža zavisili su od geografskog položaja država, kao i od tehnološkog nivoa u trenutku kreiranja samih mreža.



Sl. 8. *Tačke za realizaciju datuma EVRS2007.*

Evropski vertikalni referentni sistem EVRS (eng. European Vertical Reference System) nastao je na osnovu zahteva Evropskog kartografskog komiteta CERCO (fran. Comité Européen des Responsables de la Cartographie Officielle) da se definiše i realizuje jedan vertikalni sistem na decimetarskom nivou (0,1 m) za celu teritoriju Evrope. Za realizaciju datuma usvojen je nulti nivo kroz Normalni Amsterdamski Reper (eng. Normal Amsterdams Peil, NAP) tako da je geopotencijalna kota za NAP jednaka nuli.

Ovakva realizacija datuma ima oznaku EVRF2000 (eng. European Vertical Reference Frame 2000). Često se koristi i oznaka EVRS2000, a za sve ostale relevantne parametre koristi se Svetski referentni geodetski sistem GRS80 (eng. Geodetic Reference System 1980).

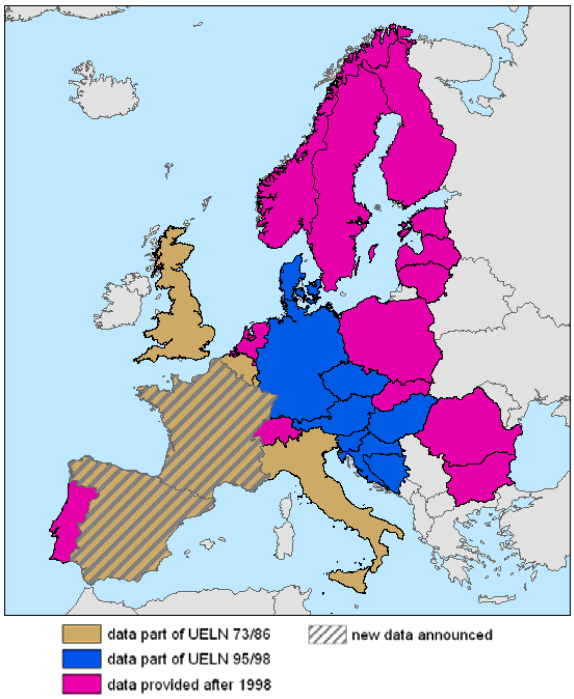
Usvajanje sistema 1995. godine predstavljalo je veliki napredak u formiranju modernog integrisanog referentnog sistema Evrope koji povezuje GPS koordinate, fizički definisane visine i visine iznad mora.

Kada je sistem i usvojen odlučeno je da se unutar sistema definišu visine iz geopotencijalnih kota u sistemu normalnih visina (Re-zolucija 2. Ankara, 1996). Na-

vedena realizacija datuma promenjena je 2007. godine uvodjenjem dodatnih datumskih tačaka pri čemu se menja i definicija i realizacija sistema (sada EVRS2007 i EVRF2007).

4.5. Ujedinjena evropska nivelmanska mreža (UELN)

Ujedinjena evropska nivelmanska mreža - UELN (eng. United European Levelling Network) predstavlja realizaciju sistema EVRS, a razvija se još od 1954. godine. Mreža je nastala kombinovanjem odredjenog broja linija nacionalnih nivelmanskih mreža prvog reda, a izravnanja se izvode još od 1954. godine. Do danas gotovo sve države Evrope su predale podatke u cilju uključenja u UELN.



Sl. 9. *Status proširene UELN mreže iz 1999. godine.*

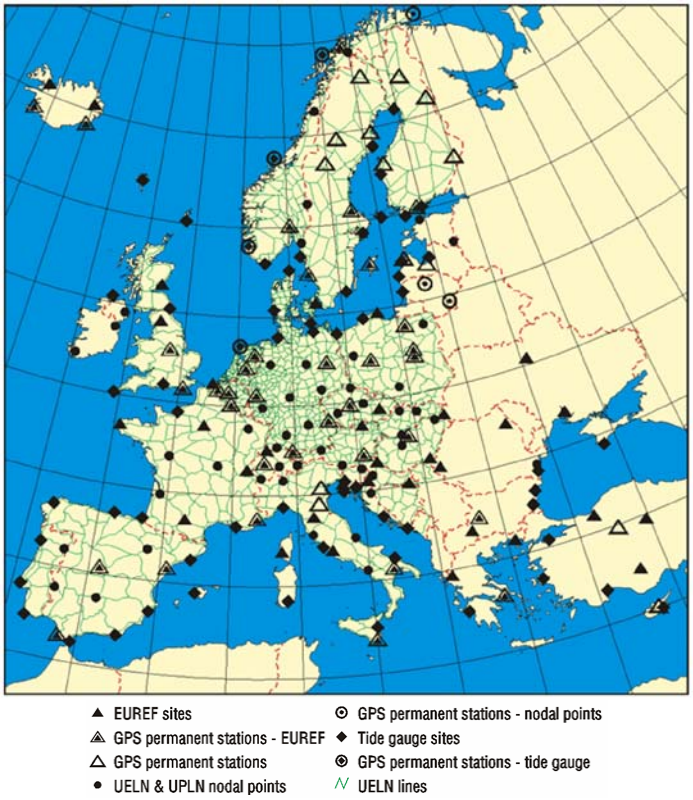
Prvo izravnanje iz 1955. godine (UELN55) oslonjeno je na NAP, a tačnost ocenjena iz izravnanja je bila ± 1,1 mm/km, pri standardnoj devijaciji u odnosu na NAP manjoj od ± 0,1 m.

Države koje participiraju u mreži neprekidno šalju podatke u Saveznu upravu za kartografiju i geodeziju u Lajpcigu - BKG (ger. Bundesamt für Kartographie und Geodäsie) koja je zadužena za obradu podataka. Kako su sve nacionalne mreže definisale svoje datume nezavisno, na osnovu srednjeg nivoa mora (MSL), definisanog korišćenjem mareografa na različitim morima i okeanima, visine u nacionalnim mrežama se medjusobno razlikuju.

4.6. Evropska ujedinjena vertikalna mreža (EUVN)

Projekat Evropske ujedinjene vertikalne mreže - EUVN (eng. European Vertical Reference Network) je projekat kojim rukovodi EUREF potkomisija. U samom početku EUVN je kreiran kao

dopuna UELN mreži u cilju medjusobnog povezivanja mareografa pri odredjivanju varijacija nivoa mora i uspostavljanju pouzdanog skupa tačaka za potrebe odredjivanja geoida Evrope, odnosno odredjivanja diskretnih vrednosti undulacija primenom metode satelitskog nivelmana (GPS/Δh). Drugim rečima, kreiranje EUVN je imalo za cilj da unificira različite datume u Evropi na nivou od nekoliko centimetara. Projektom je definisano da na svim tačkama EUVN moraju biti poznate pravougle geocentrične koordinate u sistemu ETRS89 i geopotencijalne kote, kao i visina tačaka u normalnom sistemu visina.



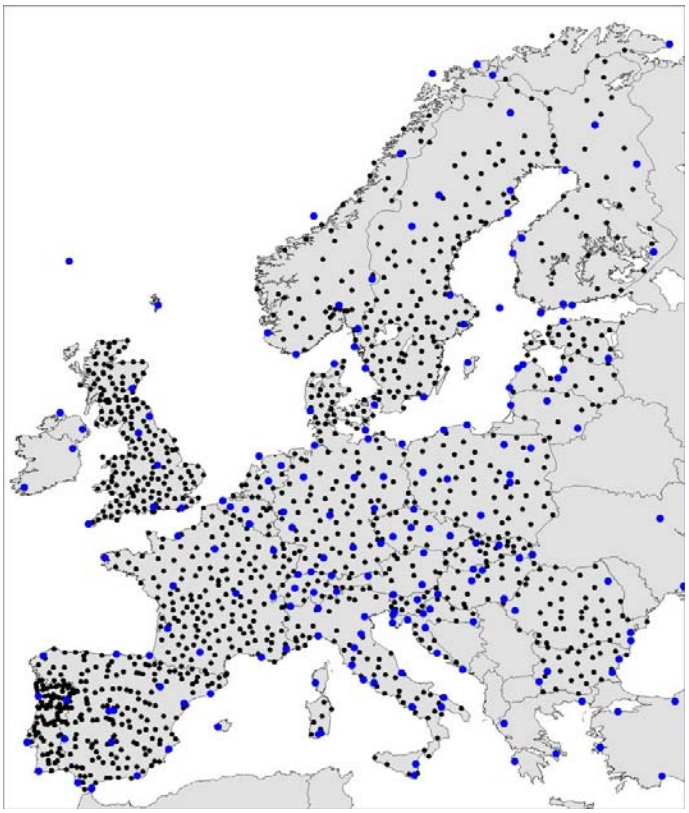
Sl. 10. *Prostorni raspored tačaka EUVN.*

Saglasno navedenom, može se reći da je na EUVN tačkama bilo neophodno odrediti elipsoidne visine primenom GPS, nivelanjem povezati EUVN i čvorne tačke UELN u cilju odredjivanja fizički definisanih visina, a pored toga neophodno i kontinuirano opažanje srednjeg nivo mora - MSL primenom mareografa. EUVN finalno sadrži 196 tačaka, pri čemu su elipsoidne visine odredjene u kampanji od 21. do 29. maja 1997. godine i oslonjene na ITRF96 epoha 1997.4.

4.7. Evropska ujedinjena vertikalna mreža (EUVN_DA)

Pored niza analiza koje su uradjene u okviru mreže EUVN izvršeno je uporedjenje evropskog geoida, koji je odredjen u okviru

Evropskog projekta za ubrzanje Zemljine teže i odredjivanje geoida-EGGP (eng. European Gravity and Geoid Project). Navedenim uporedjenjem pokazano je da se diskretne vrednosti undulacija razlikuju od EGG97 geoida za max. 20 cm. Kako je broj tačaka EUVN izuzetno mali u odnosu na površinu Evrope i kako tačke nisu adekvatno rasporedjene za odredjivanja geoida na nivou od nekoliko centimetara, pokrenuta je inicijativa da se EUVN progusti - EUVN_DA (eng. European United Vertical Network - Densification Action).



Sl. 11. *Evropska ujedinjena vertikalna mreža EUVN_DA.*

Gotovo sve države Evrope participirale su u projektu i trenutno se raspolaže sa 1495 diskretnih vrednosti undulacija. Analize podataka i uporedjenje sa geoidom EGG07 ukazuju na razlike ispod 10 cm, što je za 50 % bolje od prethodnog rešenja (EGG97/EUVN_DA). Pored navedenog uočena su neslaganja sistematske prirode na teritoriji Italije i Velike Britanije.

Svaka država koja želi da participira u projektu mora slediti sledeće standarde: buduće tačke EUVN_DA moraju biti na medjusobnom rastojanju od 50 do 100 km, reper koji pripada UELN mreži mora biti udaljen od odabranih tačaka maksi malno 10 km, pri odabiranju tačaka prednost dati reperima nacionalne mreže koja participira u UELN, elevaciona maska pri

GPS merenjima mora biti 15 stepeni, referentni sistem mora biti ETRS89 ili mora biti definisana epoha ITRF, poželjna su GPS opažanja sa sesijama od 24 časa, razlike potencijala mora biti odredjena u odnosu na najbližu UELN tačku, odabrane tačke odredjene korišćenjem navedenih standarda moraju se priključiti UELN.

5. ZAKLJUČAK

Najčešće korišćene koordinate tačaka u inženjerskoj praksi odnose se na neki lokalni elipsoid, koji definiše datum negeocentričnog sistema, kao npr. državni koordinatni sistem ili dvodimenzionalne koordinate u ravni odredjene kartografske projekcije. Medjutim, ako dve tačke iz različitih koordinatnih sistema imaju pridruženu prostornu referencu, odnosno ako su poznati projekcija sa svojim parametrima, elipsoid na koji se projektuje, kao i odnos prema referentnom prostornom sistemu, moguće je obezbediti korišćenje tih geopodataka u GIS sistemima. Dakle, geoprostorni podaci dobijeni iz različitih izvora moraju biti referencirani na isti geodetski datum i isti koordinatni sistem.

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SPATIAL REFERENCE SYSTEMS

Abstract

Geospatial data gained from different sources have to be referenced to the same geodetic datum and coordinate system. Forming of joint reference system enables easier update and geometric harmonization, access, exchange and use of geospatial data. Horizontal and vertical positions of points are no longer independent components. Development of GPS technology enabled their integration into the unique 3D datum. Geodetic datum is a base for determination the spatial reference system. Reference system is a group of fundamental points on the Earth surface with defined coordinates. The International Terrestrial Reference System (ITRS) is the most accurate global reference system. ETRS89 is used as the standard accurate GPS coordinate system in Europe. This system is a spine of every geographic and geodynamic project on the European territory, both on a national and international level.

Keywords*: GIS, geodetic datum, spatial reference systems, geospatial data.*

1. INTRODUCTION

The main characteristic of geodata is their spatial reference. Spatial position is defined related to the Earth surface. First problem that occurs is approximation. As it is known, the Earth as a celestial body can be treated from two aspects: physical and mathematical. As a physical model, the Earth can be treated as geoid – null equipotential shape, suitable for determination of height datum. Mathematical models that can be used for approximation of geoid are sphere and spheroid (rotated ellipsoid). Such interpretation enables determination the spatial position of points. However, there is a significant global diversity in selection of ellipsoid, fundamental points and initial meridian. Several hundreds of ellipsoids were defined depending on available measuring equipment, area (North or South America, Europe, Asia, etc.), range (state, continent or entire world) and political issues (for instance, Warsaw Pact vs. NATO). Besides, the initial geodata are replaced by new ones; fundamental points are changed; geodetic networks are updated or completely replaced.

2. GEODETIC DATUM

Geospatial data gained from different sources have to be referred to the same geodetic datum and coordinate system. Geodetic datum is a collection of parame-

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ters which define a coordinate system, including ellipsoid and position of its center in relation to the Earth center, and orientation in relation to the Earth's rotation axis. Geodetic datum is any numerical or geometric value, or group of values, which are used as a base for calculation the other values. Terms ellipsoid and datum are used as synonyms. Each horizontal or vertical position of some point is relative to specific geodetic datum.

Horizontal datum is a rotary ellipsoid which approximates the Earth surface, and also a sum of constants and conditions which defines its dimensions, position and orientation. If geodetic datum is used to approximate a part of the Earth surface, it is called the local datum or regional datum, and if it represents the entire Earth, it is called the global datum or geocentric datum. *Local geodetic datum* is determined in order to provide the best approximation of certain part of the Earth surface. Usually, it is defined by seven parameters:

- Two of them define ellipsoid geometry;
- Geographic latitude and longitude of target point;
- Referent azimuth of orientation;
- Geoid height of target point (usually average sea level);
- Assumption of parallelism between short semi – axis of ellipsoid and Earth rotation axis.

Throughout the history, many countries adopted and used local ellipsoids which were the best match of the Earth surface in these areas. Such concept brought high accuracy in local areas, but problems were made when it was necessary to integrate or exchange geospatial information between such areas. Until 1950's, Europe was flooded by different geodetic systems. Practically, each country had its own fundamental point and system orientation based on different ellipsoids. First official attempt of unification the national geodetic datum was the European Datum 1950 – ED50, based on the Hayford ellipsoid. After ED50, new attempts were made by the European datum ED79, ED87 and the European Terrestrial Reference System 1989 - ETRS89. Common referent system enables easier update and geometric harmonization, access, exchange and use of geospatial data. GPS technology provides geodetic positioning of points in the spatial geocentric system WGS84. Satellites, used in GPS technology, recognize the Earth as a monolith body. Since trajectories of satellites are circles around the Earth center of mass, positioning based on such technologies is logically related to the vectors aiming to geocenter. That is why it was necessary to define a coordinate system which would determine such vectors. This lead to defining the new ellipsoid, Geodetic Reference System – GRS80, in order to approximate the Earth surface as close as possible and become a solid base for determination the geocentric datum. Regardless to a fact that neither GRS80, nor WGS84 (World Geodetic System 1984) were not most suitable for the specific areas, they were accepted. A need for ideal approximation vanishes when the global survey, combined with computers, the data bases and software easily adjust results to the local parameters. Each datum is getting more accurate in time as survey becomes more accurate.

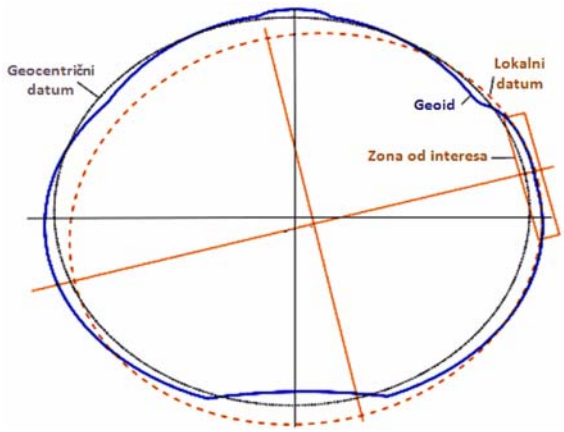


Fig. 1. *Local and geocentric datum*

Vertical datum is defined as the referent surface for determination of elevation. Traditional surveying methods use leveling for determination the elevation, in relation to the average sea level (which differs depending on the state or location). Leveling is related to geoid, so elevations are determined based on geoid. Referent surface (datum) of elevations, gained by geometric leveling, is the geoid surface. Height from null leveling surface, e.g. geoid is called elevation or orthometric height (H). In calculation of orthometric heights, besides leveling differences, the gravity acceleration is also taken into consideration.

The use of satellites provided lots of information related to the Earth shape and its gravity field, which had a significant influence to a definition of geoid surface. When simplify geoid description is needed, it is said that it matches the ideal surfaces of seas and oceans (ideal surface in terms of disregarding influences such as sea currents, tides, temperature variations, etc.). This geoid definition was primarily provided by J. B. Listing back in 1872. However, these occurrences have influence to the average sea level. In relation to the average sea level, geoid varies 1 to 2 m (Sickle, 2001), which means that such definition is no longer sustainable. Gravity force is not consistent along the Earth topographic surface. This force has its direction and intensity in any point, which means that it can be described by vectors. Surface with equal gravity potential can only be imagined. Such equipotential surface would be a real leveling surface.

Geoid suface is not mathematically regular nor is the Earth topographic surface. It has lifts and subsides. Causes for such geoid shapes are different, but the most important one is irregular mass distribution inside the Earth. If it was not the case, its shape would be very similar to the ellipsoid. However, like the Earth surface, the physical geoid surface differs from ellipsoid, in some cases up to 100 m. Elevations gained from GPS are related to the ellipsoid surface in the Geodetic Reference System (GRS80) and such elevations are called the ellipsoid elevations (h). Difficulties in transition from geometric – ellipsoid to orthometric elevations are caused by the geoid irregular shape. Differences between orthometric and ellipsoid elevations related to GRS80 geocentric ellipsoid vary from +85 m to -106 m. In Serbia, the difference is around +40 m (difference is positive if geoid surface is above ellipsoid surface). This difference is called the geoidal undulation (N) or geoidal height.

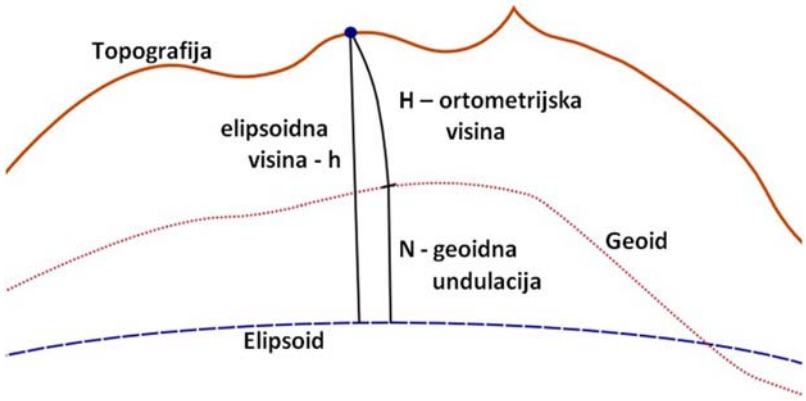


Fig. 2. *Defining the orthometric elevations*

3. DATUM TRANSFORMATION

One of the main characteristics of spatial data is spatial reference. If those data are related to the spatial entities, it is possible to combine them regardless on different coordinate systems or projections. The most commonly used coordinates are those related to some local referent ellipsoid, which defines the datum of local non – geocentric system, such as the national coordinate system, or two - dimensional coordinates in cartographic projection. Datum transformations are used for transition between different coordinate systems. They enable conversion of point coordinates from the coordinate system in Datum A to the coordinate system in Datum B (Figure 3).

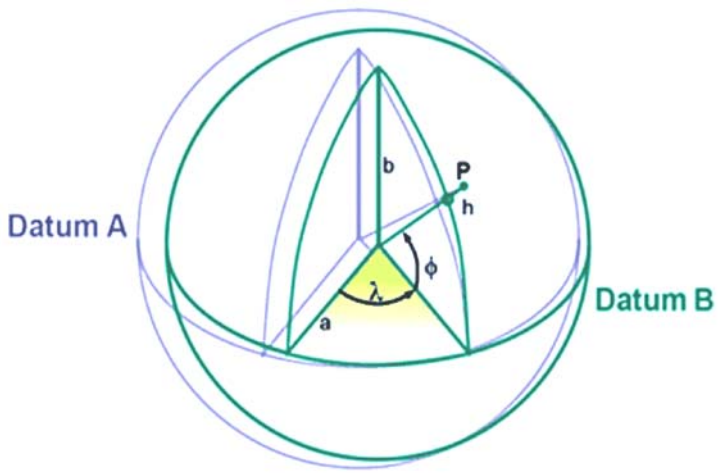


Fig. 3. *Datum transformations*

In order to equalize two coordinate systems (E1 and E2), one of them (E2) needs to be rotated around each of three axes; scale adjusted and moved into space (Figure 4). Group of parameters which define datum transformation are called the transformation parameters. In order to perform the transformation, it is needed to know seven parameters (3 translations, 3 rotations and scale), so this transformation is called the seven – parameter datum transformation, or Helmert transformation.

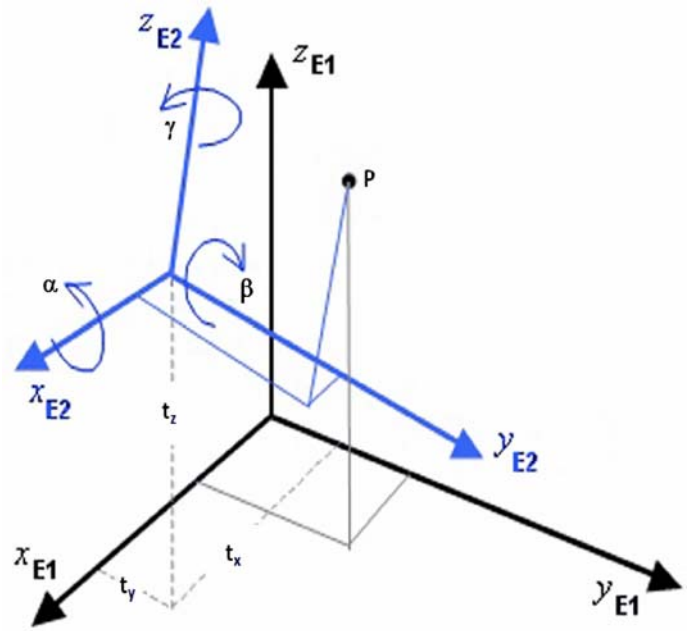
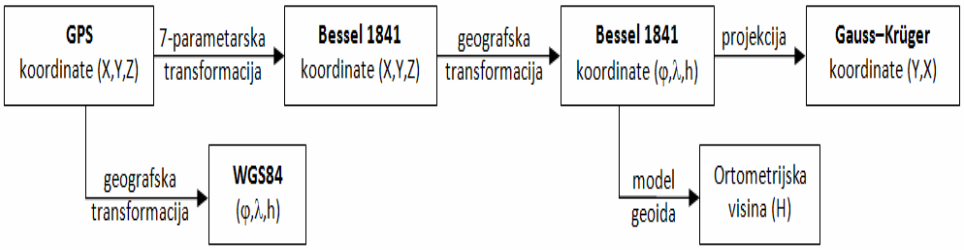


Fig. 4. *Seven – parameter datum transformation*

If two points from different coordinate systems have the joint spatial reference, e.g. if their projection parameters, ellipsoid and relation to the referent coordinate system are defined, it is possible to use the common data. In the Gauss – Kruger projection, point coordinates are defined by the projection of transverse cylinder to the Bessel 1841 ellipsoid, while coordinates, gained by GPS, are related to the WGS84 ellipsoid. Beside differences between two ellipsoids (long and short axis and oblation), their coordinate systems are also different. WGS84 ellipsoid, along with its transformation parameters, is used in Serbia. Transformation parameters enable a direct transition from WGS84 to the Bessel ellipsoid. Datum transformation provides conversion of point coordinates from WGS84 to the Bessel ellipsoid and the Gauss – Kruger coordinate system:



For the needs to show point coordinates at plans in specific projections, ore compare data from different coordinate systems, it is necessary to define the parameters of datum transformation, projection parameters and geoid model.

For accurate determination of elevation, it is necessary to define the parameters of local geoid. Since there is no local geoid in Serbia, the global EGM96 (Earth Gravitational Model 1996) is used.

4. SPATIAL REFERENCE COORDINATE SYSTEMS

4.1. International Terrestrial Reference System – ITRS

Coordinate system is always defined in relation to some geodetic datum. Since GPS is used for defining the position of points on the Earth surface, it means that coordinate system also has to be related to the Earth. Such system is called the Conventional Terrestrial Reference System - CTRS, and it is supervised by the International Earth Rotation and Reference Systems Service - IERS. CTRS is also known as the International Terrestrial Reference System - ITRS.

IERS defines sets of rules and conventions which are, along with modeling, necessary for determination the initial point, scale, orientation and time evolution of CTRS. According to the Resolution No.2, introduced by the International Union of Geodesy and Geophysics (IUGG) in Vienna in 1991, ITRS represents a group of points with their 3D coordinates which realize an ideal reference system. ITRS was realized using the International Terrestrial Reference Frame, ITRF97, based on estimated coordinates and velocities of group of stations, surveyed by different methods: GPS (Global Positioning System), VLBI (Very Long Baseline Radio Interferometry), LLR (Lunar Laser Ranging), SLR (Satellite Laser Ranging) and DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite). ITRS can be connected to the International Celestial Reference System – ICRS using the IERS Earth Orientation Parameters (EOP). The main characteristics of ITRS are as follows:

- Coordinate origin of ITRS mat-ches the Earth center of mass (geocenter);
- X - axis begins in geocenter and goes through the intersection point of the Greenwich Meridian Equator;
- Y - axis begins in geocenter, it is situated in a plane of equator middle position and it is perpendicular to X - axis;
- Z - axis is directed to middle position of the Earth rotary axis, defined in a period between 1900 and 1905.

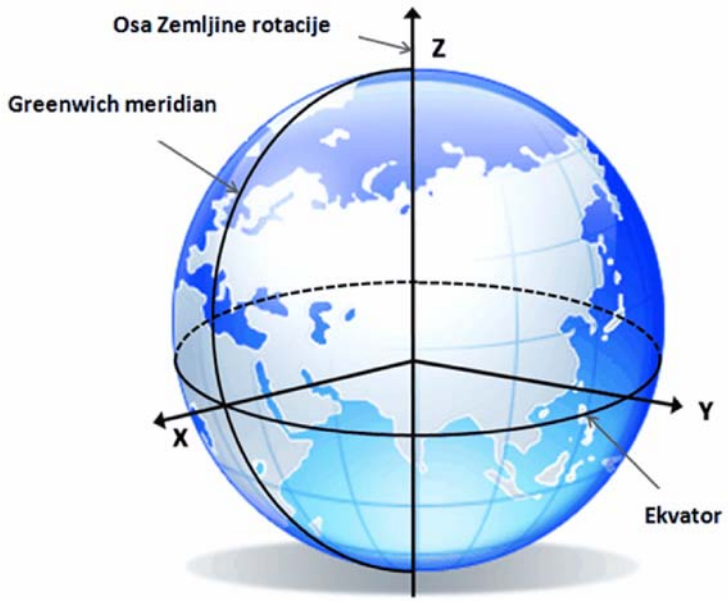


Fig. 5. *International Terrestrial Reference System – ITRS*

4.2. World Geodetic System WGS84

Global geocentric system based on ellipsoid, defined in 1979 by IUGG, was named the Geodetic Reference System GRS80. With slight corrections, in 1984, GRS80 was renamed to WGS84. WGS84 is a name for ellipsoid used as reference coordinate system. It was made by modification of Navy Navigation Satellite System (NNSS) or TRANSIT, Doppler Reference Frame (NSWC 9Z-2) in origin and scale, and rotating it to bring its reference meridian into coincidence with the BIH (Bureau International de l'Heure) defined zero meridian.

WGS84 is a geocentric coordinate system with its center matching the Earth center of mass, while its coordinate axes are defined as follows:

- Z - axis is directed to the Conventional Terrestrial Pole (CTP), e.g. its average position in a period between 1900 and 1905, defined by the International Time Bureau (BIH), based on coordinates determined for BIH stations;
- X - axis directed to the intersection of null reference meridian plane of WGS84 coordinate system and equator plane, defined by BIH, based on coordinates determined for BIH stations;
- Y - axis, situated 90o east of X - axis, is used to form right - orientated, geocentric and fixed coordinate system ECEF (Earth Centered, Earth Fixed), measured in the equator plane.

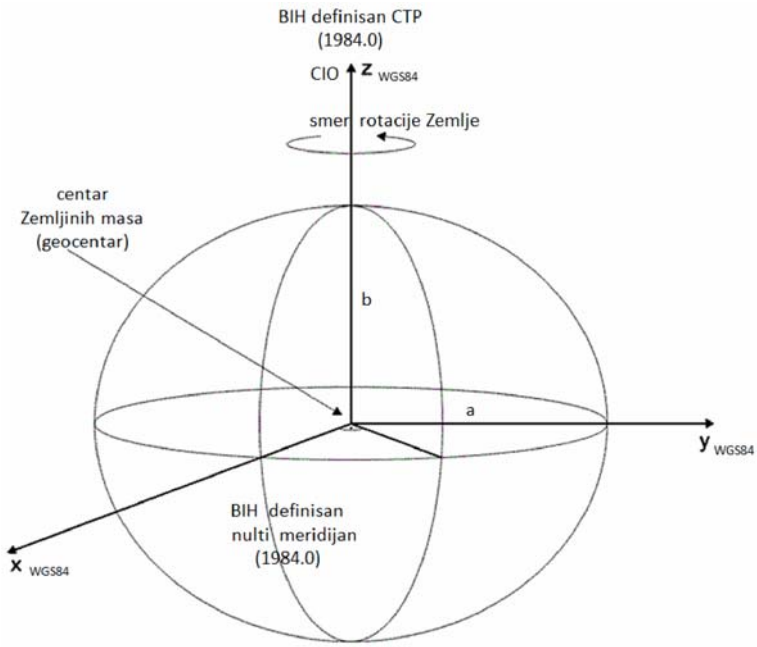


Fig. 6. *The World Geodetic System 1984 - WGS84.*

4.3. European Reference Terrestrial System ETRS89

In 1987, the International Association of Geodesy (IAG) and CERCO (Comite Européen des Responsables de la Cartographie Officielle) decided to develop a new European Reference Frame – EUREF, based on GPS technology. The idea was to develop an accurate and modern system, like WGS84, which would enable the unified data sources for international digital cartographic data, instead of numerous national datums across Europe. Since ITRS was most accurate global reference system available, EUREF decided to base its reference system to ITRS, supervised by IERS.

However, in global ITRS system, the tectonic movements of continental plates cause movements of European stations, at approximate rate of 2.5 cm per year. That was the reason for developing the European Terrestrial Reference System (ETRS89), introduced by EUREF in Florence in 1989 [2][3]. ETRS89 is geocentric system with its origin in the Earth center of mass, with coordinate axis matching position of ITRS axes in 1989. It is a regional system, tightly connected to the European continental plate, which follows its lithosphere tectonics. That is why coordinates of points in ETRS89 are time – independent in principle. Reasons for introduction of ETRS89 were the unification of national reference systems for survey, mapping, GIS technologies and navigation in Europe. ETRS89 is defined with 1 cm accuracy. Due to its geocentricity and defined time evolution in relation to ITRS, the system is suitable for using the sate-llite technologies and systems, such as the American NAVSTAR, Russian GLONASS

and European GALILEO. Coordinates are defined as three – dimensional X, Y, Z co-ordinates, while for spatial po-sitioning of points and objects in geographic coordinate system (φ, λ and h – ellipsoid height), adds GRS80 ellipsoid with the main basic and derived geometric parameters.

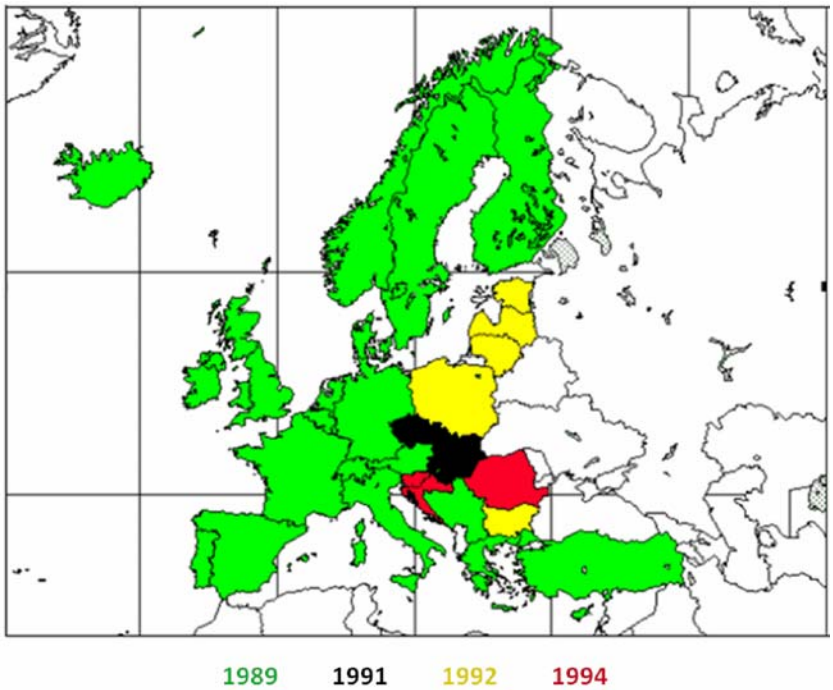


Fig. 7. *Status ETRF-89/EUREF-01 Jan.1995. Sourcer: Seeger (IfAG, Frankfurt)*

GRS80 ellipsoid is a geocentric by definition and its short semi – axis matches third coordinate axis of ETRS89, e.g. with the terrestrial rotary axis. Adoption of ETRS89 by various institutions (civil aviation, industry, national and regional agencies) as a support for referencing in Europe is a process. Structure of ETRS89 consists of: permanent GPS stations, operational centers, local and regional data processing centers, local and regional analyses centers and network coordinator (http://itrf.ensg.ign.fr/GIS/).n. There are two types of permanent stations in Europe:

- IGS stations included in IGS (International GPS Geodynamics Service) network;
- EUREF stations, included in the Permanent Tracking Network, are GPS points which are a part of theEuropean IGS. This is a system of around 200 GPS permanent stations, 16 analyses centers and the Central Bureau of EPN (EUREF Permanent Network).

4.4. European Vertical Reference System EVRS

Reference systems used in Europe were defined as follows:

Mean Sea Level (MSL) is adopted as the vertical datum;

Height of a point is defined by the geopotential elevation or geopotentional

unit, and dynamic, orthometric, normal and spheroid heights are derived from the geopotentional elevation.

Leveling networks were created based on the following assumptions: MSL was defined by the mareographs, network matchmarks were placed in geologically stable terrain, with 0.5 to 2 km spacing, difference in potential was determined using the elevation surveying data and gravity acceleration measuring data. Matchmarks were connected into leveling lines, and leveling lines into polygons. These assumptions were followed in all European countries, while establishment and design of networks varied depending on a geographic position and technological development level of each country.

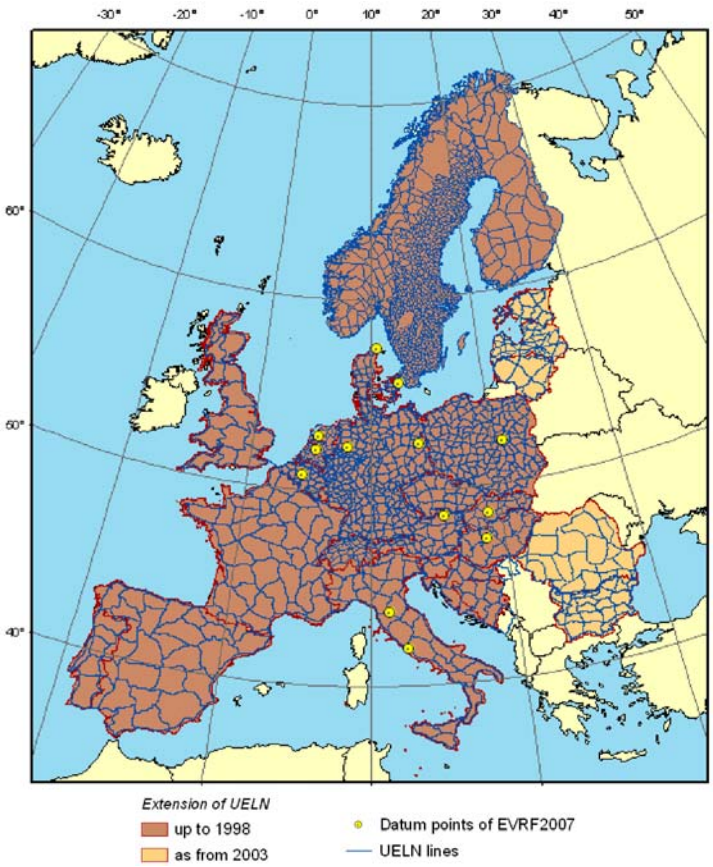


Fig. 8. *Points used for realization the EVRS2007 datum*

The European Vertical Reference System, EVRS, came as the result of demand, made by the European Cartography Committee (CERCO), to define and establish a single vertical system on a decimeter level (0.1 m) for the entire European territory. This process started with the adoption of NAP (Normal Amsterdam Peil) as the null level, which means that geopotential elevation of NAP is zero.

That is how EVRF2000 (European Vertical Reference Frame 2000) has been established. Sometimes, EVRS2000 abbreviation is also used, while for every other relevant parameter GRS80 is used.

Introduction of this system in 1995 was a huge step in making the integrated reference European system which connects the GPS coordinates, physically defined heights and elevations. When the system was established, it was decided that heights from geopotential elevations would be defined inside the system based on normal heights (Rezolution No.2, Ankara, 1996). This system was changed in 2007 by introduction the additional datum points, thus changing the system realization and definition (now called EVRS2007 and EVRF2007).

4.5 United European Leveling Network (UELN)

UELN represents the realization of EVRS, and it was developed since 1954. Network was the result of combining a certain number of lines from the national leveling networks, and leveling calculations were performed since 1954. Till now, almost each European country has provided data for including into UELN.

First leveling calculation in 1955 was based on NAP, and resulted in ± 1.1 mm/km accuracy, with a standard deviation less than ± 0.1 m.

Countries that participate in the network constantly send data to the Federal Bureau for Cartography and Geodesy in Leipzig, Germany (Bundesamt für Kartographie und Geodäsie – BKG), where data is processed. Since each national network defined its own datum, based on MSL, defined by the used mareographs at different seas and oceans, the heights in different national networks are different.

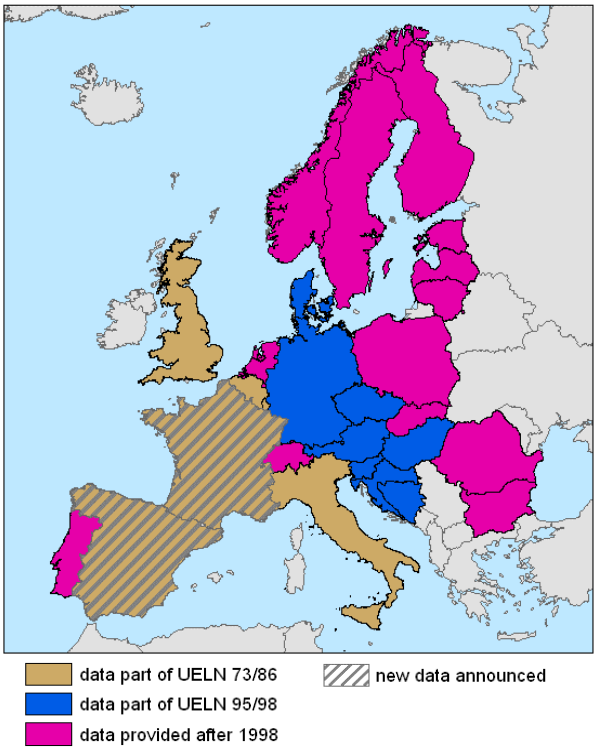


Fig. 9. *Status of extended UELN network in 1999*

4.6. European United Vertical Reference Network – EUVN

EUVN is a project led by EUREF sub commission. At the beginning, EUVN was created as an addition to UELN in order to connect the mareographs in determinationthe sea level variation and establishment the reliable group of points as a base for definition the European geoid, i.e. determination of undulation discrete values by satellite leveling (GPS/Δh).

In the other words, creation of EUVN had a goal to unify different dates in Europe to a range of several centimeters. It was defined by the project that each point of EUVN had to have determined the Cartesian geocentric coordinates in ETRS89 and geopotential elevations, as well as the point heights in normal height system.

According to this, it could be said that it was necessary to determine the ellipsoid heights by GPS, connect EUVN and UELN points by leveling in order to determine physically the defined heights and finally to provide the constant mean sea level survey by mareographs. Finally, EUVN consists of 196 points, with ellipsoid heights determined in campaign held from 21 - 29 May in 1997, which were related to ITRF96, epoch 1997.4.

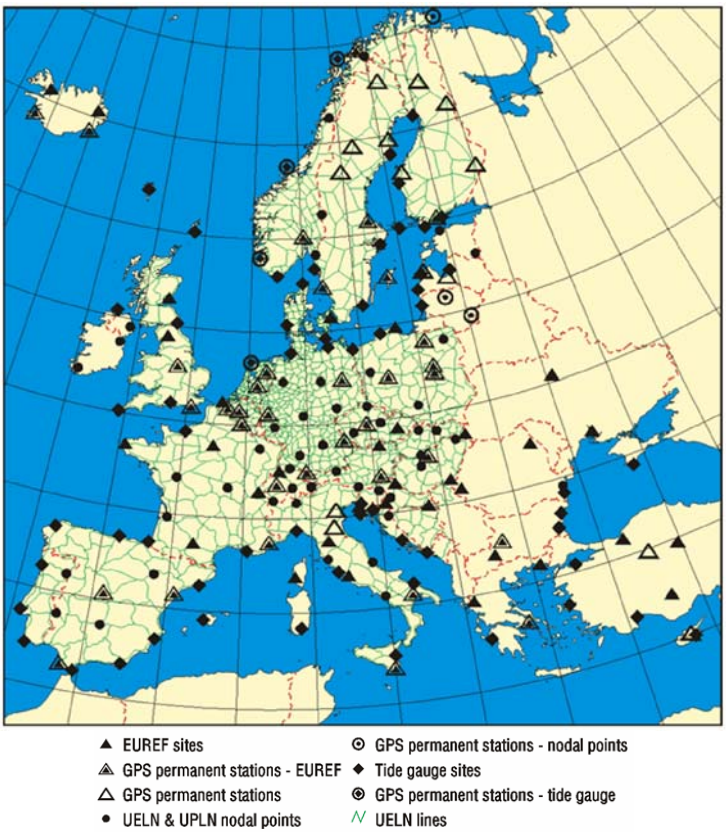


Fig. 10. *Spatial layout of EUVN points*

4.7. European united vertical network (EUVN_DA)

Beside numerous analyses inside EUVN, a comparison of European geoid was also performed. This geoid was determined inside the European Gravity and Geoid Project (EGGP). Comparison showed that discrete values of undulation differ from EGG97 geoid by not more than 20 cm.

Since number of EUVN points is extremely low in relation with area of Europe and points are not adequately placed for determination of geoid with accuracy of few centimeters, initiative for densification of EUVN was started and performed through EUVN_DA (European United Vertical Network - Densification Action). Most of the European countries participated in the project and currently there are 1495 discrete values of undulations. Data analyses and comparison with EGG07 show that differences do not exceed 10 cm, which is by 50% better than the previous solution (EGG97/EUVN_DA). Some systematic irregularities occurred on the territories of Italy and Great Britain.

Any country that wants to participate in the project have to fulfill the following standards: EUVN_DA points have to be at 50 to 100 km spacing, matchmark that belongs to UELN has to be not more than 10 km away from selected points, in selection of points mathmarks of national networks which participate in UELN will have the advantage, elevation mask for GPS survey has to be at 15°, reference system has to be ETRS89 or ITRF epoch has to be defined, GPS survey in 24 h sessions is desirable, potential differences have to be determined in relation with the nearest UELN point, selected points determined by specified standards have to be joined to UELN.

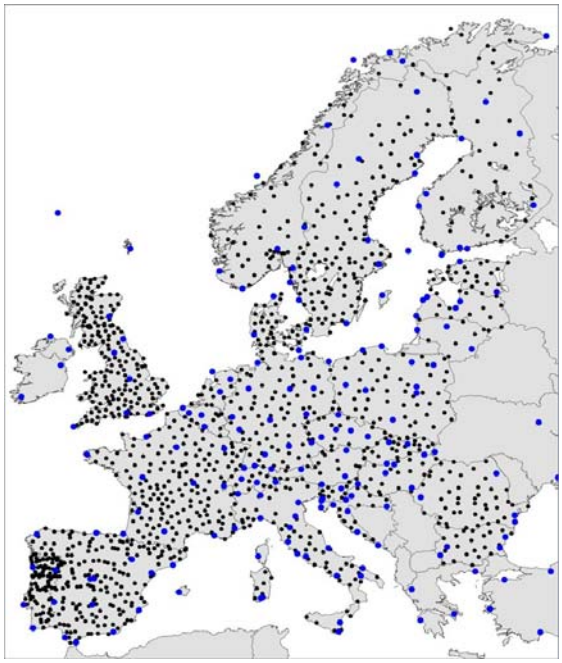


Fig. 11. *European united vertical network (EUVN_DA)*

5. CONCLUSION

In practice, the most commonly used coordinates of points belong to some local ellipsoid, which defines datum of non – geocentric system, for instance national coordinate system or 2D coordinates in plane of some cartographic projection. However, if two points from different coordinate system have joint the spatial reference, i.e. if projection with its parameters, ellipsoid to project to and relation to spatial reference system are determined, it is possible to provide the use of these data in GIS systems. Therefore, geospatial data gained from different sources have to be referenced to same geodetic datum and same coordinate system.

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METODOLOŠKI PRISTUP IDENTIFIKACIJE ASPEKATA I VREDNOVANJA UTICAJA NA ŽIVOTNU SREDINU ZA PROJEKAT "EKSPLOATACIJA MAGNEZITA U LEŽIŠTU ČAVLOVAC-MASNICA"

Izvod

U ovom radu dat je metodološki pristup identifikacije aspekata i vrednovanja uticaja na životnu sredinu u cilju optimizacije modela procene rizika zagađenja životne sredine za projekte iz oblasti rudarstva u cilju poboljšanja i unapređenja tog procesa na primeru projekta "Eksploatacija magnezita u ležištu Čavlovac – Masnica" na području opštine Čajetina.

Ključne reči: *procena uticaja, identifikacija, vrednovanje, rizik zagađenja životne sredine.*

1. UVOD

Svaka društveno odgovorna organizacija pre otpočinjanja realizacije novog projekta neophodno je da pristupi preispitivanju zahteva koji se odnose na predmetni projekat i izvrši identifikaciju aspekata životne sredine i procenu rizika zagađenja životne sredine u cilju planiranja i projektovanja mera za izbegavanje, eliminisanje i/ili smanjenje rizika zagađenja životne sredine. Životna sredina je izvor prirodnih vrednosti i prirodnih resursa, a samim tim i izvor egzistencije pa se shodno tome moramo odgovorno odnositi prema toj činjenici. Kvalitet životne sredine zavisi od održivog upravljanja prirodnim vrednostima i prirodnim resursima. U odnosu na nivo industrijalizacije, urbanizacije i rasprostranjenosti korišćenja resursa, raste i potreba za održivim upravljanjem resursima. Jedan od instrumenata dostizanja tih ciljeva je i ***procena uticaja na životnu sredinu (Environmental Impact Assessment-EIA).*** Formalni postupak, koji danas nazivamo procenom uticaja na životnu sredinu, nastao je u razvijenim zapadnim zemljama kao rezultat narastanja svesti o potrebi zaštite životne sredine. Svrha procene uticaja na životnu sredinu je da se osigura razmatranje potencijalnih uticaja na životnu sredinu svih projekata

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kod kojih se očekuju značajni aspekti životne sredine. Poslednjih godina su praktično sve zemlje Sveta uvele u svoje zakonodavstvo obavezu procene uticaja na životnu sredinu. U osnovi, sistem procene uticaja na životnu sredinu podrazumeva koordiniranu saradnju Nosioca projekta (Investitora), vladinih organa, nevladinih organizacija, i zainteresovanih grupa na utvrđivanju potencijalnih uticaja određenog projekta na životnu sredinu na osnovu čega se njegova realizacija prihvata ili odbacuje. Obaveza procene uticaja na životnu sredinu u sistemu R. Srbije pokrenuta je donošenjem Zakona o proceni uticaja na životu sredinu *(Sl. glasnik RS br. 135/04 i 36/08)*, kao i niza podzakonskih akata, čime je u potpunosti usklađen sa procesom procene uticaja u razvijenim zemljama EU. Cilj procene uticaja na životnu sredinu je obezbeđivanje da projekti, planovi razvoja, programi, politika i dr., budu održivi i prihvatljivi sa stanovišta zaštite životne sredine. Prema tome, cilj procene uticaja na životnu sredinu je: identifikacija, opisivanje, vrednovanje i utvrđivanje, mogućih neposrednih i posrednih uticaja planiranog projekta na život i zdravlje ludi, floru i faunu, zemljiše, vode, vazduh, klimu, pejzaž, materijalna i kulturna dobra, uzajamno delovanje navedenih činilaca. U skladu sa time, osnovni motiv ovog rada je da se da doprinos razvoju optimalnog modela procene rizika zagađenja životne sredine za projekte iz oblasti rudarstva u cilju poboljšanja i unapređenja tog procesa procene uticaja na životnu sredinu na primeru projekta "Eksploatacija magnezita u ležištu Čavlovac – Masnica" na području opštine Čajetina.

2. KRATAK OPIS PROJEKTA ODNOSNO PREDMETA ISTRAŽIVANJA

2.1. Lokacija projekta

Istražni prostor "Čavlovac" i "Masnica" nalazi se sa leve i desne strane kanjona reke Ribnica na Zlatiboru. Kao što se zna Zlatibor pripada prostoru sa posebnim prirodnim vrednostima i prirodnim resursima. Prostor na kome su istražene i okonturene magnezitske zone počinje na severu od južnih padina Crnog vrha, na desnoj obali reke Ribnice, gde je izdvojena magnezitska zona Čavlovac, pa preko reke Ribnice, na jug do severnih padina brda Kriva Breza, gde su izdvojene magnezitske zone Masnice. Predmetna lokacija obuhvata područje magnezitnih ležišta Čavlovac i Masnica na Zlatiboru, odnosno istražni prostor broj 1432 sa granicama koje su date u sledećoj tabeli:

Tabela 1. *Koordinate istražnog prostora [2]*

Tačka/broj	X	Y	Topografska karta sa granicama eksploatacionog polja
1.	7.388.489	4.840.504	
2.	7.389.480	4.840.141	
3.	7.389.488	4.839.342	
4.	7.389.469	4.838.991	
5	7.387.763	4.839.093	
6	7.387.706	4.839.487	

2.2. Geološka građa ležišta „Čavlovac – Masnice“

Teren Zlatibora je izgrađen od pretežno harcburgitskih i lerzolitskih varijeteta peridotita, različitog stepena serpentinizacije. Duž pojedinih ruptura, različite veličine i geneze, formirana orudnjenja magnezita od kojih su samo tri magnezitonosne zone detaljno ispitivane. Na kartiranom terenu najveće rasprostranjenje imaju lerzolitski i harcburgitski varijeteti peridotita, podređeno verlita i dunita, odnosno enstatit dunita. Svi varijeteti peridotita su serpentinisani. Magnezitsko ležište na lokalitetu Čavlovac predstavljeno je jednom većom magnezitonosnom zonom, kao i brojnim apofiznim magnezitskim žicama [3]. Magnezitska zona je izgrađena od alterisanih, limonitisanih i delom silifikovanih peridotita, u kojima se javlja sistem skoro paralelnih magnezitskih žica. Pored magnezitskih žica debljine od 0,5-2,0 m javljaju se i manja sočivasta orođnjenja moćnosti od 2-8,0 m. Za magnezitske žice je karakteristično da se često razbijaju i spajaju kako po pružanju tako i po padanju. Uočeno je i prisustvo nekoliko apofiznih žica debljine od 0,5-3,0 m, koje se dijagonalno odvajaju od rudne zone.

2.3. Opis proizvodnog procesa i njegove glavne karakteristike

Tehnološka šema proizvodnog procesa dobijanja rude magnezita iz ležišta rudnika "Čavlovac i Masnica" na Zlatiboru [3] zasnovana je na sledećim fazama rada: *otvaranje i razrada ležišta → priprema za otkopavanje i otkopavanje rude → ventilacija rudnika → odvodnjavanje rudnika → jamski transport i izvoz rude iz jame → spoljni transport (odvoz) od jame doseparacije → rekultivacija degradirane površine terena.*

2.4. Predmet i područje delovanja predmetnog projekta

Utvrđivanje predmeta i područja delovanja projekta "Eksploatacija magnezita u ležištu Čavlovac - Masnica" u opštini Čajetina podrazumeva:

a) utvrđivanje osnovne delatnosti projekta koje uključuju:
   - redovne odnosno svakodnevne aktivnosti i
   - neredovne aktivnosti koje postoje ili se mogu javiti samo povremeno (vanredna situacija ili udes);
b) utvrđivanje fizičkih granica projekta;
c) utvrđivanje granica uticaja aktivnosti projekta;
d) utvrđivanje okruženja i analiza međusobnog uticaja;
e) utvrđivanje zakonske regulative koja se odnosi na konkretan projekat.

Eksploatacija mineralnih sirovina po strukturi i karakteru tehnološkog procesa direktno se realizuje u prirodnoj sredini degradirajući istu u užem ili širem prostoru i skoro se uvek očekuju značajni uticaji na životnu sredinu. Posledice degradacije se ogledaju u vidu privremenog ili trajnog karaktera. Mogući uticaji privremenog karaktera ogledaju se u kratkotrajnom: zagađenju vazduha, zagađenju voda, zagađenju zemljišta, i emisiji buke i vibracija. Moguće posledice trajnog karaktera su: degradacija zemljišta, promena režima kretanja površinskih i podzemnih voda, uništenje vodotokova, izmeštanje komunikacija i ljudskih naseobina i uništenje autohtonog vegetacionog pokrivača. Sve faze tehnološkog procesa otkopavanja rude magnezita na ležištu Čavlovac - Masnice odvijaju se u uslovima podzemne eksploatacije, za razliku od odvoza rude sa depoa, koji je lociran ispred ulaza u jamu i obavlja se spoljnim kamionskim transportom do separacije.

2.5. Identifikacija zainteresovanih organa, organizacija i javnosti za realizaciju projekta

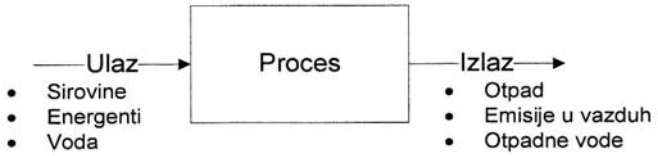
U postupku realizacije ovog projekta zainteresovana javnost su bila sva fizička ili pravna lica koja su imala interes u predmet projekta i planirane mere zaštite životne sredine koje se odnose na pred-

metni projekat. Zainteresovana javnost, odnosno strane u slučaju realizacije projekta bile su: Ministarstvo životne sredine, rudarstva i prostornog planiranja R. Srbije, Ministarstvo poljoprivrede i vodoprivrede R. Srbije, Nadležni organi i organizacije lokalne samouprave opštine Čajetina, meštani sela Jablanica, Investitori, lokalna i regionalna udruženja za zaštitu životne sredine; i druga zainteresovana javnost.

3. PRIMENJENI METODOLOŠKI PRISTUP IDENTIFIKACIJE ASPEKATA I VREDNOVANJA UTICAJA NA ŽIVOTNU SREDINU

3.1. Procesni pristup identifikacije aspekata životne sredine

Ono što je važno naglasiti je da se za identifikaciju aspekata životne sredine predlaže primena **procesnog pristupa**. Procesnim pristupom sagledavaju ju se svi elementi i aktivnosti tehnološkog procesa iz koga se sigurno očekuju ili se mogu očekivati negativni aspekti životne sredine predmetnog projekta. *Aspekat životne sredine - jeste element aktivnosti, proizvoda ili usluga koji može da bude u uzajamnom odnosu sa životnom sredinom* [7].



Sl. 1. *Model procesnog pristupa identifikacije aspekata životne sredine*

3.2. Izbor kriterijuma i metoda za vrednovanje uticaja aspekata životne sredine na životnu sredinu

Po izvršenom indetifikovanju aspekata životne sredine neophodno je da se definišu kriterijumi za vrednovanje značajnosti njihovog uticaja na životnu sredinu. Vrednovanje značajnosti aspekata životne sredine - jeste postupak utvrđivanja značajnosti aspekata životne sredine na osnovu verovatnoće njihovog pojavljivanja i očekivanih posledica po životnu sredinu. Utvrđivanje aspekata koji imaju značajan uticaj i za koje se moraju preduzeti odgovarajuće mere zaštite i mehanizami kontrole za njihovo smanjenje ili otklanjanje štetnih uticaja na životnu sredinu. Ovde treba imati na umu da je značajnost uticaja na životnu sredinu jedan relativan pojam koji sam po sebi ne može biti definisan u apsolutnim vrednostima. Izabrani metodološki pristup je omogućio prepoznavanje:

- negativnih (štetnih) uticaja na životnu sredinu od svih idetifikovanih aspekata proisteklih iz aktivnosti u realizaciji projekta;
- stvarne i potencijalne uticaje na životnu sredinu koji su rezultat aktivnosti projekta;

- osnovnih činilaca životne sredine koji mogu biti pod uticajem aspekata kao što su lokacija, vazduh, voda, zemljište, flora, fauna, kulturna baština itd.;
- moguće promene u životnoj sredini (vremenski period tokom kojeg se uticaj javlja, mogućost intenziteta jačine uticaja u tom vremenskom periodu).

Cilj indetifikovanja i vrednovanja uticaja aspekata životne sredine nesme umanjiti i promeniti zakonske obaveze Nosioca projekta. Za primenjene kriterijume postavljeni su nivoi (vrednosti) značajnosti. Vrste skala ili rangiranja su numeričke vrednosti što je od velike pomoći u dodeljivanju značajnosti recimo kvantitativno u smislu (1-najmanji, 4-najveći) ili opisno u smislu nivoa kao što su: visok, srednji, nizak, ili zanemarljiv.

U ovom slučaju primenjena je:
- metoda rangiranja značajnosti u odnosu na izračunavanje rizika (najjednostavniji matični metod procene rizika zagadjenja životne sredine);

Procena rizika zagađenja životne sredine svodi se na izračunavanje proizvoda dva faktora i to:
- faktora učestalosti (verovatnoća pojave aspekta);
- faktora ozbiljnosti pojave posledica po životnu sredinu, koje taj aspekt uzrokuje.

Tabela 2. *Faktor učestalosti*

Verovatnića pojave učestalosti aspekta životne sredine.....VU	**Ocena**
Očekuje se velika učestalost pojave aspekta životne sredine	4
Očekuje se srednja učestalost pojave aspekta životne sredine	3
Očekuje se mala učestalost pojave aspekta životne sredine	2
Očekuje se zanemarljiva pojava aspekta životne sredine	1

Tabela 3. *Faktor ozbiljnosti pojave posledica po životnu sredinu*

Ozbiljnost pojave posledica po životnu sredinu.....TP	**Ocena**
Očekuju se velike posledice i veoma veliki uticaj na kvalitet osnovnih činioca životne sredine	4
Očekuju se srednje posledice i veliki uticaj na kvalitet osnovnih činioca životne sredine	3
Očekuju se male posledice i mali uticaj na kvalitet osnovnih činioca životne sredine	2
Očekuju se zanemarljivo male posledice na kvalitet osnovnih činioca životne sredine	1

Rizik zagađenja životne sredine se izračunava kao proizvod verovatnoće pojave učestalosti određenog aspekta životne sredine i ozbiljnosti pojave posledica po kvalitet osnovnih činioca životne sredine (vazduh, voda, zemljište i dr.) i to:

$$R=VU \times TP$$

Tabela 4. *Gradacija rizika (R=VU x TP) [6]*

Rizik	Prioriteti koji se moraju primeniti u postupku kontrole procenjenog rizika
>9≤ 16	Identifikuje se potrebe za uspostavljanjem neprekidne kontrole zagađivanja životne sredine odnosno uspostavljanje stalnog monitoringa kvaliteta osnovnih činioca životne sredine.
>6≤ 9	Identifikuje se potrebe za uspostavljanjem periodične kontrole zagađivanja životne sredine odnosno vršenja periodičnog monitoringa kvaliteta osnovnih činioca životne sredine
>3≤ 6	Identifikuju se potrebe za uspostavljanjem povremene kontrole zagađivanja životne sredine odnosno vršenja povremenog monitoringa kvaliteta osnovnih činioca životne sredine
>1≤ 3	Ne identifikuju se potrebe za uspostavljanjem kontrole zagađivanja životne sredine niti preduzimanje posebnih mera zaštite, već samo rutinske mere zaštite životne sredine.

Iz izračunavanja verovatnoće učestalosti i težine posledica po kvalitet osnovnih činjenioca životne sredine može se utvrditi očekivani nivo rizika zagađenja životne sredine (tabela 5) koji se između ostalog mogu prikazati i u smislu semafora (zeleno-žuto-crveno).

Tabela 5. *Matrica procene ekološkog rizika [6]*

Verovatnoća učestalosti	Težina posledica			
	Zanemarljive	Male	Srednje	Velike
Zanemarljiva	1	2	3	4
Mala	2	4	6	8
Srednja	3	6	9	12
Velika	4	8	12	16

4. REZULTATI ISTRAŽIVANJA IDENTIFIKACIJE ASPEKATA I VREDNOVANJA UTICAJA NA ŽIVOTNU SREDINU

4.1. Procesni pristup identifikacije aspekata životne sredine

Za identifikaciju aspekata životne sredine korišćena je analiza aktivnosti tehnološkog procesa eksploatacije magnezita u ležištu "Čavlovac-Masnica" u opštini Čajetina.

Tabela 6. *Identifikacija aspekata i potencijalnih uticaja na životnu sredinu[6]*

Proces, aktivnost	Aspekt životne sredine	Stvarni ili potencijalni uticaj na životnu sredinu
Otvaranje i razrada ležišta magnezita	Izrada platoa ispred ulaza u jamu - podkop	Prodor jalovine u korito reke Ribnica od iskopa
		Emisija buke od rada rudarske mehanizacije
		Mogućnost spiranja sitnih čestica sedimentnih materija sa platoa i prodor u korito reke Ribnice
	Izrada glavne prostorije - podkopa, otvaranje i razrada ležišta	Nastajanje i odlaganje jalovine od iskopa (sterilna stena) na platou ispred ulaza u jamu
		Buka i vibracije od bušaško minerskih radova
	Rad rudarske mehanizacije na platou isped ulaza u jamu pri istovaru i utovaru rude magnezita	Emisija buke od rada rudarske mehanizacije pri istovaru i utovaru rude magnezita
		Mogućnost procurenja ulja i masti iz rudarske mehanizacije i zagađenja zemljišta na platou ispred jame
		Nastajanje komunalnog otpada pri izvođenju manipulativnih radova na platou ispred ulaza u jamu
	Izrada sanitarnog čvora za potrebe održavanja higi-jene radnika u neposrednoj blizini ulaska u jamu.	Nastajanje komunalnog otpada
		Zagađenja zemljišta od privremenog sanitarnog čvora
		Zagađenje voda od privremenog sanitarnog čvora
Priprema za otkopavanje i otkopavanje rude magnezita u ležištu	Izrada jamskih prostorija i iskop rude rudarskom mehanizacijom	Nastajanje jalovine od izrade jamskih prostorija
		Buka i vibracije od bušaško minerskih radova
		Mogućnost procurenja ulja i masti iz rudarske mehanizacije
		Emisija izduvnih gasova od rada rudarske mehanizacije
	Priprema i izvođenje minerskih radova pri iskopu rude u jami	Moguća nekontrolisana eksplozija minsko eksplozivnih sredstava usled neprop. skladišt. i/ili rada sa eksplozivima
Ventilacija jame	Rad ventilatora u ventilacionom podkopu (oknu) za provetravanje jame	Emisija buke u radnoj i životnoj sredini
		Izbacivanje izduvnih gasova rudarske mehanizacije i gasova od miniranja pri izradi jamskih prostorija
Odvodnjavanje iz jame	Drenaža voda koje dospevaju do jamskih prostorija i izlaze potkopom na površinu	Moguće zagađenje reke Ribnice zagađenim vodama usled koje izlaze iz jamskih prostorija.
Jamski transport i izvoz rude magnezita iz jame	Utovar iskopane rude u sredstva za transport, jamski transport i istovar rude magnezita na platou ispred ulaska u jamu	Mogućnost procurenja dizel goriva, ulja i masti iz rudarske mehanizacije za jamski transport rude magnezita
		Emisija izduvnih gasova od rada rudarske mehanizacije pri utovaru, transportu i istovaru rude magnezita
	Procerenje dizel goriva, ulja ili masti iz rudarske mehani-zacije koje može dospeti u jamske otpadne vode	Potencijalni udes i zagađenje voda koje podkopom izlaze iz jame, a dalje u reku Ribnicu
Odvoženje rude na dalju preradu	Utovar rude u kamion rudarskom mehanizacijom sa pogonom na dizel gorivo	Emisija buke od rada kamiona i utovarivača
		Emisija prašine od pretovara rude
		Mogućnost proc. dizel goriva, ulja i maziva iz utovarivača
Korišćenje / Skladištenje / i naftnih derivata	Privremeno uskladištenje i povremeno pretakanje nafnih derivata u rudarsku mehanizaciju	Zagađenje zemljišta naftom, uljima i mazivima
		Spiranje zagađenog zemljišta atmosferskim vodama i prodor i zagađenje reke Ribnice
		Nastanak požara pri pretakanju naftnih derivata
Koriš. / Skladištenje /minskoeksploziv-nih sredstava	Dopremanje eksploziva do jamskog radilišta, i izvođenje minerskih operacija	Mog. nastanka nekotro. eksplozija, požara i povreda ljudi
		Oštećenje ili pak rušenje objekata u neposrednoj blizini
		Oštećenje rudarske mehanizacije
Ruda magnezita	Svojstva i karakteristike magnezita prema osnovnim činiocima životne sredine	Pozitivno delovanje na oplemenjivanju ili unapređenju kvaliteta voda

4.2. Princip vrednovanja stvarnih i potencijalnih uticaja na životnu sredinu

Tabela 7. *Vrednovanje stvarnih i potencijalnih uticaja na životnu sredinu [6]*

Proces, aktivnost: **OTVARANJE I RAZRADA LEŽIŠTA MAGNEZITA ČAVLOVAC - MASNICA**			
Stvarni ili potencijalni uticaj na životnu sredinu	**Kriterijumi za vrednovanje uticaja na živ. sredinu**		
	VU	**TP**	**R**
Prodor jalovine u korito reke Ribnice od iskopa koji se vrši za ulazak u jamu	2	4	8
Emisija buke od rada rudarske mehanizacije pri izradi platoa	2	2	4
Mogućnost spiranja sitnih čestica sedimentnih materija sa platoa i zatrpavanje korita reke Ribnice	3	3	9
Nastajanje i odlaganje jalovine od iskopa (sterilna stena) na platou ulaza u jamu	2	2	4
Buka i vibracije od bušaško minerskih radova pri izradi podkopa.	2	2	4
Emisija buke od rada rudarske mehanizacije pri istovaru i utovaru rude magnezita	2	2	4
Mogućnost procurenja ulja i masti iz rudarske mehanizacije i zagađenja zemljišta na platou ispred jame	3	3	6
Nastajanje komunalnog otpada pri izvođenju manipulativnih radova na platou ispred ulaza u jamu	2	2	4
Nastajanje komunalnog otpada	2	2	4
Zagađenja zemljišta od privremenog sanitarnog čvora	2	3	6
Zagađenje voda od privremenog sanitarnog čvora	2	3	6

Tabela 8. *Vrednovanje stvarnih i potencijalnih uticaja na životnu sredinu [6]*

Proces, aktivnost: **PRIPREMA ZA OTKOPAVANJE I OTKOPAVANJE RUDE MAGNEZITA**			
Stvarni ili potencijalni uticaj na životnu sredinu	**Kriterijumi za vrednovanje uticaja na živ. sredinu**		
	VU	**TP**	**R**
Nastajanje jalovine od izrade jamskih prostorija	4	2	8
Buka i vibracije od bušaško minerskih radova pri iskopu rude u jami	4	1	4
Mogućnost procurenja ulja i masti iz rudarske mehanizacije pri iskopu rude	3	3	9
Emisija izduvnih gasova od rada rudarske mehaniz. pri iskopu rude	4	1	4
Moguća nekontrolisana eksplozija minsko eksplozivnih sredstava usled nepropisnog skladištenja i/ili rada sa istima - Potencijalni udes	/	/	$> 6 \leq 12$

Tabela 9. *Vrednovanje stvarnih i potencijalnih uticaja na životnu sredinu [6]*

Proces, aktivnost: VENTILACIJA JAME			
Stvarni ili potencijalni uticaj na životnu sredinu	**Kriterijumi za vrednovanje uticaja na živ. sredinu**		
	VU	**TP**	**R**
Emisija buke u radnoj i životnoj sredini	3	1	3
Izbacivanje izduvnih gasova rudarske mehanizacije i gasova od miniranja pri izradi jamskih prostorija	3	1	3

Tabela 10. *Vrednovanje stvarnih i potencijalnih uticaja na životnu sredinu [6]*

Proces, aktivnost: **ODVODNJAVANJE IZ JAME**			
Stvarni ili potencijalni uticaj na životnu sredinu	**Kriterijumi za vrednovanje uticaja na živ. sredinu**		
	VU	**TP**	**R**
Moguće zagađenje reke Ribnice vodama koje izlaze iz jamskih prostorija zagađenim usled rada rudarske mehanizacije.	3	3	9

Tabela 11. *Vrednovanje stvarnih i potencijalnih uticaja na životnu sredinu [6]*

Proces, aktivnost: **JAMSKI TRANSPORT I IZVOZ RUDE MAGNEZITA**			
Stvarni ili potencijalni uticaj na životnu sredinu	**Kriterijumi za vrednovanje uticaja na živ. sredinu**		
	VU	**TP**	**R**
Mogućnost procurenja dizel goriva, ulja i masti iz rudarske mehanizacije za jamski transport rude magnezita	3	3	9
Emisija izduvnih gasova od rada rudarske mehanizacije pri utovaru, transportu i istovaru rude magnezita	4	1	4
Potencijalni udes i zagađenje voda koje izlaze iz jame, a dalje idu u reku Ribnicu	/	/	$> 6 \leq 12$

Tabela 12. *Vrednovanje stvarnih i potencijalnih uticaja na životnu sredinu*

Proces, aktivnost: **SPOLJNI TRANSPORT RUDE DO SEPARACIJE**			
Stvarni ili potencijalni uticaj na životnu sredinu	**Kriterijumi za vrednovanje uticaja na živ. sredinu**		
	VU	**TP**	**R**
Emisija buke od rada kamiona i utovarivača	3	1	3
Emisija prašine od pretovara rude	3	1	3
Mogućnost procurenja dizel goriva, ulja i maziva iz kamiona i utovarivača	3	3	9

Tabela 13. *Vrednovanje identifikovanih aspekata životne sredine [6]*

Proces, aktivnost: KORIŠĆENJE I PRIVREMENO SKLADIŠTENJE I NAFTNIH DERIVATA			
Stvarni ili potencijalni uticaj na životnu sredinu	**Kriterijumi za vrednovanje uticaja na živ. sredinu**		
	VU	**TP**	**R**
Zagađenje zemljišta naftom, uljima i mazivima	3	3	9
Spiranje zagađenog zemljišta atmosfersk. vodama, prodor i zagađenje reke Ribnice	3	3	9
Nastanak požara pri pretakanju naftnih derivata	3	3	9

Tabela 14. Vrednovanje stvarnih i potencijalnih uticaja na životnu sredinu [6]

Proces, aktivnost: KORIŠĆENJE I SKLADIŠTENJE MINSKO-EKSPLOZIVNIH SREDSTAVA			
Stvarni ili potencijalni uticaj na životnu sredinu	**Kriterijumi za vrednovanje uticaja na živ. sredinu**		
	VU	**TP**	**R**
Mogućnost nastanka nekotrolisanih eksplozija, požara i povreda ljudi	3	3	9
Oštećenje ili pak rušenje objekata u neposrednoj blizini	3	3	9
Oštećenje rudarske mehanizacije	3	3	9

NAPOMENA: *Stvarni ili potencijalni uticaj na životnu sredinu gde može nastati UDES ili VANREDNA SITUACIJA se ne vrednuje već se automatski tretira kao ZNAČAJAN ASPEKT ŽIVOTNE SREDINE, za koji je potrebno planirati odgovarajuće mere zaštite.*

4.3. Registar značajnih aspekata životne sredine sa predlogom mera zaštite životne sredine

Nakon izvršene identifikacije i vrednovanja uticaja aspekata na životnu sredinu utvrđen je registar značajnih aspekata za koje je potrebno primeniti mere za eliminisanje, smanjenje rizika i uspostavljanje kontrole nad procenjenim rizicima zagađenja životne sredine.

Tabela 15. Registar značajnih aspekata životne sredine [6]

R. br.	**Registrovani značani aspekti životne sredine**	**Rizik**	**Mere zaštite životne sredine koje treba preduzeti**				
			Tehno-loške	**Tehničke**	**Organi-zacione**	**Sanitarno higijenske**	**Administra-tivne**
1.	Prodor jalovine u korito reke Ribnica od iskopa koji se vrši za ulazak u jamu	8	✓	✓	✓	/	✓
2.	Mogućnost spiranja sedimentnih materija sa platoa i zamućenje reke Ribnice	9	✓	✓	✓	/	✓
3.	Nastajanje i odlaganje jalovine od iskopa (sterilna stena) na platou ispred ulaza u jamu	6	✓	✓	✓	/	/
4.	Mogućnost procurenja ulja i masti iz rudarske mehanizacije i zagađe-nja zemljišta na platou ispred jame	9	✓	✓	✓	/	/
5.	Nastajanje komunalnog otpada pri izvođenju manipulativnih radova na platou ispred ulaza u jamu	6	/	/	✓	✓	✓
6.	Nastajanje komunalnog otpada	9	/	/	✓	✓	✓
7.	Zagađenja zemljišta od privremenog sanitarnog čvora	9	/	✓	✓	✓	✓
8.	Zagađenje voda od privremenog sanitarnog čvora	9	/	✓	✓	✓	✓
9.	Nastajanje jalovine od izrade jamskih prostorija	8	✓	✓	/	/	/
10.	Mogućnost procurenja ulja i masti iz rudarske mehan. pri iskopu rude	9	/	/	✓	/	/

11.	Moguće zagađenje reke Ribnice vodama zagađenim usled rada rudarske mehanizacije koje izlaze iz jamskih prostorija	9	✓	✓	✓	/	/
12.	Mogućnost procurenja dizel goriva, ulja i masti iz rudarske mehanizacije za jamski transport rude magnezita	9	/	/	✓	/	/
13.	Mogućnost procurenja dizel goriva, ulja i maziva iz kamiona i utovarivača	9	/	/	✓	/	/
14.	Zagađenje zemljišta naftom, uljima i mazivima	9	/	/	✓	/	/
15.	Spiranje zagađenog zemljišta atmosferskim vodama i prodor i zagađenje reke Ribnice	9	✓	/	✓	/	/
16.	Nastanak požara pri pretakanju naftnih derivata	9	/	/	✓	/	/
17.	Mogućnost nastanka nekotrolisanih eksplozija, požara i povreda ljudi	9	/	✓	✓	/	/
18.	Oštećenje ili pak rušenje objekata u neposr. blizini od nek. eksplozija	9	/	✓	✓	/	/
19.	Oštećenje rudarske mehanizacije od nekontrolisanih eksplozija	9	/	✓	✓	/	/

6. ZAKLJUČAK

Politika zaštite životne sredine u realizaciji određenog projekta treba da se zasniva na poznavanju aspekata životne sredine i značajnih uticaja na životnu sredinu koje konkretni projekat uzrokuje.

Na osnovu prethodnih iskustava i kao i na osnovu ovih istraživanja može se zaključiti da je u ovom radu prikazani metodološki pristup identifikacije aspekata i vrednovanja uticaja na životnu sredinu projekta "EKSPLOATACIJA MAGNEZITA U LEŽIŠTU ČAVLOVAC – MASNICE" dao optimalne rezultate procene nivoa rizika zagađenja životne sredine i dobio još jednu potvrdu podobnosti za dalju primenu u istim ili sličnim projektima i da će biti od značajne koristi za dalji razvoj optimizacije ovog metodološkog postupka. Na osnovu napred navedenih rezultata propisane su odgovoarajuće mere zaštite životne sredine koje su prikazane u okviru Studija procene uticaja na životnu sredinu za projekat "EKSPLOATACIJA MAGNEZITA U LEŽIŠTU ČAVLOVAC - MASNICE".

Predmetna studija je bila predmet javnog uvida i javne rasprave. Nakon završene procedure izdata je i odgovarajuća saglasnost na studiju procene uticaja što se može uzeti u obzir kao potvrda podobnosti primenjenog metodolškog pristupa.

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METHODOLOGICAL APPROACH TO THE IDENTIFICATION AND ENVIRONMENTAL IMPACT ASSESSMENT FOR THE PROJECT“ MAGNESITE MINING IN THE DEPOSIT ČAVLOVAC-MASNICA“

Abstract

This work presents a methodological approach to the identification of aspects and evaluation the environmental impact, in order to optimize the model of risk assessment of environmental pollution for the mining projects, in order to improve and advance this process on the example of the project "Magnesite Mining in the Deposit Čavlovac - Masnica" in the area of the municipality Čajetina.

Keywords: *impact assessment, identification, evaluation, risk of environmental pollution*

1. INTRODUCTION

It is necessary that every socially responsible organization, before beginning the implementation of a new project, to approach the review of requirements related to the subject project and identifies the environmental aspects and risk assessment of environmental pollution in order to plan and design measures to prevent, eliminate and/or reduce the risk of environment pollution. Environment is a source of natural values and natural resources, and thus a source of existence, and therefore we have to deal responsibly with that fact. Quality of the environment depends on sustainable management of natural values and natural resources. In relation to the level of industrialization, urbanization and spread of the use of resources, the need for sustainable management of resources also increases. One of the instruments to achieve these goals is the **environmental impact assessment** (EIA). Formal procedure, now known as the environmental impact assessment, originated in developed countries as the result of growing awareness of the need for environmental protection.

The purpose of environmental impact assessment is to ensure a consideration of potential environmental impact of all projects which are expected to significant environmental aspects. In recent years,

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virtually all countries of the world have introduced into their legislation the obligation of assessment the environmental impact. Basically, the system of environment impact assessment involves a coordinated cooperation of the Project Holder (Investor), governmental bodies, NGOs, and interested groups to identify the potential impacts of a certain project on the environment, based on which the implementation of the same is accepted or rejected. The obligation of environmental impact assessment in the system of the Republic of Serbia was launched by the enactment of the Law on Environmental Impact Assessment on the life environment (*Official Gazette RS, Nos. 135/04 and 36/08*), and a number of by-laws, which is in a full compliance in line with the process of impact assessment in developed countries of the EU. The aim of environment impact assessment is to ensure that the projects, development plans, programs, policies, and others are sustainable and acceptable from the point of view of environmental protection. Therefore, the aim of environmental impact assessment is: identification, description, evaluation and identification the potential direct and indirect impacts of the planned project on the life and health of people, flora and fauna, soil, water, air, climate, landscape, material and cultural goods, the interaction of given factors. Accordingly, the main motive of this work is to contribute to the development of an optimum model of risk assessment the environmental pollution for mining projects, in order to improve and advance this process of environmental impact assessment on the example of the project "Magnesite Mining in the Deposit Čavlovac - Masnica" in the area of the municipality Čajetina.

2. BRIEF DESCRIPTION OF THE PROJECT OR THE CASE STUDY

2.1. Location of the Project

The exploration area "Čavlovac" and "Masnica" is located on the left and right side of the river Ribnica canyon on Zlatibor. As it is known, Zlatibor belongs to the area with special natural values and natural resources. The area, in which the magnesite zones were explored and contoured, begins in the north from the southern slopes of Crni vrh, on the right bank of the river Ribnica, where the magnesite zone Čavlovac is separated, and over the river Ribnica, to the south to the northern slopes of the hill Kriva Breza, where the magnesite zones are separated. The subject site comprises the area of magnesite deposit Čavlovac and Masnica on Zlatibor, i.e. the exploration area No. 1432 with the limits given in the following Table:

Table 1 *Coordinates of exploratory area [2]*

Point/No.	X	Y	Topographic map with borders of exploitation field
1.	7.388.489	4.840.504	
2.	7.389.480	4.840.141	
3.	7.389.488	4.839.342	
4.	7.389.469	4.838.991	
5	7.387.763	4.839.093	
6	7.387.706	4.839.487	

2.2. Geological structure of deposit "Čavlovac – Masnica"

The Zlatibor field is built mainly of harzburgitic and lherzolitic peridotite varieties, of different degree of serpentinization. Magnesite mineralizations were formed along the certain ruptures of different size and genesis, out of which only three are magnesite-bearing zones, investigated in detail.

On the mapped terrain, the harzburgitic and lherzolitic peridotite varieties have the largest extend, subordinated to verlite and dunite or enstatite dunite. All varieties of peridodite are serpentinized. The magnesite deposit Čavlovac deposit is represented by a large magnesite-bearing zone, as well as numerous apophysis veins[3].

Magnesite zone was constructed from altered, limonited and partly silicifed peridotite, in which almost parallel system of magnesite veins occurs. Besides the magnesite veins, thickness of 0.5 to 2.0 m, there are smaller lenticular mineralization, thickness of 2 to 8.0 m. Magnesite veins are characteristic in a fact that they are often broken and connected both on expanding and falling. The presence of several apophysis veins, thickness of 0.5 to 3.0 m, was observed, which are diagonally separated from the ore zone.

2.3. Description the production process and its main characteristics

Technological scheme of the production process for mining the magnesite ore from the mine deposit "Čavlovac and Masnica" on Zlatibor [3] is based on the following phases of operation: *opening and development of deposit → preparation for mining and ore mining → mine ventilation → mine drainage → underground pit ore transportation and haulage → external transportation from the pit to the separation → reclamation of degraded terrain surfaces.*

2.4. Subject and area of the project activity

Identification the subject and area of the project "Mining of magnesite in the deposit "Čavlovac-Masnica" in the municipality Čajetina includes:

a) Determining the main activities of the project, including:
- Regular or daily activities, and
- Irregular activities that exist or may occur only occasionally (emergency or accident);

b) Determining the physical boundaries of the project;

c) Determining the limits of the impact of the project activities;

d) Determining the environment and analysis of mutual effect;

e) Determining the regulations pertaining to the specific project.

Mining of mineral resources by the structure and character of the technological process is implemented directly in the natural environment degrading the same in narrower or wider area and almost always the significant impacts on the environment are expected. Consequences of degradation are reflected in the form of a temporary or permanent character. Possible temporary impacts are reflected in a short-term: air pollution, water pollution, soil pollution, and noise and vibration emission.

Possible consequences of a permanent character are: land degradation, changing the regime of movement the surface water and groundwater, watercourses destruction, displacement of communications and human settlements and destruction of autochthonous vegetation cover. All stages of the technological process of magnesite ore mining in the deposit Čavlovac - Masnica take place in the conditions of underground mining, as opposed to the ore transport from a depot, which is located at the entrance to the pit, and it is performed by external trucks to the separation.

2.5. Identification the interested bodies, organizations and t public for the project implementation

In the process of this project implementation, the interested public was all physical or legal entities who have an interest in the subject of the project and planned environmental protection measures relating to the subject project. The interested public, or in the case of the project implementation, were: The Ministry of Environment, Mining and Spatial Planning of the Republic of Serbia, the Ministry of Agriculture and Water Management of the Republic of Serbia, authorities and local government organizations of the municipality Čajetina, residents of the village of Jablanica, investors, local and regional associations for the environmental protection, and other interested public.

3. THE APPLIED METHODOLOGICAL APPROACH OF IDENTIFICATION THE ASPECTS AND EVALUATION TO THE ENVIRONMENTAL IMPACT

3.1. Process approach to the identification the environmental aspects

The important is to identify the environmental aspects, suggested by the use of a process approach. Process approach perceives all elements and activities of the technological process of which it is certainly expected or could be expected the negative environmental aspects of the subject project. *Aspect of the environment is an element of activities, products or services that may be in the mutual relationship with the environment* [7].

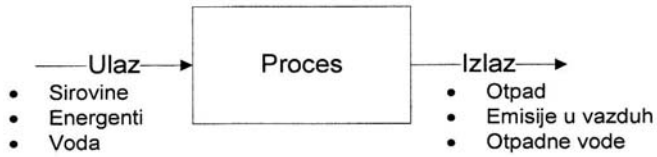

Fig. 1. *Model of process approach of identification the environmental aspects*

3.2. Selection the criteria and methods for evaluation the impact of environmental aspects on the environment

Upon performed identification the aspects of the environment, it is necessary to define the criteria for evaluation the significance of their impact on the environment. Evaluation the significance of environmental aspects is the process of determining the significance of environmental aspects on the basis of their probability of occurrence and expected effects on the environment. Determining the aspects that have a significant impact and for which the appropriate measures have to be taken as well as the control mechanisms for their reduction or elimination the harmful impacts on the environment. It should be borne in mind that the significance of the environmental impact is a relative term that itself cannot be defined in the absolute values. The selected methodological approach has enabled the identification of:

- Negative (adverse) impact on the environment of all identified aspects arising from the activities of the project implementation;

- Actual and potential impacts on the environment resulting from the project activities;
- Basic environmental factors that can be influenced by the aspects such as location, air, water, soil, flora, fauna, cultural heritage, etc.;
- Possible changes in the environment (the time period during which the impact occurs, possibility of measuring the intensity of the impact in that time).

The aim of identification and evaluation the impact of environmental aspects must not diminish and change the legal obligations of the Project holder. The levels (values) of significance are set for the applied criteria. Types of scales or ranking are the numerical values which are of great help in assigning the significance, for example in terms of quantity (1-minimum, 4-maximum) or a descriptive level in terms such as: high, medium, low or negligible.

In this case, the following is applied:

- Method of ranking the significance in relation to the calculation of risk (the simplest matrix method for the risk assessment for environmental pollution);

The risk assessment of environmental pollution is reduced to the calculation of product of two factors, as follows:

- Frequency factor (probability of aspect occurrence);
- Factor of seriousness of environmental consequences, which that aspect has caused.

Table 2. *Frequency factor*

Probability of occurrence the frequency of environmental aspects .....VU	**Rating**
High frequency of occurrence the environmental aspects is expected	4
Medium frequency of occurrence the environmental aspects is expected	3
Low frequency of occurrence the environmental aspects is expected	2
Negligible frequency of occurrence the environmental aspects is expected	1

Table 3. *Seriousness factor of impacts on the environment*

Seriousness of impacts on the environment……TP	**Rating**
High impacts and very big effect on the quality of basic environmental factors are expected	4
Medium impacts and very big effect on the quality of basic environmental factors are expected	3
Low impacts and very big effect on the quality of basic environmental factors are expected	2
Negligible impacts and very big effect on the quality of basic environmental factors are expected	1

Risk of environmental pollution is calculated as the product of the probability of occurrence the frequency of a particular aspect of the environment and the seriousness of consequences for the quality of primary environmental factors (air, water, land, etc.) as follows:

$$R=VU \times TP$$

Table 4. *Gradation of risks (R=VU x TP) [6]*

Risk	Priorities to be applied in the procedure of control the assessed risk
>9≤ 16	The needs are identified to establish the permanent control of environmental pollution or establishment the permanent monitoring of the quality of basic environmental factors
>6≤ 9	The needs are identified to establish the periodical control of environmental pollution or carrying out the periodical monitoring of the quality of basic environmental factors
>3≤ 6	The needs are identified to establish the occasional control of environmental pollution or carrying out the occasional monitoring of the quality of basic environmental factors
>1≤ 3	The needs are not identified to establish the control of environmental pollution nor carrying taking the special measures of protection, but only the routine measures of environmental protection measures

From calculating the probability of frequency and severity of consequences for the quality of basic factors of environment, the expected level of environmental risk can be determined (Table 5), which among other things can be shown in terms of the traffic light (green-yellow-red).

Table 5. *Matrix of assessment the environmental risk [6]*

Probability of frequency	Weight of consequences			
	Negligible	Low	Medium	High
Negligible	1	2	3	4
Low	2	4	6	8
Medium	3	6	9	12
High	4	8	12	16

4. RESULTS OF INVESTIGATION THE IDENTIFICATION OF ASPECTS AND EVALUATION THE ENVIRONMENTAL IMPACT

4.1. Process approach to the identification of environmental aspects

For identification the environmental aspects, it was used the analysis of activities of the technological process of mining the magnesite deposit "Čavlovac-Masnica" in the municipality Čajetina.

Table 6. *Identification the aspects and potential impact of the environment [6]*

Process, activity	Environmental aspect	Real or potential impact on the environment
Opening and development the deposit of magnesite	Making the plateau in front of the pit - drift	Penetration of waste in the river bed of Ribnica
		Noise emissions from the operation of mining machines
		Possibility of leaching the fine particles of sediment material from the plateau and penetration into the river bed of Ribnica
	Development of the main room - drift, opening and development of deposit	Formation and disposal of overburden of excavation (sterile rocks) in front of the entrance to the pit
		Noise and vibration from drilling and blasting
	Operation of mining equipment on the plateau in front of the entrance to the pit in the loading and unloading of magnesite ore	Noise emissions from the operation of mining machines in the loading and unloading of magnesite ore
		The possibility of leakage from oil and grease from mining machinery and land pollution in front of the pit
		Municipal waste in the execution of manipulative work in front of the entrance to the pit
	Making sanitary facilities for hygiene maintenance of workers near the entrance to the pit.	Municipal waste
		Soil contamination from temporary sanitary facili-ties
		Water pollution from temporary sanitary facilities
Preparing for mining and excavation the magnesite ore in the deposit	Making underground rooms and excavation ore by mining machinery	The formation of slag from making parts of the mine
		Noise and vibration from blasting – drilling opera-tions
		The possibility of leakage from oil and grease from the mining equipment
		Exhaust emissions from the operation of mining machines
	Preparation and execution of blasting works during excavation of ore in the pit	Chance of uncontrolled explosions of blasting agents due to improper storage and / or work with explo-sives
Pit ventilation	Fan operation in the ventilation drift for pit ventilation	Noise emission in living and working environments
		Wheel emissions of mining mechanization of mining and gas development in parts of the mine
Pit dewatering	Drainage of water in the pit rooms and out to the surface by drift	Possible contamination of the river Ribnica polluted water due to coming out of parts of the mine.
Pit transport and haulage of magnesite ore from the pit	Loading of mined ore in the means of transport, pit transport and unloading of magnesite ore on a plateau in front of the entrance to the pit	The possibility of leakage of diesel fuel, oil and grease pit mining equipment for the transport of magnesite ore
		Exhaust emissions from the operation of mining machines for loading, transporting and unloading of magnesite ore
	Leakage of diesel fuel, oil or grease from mining machinery that can reach the underground wastewater	Potential accidents and contamination of water out of the pit, and further into the river Ribnica
Ore transport for further processing	Loading of ore using the mining machin-ery in the truck driven by diesel fuel	The emission of noise from the trucks and loaders
		Dust emissions from the loading of ore
		Able to go. diesel fuel, oil and lubricants from the loader
Use/ storage / iol deriva-tives	Temporary storage and periodical trans-ferring the petroleum products in the mining machinery	Soil pollution by oil, oil and lubricants
		Runoff of contaminated soil and atmospheric water penetration and pollution of the river Ribnica
		Occurrence of fire from loading petroleum products
Use/ storage / blasting agents	Delivery of explosives to the pit site, and carrying out the blasting operations	Possibility of occurrence the explosions, fires and injuries of people
		Damage or destruction of buildings in the immediate vicinity of
		Damage to mining equipment
Magnesite ore	Properties and characteristics of magnesia according to the basic environmental factors	Positive effect on the breeding and improvement of water quality

4.2. The principle of evaluation the actual and potential impacts on the environment

Table 7. *Evaluation the actual and potential impacts on the environment [6]*

PROCESS, ACTIVITY: OPENING AND DEVELOPMENT THE MAGNESITE DEPOSIT ČAVLOVAC – MASNICA			
Actual and potential impacts on the environment	**Criteria for evaluation the environmental impact**		
	VU	**TP**	**R**
Penetration of waste in the river bed Ribnice of excavation in front to the entrance in the pit	2	4	8
Noise emissions from the operation of mining machines in the preparation of the plateau	2	2	4
Possibility of leaching the fine particles of sediment material from the plateau and backfilling the riverbed of Ribnica	3	3	9
The formation and disposal of overburden excavation (sterile rocks) on the plateau of the entrance to the cave	2	2	4
Noise and vibration from blasting-drilling in making the drift	2	2	4
Noise emissions from the operation of mining machines in the loading and unloading of magnesite ore	2	2	4
The possibility of leakage from oil and grease from mining machinery and land pollution in front of the pit	3	3	6
Municipal waste in the execution of manipulative work in front of the entrance to the pit	2	2	4
Municipal waste	2	2	4
Soil contamination from temporary sanitary facilities	2	3	6
Water pollution from temporary sanitary facilities	2	3	6

Table 8. *Evaluation the actual and potential impacts on the environment [6]*

PROCESS, ACTIVITY: PREPARATION FOR MINING AND EXCAVATION THE MAGNESITE ORE			
Actual and potential impacts on the environment	**Criteria for evaluation the environmental impact**		
	VU	**TP**	**R**
The formation of waste from making the mining facilities	4	2	8
Noise and vibration from blasting- drilling works in the excavation of ore in the pit	4	1	4
The possibility of leakage from oil and grease from the mining equipment at mining excavation	3	3	9
Exhaust emissions from the mining operation machinery in the excavation of ore	4	1	4
Chance of uncontrolled explosions of blasting agents due to improper storage and / or work with the same - Potential accident	/	/	> 6≤ 12

Table 9. *Evaluation the actual and potential impacts on the environment [6]*

Process, activity: PIT VENTILATION			
Actual and potential impacts on the environment	**Criteria for evaluation the environmental impact**		
	VU	**TP**	**R**
Noise emission in living and working environments	3	1	3
Exhaust emissions from the mining operation machinery in the excavation of ore	3	1	3

Table 10. *Evaluation the actual and potential impacts on the environment [6]*

Process, activity: PIT DEWATERING			
Actual and potential impacts on the environment	**Criteria for evaluation the environmental impact**		
	VU	**TP**	**R**
Possible contamination of the river Ribnica by water coming out of parts of the mine polluted by the operation of mining machinery	3	3	9

Table 11. *Evaluation the actual and potential impacts on the environment [6]*

Process, activity: PIT TRANSPORT AND HAULAGE OF MAGNESITE ORE			
Actual and potential impacts on the environment	**Criteria for evaluation the environmental impact**		
	VU	**TP**	**R**
Possibility of leakage of diesel fuel, oil and grease from the mining equipment for the pit transport of magnesite ore	3	3	9
Exhaust emissions from the operation of mining machines for loading, transporting and unloading of magnesite ore	4	1	4
Potential accidents and contamination of water coming out of the pit, and go away into the river Ribnica	/	/	>6≤ 12

Table 12. *Evaluation the actual and potential impacts on the environment*

Process, activity: EXTERNAL TRANSPORT OF ORE TO SEPARATION			
Actual and potential impacts on the environment	**Criteria for evaluation the environmental impact**		
	VU	**TP**	**R**
emission of noise from the trucks and loaders	3	1	3
Dust emissions from the loading of ore	3	1	3
Possibility of leakage of diesel fuel, oil and lubricants from the truck and loader	3	3	9

Table 13. *Evaluation the actual and potential impacts on the environment [6]*

Process, activity: USE AND TEMPORARY STORAGE OF OIL DERIVATES			
Actual and potential impacts on the environment	**Criteria for evaluation the environmental impact**		
	VU	**TP**	**R**
Soil pollution by oil, oil and lubricants	3	3	9
Washing of contaminated soil of atmospheric water, penetration and contamination of the river Ribnica	3	3	9
Occurrence of fire from refueling the oil derivates	3	3	9

Table 14. *Evaluation the actual and potential impacts on the environment [6]*

Process, activity: USE AND STORAGE THE BLASTING AGENTS			
Actual and potential impacts on the environment	**Criteria for evaluation the environmental impact**		
	VU	**TP**	**R**
Possibility of occurrence the uncontrolled explosions, fires and injuries of people	3	3	9
Damage or destruction of buildings in the immediate vicinity	3	3	9
Damage of mining equipment	3	3	9

NOTE: *Actual or potential impact on the environment where the ACCIDENT or EMERGENCY SITUATION may arise is not measured, but it is automatically treated as a SIGNIFICANT ASPECT OF THE ENVIRONMENT, which needs planning of appropriate protective measures.*

4.3. Register of significant environmental aspects with proposed environmental protection measures

After carried out identification and evaluation the aspects of impact on the environment, the Register of important aspects was established that need to have the implemented measures to eliminate, reduce risk and maintain the control over their estimated risks of environmental pollution.

Table 15. *Register of significant environmental aspects [6]*

No	**Registered significant aspect of the enviuronment**	**Risk**	**Environmental protection measures to be undertaken**				
			Technol.	**Technical**	**Organizational**	**Sanitary-hygienic**	**Administrative**
1	Penetration of waste in the river bed of Ribnica on excavation for entrance into the pit	8	✓	✓	✓	/	✓
2	The possibility of erosion of sedimentary material from the plateau and blurring of the river Ribnica	9	✓	✓	✓	/	✓
3	The formation and disposal of overburden excavation (sterile rocks) in front of the entrance to the pit	6	✓	✓	✓	/	/
4	The possibility of leakage from oil and grease from mining machinery and land pollution on a plateau in front of the pit	9	✓	✓	✓	/	/
5	Municipal waste in the execution of manipulative work in front of the entrance to the pi	6	/	/	✓	✓	✓

6	Municipal waste	9	/	/	✓	✓	✓
7	Soil contamination from temporary sanitary facilities	9	/	✓	✓	✓	✓
8	Water pollution from temporary sanitary facilities	9	/	✓	✓	✓	✓
9	The formation of waste from making the mine facilities	8	✓	✓	/	/	/
10	The possibility of leakage from oil and grease from mining machinery in the excavation of ore	9	/	/	✓	/	/
11	Possible contamination of the river Ribnica by the water polluted of mining machinery coming out of the mine facilities	9	✓	✓	✓	/	/
12	The possibility of leakage of diesel fuel, oil and grease from pit mining equipment for the transport of magnesite ore	9	/	/	✓	/	/
13	The possibility of leakage of diesel fuel, oil and lubricants from the trucks and loaders	9	/	/	✓	/	/
14	Soil pollution by oil, oil and lubricants	9	/	/	✓	/	/
15	Runoff of contaminated soil and atmospheric water penetration and pollution of the river Ribnica	9	✓	/	✓	/	/
16	Occurrence of fire from refueling oil derivates	9	/	/	✓	/	/
17	Uncontrolled possibility of explosions, fires and injuries of people	9	/	✓	✓	/	/
18	Damage or destruction of buildings in near the uncontrolled explosion	9	/	✓	✓	/	/
19	Mining equipment damage from uncontrolled explosion	9	/	✓	✓	/	/

6. CONCLUSION

Environmental policy in the implementation of a specific project should be based on knowledge the environmental aspects and significant impacts on the environment caused by the specific project.

Based on the previous experience and as the basis of these investigations, it can be concluded that a methodological approach, present in this work, to the identification and evaluation aspects of the environmental impact of the project "MAGNESITE MINING IN THE DEPOSIT CAVLOVAC - MASNICE" gave the best results of assessment the level of risk of environmental pollution and got another confirmation of suitability for further use in the same or similar projects, and that it will be highly useful for further optimization the development of this methodological procedure. Based on the above results, the suitable environmental protection measures are prescribed and present within the Study on environmental impact assessment for the Project "MAGNESITE MINING IN THE DEPOSIT CAVLOVAC – MASNICE“. This study was the subject to public review and public debate. After completion of the procedure, a corresponding consent was give to the study of the impact assessment, what can be considered as a confirmation of eligibility the applied methodological approach.

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PETKOM-30 REAGENT A NEW COLLECTOR FOR COPPER MINERALS

Abstract

This paper presents the results obtained with flotation reagents in comparison to conventional reagents, on flotation test´s at laboratory level with minerals at the Plants. At the test´s, collectors from those Plants were used and these new reagents, with a modification of the particle size distribution, Collector dosage and ph of the pulp. These new reagents achieve better metallurgical parameters regarding the standard collector, increasing the law of copper in the concentrate and recovery. Furthermore this reagent has a positive effect, since it is based on a mixture of salts 2-mercaptobenzotiazol, has a reduced toxicity in compared to conventional reagents that causes a better impact on the environment.

Keywords: *Petkom collectors, recovery, copper.*

1. SUMMARY

The mining industry in Chile plays a fundamental role on the economy, since we are the leading producer of copper in the world, third in molybdenum, fifth in silver, fourteen in gold, in industrial minerals we are first in iodine and in lithium. We also contemplate other minerals as iron, manganese, lead, zinc and industrial minerals. The characteristics of these mining companies are mayor installations, which uses water, energy, natural resources and chemical products [1,2].

The ore flotation is still one of the most important processes in the benefit of the minerals. This method has permitted economic ore exploitation of low law and of a complex mineralogical composition, which in other times would have been impossible to process.

The ore flotation is a concentration technique which takes advantage of the difference between superficial properties or interfacial of the minerals and the gangue. It´s based on the adherence of some solids to gas bubbles generated in the slurry (pulp) by some external device, in the flotation cell. The air bubbles transport the solids to the surface where they are collected and recovered as concentrated. The fraction that doesn´t adhere to

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the bubbles remains in the pulp and constitute the tailing. This way the condition of floatability is a strong adherence between the useful particles and the bubbles, which needs to be able to support the agitation and turbulence in the cell. These particles are meant to be hydrophobic, or water repellent, contrary to the particles that constitute the tailing, which are hydrophilic.

To be able to obtain a good concentration in the cleaning stage of the concentrate, it requires that the useful species that constitute the ore, are separated from each other or released, this liberation of the useful particles is not necessary in the primer step of flotation [3].

The flotation is an operation of several complex physical-chemical processes, based on the differences of free energy of the involved interfaces (solid/liquid, solid/gas and liquid/gas), in which the valuable minerals are separated from the gangue due to the differences in their hydrophobicity. In most floatation systems, the particles surface turns hydrophobic by the selective absorption of the surfactants called collectors. The hydrophobic particles are aerophilic and are recovered in the foam, while the hydrophilic particles remain suspended in the slurry and are discharged in the tailings.

The floatation effectiveness is significantly determined by the application of the collectors, which increase the hydrophobic surface of minerals, and therefore increases the affinity by the bubble air. For this reason, the ore floatation process is complex and needs to adjust properly the collector to be able to obtain a high selectivity [4].

Contrary to other concentration methods, in floatation it´s possible to vary the difference between the useful properties and the gangue, modifying the chemical environment and the electrochemical of the system through a proper selection of the chemical reagents added, collectors, foaming agents, activators, depressants or Ph modifiers.

In this context the floatation reagents play an important role in the process, which by being fed to the flotation circuit, they achieve certain specific functions which makes possible the separation of the valuable minerals from the gangue. However the selection of reagents is not an easy task due to a number of technical difficulties presented during the process, like the mineralogical complexity of the ore among other aspects. Furthermore, the use of biodegradables reagents is without no doubt one of the necessary actions in the mining metallurgic industry, for which it needs to comply with the necessity of avoiding negative environmental impacts [5,6].

Copper minerals in Chile are flotated with xanthate type collectors. The mining companies have shifted to sustainability supported by the use of innovating and clean technologies. In this context, the new models of mining business, are not only trying to minimize the waste generation and effluents, but above all, regain the existing environmental liabilities and assuming a reagent flotation supply more atmosphere friendly.

The main object of this paper is to show the improvements produced by these new reagents of flotation. This way the performed flotation tests are focused on finding the advantages of the Petkom reagents, both in technical, environmental and economic aspects, regarding to metallurgy parameters of the standard reagents [6,7].

2. EXPERIMENTAL DEVELOPMENT

2.1. Materials and equipments

The Petkom 30 reagents are aqueous solutions of salts of 2-mercaptobenzothiazole, Limonac 1658 and water. It´s a selective collector and a corrosion inhibitor for minerals of copper, gold and silver. It´s a red-

yellow color liquid, without any defined odour(smell) , has an intensity between 1,20 to 1,22 kg/L and is water-soluble. The mineral samples for the flotation tests were obtained in the industrial plant M.A Matta of the National Mining Company, COEMIN S.A and Mining Company Atacama Kozan.

These samples were ground below 20 meshes and quartered by the quartering and paleo method leaving samples of approximately 20 kilograms as witness; the other sample was homogenized through a quartering rifle until obtaining 1.300 grams of samples approximately.

A kinetic grinding system was made to determine the time of grinding of the mineral sample. This was made in a roller mill, with a percentage of pulp solid in the mill of 60% of solids.

The flotation tests were made in a Denver cell D-12. The pulp obtained from the milling is adjusted to a 2,7 litres of volume, with a specific weigh mineral of 3,6 kg/L, the percentage of solids for the flotation was 35% in solids. The reagents are added according to the company's standard proportion.

The products obtained were filtrated and dried at 90° C to avoid the sublimation of some of the elements, especially sulphur. Once dried they were weighed and registered, and then they were quartered to obtain a representative part of the sample sent to chemical analyze.

2.2. STUDIED CASES

2.2.1. Manuel Antonio Matta Plant

Flotation tests were made at laboratory level to analyze the behavior of the Petkom reagents against the reagents used at the industrial plant, before three different samples of sulphured mineral. For the test of the plant 25 g/t of collector SF-323 was used and as foaming F-810 25 g/t. For the test´s where Petkom collector was used it was of 30g/t and the same foaming 25 g/t.

Flotation test´s were made besides, to analyze the decreased pH from the pulp and different dosages of the reagent Petkom 30 (50 g/t and 60 g/t) in front of the conventional reagent used at the Plant at pH 10, 5.

2.2.2. Atacama Kozan

Flotation test´s were made at laboratory level to analyze the Petkom reagents behavior against the reagents used at the Plant with the object to analyze the pH of the pulp. The test´s were made at a Ph of 8,5 and 9,5 with a dosage of Petkom of 50 and 60 g/t, trying to maintain the recovery of copper obtained at the Plant at 10,5 pH.

The conditions used were at a 5 minutes conditioning, 15 minutes of flotation, 35% percentage of solids, 60% of grading(particle size distribution)- 200 Tyler mesh.

2.2.3. Coemin Plant

The flotation test´s made at laboratory level were made with a mineral from the Explorer and Explotation Chilean Mining Company- Rumanian COEMIN S.A. These rougher flotation test´s had as objective to analyze the Petkom reagents in front of the actual used reagents at the Plant, that are 50 g/t of isobutyl xanthate, 40 g/t of ethyl xanthate and 23 g/t of MX 7017.

3. RESULTS AND DISCUSSION

3.1. A. M. Matta Plant

The results obtained at the flotation test´s to evaluate the behavior of the three processed minerals at M.A Matta Plant, are reagents used at the Plant and the Petkom reagent are shown on the following tables.

On table 1, one can observe that on the test using the Plant´s reagents, the recovery of copper reaches a total of 88,5% and 93,9% of insoluble copper. While with

Petkom 30 reagent it was of 87,3% and of 93,2% of insoluble copper. When comparing the obtained law of concentrate, the one with Petkom reagent is greater.

Table 1. *Results obtained with the reagents for mineral 1.*

	Flow	Weith (g)	Law Cu_T (%)	Law $Cu_{ins.}$ (%)	Rec. Cu_T (%)	Rec. $Cu_{ins.}$ (%)
Plant	Conc.	140,0	9,96	9,96	88,5	93,9
	Tailing	1094,0	0,16	0,18	11,5	6,1
	Feed.	1234,0	1,27	1,20	100,0	100,0
Petkom	Conc.	130,0	10,52	10,52	87,3	93,2
	Tailing	1104,0	0,18	0,09	12,7	6,8
	Feed.	1234,0	1,27	1,19	100,0	100,0

Table 2 presents the results obtained with the reagent used at the Plant and the one tested for mineral 2. One observe that the recovery of the total copper is of 95,8%, the insoluble copper is of 97,8%. The same table shows that when Petkom 30 reagent was used, the recovery was greater of the total copper and of insoluble copper. Regarding to the law of the obtained concentrates, with the Petkom reagent an increase of 0, 96% of copper is produced.

Table 2. *Results obtained with the reagents for mineral 2.*

	Flow	Weith (g)	Law Cu_T (%)	Law $Cu_{ins.}$ (%)	Rec. Cu_T (%)	Rec. $Cu_{ins.}$ (%)
Plant	Conc.	125,0	14,46	14,46	95,8	97,8
	Tailing	1117,0	0,07	0,04	9,2	2,2
	Feed.	1242,0	1,52	1,49	100,0	100,0
Petkom	Conc.	1126,0	15,42	15,42	96,8	98,4
	Tailing	116,0	0,05	0,03	3,2	1,6
	Feed.	1242,0	1,49	1,47	100,0	100,0

On table 3, one can observe results obtained for mineral 3. The recovery reached a value of 88,9% and 94,9% of insoluble copper. The same mineral but using reagent Petkom, the reached recovery was of 87,8% and 93,8% of insoluble copper. The law of the concentrate obtained is greater than 1,17% Cu.

Table 3. *Results obtained with the reagents for mineral 3.*

	Flow	Weith. (g)	Law Cu_T (%)	Law $Cu_{ins.}$ (%)	Rec. Cu_T (%)	Rec. $Cu_{ins.}$ (%)
Planta	Conc.	153,0	11,02	11,02	88,9	94,9
	Tailing	1082,0	0,20	0,09	11,1	5,1
	Feed.	1235,0	1,54	1,44	100,0	100,0
Petkom	Conc.	1098,0	12,19	12,19	87,8	93,8
	Tailing	136,0	0,21	0,10	12,2	6,2
	Feed.	1234,0	1,53	1,43	100,0	100,0

Figure 1 shows the results of recovery and law of copper in the concentrate obtained in the tests to evaluate the dosage of Petkom at pH 9,5.

One observe on the figure that on both test´s using Petkom one obtain greater recoveries (94,8% and 90,8% respectively) as well the law of copper in the concentrate (10,45% and 12,64%), when i reagents used at the Plant (recovery of 90,4% and 7,21% of copper) This shows that is possible to obtain concentrates with laws and greater recoveries than the obtained at a pH of 10,5 using the reagents of the Plant, with a considerable decreased of lime, which implies a minor cost of operation in the process.

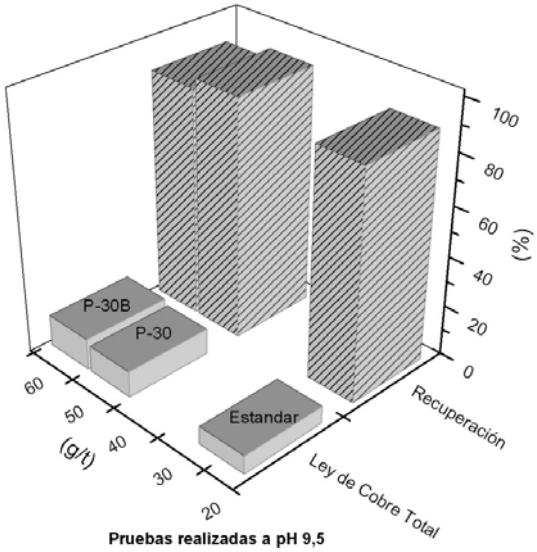

Fig. 1. *Effect of the dose of reagent and ph of the recovery and law of concentrate.*

3.2. Atacama Kozan

Figure 2 presents the recovery and law of copper in the concentrate versus the dosage of the reagent Petkom to a granulometry (particle size distribution) of 60% below the 200 mesh to a pH of 8,5 compared to the test with the reagents used in the Plant that were made at a pH of 10,5 and 70% below the 200 mesh.

One observe on the figure that the recovery obtained with the reagent Petkom are similar to the obtained with the reagent used at the Plant of Atakama Kozan for concentrates of 50 g/t and 60 g/t (93,3% and 93,5% against a 93,8%) According to the law of copper in the concentrate one can observe that on the two test´s made with the reagent Petkom, they are higher than with the reagent used on the Plant, for the dosage of 50 g/t and 60 g/t the law of copper on the concentrate is of 8,94% and 8,2%, while for the standard test, the law of copper obtained is of 6,6%.

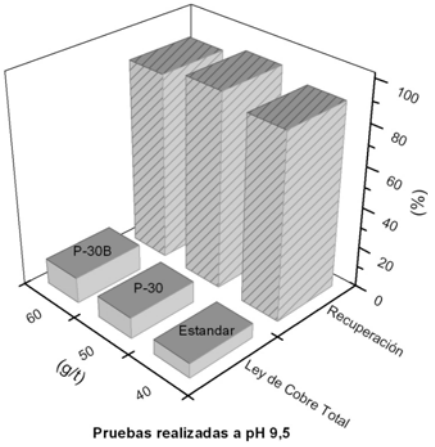

Fig. 2. *Effect of the reagent dosage and pH of the recovery and law of concentrate.*

Figure 3 presents the recovery and law of copper in the concentrate versus the reagent Petkom dosage to a granulometry-(particle size distribution) of 60% below the mesh 200 at a 9,5 pH, compared with the test where reagents of the Plant were used at a pH of 10,5 and 70% below mesh 200.

One observe on the figure that the recovery obtained with reagent Petkom are similar to the obtained with the reagent used at the Atacama Kozan Plant (96,3% and 92,4% against a 93,8%). The law of copper on the obtained concentrates, with the reagent Petkom these are pretty higher (9, 34% and 10, 57% against a 6, 6% of copper)

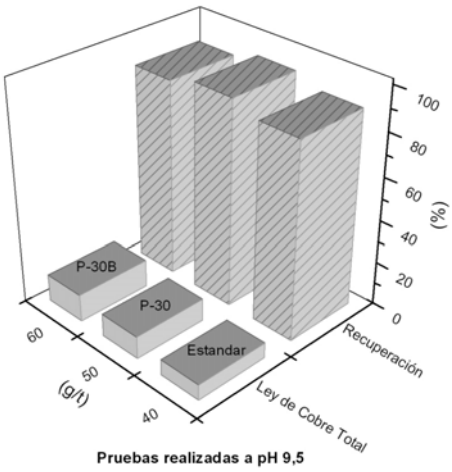

Fig. 3. *Effect of the reagent dosage and pH on the recovery and law of concentrate.*

3.3. Coemin Plant

Table 7 presents the results obtained on the flotation test using the Plant´s reagent´s. One can observe that the law of copper on the obtained concentrates reaches a value of 9,58% and the recovery obtained is of 97, 2%.

Table 7. *Test results made with the Plant´s reagents.*

Flow	Weith (g)	Law Cu_T (%)	Rec. Cu_T (%)
Feeding.	1167	1,24	100,0
Concentrate	147,6	9,58	97,2
Tailing	1019,4	0,041	2,8

Table 8. *Mass results and law obtained with the Petkom reagents.*

Flow	Weith (g)	Law Cu_T (%)	Rec. Cu_T (%)
Feeding.	1167	1,24	100,0
Concentrate	125,8	10,97	95,2
Tailing	1041,2	0,067	4,8

On table 9 the results of the flotation test´s are presented with the Petkom reagents, varying the dosage of the collector. The results show that the recovery and the law on the concentrates obtained are greater than the ones obtained with the reagents used at the Plant as the dosage of the collector is increased.

Table 9. *Mass Results and obtained laws.*

Dosage	**Flow**	**Weith (g)**	**Law Cu_T (%)**	**Rec. Cu_T (%)**
30 g/t	Concentrate	128,9	10,70	95,1
	Tailing	1038,1	0,07	4,9
	Feeding.	1167	1,24	100,0
35 g/t	Concentrate	125,7	11,22	97,3
	Tailing	1041,7	0,05	2,7
	Feeding.	1167	1,24	100,0
40 g/t	Concentrate	120,6	11,68	97,1
	Tailing	1046,4	0,04	2,9
	Feeding.	1167,0	1,24	100,0

The results of the flotation test´s varying the pH of the pulp between 10,5; 10,0 and 9,0 are shown on figure 4. One observe that at pH 10,5 the recovery is of 97,5% and the law of copper in the concentrate is of 11,53%, these values decreases as the pH descend reaching a recovery of 94,1 and a law of concentrate of 9,82% at a pH of 9.

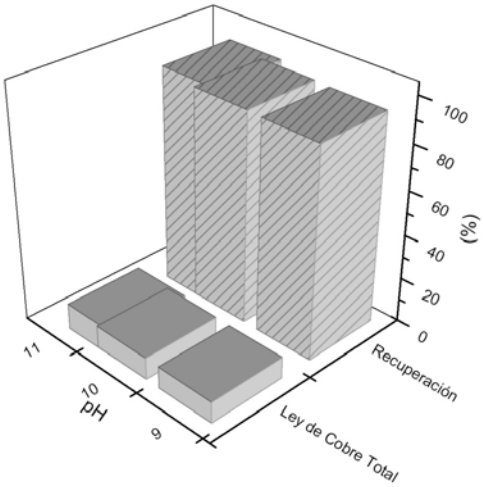

Fig. .*The effect of the pH on the recovery and law of the concentrate.*

4. CONCLUSIONS

Based on the results obtained at the flotation test´s with the minerals of the Plants M.A Matta, Coemin and Atacama Kozan one can conclude the following.

- The Petkom 30 reagent can replace the actual reagents used in the copper mineral flotation used at these Plants.
- After comparing the results, one can observe that under the same conditions of quality operation of the obtained concentrates they are mayor with the Petkom reagent than with the actual used at the three Plants.
- On the tests made, the characteristic of corrosion inhibitor of Petkom reagent was not analyzed.

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KOMITET ZA PODZEMNU EKSPLOATACIJU MINERALNIH SIROVINA UDK: 622

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IZBOR RUDNOG LEŽIŠTA KOMBINOVANOM PRIMENOM TOPSIS I AHP METODE

Izvod

U radu je predložena metodologija izbora rudnog ležišta primenom TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) i AHP metode (Analytic Hierarchy Process). Predložena metodologija je zasnovana na primeni metoda višekriterijumskog odlučivanja, pri čemu je AHP metoda primenjena za određivanje težina kriterijuma. Efikasnost predložene metodologije prikazana je primenom realne studije slučaja.

***Ključne reči**: Izbor rudnog ležišta; TOPSIS; AHP; MCDM: tehnički kriterijumi*

UVOD

Višekriterijumsko odlučivanje (multiple criteria decision making – MCDM) se generalno može opisati kao proces izbora jedne iz skupa raspoloživih alternativa, koja najefikasnije ispunjava postavljene ciljeve. Tokom poslednje dve decenije značajna pažnja je usmerena na razvoj i primenu MCDM metoda u rešavanju problema i dilema u oblasti upravljanja prirodnim resursima. Primeri se mogu naći u mnogim časopisima [1, 2, 3, 4, 5, 6, 7]. Značajan broj radova se bavi primenom ovih metoda u oblasti obnovljivih resursa i održivog razvoja [8, 9, 10]. Ali šta je sa primenom MCDM metoda u odlučivanju u mineralnoj industriji i metalurgiji? Neki autori su se bavili ovim pitanjima.

Izbor metode rudarenja je veoma česta tema u oblasti mineralnih resursa. Alpay i Yavuz su razmatrali sistem za podršku odlučivanju u izboru metode podzemnog rudarenja [11]. Naghadehi *et al.* su učinili nešto slično. Oni su predložili fazi AHP za određivanje optimalnog metoda rudarenja u iranskom rudniku [12]. Azimi *et al.* su rangirali strategije rudarskog sektora pomoću AHP i TOPSIS metode u okviru SWOT-a [13]. Samimi Namin *et al.* su predložili novi model, baziran na fazi odlučivanju, za izbor metoda rudarenja [14].

U ovom radu je predloženo korišćenje TOPSIS-a, između ostalih MCDM metoda, u preliminarnoj analizi za izbor odgovarajućeg rudnog ležišta za eksploataciju. AHP je upotrebljen za određivanje težina kriterijuma. Rad je organizovan na sledeći način: u drugom delu pažnja je usmerena na TOPSIS i AHP; u trećem delu je prikazan numerički primer koji je baziran na realnim podacima; a zatim sledi zaključak u četvrtom delu.

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2. KOMBINACIJA TOPSIS I AHP METODE

TOPSIS su razvili Hwang i Yoon [15]. Navedena metoda je takođe prikazana u radu Chena i Hwanga [16], u kome je dat i osvrt na rad Hwanga i Yoona. TOPSIS nastoji da definiše idealno i anti-idealno rešenje [17]. Osnovni princip je da izabrana alternativa treba da ima najmanju distancu od idealnog rešenja.

AHP je predložio Saaty [18, 19] za oblikovanje subjektivnih procesa odlučivanja baziranih na više kriterijuma u hijerarhijskoj strukturi. Saaty je konstatovao da je najkreativniji zadatak u odlučivanju biranje faktora koji su važni za određenu odluku. U AHP-u donosilac odluke strukturiše izabrane faktore hijerarhijski, prema opadajućem redosledu od sveukupnog cilja do kriterijuma, sub-kriterijuma i alternativa na uzastopnim nivoima [20]. Ovaj model je takođe pogodan za determinisanje relativnih težina kriterijuma u odgovarajućoj hijerarhijskoj strukturi. Postoje brojne metode za determinisanje težina u AHP-u. Neke od njih su:

- metod aritmetičkih sredina normalizovanih kolona (average of normalized columns – ANC),
- metod normalizovanih suma redova (normalization of row average – NRA), i
- metod normalizovanih geometrijskih sredina redova (normalization of the geometric mean of the rows – NGM) [21].

TOPSIS i AHP su dokazano korisni za modeliranje i analizu različitih situacija u odlučivanju u raznim poljima nauke i tehnologije [15, 18]. Navedene metode su usmerene na rešavanje problema koji su vezani za izbor jedne alternative od više ponuđenih. AHP metod je pogodan za primenu i kod opipljivih i kod neopipljivih kriterijuma, naročito kada subjektive procene pojedinaca čine važan deo procesa odlučivanja. TOPSIS je prikladniji za opipljive kriterijume [22]. Sledeći koraci predstavljaju proceduru kombinovanog TOPSIS-a i AHP-a:

Korak 1. ***Determinisati cilj i evaluacione kriterijume.***

Korak 2. ***Prikazati u obliku matrice sve raspoložive informacije o kriterijumima.*** Tabela 1 predstavlja informacionu tabelu TOPSIS-a [23]:

Tabela 1. *Informaciona tabela TOPSIS-a*

Alterantive	***Kriterijumi***			
	C_1	C_2	...	C_j
A_1	x_{11}	x_{12}	...	x_{1j}
A_2	x_{21}	x_{22}	...	x_{2j}
⋮	⋮	⋮	⋮	⋮
A_i	x_{n1}	x_{n2}	...	x_{ij}
W	w_1	w_2	...	w_j

gde:

$A_1, A_2, ..., A_i$ predstavljaju moguće alternative između kojih donosilac odluke treba da bira,

$C_1, C_2, ..., C_j$ su kriterijumi kojima se vrednuju performanse alternativa,

x_{ij} je ocena alternative A_i u odnosu na kriterijum C_j,

w_j je težina kriterijuma C_j,

$i = 1,...,m,$ gde je m broj alternativa, a

$j = 1,...,n,$ gde je n broj kriterijuma [24].

Kriterijumi izraženi u kvalitatvnim pokazateljima treba da budu transformisani u kvantitativne pokazatelje. U tu svrhu se koristi numerička skala prikazana u Tabeli 2:

Tabela 2. *Transformisanje kvalitativnih u kvantitativne pokazatelje*

Kvalitativni pokazatelji	**Kvantitativni pokazatelji**	
	prihodni - max	**rashodni - min**
Veoma visok	9	1
Visok	7	3
Prosečan	5	5
Nizak	3	7
Veoma nizak	1	9

Korak 3. ***Izračunati normalizovanu matricu odlučivanja.*** Normalizovana vrednost r_{ij} se računa na sledeći način:

$$r_{ij} = x_{ij} / \sqrt{\sum_{i=1}^{m} x_{ij}^2} \qquad (1)$$

Korak 4. ***Determinisati relativni značaj različitih kriterijuma u skladu sa postavljenim ciljem.*** Neophodno je konstruisati matricu poređenja u parovima primenom fundamentalne skale AHP-a. Navedena skala je prikazana u Tabeli 3 [19]:

Tabela 3. *Fundamentalna skala AHP-a*

Evaluaciona skala	**Objašnjenje**
1	Jednaka važnost
3	Malo važnije
5	Mnogo važnije
7	Izuzetno važnije
9	Najvažnije
2, 4, 6, 8	Međuvrednosti predložene skale

Kriterijum koji se poredi sam sa sobom se uvek označava sa 1. Unosi u osnovnoj dijagonali matrice upoređivanja, takođe, uvek iznose 1.

Kada je izvršeno poređenje u parovima kriterijuma i sa kriterijumom j, potrebno je sačiniti matricu, u kojoj a_{ij} reprezentuje komparativnu prednost kriterijuma C_i u odnosu na kriterijum C_j. U matrici $a_{ij} = 1$ je kada je $i = j$ i $a_{ji} = a_{ij}$.

Tabela 4. *Matrica poređenja u parovima*

	C_1	C_2	C_3	…	C_j
C_1	a_{11}	a_{12}	a_{13}	…	a_{1j}
C_2	a_{21}	a_{22}	a_{23}	…	a_{2j}
. . .	. . .	. . .	. . .	. . .	. . .
C_j	a_{j1}	a_{j2}	a_{j3}	…	a_{jj}

Zatim treba izračunati normalizovanu težinu w_j svakog kriterijuma korišćenjem sledećih formula:

$$GM_i = \left(\prod_{i=1}^{n} a_{ij} \right)^{1/n}, \qquad (2)$$

$$w_j = GM_i \,/\, \sum_{i=1}^{n} GM_i \qquad (3)$$

Sledi determinisanje maksimalne sopstvene vrednosti matrice poređenja $\lambda_{\max}$ i izračunavanje indeksa konzistentnosti CI :

$$CI = (\lambda_{max} - n)/(n-1) \qquad (4)$$

Nakon toga, računa se slučajni indeks konzistenstnosti RI za kriterijume koji su korišćeni u procesu odlučivanja. U Tabeli 5 su prikazani navedeni indeksi:

Tabela 5. *Slučajni indeks konzistenstnosti*

Broj kriterijuma	1	2	3	4	5	6	7	8	9
Slučajni indeks konzistenstnosti	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Zatim se pristupa izračunavanju koeficijenta konzistentnosti CR pomoću sledeće formule:

$$CR = CR/RI \qquad (5)$$

Ako vrednost CR iznosi 0.1 ili je niža, smatra se prihvatljivom i odražava pravilno prosuđivanje.

Korak 5. ***Formirati težinski normalizovanu matricu odlučivanja.*** Težinski normalizovana vrednost v_{ij} se računa na sledeći način:

$$v_{ij} = w_j r_{ij} \qquad (6)$$

Korak 6. ***Determinisati idealno rešenje*** A^+ ***i anti-idealno rešenje*** A^-**.** Idealno A^+ i anti-idealno rešenje A^- se računa korišćenjem sledećih formula:

$$A^+ = \{v_1^+, ..., v_n^+\} = \left\{ \left(\max_i v_{ij} \mid i \in I' \right), \left(\min_i v_{ij} \mid i \in I'' \right) \right\}, \qquad (7)$$

$$A^- = \{v_1^-, ..., v_n^-\} = \left\{ \left(\min_i v_{ij} \mid i \in I' \right), \left(\max_i v_{ij} \mid i \in I'' \right) \right\}, \qquad (8)$$

gde se I' odnosi na skup prihodnih kriterijuma, a I'' na skup rashodnih kriterijuma.

Korak 7. ***Izračunati odstojanje svake alternative od idealnog rešenja*** D_i^+ ***i anti-idealnog rešenja*** D_i^- ***korišćenjem n-dimenzionalne Euklidove distance.*** Odstojanje D_i^+ i D_i^- se računa na sledeći način:

$$D_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^+ \right)}, \qquad (9)$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^-\right)}. \qquad (10)$$

Korak 8. ***Izračunati relativnu blizinu idealnom rešenju.*** Relativna blizina idealnom rešenju je definisana na sledeći način:

$$C_i^+ = D_i^- / \left(D_i^+ + D_i^-\right), \qquad (11)$$

gde je $0 \le C^+ \le 1$.

Ako je alternativa i bliža A^+, onda se C_i približava 1.

Korak 9. ***Rangirati alternative.*** Alternative se mogu rangirati po opadajućem redosledu C_i.

3. IZBOR RUDNOG LEŽIŠTA

Centralna Srbija raspolaže različitim prirodnim resursima čija eksploatacija može obezbediti prosperitet navedenom području. Među prirodnim resursima nalaze se i rudna ležišta koja nisu iskorišćena na pravi način. Osnovni metal koji se nalazi u ovim ležištima je bakar praćen određenim količinama srebra i zlata. Zaključeno je da će eksploatacija pravog rudnog ležišta, koje poseduje najbolje karakteristike, doprineti ekonomskom rastu u Centralnoj Srbiji. Upoređena su sledeća rudna ležišta:

- ***A_1* - Južni revir – opština Majdanpek**
- ***A_2* - Severni revir – opština Majdanpek**
- ***A_3* – Borska reka – opština Bor**
- ***A_4* - Cerovo – opština Bor**

Osnovno pitanje koje se nameće glasi: *Koje ležište treba da ima prvenstvo u eksploataciji?*

U razvoju sistema za podršku odlučivanju za evaluaciju i izbor rudnog ležišta korišćena je TOPSIS metoda, a za determinisanje težina kriterijuma AHP metoda. Kriterijumi na kojima se bazira višekriterijumska analiza su isključivo tehnički. Nije uzet u obzir uticaj koji eksploatacija ima na životnu sredinu, niti ekonomski aspekt eksploatacije. Kriterijumi su sledeći:

- ***C_1*-Sadržaj bakra u rudi** (%). Prednost ima ležište čiji je sadržaj bakra u rudi veći.
- ***C_2*-Sadržaj srebra u rudi** (g/t). Prednost ima ležište čiji je sadržaj srebra u rudi veći.
- ***C_3*-Sadržaj zlata u rudi** (g/t). Prednost ima ležište čiji je sadržaj zlata u rudi veći.
- ***C_4*-Ispitanost bilansnih rezervi.** Ispitane količine minerala u rudnom ležištu ili delu ležišta koje mogu biti racionalno i ekonomično iskorišćene pomoću postojeće tehnike i tehnologije za eksploataciju i preradu. Bolje ispitana ležišta imaju prednost.
- ***C_5*-Lokacija.** Geoprostorni položaj rudnog ležišta i saobraćajna infrastruktura. Poželjno je ležište koje ima bolju poziciju i koje je bliže glavnim magistralama.
- ***C_6*-Rudarsko-geološki uslovi eksploatacije.** Oni uključuju mnoge karakteristike rudnog ležišta, kao što su: oblik rudnog tela, dubina zaleganja, kontakt sa okolnim stenama, a koje su veoma značajne za izbor metoda eksploatacije i imaju uticaja na troškove eksploatacije.

Informacije o rudnim ležištima su preuzete iz studije koja predstavlja deo šire studije pod nazivom *Potencijali ekonomskog razvoja Timočke Krajine* i iz *Field guide-a*. [25, 26].

3.1. Primer

Primena kombinacije TOPSIS i AHP metode u rangiranju rudnih ležišta Centralne Srbije prikazana je na osnovu numeričkog primera. Tri eksperta su izvršila evaluaciju četiri rudna ležišta A_1, A_2, A_3 i A_4 na osnovu šest evaluacionih kriterijuma $C_1, C_2, C_3, ..., C_6$, koji su prethodno navedeni.

Tabela 6. *Sirovi podaci*

	Sadržaj bakra %	**Sadržaj srebra g/t**	**Sadržaj zlata g/t**	**Ispitanost bilansnih rezervi**	**Lokacija**	**Rudarsko-geološki uslovi eksploatacije**
	max	**max**	**max**	**max**	**min**	**max**
Južni revir	0.335	1.260	0.188	visok	srednji	visok
Severni revir	0.306	2.001	0.263	visok	srednji	visok
Borska reka	0.620	1.920	0.240	visok	vrlo nizak	vrlo nizak
Cerovo	0.340	1.800	0.110	visok	nizak	nizak

Kvalitativni podaci su prevedeni u kvantitativne primenom numeričke skale koja je prikazana u Tabeli 2.

Tabela 7. *Početna matrica odlučivanja*

	Kriterijumi					
	C_1	C_2	C_3	C_4	C_5	C_6
Alternative	Sadržaj bakra %	Sadržaj srebra g/t	Sadržaj zlata g/t	Ispitanost bilansnih rezervi	Lokacija	Rudarsko-geološki uslovi eksploatacije
	max	max	max	max	min	max
A_1	0.335	1.260	0.188	7	5	7
A_2	0.306	2.001	0.263	7	5	7
A_3	0.620	1.920	0.240	7	9	1
A_4	0.340	1.800	0.110	7	7	3

Tabela 8. *Normalizovana matrica odlučivanja*

	Kriterijumi					
Alternative	C_1	C_2	C_3	C_4	C_5	C_6
	max	**max**	**max**	**max**	**min**	**max**
A_1	0.3987	0.3561	0.4504	0.5000	0.3727	0.6736
A_2	0.3642	0.5656	0.6301	0.5000	0.3727	0.6736
A_3	0.7380	0.5427	0.5750	0.5000	0.6708	0.0962
A_4	0.4047	0.5088	0.2635	0.5000	0.5217	0.2887

Koraci 1, **2** i **3** su izvršeni.

Korak 4. U cilju determinisanja relativne važnosti svih mogućih parova kriterijuma uz poštovanje osnovnog cilja, konsultovana su tri eksperta iz oblasti rudarstva. Njihove ocene su date u matricama u vidu razlomaka (Tabela 9, Tabela 10 i Tabela 11). Za prikazivanje ocena je korišćena fundamentalna skala AHP-a, prikazana u Tabeli 3. Relativne normalizovane težine w_j svakog kriterijuma j su izračunate primenom formula (2) i (3). Koeficijent konzistentnosti CR je proveren pomoću formula (4) i (5).

Tabela 9. *Matrica poređenja u parovima - Ekspert 1*

	C_1	C_2	C_3	C_4	C_5	C_6	w_j
C_1	1	9	1	1	7	1	0.233
C_2	1/9	1	1/9	1/9	1/7	1/7	0.020
C_3	1	9	1	1	7	1/3	0.194
C_4	1	9	1	1	5	1/3	0.183
C_5	1/7	7	1/7	1/5	1	1/7	0.047
C_6	1	7	3	3	7	1	0.322
				$CR = 9.96\%$			

Tabela 10. *Matrica poređenja u parovima - Ekspert 2*

	C_1	C_2	C_3	C_4	C_5	C_6	w_j
C_1	1	5	3	1/7	1/5	1/3	0.079
C_2	1/5	1	1/3	1/9	1/9	1/7	0.024
C_3	1/3	3	1	1/9	1/7	1/5	0.042
C_4	7	9	9	1	3	1	0.376
C_5	5	9	7	1/3	1	1/3	0.197
C_6	3	7	5	1	3	1	0.284
				$CR = 8.64\%$			

Tabela 11. *Matrica poređenja u parovima - Expert 3*

	C_1	C_2	C_3	C_4	C_5	C_6	w_j
C_1	1	9	3	5	7	1/3	0.271
C_2	1/9	1	1/7	1/5	1/3	1/9	0.023
C_3	1/3	7	1	3	5	1/5	0.144
C_4	1/5	5	1/3	1	3	1/5	0.079
C_5	1/7	3	1/5	1/3	1	1/9	0.040
C_6	3	9	5	5	9	1	0.443
				$CR = 7.53\%$			

Tri različita suda i zbog toga tri različite težine su svedene na zajedničku primenom formule (2). Dobijene težine, prikazane u Tabeli 12, su normalizovane primenom formule (3) zbog toga što ukupan rezultat nije iznosio 1.

Korak 5. Težinski normalizovana matrica odlučivanja je dobijena primenom formule (6) i prikazana je u Tabeli 12.

Tabela 12. Težinski normalizovana matrica odlučivanja

	Kriterijumi					
	C_1	C_2	C_3	C_4	C_5	C_6
Težine	0.192	0.025	0.118	0.198	0.080	0.386
Alterantive	max	max	max	max	min	max
A_1	0.0766	0.0089	0.0531	0.0990	0.0298	0.2600
A_2	0.0699	0.0141	0.744	0.0990	0.0298	0.2600
A_3	0.1417	0.0136	0.0679	0.0990	0.0537	0.0371
A_4	0.0777	0.0127	0.0311	0.0990	0.0417	0.1114

Korak 6. Idealno A^+ i anti-idealno rešenje A^-, prikazano u Tabeli 13, je izračunato putem formula (7) i (8).

Tabela 13. Idealno A^+ i anti-idealno rešenje A^-

A^+	0.1417	0.0141	0.0744	0.0990	0.0298	0.2600
A^-	0.0699	0.0089	0.0311	0.0990	0.0537	0.0371

Korak 7. Odstojanja D_i^+ i D_i^- su određena primenom formula (9) i (10). Rezultati su prikazani u Tabeli 14, I i II kolona.

Korak 8. Relativna blizina određenog rešenja idealnom C_i je izračunata pomoću formule (11) i prikazana je u Tabeli 14, III kolona.

Tabela 14. Odstojanje i relativna blizina idealnom rešenju

Alternative	D_i^+	D_i^-	C_i
	I	**II**	**III**
A_1	0.0687	0.2253	0.7663
A_2	0.0718	0.2283	0.7609
A_3	0.2242	0.0808	0.2648
A_4	0.1679	0.0757	0.3109

Korak 9. U skladu sa dobijenim rezultatima, rangiranje je sledeće (Tabela 15):

Tabela 15. Rang

Alternative	C_i	**Rang**
A_1	0.7663	1
A_2	0.7602	2
A_3	0.2648	4
A_4	0.3109	3

4. ZAKLJUČAK

Konačni rezultati pokazuju da je rudno ležište Južni revir ispravan izbor u postojećim uslovima. Za njim sledi Severni revir, treći je Cerovo, a na poslednjem mestu se nalazi Borska reka. Kao što je ranije rečeno, u obzir su uzeti samo tehnički aspekti i to: sadržaj određenog metala, ispitanost bilansnih rezervi, lokacija i rudarsko-geološki uslovi eksploatacije, te su dobijeni rezultati vezani isključivo za te kriterijume.

Predložena metodologija, zasnovana na TOPSIS i AHP metodi, pomaže u izboru rudnog ležišta i može biti korisna u preliminarnoj analizi. Metodologija može obuhvatiti bilo koji broj kriterijuma i nudi objektivniji, jednostavniji i konzistentniji pristup izboru rudnog ležišta. Ova metodologija se može primeniti u evaluaciji i rangiranju različitih skupova alternativnih rudnih ležišta. Takođe, izbor rudnih ležišta se može zasnivati na različitim kriterijumima, ne samo na tehničkim aspektima eksploatacije.

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ORE DEPOSIT SELECTION USING THE COMBINED TOPSIS AND AHP METHOD

Abstract

This paper proposes a methodology for ore deposit selection using TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) and AHP method (Analytic Hierarchy Process). The proposed methodology is based on the use of multi-criteria decision making methods, where AHP method is used to determine the criteria weights. The efficiency of proposed methodology is shown using the real case study.

Keywords: *ore deposit selection, TOPSIS, AH, MCDM, technical criteria*

1. INTRODUCTION

The multiple criteria decision making (MCDM) can be generally described as the process of selecting one from a set of available alternatives, which meets the most efficiently the set objectives of choice. Over the past two decades, a significant attention has been focused on development and using the MCDM methods in resolving problems and dilemmas in the field of natural resource management. Examples can be found in many journals [1, 2, 3, 4, 5, 6, 7]. There is a significant number of papers about using these methods in the field of renewable resources and sustainable development [8, 9, 10]. But, what about use the MCDM methods in making decisions in mineral industry and metallurgy? Some authors have studied these issues.

In the field of mineral resources, a selection of mining method by MCDM is a very common theme. Alpay and Yavuz considered a decision support system for underground mining method selection [11]. Naghadehi *et al.* did something similar. They proposed fuzzy analytic hierarchy process in determining an optimum mining method for mine in Iran [12]. Azimi *et al*. ranked strategies of mining sector through AHP and TOPSIS in a SWOT framework [13]. Samimi Namin *et al*. proposed a new model for mining method selection of mineral deposit, based on fuzzy decision making [14].

In this paper, TOPSIS is proposed, among other MCDM methods, for the use in preliminary analysis in selection the appropriate ore deposit for exploitation. AHP is used in determining the weights of criteria. The paper is organized as follows: in section 2, the attention is paid to TOPSIS and AHP; in section 3, a numerical example is given, based on real data; and section 4 contains conclusions.

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2. COMBINATION OF TOPSIS AND AHP METHOD

TOPSIS is developed by Hwang and Yoon [15]. This method is also present in a work by Chen and Hwang [16], with reference to Hwang and Yoon. TOPSIS attempts to define the ideal and anti-ideal solution [17]. The main principle is that the chosen alternative should have the shortest distance from the ideal solution.

AHP was proposed by Saaty [18, 19] to model subjective decision-making processes, based on multiple criteria in a hierarchical system. Saaty said that the most creative task in a decision making is to choose the important factors for that decision. In AHP, a decision maker arranges these selected factors in a hierarchic structure descending from an overall goal to the criteria, sub-criteria and alternatives in successive levels [20]. This model is also convenient to determine the relative weights according to the appropriate hierarchical system. There are numerous methods for determining the weights in AHP. Three of them are:

- average of normalized columns (ANC),
- normalization of row average (NRA), and
- normalization the geometric mean of t rows (NGM) [21].

TOPSIS and AHP are logically proved to be useful for modeling and analyzing various types of decision making situations in numerous fields of science and technology [15, 18]. These methods are attached to solving a problem which is connected to selection an alternative from a number of alternatives. The AHP can deal with tangible as well as non-tangible criteria, especially where subjective judgments of different individuals constitute an important part of a decision process. The TOPSIS is more appropriate for tangible criteria [22]. Following steps represent combined TOPSIS and AHP procedure:

Step 1. ***Determine a goal and evaluation criteria***

Step 2. ***Represent in a matrix form all available information about the criteria.*** Table 1 represents TOPSIS information table [23]:

Table 1 *Information table of TOPSIS*

Alternatives	***Criteria***			
	C_1	C_2	…	C_j
A_1	x_{11}	x_{12}	…	x_{1j}
A_2	x_{21}	x_{22}	…	x_{2j}
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
A_i	x_{n1}	x_{n2}	…	x_{ij}
W	w_1	w_2	…	w_j

where:

$A_1, A_2, ..., A_i$ represent possible alternatives among which a decision maker has to choose,

$C_1, C_2, ..., C_j$ are criteria with which alternative performance are measured,

x_{ij} is rating of alternative A_i with respect to the criteria C_j,

w_j is the weight of the criteria C_j,

$i = 1,...,m$, m is number of alternatives, and

$j = 1,...,n$, n is number of criteria [24].

When some of criteria are shown as the qualitative values, they need to be changed into quantitative values. For that purpose. a numerical scale, shown in Table 2, is used:

Table 2. *Transformation of linguistic scales into quantitative values*

Linguistic scale	Quantitative value	
	benefit - max	cost - min
Very high	9	1
High	7	3
Average	5	5
Low	3	7
Very low	1	9

Step 3. ***Calculate a normalized decision matrix***. The normalized value r_{ij} is calculated as:

$$r_{ij} = x_{ij} / \sqrt{\sum_{i=1}^{m} x_{ij}^2} . \qquad (1)$$

Step 4. ***Determine the relative importance of different criteria with respect to the following goal.*** Construct a pairwise comparison matrix using the fundamental scale of AHP. This scale is present in Table 3 [19]:

Table 3. *Fundamental scale of AHP*

Evaluation scale	Definition
1	Equally important
3	Slightly more importance
5	Strongly more importance
7	Demonstrably more importance
9	Absolutely more importance
2, 4, 6, 8	Medium value of adjacent scale

A criterion, compared by itself, is always assigned with 1. The main diagonal entries of comparison matrix also are always 1.

When the pairwise comparison of criterion i with criterion j yields is performed, then there is a need for a square matrix, where a_{ij} denotes the comparative importance of criterion C_i with respect to criterion C_j. In the matrix $a_{ij} = 1$, when $i = j$ and $a_{ji} = a_{ij}$.

Table 4. *Pairwase comparison matrix*

	C_1	C_2	C_3	…	C_j
C_1	a_{11}	a_{12}	a_{13}	…	a_{1j}
C_2	a_{21}	a_{22}	a_{23}	…	a_{2j}
.	.	.	.	.	.
C_j	a_{j1}	a_{j2}	a_{j3}	…	a_{jj}

Calculate relative normalized weight w_j of each criterion using the following formulae:

$$GM_i = \left(\prod_{i=1}^{n} a_{ij}\right)^{1/n}, \qquad (2)$$

$$w_j = GM_i / \sum_{i=1}^{n} GM_i. \qquad (3)$$

Then, determine maximum eigenvalue λ_{max} and calculate the consistency index CI :

$$CI = (\lambda_{max} - n)/(n-1). \qquad (4)$$

After that, the random index RI , for the number of criteria used in the decision making, has to be obtained. Table 5 shows this index:

Table 5. *Random index details*

Number of Criteria	1	2	3	4	5	6	7	8	9
Random Index	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Then, the consistency ratio CR is calculated using the following formula:

$$CR = CR/RI. \qquad (5)$$

If value of CR is 0.1 or less than it is considered as acceptable, and it reflects an appropriate judgment.

Step 5. ***Create the weighted normalized decision matrix.*** The weighted normalized value v_{ij} is calculated as:

$$v_{ij} = w_j r_{ij} \qquad (6)$$

Step 6. ***Determine ideal solution*** A^+ ***and anti-ideal solution*** A^-**.** The ideal solution A^+ and anti-ideal solution A^- are calculated using the following formulae:

$$A^+ = \{v_1^+, ..., v_n^+\} = \\ = \left\{\left(\max_i v_{ij} \mid i \in I'\right), \left(\min_i v_{ij} \mid i \in I''\right)\right\}, \qquad (7)$$

$$A^- = \{v_1^-, ..., v_n^-\} = \\ = \left\{\left(\min_i v_{ij} \mid i \in I'\right), \left(\max_i v_{ij} \mid i \in I''\right)\right\}, \qquad (8)$$

where I' is associated to a set of benefit criteria, and I'' is associated to a set of cost criteria.

Step 7. ***Calculate the separation of each alternative from ideal solution*** D_i^+***, and anti-ideal solution*** D_i^- ***using the n-dimensional Euclidean distance.*** The ideal solution D_i^+ and anti-ideal solution D_i^- are calculated as:

$$D_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^+\right)}, \qquad (9)$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^-\right)}. \qquad (10)$$

Step 8. ***Calculate the relative closeness to the ideal solution.*** The relative closeness to the ideal solution is defined as:

$$C_i^+ = D_i^- / \left(D_i^+ + D_i^-\right), \qquad (11)$$

where $0 \le C^+ \le 1$.

If an alternative i is closer to A^+, than C_i approaches to 1.

Step 9. ***Rank the preference order.*** A set of alternatives can be preferentially ranked according to the descending order of C_i.

3. ORE DEPOSIT SELECTION

Central Serbia has various natural resources whose exploitation could bring prosperity to this area. Among these natural resources, there are ore deposits, which are not properly used. The main metal in these deposits is copper including some amount of silver and gold. It is concluded that exploitation of the right ore deposit with the best characteristics, would lead to the economic growth of Central Serbia. The compared ore deposits are:

- ***A_1* – South Mining District – Majdanpek municipality**
- ***A_2* – North Mining District - Majdanpek municipality**
- ***A_3* - Borska reka - Bor municipality**
- ***A_4* - Cerovo - Bor municipality**

So, the main question is: *Which of these deposits should have priority in exploitation?*

TOPSIS method is used for development a decision support system for evaluation and selection the ore deposit, and AHP method for determining the weights of criteria. The criteria, under which the multi-criteria analysis is performed, are only technical. The effect of exploitation on the environment, as well as the economic aspect of exploitation, is not taken into account. The criteria are following:

- ***C_1*-Copper content in the ore** (%). The ore deposit with higher copper content has the advantage.
- ***C_2*-Silver content in the ore** (g/t). The ore deposit with higher silver content has the advantage.
- ***C_3*-Gold content in the ore** (g/t). The ore deposit with higher gold content has the advantage.
- ***C_4*-Testing the balance reserves.** Tested amounts of minerals in the ore deposit or a part of deposit, which can be rationally and economically recovered using the present techniques and technologies of exploitation and processing. Better tested deposits have the advantage.
- ***C_5*-Location.** Geospatial position of the ore deposit and transport infrastructure. The ore deposit which has better position and which is closer to the major highways is desirable.
- ***C_6*-Mining-geological conditions of exploitation.** Mining-geological conditions include many characteristics of ore deposit, such as: shape of ore body, depth, contact with the surrounding rocks and others that are very significant for selection the exploitation method and have influence on the exploitation costs.

Information about compared ore deposits are taken from the study that is a part of the extensive study *Potentials of Economic Development of the Timok Region* and from *Field Guide* [25,26].

3.1. Example

A numerical example is illustrated for presentation the combined TOPSIS and AHP for ranking the ore deposits in Central Serbia. Four ore deposits A_1, A_2, A_3 and A_4 are evaluated by three experts against six evaluating criteria $C_1, C_2, C_3, ..., C_6$, which are above mentioned.

Table 6. *Raw data*

	Copper content %	Silver content g/t	Gold content g/t	Testingof balance reserves	Location	Mining-geological conditions of exploitation
	max	max	max	max	min	max
S.M.District	0.335	1.260	0.188	high	average	high
N.M.District	0.306	2.001	0.263	high	average	high
Borska reka	0.620	1.920	0.240	high	very low	very low
Cerovo	0.340	1.800	0.110	high	low	low

Qualitative data are changed into quantitative using the numerical scale, shown in the Table 2.

Table 7. *Initial decision matrix*

	Criteria					
	C_1	C_2	C_3	C_4	C_5	C_6
Alternatives	Copper content %	Silver content g/t	Gold content g/t	Testing of balance reserves	Location	Mining-geological conditions of exploitation
	max	max	max	max	min	max
A_1	0.335	1.260	0.188	7	5	7
A_2	0.306	2.001	0.263	7	5	7
A_3	0.620	1.920	0.240	7	9	1
A_4	0.340	1.800	0.110	7	7	3

Normalized decision matrix (Table 8) is calculated by the formula (1).

Table 8. *Normalized decision matrix*

	Criteria					
Alternatives	C_1	C_2	C_3	C_4	C_5	C_6
	max	max	max	max	min	max
A_1	0.3987	0.3561	0.4504	0.5000	0.3727	0.6736
A_2	0.3642	0.5656	0.6301	0.5000	0.3727	0.6736
A_3	0.7380	0.5427	0.5750	0.5000	0.6708	0.0962
A_4	0.4047	0.5088	0.2635	0.5000	0.5217	0.2887

Note that **Steps 1**, **2** and **3** are done.

Step 4. In order to determine the relative importance of all possible pairs of criteria with respect to the overall goal, three experts in the field of mining are consulted. Their judgments are arranged

into matrixes. The pairwise comparison judgment on the criteria is shown as the equation in all three matrixes (Table 9, Table 10, Table 11). The fundamental scale of AHP, shown in Table 3, is used in entering the judgments. The relative normalized weights w_j of each criterion j is calculated by the formulae (2) and (3). The consistency ratio CR is checked by the formulae (4) and (5).

Table 9. *Pairwise matrix - Expert 1*

	C_1	C_2	C_3	C_4	C_5	C_6	w_j
C_1	1	9	1	1	7	1	0.233
C_2	1/9	1	1/9	1/9	1/7	1/7	0.020
C_3	1	9	1	1	7	1/3	0.194
C_4	1	9	1	1	5	1/3	0.183
C_5	1/7	7	1/7	1/5	1	1/7	0.047
C_6	1	7	3	3	7	1	0.322
$CR = 9.96\%$							

Table 10. *Pairwise matrix - Expert 2*

	C_1	C_2	C_3	C_4	C_5	C_6	w_j
C_1	1	5	3	1/7	1/5	1/3	0.079
C_2	1/5	1	1/3	1/9	1/9	1/7	0.024
C_3	1/3	3	1	1/9	1/7	1/5	0.042
C_4	7	9	9	1	3	1	0.376
C_5	5	9	7	1/3	1	1/3	0.197
C_6	3	7	5	1	3	1	0.284
$CR = 8.64\%$							

Table 11. *Pairwise matrix - Expert 3*

	C_1	C_2	C_3	C_4	C_5	C_6	w_j
C_1	1	9	3	5	7	1/3	0.271
C_2	1/9	1	1/7	1/5	1/3	1/9	0.023
C_3	1/3	7	1	3	5	1/5	0.144
C_4	1/5	5	1/3	1	3	1/5	0.079
C_5	1/7	3	1/5	1/3	1	1/9	0.040
C_6	3	9	5	5	9	1	0.443
$CR = 7.53\%$							

Three different judgments and therefore, different weights, are reduced to a common weight by the formula (2). Calculated weights are normalized by the formula (3) because the total result was not 1, and they are as in Table 12.

Step 5. The weighted normalized decision matrix is calculated by the formula (6) and shown in Table 12.

Table 12. *Weighted normalized decision matrix*

	Criteria					
	C_1	C_2	C_3	C_4	C_5	C_6
Weights	0.192	0.025	0.118	0.198	0.080	0.386
Alterantives	max	max	max	max	min	max
A_1	0.0766	0.0089	0.0531	0.0990	0.0298	0.2600
A_2	0.0699	0.0141	0.744	0.0990	0.0298	0.2600
A_3	0.1417	0.0136	0.0679	0.0990	0.0537	0.0371
A_4	0.0777	0.0127	0.0311	0.0990	0.0417	0.1114

Step 6. The ideal A^+ and anti-ideal solutions A^- are determined by the formulae (7) and (8), and they are as in Table 13.

Table 13. *The ideal A^+ and anti-ideal solutions A^-*

A^+	0.1417	0.0141	0.0744	0.0990	0.0298	0.2600
A^-	0.0699	0.0089	0.0311	0.0990	0.0537	0.0371

Step 7. The separation measures D_i^+ and D_i^- are determined by using the formulae (9) and (10). The results are shown in Table 14, columns I and II.

Step 8. Relative closeness of particular solution to the ideal solution C_i is calculated by the formula (11), and it is given in Table 14, column III.

Table 14. *The separation measures and relative closeness to the ideal solution*

Alternative	D_i^+	D_i^-	C_i
	I	**II**	**III**
A_1	0.0687	0.2253	0.7663
A_2	0.0718	0.2283	0.7609
A_3	0.2242	0.0808	0.2648
A_4	0.1679	0.0757	0.3109

Step 9. According to the results, the rank is the following (Table 15):

Table 15. *Ranking results*

Alternative	C_i	Rank
A_1	0.7663	1
A_2	0.7602	2
A_3	0.2648	4
A_4	0.3109	3

4. CONCLUSION

The final results show that the ore deposit South Mining District is the appropriate choice for the given conditions. The second choice is the North Mining District, the third is Cerovo, and the last one is Borska reka. As it was discussed previously, only technical aspects were taken into consideration, such as content of certain metals, testing the balance reserves, location, and mining-geological conditions of exploitation and the results were obtained according to that criteria.

The proposed methodology based on TOPSIS and AHP helps in the ore deposit selection and it is useful in the preliminary analysis. The methodology can consider any number of criteria and offers more objective, simple and consistent approach to the ore deposit selection. This methodology could be used in evaluating and ranking any given set of alternative ore deposits. It can be used for the ore deposit selection according to different criteria, not only to technical aspects of exploitation.

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UTICAJ RAZLIČITIH KOLEKTORA NA ISKORIŠĆENJE BAKRA I PLEMENITIH METALA RUDNOG TELA TENKA 3***

Izvod

U ovom radu prikazan je deo tehnoloških ispitivanja koja su obavljena sa ciljem definisanja optimalnih uslova flotacijske koncentracije rude ležišta Tenka 3 – Severni revir, rudnika bakra Majdanpek. Dati prikaz odnosi se na ispitivanje uticaja kolektora NaIPX, 3418A i AP5500 kao i pH vrednosti pulpe na pojedine tehnološke pokazatelje (iskorišćenja bakra i plemenitih metala) procesa osnovnog flotiranja. Utvrđeno je da se generalno najbolja iskorišćenja bakra i zlata u osnovnom koncentratu bakra postižu primenom kombinacije kolektora 3418A i AP5500, dok se najbolja iskorišćenja srebra u osnovnom koncentratu bakra postižu primenom natrijum izopropil ksantata. Pored toga, veća iskorišćenja zlata i srebra dobijena su pri nižim pH vrednostima pulpe, dok, s druge strane, nije uočena jasna zavisnost iskorišćenja bakra od pH vrednosti pulpe u ispitivanom opsegu pH (10,0 – 11,5).

Ključne reči: *bakar, zlato, srebro, kolektor, iskorišćenje*

1. UVOD

Područje Tenke predstavlja obodni deo rudnog tela Severnog revira koji je, zahvaljujući tektonskim, fizičko-mehaničkim i termodinamičkim uslovima predstavljao pogodno tlo za nastanak različitih rudnih mineralizacija. Rudna tela su formirana u čvorištima rasednih zona u kojima je došlo do drastičnog opadanja temperature i pritiska hidrotermalnih, rudonosnih rastvora u odgovarajućoj litološkoj sredini [1,4].

Problematika ovog naučno-istraživačkog rada suštinski predstavlja ispitivanje mogućnosti valorizacije korisnih komponenti (bakra i plemenitih metala) iz kompleksne sirovine koja je karakteristična za ovaj deo ležišta površinskog kopa Seve-

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rni revir. To se, pre svega, odnosi na relativno visok sadržaj korisnih komponenti uz visok sadržaj pirita, strukturno-teksturne osobine rude i sadržaj glinovitih frakcija, mineraloški sastav i način srastanja korisnih i jalovih minerala itd [2]. Poznato je da su ležišta na lokaciji Tenka (Tenka 1, Tenka 2, Tenka 3) polimetaličnog tipa i da pored bakra, sadrže i minerale olova i cinka u određenoj meri [1]. Sa tog aspekta, definisanje optimalih uslova prerade rude ovih karakteristika i dobijanje komercijalnog proizvoda uz zadovoljavajuće tehnološke efekte, predstavlja komplikovan zadatak i zahteva ozbiljan istraživački pristup tehnološkim ispitivanjima.

Bitan faktor za koncepciju laboratorijskih ispitivanja predstavlja primena postojećih tehnoloških rešenja i parametara iz tekuće proizvodnje u flotaciji RBM [2,3].

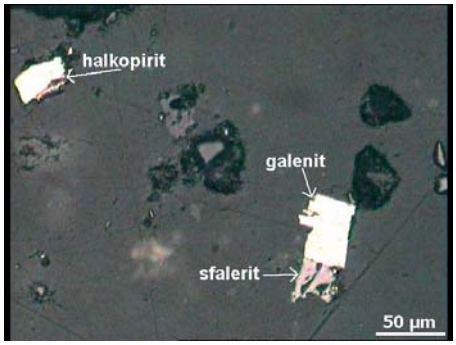
2. KARAKTERIZACIJA POLAZNIH UZORAKA

Polazni uzorci uzeti su sa 3 lokacije graničnog dela ležišta Tenka 3. Nakon drobljenja i homogenizacije svakog od uzoraka sa pomenutih lokacija, formiran je kompozitni uzorak (u masenom odnosu 1:1:1) na kome su izvršena planirana laboratorijska ispitivanja. Hemijski sastav pojedinačnih uzoraka, kao i kompozitnog uzorka prikazan je u tabeli 1. Sadržaj vlage u kompozitnom uzorku iznosio je 6,6%.

Tabela 1. *Hemijski sastav uzoraka iz rudnog tela Tenka 3*

Naziv uzorka	Sadržaj komponente [%]							
	Pb [%]	Zn [%]	Cu [%]	Cu_{sulf} [%]	Cu_{ox} [%]	S [%]	Au [g/t]	Ag [g/t]
T_3 lokacija 1	0,06	0,0075	0,63	0,608	0,0175	17,86	<0,03	1,65
T_3 lokacija 2	0,10	0,0160	0,30	0,288	0,0120	41,59	1,50	4,65
T_3 lokacija 3	0,06	0,0240	0,49	0,462	0,0320	6,11	<0,03	10,4
Kompozit	0,073	0,016	0,473	0,453	0,021	21,853	0,520	5,567

Kvalitativna mineraloška analiza urađena je pod polarizacionim mikroskopom za odbijenu svetlost u vazduhu, sa identifikacijom rudnih i nerudnih minerala. Kod uzorka uzetih sa sve tri lokacije utvrđeno je prisustvo minerala pirita, halkopirita, limonita, kvarca, silikata i karbonata. Uzorak sa lokacije 1 sadrži još i tetraedrit, dok su u uzorku sa lokacije 3 (slika 1) pored navedenih minerala prisutni i bornit, galenit i sfalerit.



Sl. 1. *Uzorak T_3 lokacija 3. Polimetalična ruda*

Kompozitni uzorak, čija je gornja granična krupnoća iznosila 2 mm, dalje je mlevenjem sveden na finoću od 60% –0,074 mm, čime je postignuta optimalna krupnoća mineralnih zrna (prema mineraloškoj analizi) za potrebe opita flotacijske koncentracije. Granulometrijski sastav samlevene mineralne sirovine prikazan je u tabeli 2. Prirodna pH vrednost pulpe sa masenim učešćem čvrste faze od 32% iznosila je 7,43.

Tabela 2. *Granulometrijski sastav samlevene rude (kompozit)*

Klasa krupnoće [mm]	**Učešće klase krupnoće [%]**	
	Parcijalno	**Kumulativno, prosev**
+0.589	0,36	100,00
-0,589+0.295	8,18	99,64
-0,295+0,104	25,29	91,46
-0,104+0,074	7,56	66,17
-0,074+0,052	13,77	58,61
-0,052+0,037	5,12	44,84
-0,037+0,000	39,72	39,72
Ukupno:	100,00	

3. TEHNOLOŠKI USLOVI ISPITIVANJA

Laboratorijska tehnološka ispitivanja uslova flotacijske koncentracije su obuhvatila promenu relevantnih tehnoloških parametara u opsegu postojećih vrednosti primenljivih u flotacijskom pogonu Majdanpek, i to:

- Ispitivanja su urađena kroz šest serija opita osnovnog flotiranja.
- Svaka serija se sastojala iz četiri opita, pri čemu je pH vrednost pulpe po opitima iznosila 10,0, 10,5, 11,0 i 11,5.
- Gustina pulpe u mlevenju je u svim opitima iznosila 70% čvrste faze.
- Gustina pulpe u flotiranju je u svim opitima iznosila 32% čvrste faze.
- Finoća mlevenja je u svim opitima iznosila 60% –0,074 mm (krupnoća pri kojoj se ostvaruje optimalno oslobađanje korisnih minerala)
- Kao penušač u svim opitima korišćen je AEROFROTH 76A uz preporučenu potrošnju od strane proizvođača
- Kao kolektori su korišćeni sledeći reagensi i njihove kombinacije:
  - NaIPX (natrijum izopropil ksantat) kao dobar kolektor sulfidnih minerala,
  - 3418 A (ditiofosfinat), kojeg karakterišu dobri rezultati u pogledu iskorišćenja zlata i srebra i
  - AP 5500 (etoksikarbonil tiourea), reagens koji je u teoriji i praksi poznat kao dobar kolektor sulfidnih minerala bakra i veoma selektivan u odnosu na sulfide gvožđa i pri nižim pH vredostima pulpe.

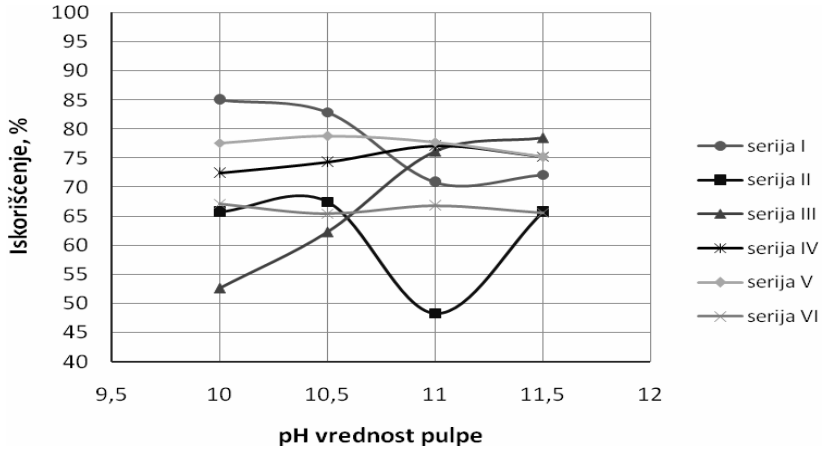
- Utrošak kolektora, bilo samostalno ili u kombinaciji iznosio je 40 g/t rude u svim opitima osnovnog flotiranja. Ova doza kolektora određena je na osnovu sadržaja sulfidnih minerala jer treba imati u vidu da je osim minerala bakra sadržaj pirita u rudi veoma visok (oko 30%). Potrošnja pojedinih kolektora po serijama opita prikazana je u tabeli 3.
- U svim opitima vreme kondicioniranja iznosilo je 7 minuta, a vreme osnovnog flotiranja 18 minuta. Kolektori su dodavani u tri jednake doze i to jedna doza u kondicioniranju i dve u osnovnom flotiranju.

Tabela 3. *Potrošnja kolektora u opitima flotacijske koncentracije, posmatrano po serijama opita*

Serija opita	Potrošnja kolektora [g/t suve rude]		
	NaIPX	3418 A	AP 5500
I	/	40	/
II	/	/	40
III	40	/	/
IV	24	16	/
V	/	20	20
VI	24	/	16

4. REZULTATI I DISKUSIJA

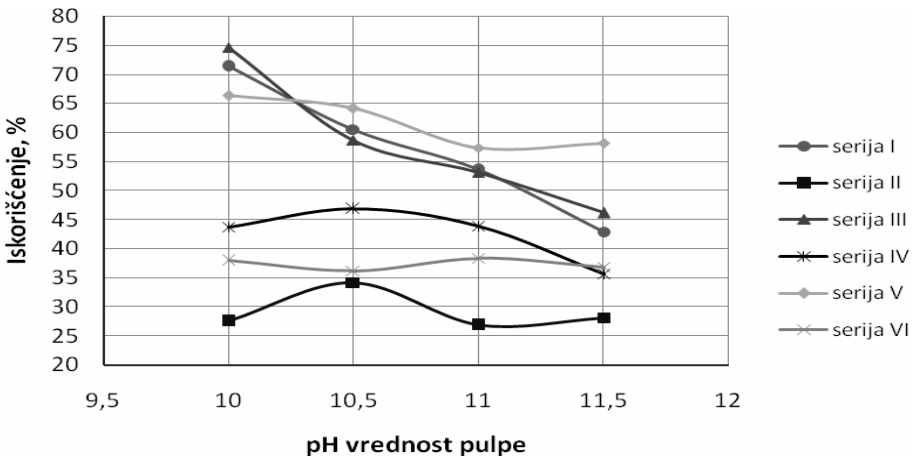
Iskorišćenje bakra u osnovnom koncentratu bakra po serijama opita prikazano je na slici 2.



Sl. 2. *Iskorišćenje bakra po serijama opita*

Sa slike 2 se vidi da su, generalno, najpovoljnija iskorišćenja bakra u osnovnom koncentratu bakra ostvarena u četvrtoj i petoj seriji opita. Očigledno je da primena kombinacije kolektora u osnovnom flotiranju (3418 A i NaIPX u IV seriji; 3418 A i AP5500 u V seriji) daje bolje rezultate u pogledu iskorišćenja bakra nego što je to slučaj kada se ovi kolektori primene pojedinačno (prve tri serije opita). Visoke vrednosti iskorišćenja bakra u osnovnom koncentratu (preko 80%) koje su dobijene u prvoj seriji opita objašnjavaju se velikim masenim učešćem osnovnog koncentrata [2]. Zavisnost iskorišćenja bakra od pH vrednosti pulpe u ovim ispitivanjima nije eksplicitno uočljiva.

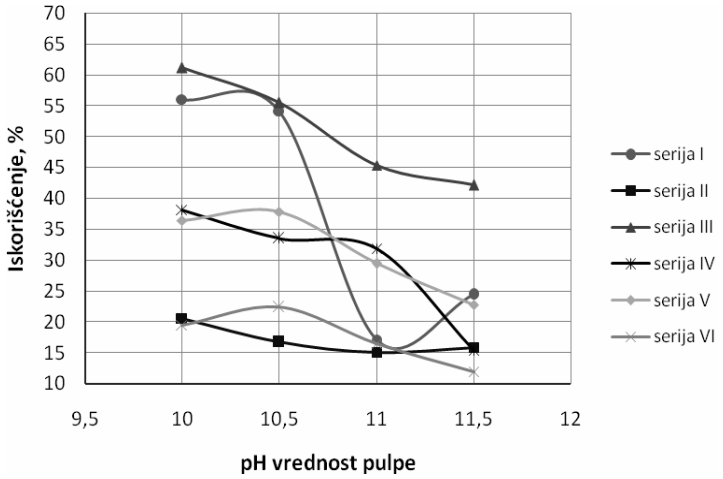
Iskorišćenje zlata u osnovnom koncentratu bakra po serijama opita prikazano je na Slici 3.



Sl. 3. *Iskorišćenje zlata po serijama opita*

Najpovoljnija iskorišćenja zlata u osnovnom koncentratu bakra ostvarena su u serijama opita I, III i V, što se može jasno uočiti na slici 3. Ipak, generalno gledano, najveća iskorišćenja zlata ostvarena su u seriji opita V u kojoj je korišćena kombinacija kolektora 3418A i AP5500 u procentualnom masenom odnosu 50:50. Pored toga, može se zaključiti da se, bez obzira na vrstu kolektora, veća iskorišćenja zlata u osnovnom koncentratu bakra dobijaju pri nižim pH vrednostima pulpe.

Iskorišćenje srebra po serijama opita prikazano je na slici br. 4.



Sl. 3. *Iskorišćenje srebra po serijama opita*

Sa slike 4 se vidi da su najpovoljnija iskorišćenja srebra u osnovnom koncentratu bakra ostvarena u seriji opita III u kojoj je kao kolektor korišćen NaIPX. Upotreba ostalih kolektora, kao i njihovih kombinacija sa natrijum izopropil ksantatom nije dala zadovoljavajuće rezultate u pogledu iskorišćenja srebra. Analogno iskorišćenju zlata, veća iskorišćenja srebra u osnovnom koncentratu bakra dobijaju se pri nižim pH vrednostima pulpe.

5. ZAKLJUČAK

Upotreba kolektora NaIPX samostalno (serija opita III), daje visoko iskorišćenje metala (posebno zlata i srebra), ali se mora napomenuti da je pri tom dobijena velika masa osnovnog koncentrata, sa relativno niskim sadržajem bakra [2].

Kombinovanje NaIPX sa ostala dva kolektora kao rezultat daje smanjenje mase osnovnog koncentrata [2], uz blago povećanje iskorišćenja bakra pri nižim pH vrednostima pulpe, pod uslovom da se koristi u istom odnosu kao što je to slučaj u proizvodnji flotacije RBM (40:60% u korist ksantata). S druge strane, ove kombinacije kolektora nepovoljno utiču na iskorišćenja zlata i srebra (serije opita IV i VI).

Samostalnom primenom kolektora 3418A (serija opita I) postižu se zadovoljavajuća iskorišćenja bakra, srebra i zlata samo pri nižim pH vrednostima pulpe, dok sa povećanjem pH vrednosti pulpe, iskorišćenja metala opadaju. Međutim, ponovo treba naglasiti da su razlike u masama osnovnih koncentrata u ovoj seriji opita velike [2].

Primenom kolektora AP5500 (serija opita II) nisu postignuti zadovoljavajući rezultati, dok je u kombinaciji sa 3418A (serija opita V) došlo do značajnog poboljšanja tehnoloških rezultata. Generalno se može tvrditi da su u ovoj seriji opita ostvarena najbolja iskorišćenja metala u toku celokupnog ispitivanja. Ovim se potvrđuje pozitivan efekat sinergijskog dejstva dva savremena kolektora različitog porekla i karakteristika.

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THE EFFECT OF DIFFERENT COLLECTORS ON RECOVERY OF COPPER AND PRECIOUS METALS OF THE ORE BODY TENKA 3***

Abstract

This work presents a part of technological testing that were conducted in order to define the optimum conditions of flotation concentration of the ore from the deposit Tenka 3 - North Mining District, Majdanpek copper mine. Provided description refers to testing the effect of collectors NaIPX, 3418 and AP5500 as well as the pH value of pulp to the certain technical indicators (recovery of copper and precious metals) of the rough flotation process.It was found that generally the best recoveries of copper and gold in the basic copper concentrate are obtained using a combination of collectors 3418 and AP5500, while the best silver recovery in the basic copper concentrate is obtained using the sodium isopropyl xanthate. In addition, higher recoveries of gold and silver were obtained at lower pH value of pulp, while, on the other hand, a clear dependence of copper recovery on pH value was not observed in tested pH range (10.0 to 11.5).

Keywords: *copper, gold, silver, collector, recovery*

1. INTRODUCTION

The area of Tenka is a peripheral part of the ore body North Mining District, which, owing to tectonic, physical-mechanical and thermodynamic conditions represented a fertile ground for formation different ore mineralization. The ore bodies were formed in the nodes fault zones, where a drastic decrease in temperature and pressure of hydrothermal ore bearing solutions occur in the corresponding lithologic environment [1,4].

The problems of this scientific-research work essentially present the research of possible valorization of useful components (copper and precious metals) from the complex raw material that is characteristic for this part of the deposit of the open pit North Mining District. This is primarily related to the relatively high content of useful components with high pyrite content, structural-textural properties of ore and content of clay fractions,

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mineralogical composition and method intergrowth the useful and barren minerals, etc. [2]. It is known that the deposits on the location Tenka (Tenka 1, Tenka 2, Tenka 3) are of polymetallic type and in addition to copper, they also contain lead and zinc minerals to some extent [1]. From that aspect, defining the optimum conditions of ore with these characteristics and obtaining a commercial product with satisfactory technological effects, presents a complicated task and requires a serious research approach to technological testing.

An important factor for the conception of laboratory testing is the application of existing technology solutions and parameters from current production in the flotation of RBM [2,3].

2. CHARACTERIZATION OF STARTING SAMPLES

The starting samples were taken from 3 locations of border part of the deposit Tenka 3. After crushing and homogenization of each samples from these locations, a composite sample was formed (in the weight ratio 1:1:1) in which the planned laboratory tests were carried out. Chemical composition of individual samples as well as composite sample is shown in Table 1. Moisture content in the composite sample was 6.6%.

Table 1. *Chemical composition of samples from the ore body Tenka 3*

Name of sample	Content of component [%]							
	Pb [%]	Zn [%]	Cu [%]	Cu_{sulf} [%]	Cu_{ox} [%]	S [%]	Au [g/t]	Ag [g/t]
T_3 location 1	0.06	0.0075	0.63	0.608	0.0175	17.86	<0.03	1.65
T_3 location 2	0.10	0.0160	0.30	0.288	0.0120	41.59	1.50	4.65
T_3 location 3	0.06	0.0240	0.49	0.462	0.0320	6.11	<0.03	10.4
Composite	0.073	0.016	0.473	0.453	0.021	21.853	0.520	5.567

Qualitative mineralogical analysis was carried out under the polarizing microscope for reflected light in the air, with identification the ore and barren minerals. The presence of minerals pyrite, chalcopyrite, limonite, quartz, silicate and carbonate is determined in samples taken from all three locations. Sample from the location 1 contains tetrahedrite, while bornite, galena and sphalerite are present in the sample from location 3 (Figure 1) in addition to the mentioned minerals.

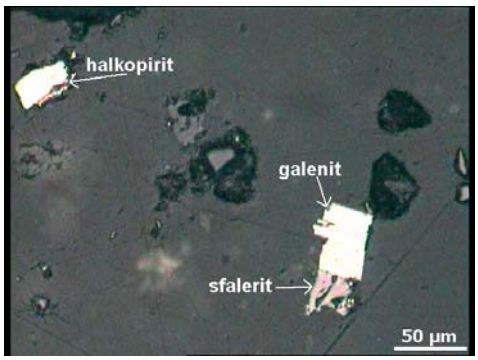

Fig. 1. *Sample T_3 location 3, polymetallic ore*

Composite sample with the upper limit coarseness of 2 mm, was further reduced by grinding to fineness of 60% -0.074 mm, thus achieving the optimum coarseness of mineral grains (according to the mineralogical analysis) for the needs of flotation concentration experiments. Grain-size distribution of ground mineral resources is shown in Table 2. Natural pH value of the pulp with mass participation of the solid phase of 32% was 7.43.

Table 2. *Grain-size distribution of ground ore (composite)*

Size class [mm]	Participation of size class [%]	
	Partial	Cumulatively, undersize
+0.589	0.36	100.00
-0.589+0.295	8.18	99.64
-0.295+0.104	25.29	91.46
-0.104+0.074	7.56	66.17
-0.074+0.052	13.77	58.61
-0.052+0.037	5.12	44.84
-0.037+0.000	39.72	39.72
Total:	100.00	

3. TECHNOLOGICAL CONDITIONS OF TESTING

Laboratory technological testing the conditions of flotation concentration included a change of relevant technological parameters in the range of existing values, applicable in the Flotation Plant Majdanpek, as follows:

- Tests were carried out through six series of experiments of rough flotation,
- Each series consisted of four experiments, in which the pH value of pulp by experiments was 10.0, 10.5, 11.0 and 11.5,
- Pulp density in grinding in all experiments was 70% solid phase,
- Pulp density in flotation in all experiments was 32% solid phase,
- Grinding fineness in all experiments was 60% -0.074 mm (coarseness at which the optimum release of useful minerals is realized),
- AEROFROTH 76A was used as a frother in all experiments with recommended consumption by the manufacturer,
- The following reagents and their combinations were used as collectors:
  - NaIPX (sodium isopropyl xanthate) as a good collector of sulphide minerals,
  - 3418 A (ditiofosfinate), characterized by good results in terms of gold and silver recovery, and
  - AP 5500 (ethoxycarbonyl thiourea), a reagent that is known, in theory and practice, as a good collector of copper sulphide minerals and it is very selective with respect to iron sulfides at low pH value of pulp.
- Consumption of collectors, either independently or in combination was 40 g/t of ore in all experiments of rough flotation. This collector dosage is determined based on content of sulfide minerals because it should be noted that in addition to copper mineral, pyrite content in the ore is very high (about 30%). Consumption of individual collectors by series of experiments is shown in Table 3.

In all experiments, the conditioning time was 7 minutes; the time of rough flotation was 18 minutes. Collectors were added in three equal doses and one dose in conditioning and two doses in rough flotation.

Table 3. *Consumption of collectors in the flotation concentration experiments, observed by series of experiments*

Series of experiments	Consumption of collectors [g/t dry ore]		
	NaIPX	3418 A	AP 5500
I	/	40	/
II	/	/	40
III	40	/	/
IV	24	16	/
V	/	20	20
VI	24	/	16

4. RESULTS AND DISCUSSION

Copper recovery in basic copper concentrate by series of experiments is present in Figure 2.

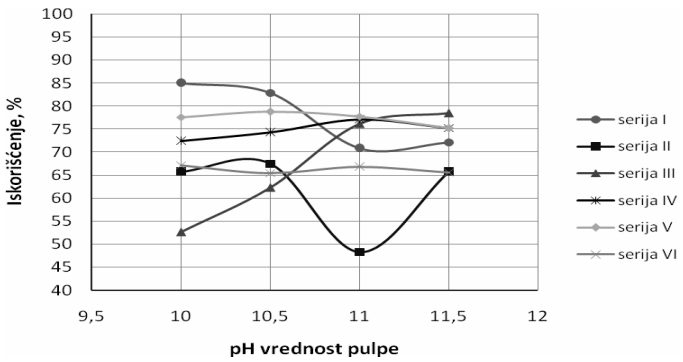

Fig. 2. *Copper recovery by series of experiments*

Figure 2 shows that, in general, the most favorable recoveries of copper in the basic copper concentrate were realized in the fourth and fifth series of experiments. It is obvious that the use of combination the collectors in the rough flotation (3418 A and NaIPX in the IV series; 3418 A and AP5500 in the V series) gives better results in terms of copper recovery than it is the case when these collectors are used individually (the first three series of experiments). High values of copper recovery in the basic concentrate (over 80%), obtained in the first series of experiments, are explained by a large mass participation of basic concentrate [2]. Dependence of copper recovery on pH value of the pulp in the present testing is not explicitly visible.

Gold recovery in the basic copper concentrate by series of experiments is present in Figure 3.

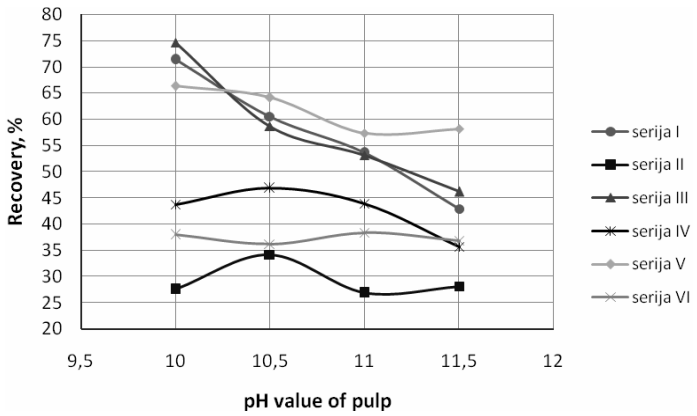

Fig. 3. *Gold recovery by series of experiments*

The most favorable gold recoveries in the basic copper concentrate were achieved in series of experiments I, III and V, as can be clearly seen in Figure 3. However, in general, the highest gold recoveries were realized in the V series of experiments in which a combination of collectors 3418A and AP5500 was used in the percentage mass ratio of 50:50. In addition, it can be concluded that, regardless of the collector type, the highest gold recovery in the copper concentrate are obtained at lower pH values of the pulp.

Silver recovery by series of experiments is present in Figure 4.

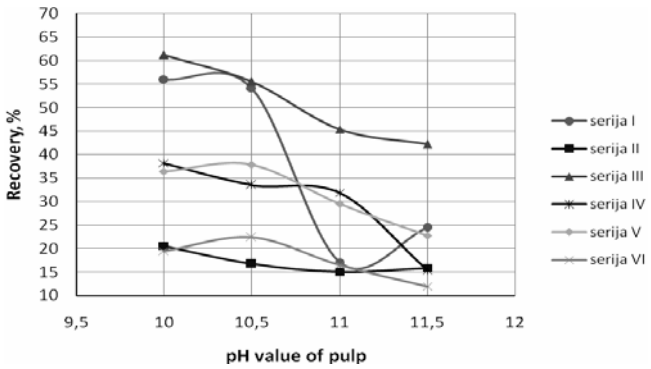

Fig. 4. *Silver recovery by series of experiments*

Figure 4 shows that the best silver recovery in the basic copper concentrate was realized in the III in series of experiments in which NaIPX was used as a collector. The use of other collectors as well as their combination with sodium isopropyl xanthate did not give the satisfactory results in terms of silver recovery. The analogue gold recovery and higher silver recoveries silver in the basic copper concentrate are obtained at lower pH values of the pulp.

5. CONCLUSION

The use of NaIPX collector independently (III series of experiments), provides high recovery of metals (especially gold and silver), but it must be noted that large mass of basic concentrate was obtained during this with a relatively low content of copper [2].

Combining NaIPX with the other two collectors as the result gives the weight reduction of basic concentrate [2], with a slight increase of copper recovery at lower pH values of the pulp, provided that it is used in the same ratio as it is the case in the production of the Flotation Plant RBM (40:60% in favor of xanthate). On the other hand, this combination of collector adversely affects gold and silver recoveries (series of the IV and VI experiments).

By independent use of 3418 collector (I series of experiments), the satisfactory recovery of copper, silver and gold was achieved only at lower pH values of the pulp, whereas with increasing pH value of the pulp, the metal recoveries decrease. However, it should be noted again that the differences in the masses of basic concentrates in this series of experiments are high [2].

Using AP5500 collector (II series of experiment) were not achieved the satisfactory results, until in combination with 3418 (V series of experiment) led to a significant improvement of technological results. Generally, it can be stated that, in this series of experiments, the best utilization of metals was realized throughout the entire testing. This confirms the positive effect of synergetic action of two contemporary collectors of different origins and characteristics.

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Stanko Stankov[*]

NADZORNO – UPRAVLJAČKI SISTEM KUPOLNE PEĆI U POGONU ZA PROIZVODNJU MINERALNE VUNE[**]

Izvod

Kupolna peć je jedna od najvažnijih tehničko – tehnološka celina relativno složenog postrojenja za proizvodnju mineralne vune. Mineralna vuna, koja nalazi široku primenu u građevinarstvu i industriji kao materijal za toplotnu i zvučnu izolaciju i zaštitu od požara, dobija se topljenjem kamena u kupolnoj peći. U radu je razmatrana kupolna peć koja je instalirana u Fabrici mineralne vune u Surdulici. Primenom ekoloških veziva, recikliranjem otpadnog materijala i spaljivanjem dimnih gasova koji nastaju u procesu topljenja zadovoljeni su strogi ekološki zahtevi. Rekonstrukcijom upravljačkog sistema peći i prateće opreme poboljšana je energetska efikasnost, povećan je stepen iskorišćavanja sirovina, a procenat otpada je minimiziran. Doziranje materijala i procesi u peći odvijaju se pod nadzorom lokalne upravljačke jedinice koja je povezana sa centralnim sistemom nadzora i upravljanja proizvodnog pogona. Zadavanje i pregled tehnoloških veličina i parametara vrši se na operatorskom panelu koji je povezan sa upravljačkom jedinicom. Posle odgovarajuće obrade informacije se prezentuju operateru (korisniku) u vidu procesnih promenljivih (tagova) koje su funkcije vremena (trendovi) ili u obliku tabela određene strukture.

Ključne reči: *kupolna peć, kamen, mineralna vuna, nadzor, upravljanje*

1. UVOD

Mineralna vuna je izolacioni material neorganskog porekla koja služi kao toplotni i zvučni izolator u građevinarstvu i industriji (termička zaštita vodovodnih i kanalizacionih cevi, naftovoda, toplovoda, gasovoda i sl.). Koristi se i kao materijal za protivpožarnu zaštitu imajući u vidu da se topi na 1000°C. Dobre osobine mineralne vune su i vodootpornost (ne upija vodu), paropropusnost, otpornost na mikroorganizme i insekte, hemijska stabilnost i otpornost na delovanje hemikalija. Sirovine za proizvodnju mineralne vune su: kamen vulkanskog porekla (dijabaz i dolomit, u manjoj meri bazalt). Osnovnim sirovinama se dodaju briketi koji se dobijaju preradom otpada

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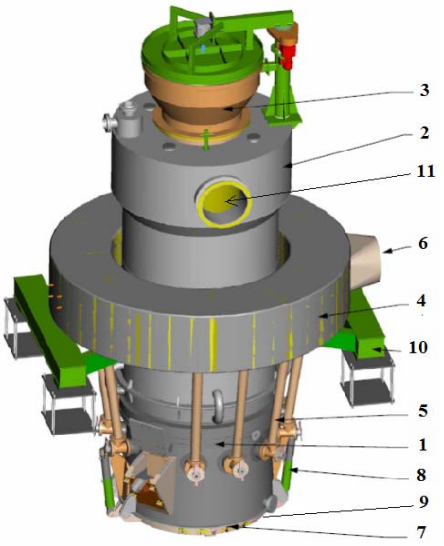
iz tehnološkog procesa uz dodatak cementa, čime se postiže zatvoreni krug potpune reciklaže otpadnog materijala. Osnovna hemijska jedinjenja koja ulaze u sastav navedenih sirovina su oksidi silicijuma, aluminijuma, kalcijuma, magnezijuma i gvožđa. Za proces topljenja sirovina kao energent se koristi koks. Sirovine se po određenoj recepturi doziraju u kupolnu peć u kojoj se tope na temperaturi od 1450°C [1]. Dodatni energent je gas (ili nafta), kojim se napaja poseban gorionik za spaljivanje dimnih gasova nastalih u kupolnoj peći, što omogućava smanjenje emisije gasova ispod dozvoljene granice. Savremen način prečišćavanja dimnih gasova (eliminacija prašine i ugljen monoksida) i vraćanje značajne količine energije u proces proizvodnje doprinosi povećanju efikasnosti. Procesi koji se odvijaju u peći su vrlo složeni i raznoliki: sagorevanje koksa, procesi razmene toplote, topljenje kamena, pri čemu nastaju fizičko-hemijske transformacije materijala iz jednog agregatnog stanja u drugo. Masa dobijena procesom topljenja u kupolnoj peći se kontrolisano dovodi na točkove centrifuga gde se vrši njeno raspredanje [2]. Točkovi centrifuga razbijaju masu u kapljice. Istovremeno se kroz točkove pomoću ventilatora visokog pritiska uduvava vazduh koji nastale kapljice razvlači u vlakna. Ovde se u raspršenom stanju dozira i određena količina vezivnih sredstava. Ranije korišćena vezivna sredstva na bazi forma-ldehida i fenola, koji predstavljaju opasnost po ljudsko zdravlje zbog poten-cijalnih kancerogenih uticaja, zamenjena su vezivnim materijalima od prirodnih sirovina bez dodataka veštačkih boja i aditiva. U osnovi novog veziva je biljni skrob koji se pretvara u inertni polimer tokom procesa proizvodnje mineralne vune. Kroz maglu veziva nastala vlakna se duvaju pomoću ventilatora u sabirnu komoru i tako nastaje primarni filc mineralne vune, koji se dalje termički tretira u polikondenzacionoj komori (temperatura oko 250 °C) gde dobija odgovarajući oblik i stepen tvrdoće. Potom se vrši sečenje prema zadatim dimenzijama [3]. Na ovaj način dobija se mineralna vuna kao ekološki građevinski material, prepoznatljiv po prirodnoj braon boji. Rad kupolne peći, prateće opreme i uređaja odvija se automatski. To obezbeđuje upravljačka jedinica (PLC – programmable logic controller). U sprezi s kontrolerom je operatorski panel, na kome je kreiran određen broj SCADA (supervisory control and data acquisition) ekrana koji služe za vizuelizaciju procesa i prikaz karakterističnih veličina. Preko ulaza analognih (AI) i digitalnih (DI) modula kontrolera dobijaju se sa senzora i prekidačkih elemenata podaci značajni za rad kupolne peći. Sa izlaza analognih (AO) i digitalnih modula (DO) prosleđuju se komandni signali do izvršnih organa u cilju održavanja procesnih veličina i parametara u zadatim opsezima.

2. KONFIGURACIJA KUPOLNE PEĆI I PROCES ŠARŽIRANJA

Na slici 1 prikazan je model kupolne peći za topljenje kamena. Kapacitet peći je 7 ÷ 9 t/h.



Sl. 1. *Model kupolne peći*

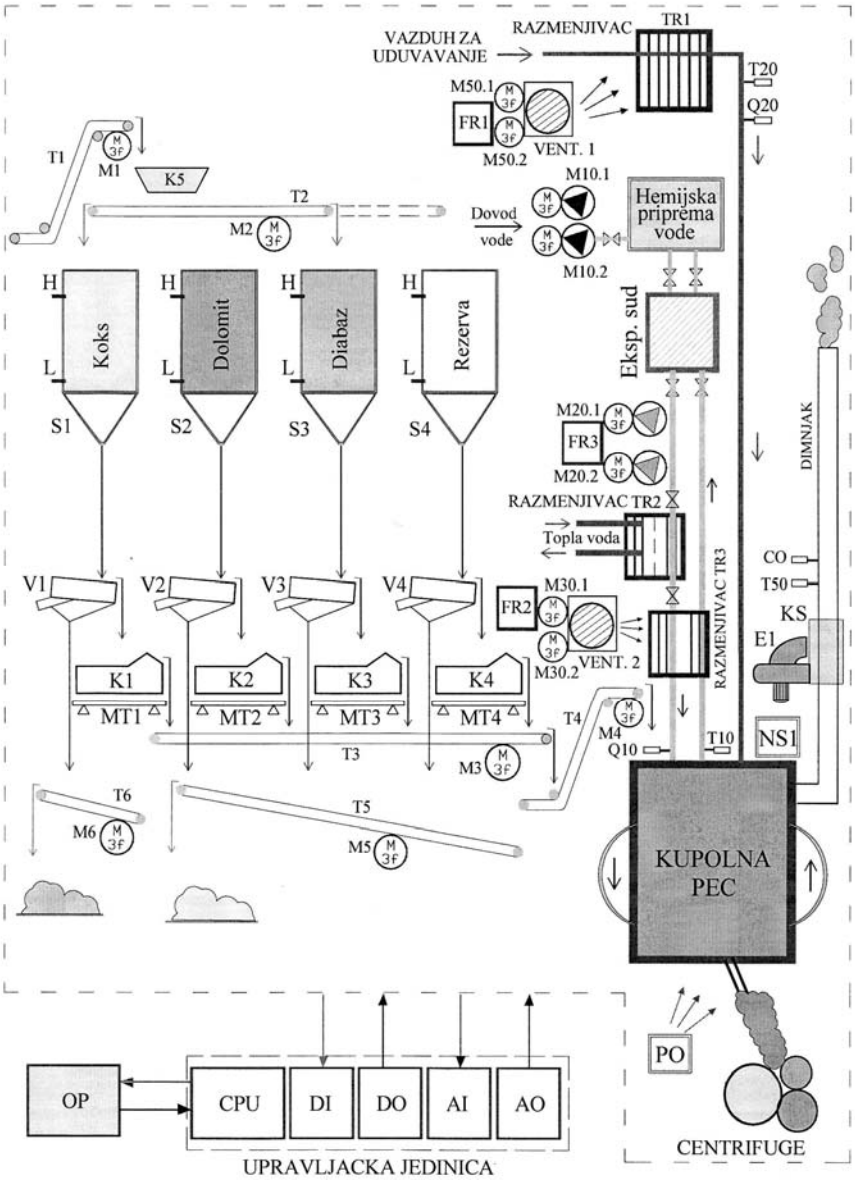
U sklopu peći nalaze se sledeći elementi: 1 – donji deo kupolne peći, 2 – gornji deo kupolne peći, 3 – grlo peći s rotirajućim levkom, 4 – prsten vazduha za uduvavanje, 5 – priključni vodovi vazduhaza uduvavanje, 6 – priključak vazduha za uduvavanje, 7 – podnožje, 8 – hidraulični cilindar za zatvaranje podnožja peći, 9 – držač zatvarača otvora za ispuštanje peći, 10 – nosač kupolne peći, 11 – otvor za ispuštanje gasova.

Za topljenje kamena kao gorivo se upotrebljava koks (1100 kg/h). Količina rastopa je oko 7,7 t/h. U procesu se stvara sirovo gvožđe (oko 0.2 t/h). Za ovu količinu kamena potrebna je određena količina vazduha koji se uduvava u unutrašnjost peći (oko 6500 m^3/h). Temperatura ovog vazduha je od 450°C do 650°C. Potrebna količina kiseonika je oko 300 m^3/h. U toku rada neophodno je hladiti zidove peći. Protok vode za hlađenje je 130 m^3/h, a temperatura 75°C. Na izlazu sistema za hlađenje temperatura vode je 83°C. Količina dimnih gasova je oko 8500 m^3/h a njihova temperatura oko 165°C. Šaržiranje materijala (kamena, briketa, koksa) vrši se preko grla peći, koje je u sklopu rotirajućeg levka pomoću koga se vrši mešanje šarže. Brzina rotacije levka u funkciji je zahteva tehnologije. Na grlu se nalazi poklopac koji se zatvara po završetku procesa šaržiranja. Peć se održava napunjenom zbog sušenja sirovina i hemijskih procesa oksidacije i redukcije, a informacija o napunjenosti dobija se preko senzora NS1 instaliranog na vrhu peći. Kada upravljački sistem dobije informacija da je peć prazna, hidraulički cilindar otvara poklopac i materijal se sipa u peć. Po dostizanju zadatog nivoa prestaje doziranje i poklopac se zatvara. Sastav šarže je promenljiv i zavisi od hemijskog sastava sirovina. Masa šarže je oko 1100 kg. Najšešća kombinacija je koks 110 kg u letnjem periodu (zimi je zbog vlage potrebna veća količina koksa), zatim dolomit 180 kg kao material za korekciju, osnovna sirovina - dijabaz 600 kg i reciklirana mineralna vuna u vidu briketa 200 kg. Hemijski sastav šarže treba da bude odgovarajući, kako bi se dobila odgovarajuća žilavost (viskoznost) rastopa. Ovo je potrebno da bi se omogućilo, pomoću centrifuga, raspršivanje mase u fine kapljice i ispredanje vlakana. Temperatura rastopa je promenljiva i zavisi od hemijskog sastava sirovina. Iznosi oko 1450°C, a meri se opričkim pirometrom PO na izlazu iz peći i prikazuje se na ekranu operatorskog pa-nela. Proces topljenja je kontinualan (peć se drži uvek napunjenom). Trajanje procesa od šaržiranja do pojave rastopa na izlazu iz peći je 1,5h.

3. PRATEĆA OPREMA KUPOLNE PEĆI

Infrastruktura kupolne peći počinje od skladišta sirovina gde se nalaze sirovine diabaz, dolomit, briketi i koks. Na slici 2 prikazana je tehnološka šema kupolne peći s pratećom opremom i uređajima. Sirovine koje su prethodno pripremljene (prosejavanje i određena granulacija) se po određenom redosledu, uz pomoć odgovarajuće mehanizacije, postavljaju na kosi transporter T1, koga pokreće elektromotor M1. Posuda K5 na dvosmernom transporteru T2 (pokretan elektromotorom M2) prihvata dopremljenu sirovinu i sipa je, pomoću hidrauličkog cilindra koji je povezan s posudom, u odgovarajući silos (silosi S1, S2, S3, S4). U silosima se mere diskretno nivoi (L – donji nivo i H gornji nivo). Kada se dostigne gornji nivo u određenom silosu prestaje doziranje odgovarajuće sirovine. Sirovinama iz silosa se zatim pune sudovi koji su povezani s vibracionim elementima (V1, V2, V3, V4) ispod kojih su postavljene posude K1, K2, K3, K4. Težine materijala (sirovina) koji se sipaju u ove posude mere se pomoću mernih traka (MT1, MT2, MT3, MT4). Kada se dostigne programirana težina isključuju se vibracioni

elementi čime prestaje doziranje sirovina. Preko dvo-smernog transportera T3 (elektromotor M3) odmerene sirovine odvoze se na transporter T4 (elektromotor M4) kojim se sirovine ubacuju u kupolnu peć. Transporter T5 skuplja neznatne delove sirovina koje se prosipaju prilikom doziranja.

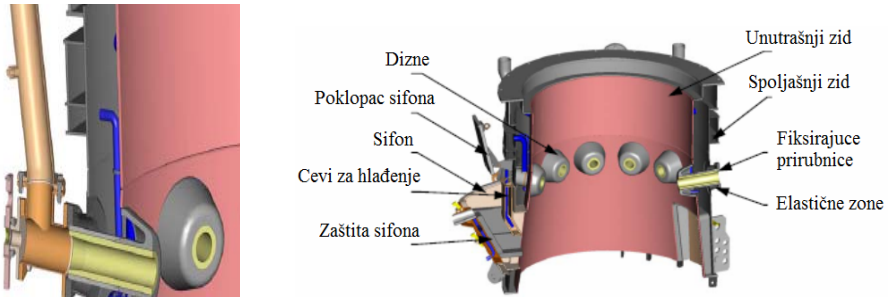


Sl. 2. *Kupolna peć s pripadajućom infrastrukturom, povezana sa upravljačkim sistemom*

Ovaj materijal se kasnije odvozi na skladište sirovina. Prosuti delovi koksa se skupljaju preko transportera T6. Potpalom ubačenih drva na dnu peći pali se koks koji topi kamen u peći, u kojoj se meri nivo i temperatura rastopa.

4. ZAGREVANJE VAZDUHA ZA SAGOREVANJE

Za odvijanje procesa sagorevanja koksa i topljenja sirovina u kupolnoj peći neophodno je uduvavanje vazduha. To je okolni vazduh koji se zahvata od strane frekventno regulisanog ventilatora M50.1 ili M50.2 (slika 2) i vodi se u rekuperator TR (komora za spaljivanje dimnih gasova, koja ima zadatak prečišćavanja gasova spaljivanjem). Rad frekventnog regulatora se odvija na osnovu zadatog protoka vazduha (merač Q20). Zagrejani vazduh, čija se temperature meri senzorom T20, se kroz kružnu cev uduvava preko dizni (slika 3), koje su ugrađene u donjem delu kupolne peći. Povremeno se preko dizni ubacuje i kiseonik. On ima nezavisnu regulaciju počev od postrojenja za uskladištenje do ubacivanja odmerene količine.



Sl. 3. *Instalacija za uduvavanje vazduha u donji deo kupolne peći*

U tehnološkom smislu donji deo kupolne peći je najznačajniji njen element jer se ovde u najvećoj meri odvija proces topljenja, pri čemu se oslobađa velika količina toplotne energije budući da se proces odvija na visokim temperaturama (za predmetnu kupolnu peć temperatura topljenja je 1450 ÷ 1480°C). U ovom delu peć trpi i najveće opterećenje usled visokih temperatura i pritisaka gde dolazi do trenja materijala koji se topi i unutrašnjosti zidova peći. Prilikom sagorevanja koksa i topljenja sirovina u kupolnoj peći oslobađaju se dimni gasovi. Ovi gasovi koji nastaju tokom sagorevanja šarži izlaze iz peći kroz ispusni sistem i odvode se u predgrevač vazduha za uduvavanje, čime se koristi energija ovih gasova. Sami gasovi se spaljuju gorionikom E1, koji je s pogonom na naftu ili tečni naftni gas (TNG). Na ovaj način smanjuje se procenat nastalih gasova ispod dozvoljene granice i zadovoljavaju se strogi ekološki standardi.

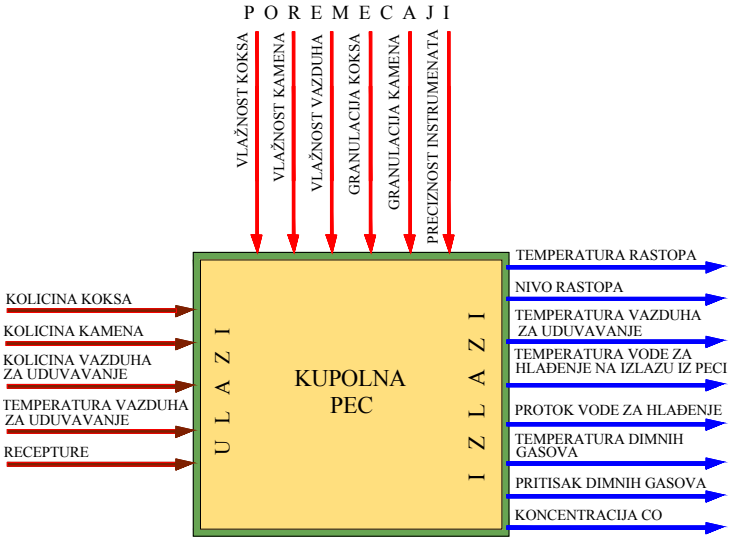
5. HLAĐENJE KUPOLNE PEĆI

Tokom procesa topljenja moraju se zidovi peći kontrolisano hladiti. Hlađenje se vrši vodom. Sistem hlađenja je kružni sa otvorenom ekspanzijom i prinudnom cirkulacijom (slike 2 i 5). Voda se iz mreže najpre dovodi pomoću pumpi M10.1, M10.2 (radna i rezervna) u sistem za hemijsku pripremu, gde se vrši omekšavanje vode. Pomoću centrifugalnih cirkulacionih pumpi M20.1, M20.2 (radna i rezervna) koje su vezane preko frekventnog regulatora FR3, voda odlazi u

dva redno povezana razmenjivača i dalje struji u prostor koji se nalazi između spoljašnjegnjeg i unutrašnjeg plašta kupolne peći. Kriterijum za rad regulatora FR3 je zadati protok vode za hlađenje kupolne peći. Ovde se meri temperaura (Pt100 senzor - T10), pritisak vode u cevovodu (senzor pritiska – P10) i protok vode (merač Q10). Prvi razmenjivač je pločasti i on u primarnom krugu zagreva vodu za sistem grejanja kojim se greje proizvodni pogon. Drugi je vazdušni razmenjivač koga hlade dva ventilatora vođena frekventnim regulatorom FR2. Kriterijum za rad ovog regulatora je održavanje temperature vode za hlađenje (oko 75°C).

6. UPRAVLJANJE I NADZOR

Kupolna peć kao objekat upravljanja predstavlja jedan multivarijabilni sistem čija je strukturna blok šema data na slici 4 na kojoj su prikazani ulazne i izlazne veličine kao i poremećaji.

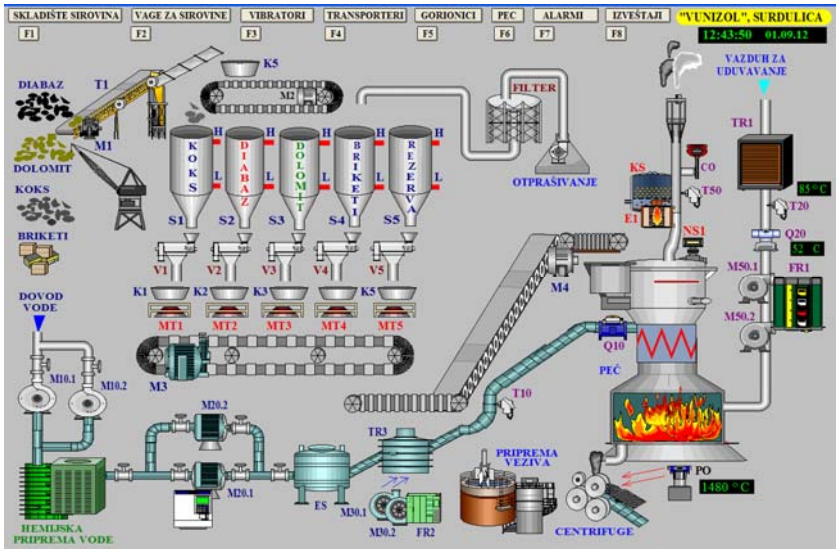


Sl. 4. *Strukturna šema kupolne peći sa aspekta upravljanja*

Rad uređaja i opreme kontrolisan je od strane upravljačke jedinice. To je PLC Siemens S7 1200 koji ima modularnu strukturu. Primenjeni PLC ima mogućnost serijske komunikacije preko protokola RS – 232 i RS – 485, korišćenjem dodatnih modula. Može se koristiti i MODBUS protokol (preko modula RS – 485) kao i USS protokol (Universal Serial Interface Protocol) za komunikaciju sa Simensovim frekvencijskim pretvaračima koji podržavaju ovaj protokol [4, 5, 6]. Ova upravljačka jedinica ima i PROFINET (jedna vrsta otvorenog Ethernet standarda) priključak što joj omogućuje povezivanje s drugim elementima automatizacije i sistemima koji poseduju ovaj priključak. Zahvaljujući ovome moguće je povezivanje više PLC–ova i operatorskih panela preko protokola komunikacije koji se zasnivaju na ethernet i TCP / IP (**T**ransport **C**ontrol **P**rotocol / **I**nternet **P**rotocol) protokolima. Pri izradi projekta relativno lako i brzo se konfiguriše PROFINET komunikacija na relaciji PLC – operator panel. Kreiranje i konfiguracija tagova (simboličkih imena ulaza i izlaza)

ista je i za upravljački program PLC – a i nadzorno – upravljačku aplikaciju operatorskog panela [7, 8].

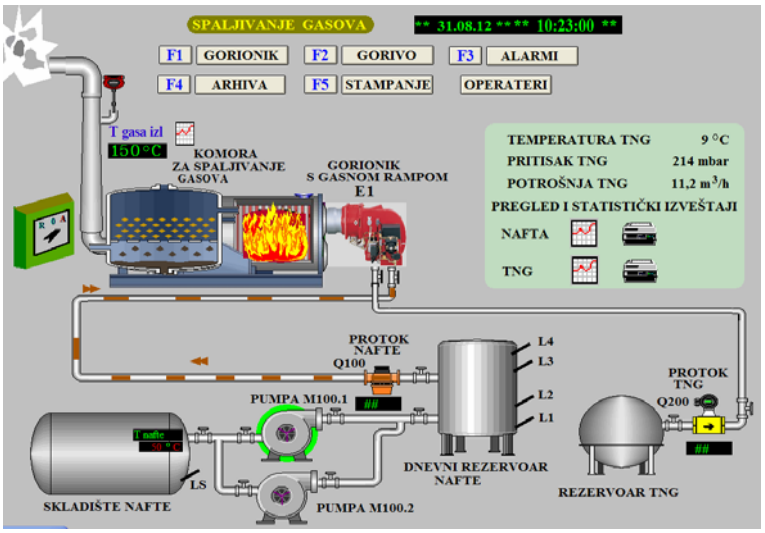
Zadavanje i pregled parametara kupolne peći i prateće opreme vrši se na operatorskom kolor panelu KTP 1000 koji povezan s PLC – om čini upravljački sistem pod čijim nadzorom su prekidački elementi, senzori i izvršni organi. Konfiguracija i programiranje jedinice S7 1200 i razvoj nadzorno – upravljačkog programa za operatorski panel vrši se pomoću programskog paketa *TIA Portal* koji ima integrisan STEP 7 Basic za kontroler i *WINCC* za vizuelizaciju preko panela KTP. Koncipiranje upravljačke logike sa S7–1200 vrši se izborom i spajanjem različitih modula. Na centralnu procesorsku jedinicu (***C**entral **P**rocessing **U**nit–CPU*), prema zahtevima procesa kojim se želi upravljati dodaju se različite vrste signalnih i komunikacijskih modula. Kreiranje aplikacije u *TIA Portalu* odvija se u nekoliko koraka: koncipiranje projekta; planiranje konfiguracije PLC – a, ulaznih, izlaznih i drugih modula, izrada i konfigurisanje mrežnih veza između uređaja, pisanje upravljačkog programa za PLC, pisanje programa za operator panel, učitavanje napisanih aplikacija u PLC i panel, provera rada i otklanjanje grešaka u aplikacijama. Nakon formiranja novog projekta bira se u *Devices & Networks* meniju opcija *Add new device,* čime se u projekt postavljaju odgovarajući PLC i operator panel. U zavisnosti od izbora dalje se radi s programom *STEP 7 Basic* u kome se razvija upravljački program ako je odabran *SIMATIC PLC,* odnosno sa alatom *WINCC* ako je odabran operator panel, na kome se kreiraju SCADA stranice. Jedan SCADA ekran na kome je predstavljena tehnološka šema kupolne peći prikazan je na slici 4.



Sl. 5. *Tehnološka šema kupolne peći s pratećom infrastrukturom (SCADA ekran)*

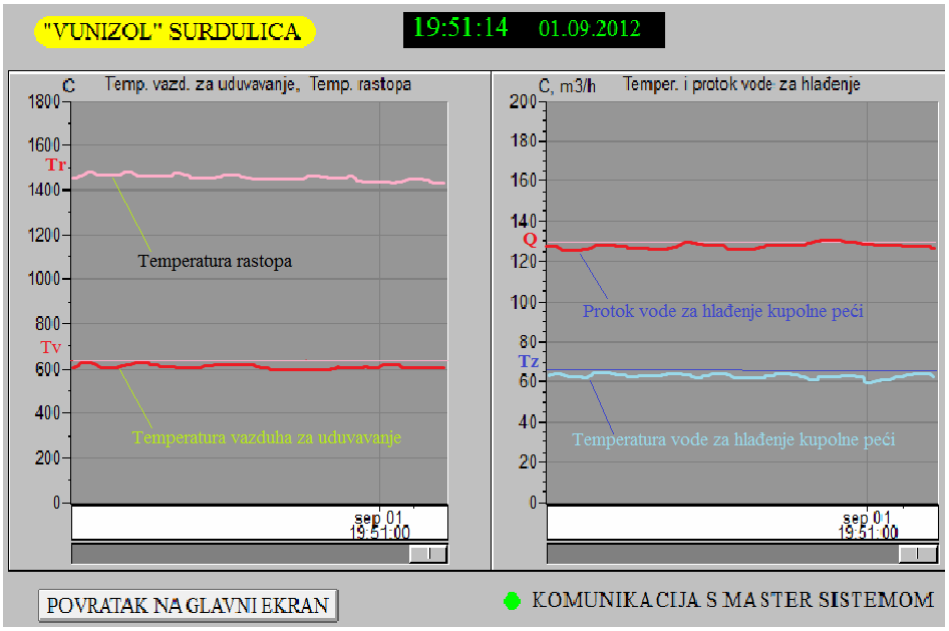
Na SCADA ekranu datom na slici 6 predstavljen je sistem za spaljivanje dimnih gasova. Na pomenutoj slici dati su karakteristični parametri gorionika kada je kao gorivo korišćen TNG. Procesor kontrolera poseduje korisničku i sistemsku memoriju.

Korisnička memorija se sastoji iz memorije za učitavanje (ROM – read only memory), koja je neizbrisiva (nonvolatile) memorija i radne memorije (RAM – random access memory), koja je izbrisiva (volatile) jer se po nestanku napajanja brišu podaci [9, 10]. Aplikativni program i parametri za konfiguaciju kontrolera unose se u ROM memoriju, koja je integrisana u centralnoj procesorskoj jedinici - CPU (central processing unit). Tokom prelaza procesora iz stanja STOP u stanje RUN, kopiraju se iz ROM – a u RAM programi i podaci potrebni za izvršavanje programa. U sklopu CPU jedinice je i sistemska memorija u kojoj se nalaze adrese promenljivih. Adresna područja memorije su: ulazi (I), izlazi (Q), bit memorijski prostor (M), prostor za blokove podataka (DB) i lokalna (privremena) memorija (L).



Sl. 6. *SCADA ekran sistema za spaljivanje dimnih gasova*

Operator panel kao interfejs prema korisniku daje vizuelnu predstavu celog sistema, omogućava zadavanje i pregled karakterističnih veličina i parametara, a PLC izvršava regulaciju rada kupolne peći. Pomoću trend grafova (slika 7) ili tabelarno mogu se pratiti zadate i trenutne vrednosti relevantnih veličina kupolne peći poput temperature rastopa, temperature i protoka vazduha za uduvavanje, temperature i protoka rashladne vode, protoka gasa (nafte) za pogon gorionika pomoću koga se vrši spaljivanje dimnih gasova, potrošene količine sirovina (kamena, koksa, briketa i veziva) za određen vremenski period. Formiraju se i na zahtev štampaju smenski, dnevni i periodični izveštaji. Prate se statusi ventilatora, pumpi, elektromagnetnih ventila, motora transportera, sistema za hemijsku pripremu vode. Ukoliko određene veličine dostignu vrednosti koje su izvan zadatog opsega generišu se alarmi sa opisom mesta i vremena nastanka, uz svetlosnu i zvučnu signalizaciju. Na operatorskom panelu se ispisuje odgovarajuća tekstualna poruka i zahtev operateru da potvrdi alarm. Pojavljuje se lista mogućih uzroka kvarova što olakšava rad službi održavanja i skraćuje vreme zastoja.



Sl. 7. *Trend graf karakterističnih veličina kupolne peći*

7. ZAKLJUČAK

Rekonstrukcija upravljačkog sistema kupolne peći, koji se zasniva na PLC konfiguraciji u sprezi sa operatorskim panelom, doprinela je povećanju efikasnosti rada kupolne peći a samim tim povećana je efikasnost i produktivnost proizvodnog pogona mineralne vune. Mineralna vuna se proizvodi od sirovina koje se nalaze u prirodi i/ili od recikliranih sirovina, a njena vlakna su povezana sredstvom koje je ekološki prihvatljivo i biorazgradivo. Otpaci koji nastaju u procesu proizvodnje ili otpadna vuna s gradilišta drobe se i melju u granulat. Dodavanjem peska i cementa ovim otpacima dobijaju se briketi koji služe kao sirovina. Kamena vuna kao izolacioni materijal u celosti se dobija iz prirodnih sirovina. Tokom procesa proizvodnje iz jednog kubnog metra sirovina dobija se višestruko veća zapremina izolacionog materijala uz minimalnu potrošnju energenata. Spaljivanjem dimnih gasova smanjena je emisija štetnih materija tokom proizvodnje i izloženost radnika na radnom mestu. SCADA sistem na operatorskom panelu poseduje funkcije nadzora i upravljanja. Omogućeno je operateru nadgledanje procesa i eventualna korekcija upravljanja ukoliko nastane neka specifična situacija. Sistem upravljanja i nadzora vrši neposredno merenje tehno-loških veličina i na osnovu implementiranih algoritama upravlja izvršnim organima. Sistem pruža vizuelizaciju tehnološkog procesa i instalirane opreme, alarmiranje u slučaju kvarova i dostizanja kritičnih vrednosti određenih tehnoloških veličina, arhiviranje tehnoloških parametara, događaja i akcija operatera, automatsku zaštitu i blokadu uređaja i opreme pri nastanku kritičnih situacija. Ovim je obezbeđen visok

nivo kontrole i organizacije proizvodnje, smanjeno je vreme zastoja proizvodnje i olakšan je rad službi održavanja. Formirana arhiva i adekvatna interpretacija relevantnih podataka karakterističnih za tehnološki proces, omogućavaju tehnolozima neophodne informacije o toku procesa i olakšavaju im pronalaženje novih tehnoloških rešenja i poboljšanje postojećih.

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MONITORING AND CONTROL SYSTEM OF CUPOLA FURNACE AT THE PLANT FOR MINERAL WOOL PRODUCTION[**]

Abstract

Cupola furnace is one of the most important technical-technological units of the quite complex plant for mineral wool production. Mineral wool, which has wide application in civil engineering and industry as material for thermal and audio isolation and fire protection, is obtained by melting stone at cupola furnace. Cupola furnace, installed in the Factory for mineral wool production in Surdulica, is considered in this paper. The strict environmental requirements are satisfied applying ecological binders, recycling waste material, burning flue gases occurred in melting process. By reconstruction of furniture control system and following equipment control system, the energy efficiency, higher utilization level of raw material and minimization of waste material percentage were provided. Materials dosage and processes in furniture are monitored by local control unit connected with central system of monitoring and production plant control. Setting and review the technological variables and parameters are done on a display terminal connected with control unit. After appropriate processing, information is present to the operator (user) in a form of process variables (tags) which are time functions (trends) or in form of certain structure table.

Keywords: *cupola furniture, stone, mineral wool, monitoring, control*

1. INTRODUCTION

The mineral wool is an inorganic insulation material, used as a thermal and sound insulation in construction and industry (thermal protection of water supply and sewer pipes, oil-pipelines, heating-pipelines, gas-pipelines, etc.). Since it melts at temperature of 1000 °C, the mineral wool is also used as a material for fire protection. Good qualities of mineral wool are water-resistance (does not absorb water), water vapor permeability, resistance to micro-organisms and insects, chemical stability and resistance to the action of chemicals. Raw materials for manufacture the mineral wool are volcanic rocks (diabase and dolomite, small quantities of basalt). The briquettes

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obtained from the processing of waste technological processes with the addition of cement are added to the basic raw materials. It results in a complete closed loop recycling of waste materials. The basic chemical compounds that are the parts of these materials are oxides of silicon, aluminum, calcium, magnesium and iron. Coke is used as fuel for the melting process of raw materials. These materials are dosed in the cupola furnace at a specific prescription and they melt at temperature of 1450 °C [1].

Gas (or oil) is the additional fuel that powers a separate burner for burning waste gases produced in cupola furnace. That allows reducing emissions below allowable limits. Modern way of purification the flue gases (elimination of dust and carbon monoxide) and recurrence of a significant amount of energy in the production process contribute to increasing efficiency. The processes taking place in the furnace are complex and varied: the combustion of coke, processes of heat transfer, melting of rocks. The results are physical and chemical transformation of materials from one physical state to another. The mass produced in the process of melting cupola furnace is led by control to the wheels of centrifuge where its untwisting is done [2]. The wheels of centrifuge break mass in the droplets. At the same time, the air is blown through the wheels by high pressure fan and it stretches formed droplets into the fibers. A certain amount of binder in a dispersed state is fed here. Previously used binders, based on formaldehyde and phenol, which pose a threat to human health because of the potential carcinogenic effects, were replaced by bonding material from natural ingredients with no artificial and color additives. A plant starch is in the base of the new binder that turns into an inert polymer during the manufacturing process of mineral wool. Protein fibers are blown through the fog binders by fans into a collecting chamber and in this way the primary mineral wool felts arise. It is heat-treated in the polycondensation chamber (temperature around 250 °C), where it receives the appropriate form and degree of hardness. After that, cutting by the given dimensions is done [3]. By this way, the mineral wool as eco building material is obtained, known for its natural brown color. Functioning of the cupola furnace, associated equipment and devices are automatic. It is provided by a control unit (PLC - programmable logic controller). Display terminal is in conjunction with a controller, and the certain number of SCADA (Supervisory Control and Data Acquisition) screens is created on it. These SCADA screens are used for process visualization and display the characteristic values. Data from the sensors and switching elements are provided via analog (AI) and digital input (DI) module of the controllers, what is important for cupola furnaces function. From the outputs of analog (AO) and digital modules (DO), the command signals are sent to the executive in order to maintain process variables and parameters within particular ranges.

2. CONFIGURATION OF CUPOLA FURNACE AND CHARGING PROCESS

Figure 1 shows a model of cupola furnace for stone melting. The furnace capacity is 7÷9 t/h.

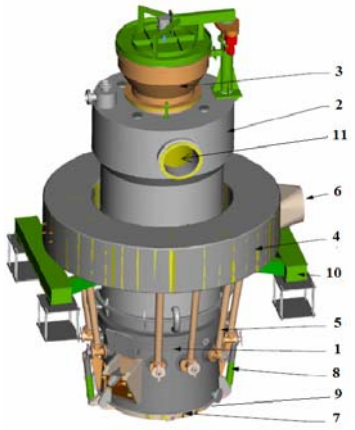

Fig. 1. *Cupola furnace model*

The furnace includes the following elements: 1 - lower part of cupola furnace, 2 - upper part of cupola furnace, 3 - throat of furnace with rotary funnel, 4 - ring for air insufflation, 5 - connecting lines for air insufflation, 6 - connection for air insufflation, 7 - base, 8 - hydraulic cylinder for closing bases of furnace, 9 - shutter holder of aperture for furnace discharge, 10 - support of cupola furnace, 11 - gas-release opening.

Coke is used as a fuel for stone melting (1,100 kg/h). The melt amount is about 7.7 t/h. The process produces crude iron (about 0.2 t/h). This amount of stone requires the certain amount of air that is blown into the furnace (about 6,500 m^3/h). The air temperature is from 450 °C to 650 °C. The necessary amount of oxygen is about 300 m^3/h. It is necessary to cool the furnace walls during the operation. The flow of cooling water is 130 m^3/h and temperature is 75 °C. At the outlet of the cooling system water temperature is 83 °C. The amount of flue gases is about 8,500 m^3/h and their temperature is about 165 °C. Batching of materials (stone, briquettes, coke) is done through the furnace throat, which is the part of rotating funnel, used to mix batches. Rotation speed of the funnel serves technological requirements. There is a cover on the throat which is closed at the end of the charging process. The furnace is maintained charged due to the drying of raw materials and chemical processes of oxidation and reduction, and charge information is obtained through sensors NS1, installed on the top of stove. When the control system receives information that the furnace is empty, hydraulic cylinder opens the lid and the material is poured into the furnace. After reaching the set level, dispensing stops and lid closes. Batch composition is variable and depends on the chemical composition of the raw materials. Batch mass is about 1,100 kg. The most frequent combination is coke 110 kg in summer (due to humidity, higher amounts of coke is needed in winter), and 180 kg dolomite as material for the correction, the basic raw material - 600 kg diabase and recycled mineral wool in the form of briquettes 200 kg. The chemical composition of the batch should be appropriate, in order to obtain the adequate toughness (viscosity) of melt. This is necessary to allow, using a centrifuge, spraying the mass into the fine droplets and spinning of fibers. Melt temperature is variable and depends on chemical composition of raw materials. It is approximately 1,450 °C and it is measured by optical pyrometer PO on the outlet of the furnace, and it is shown on the screen of operator panel. Melting process is continuous (always keeps the furnace filled). Duration of the charging process from batching to occurrence of melt on the furnace outlet is 1.5 h.

3. SUPPORTING EQUIPMENT OF CUPOLA FURNACE

Infrastructure of cupola furnace begins with the raw materials warehouse where raw materials are diabase, dolomite, coke and briquettes. Figure 2 shows the technology layout of cupola furnace with necessary equipment and devices. Raw materials that were previously prepared (sieving and some grit) in a specific order, with a help of appropriate machinery, are put on oblique conveyor T1, which is powered by electrical motor M1. K5 vessels in two-way conveyor T2 (an electrical motor M2) accepts prepared raw material and infuse it into the appropriate silo (silos S1, S2, S3, S4) using a hydraulic cylinder, which is connected to the vessel. Discrete levels are measured in the silos (L - lower level and upper level H). When the upper level is reached, dosing of suitable raw materials stops in a particular silo. Then, raw material from the silo fills the tanks that are connected to vibrating elements (V1, V2, V3, V4) under which the vessels are set K1, K2, K3, K4. The material weights (raw

materials) that are poured into these containers are measured using strain gages (MT1, MT2, MT3, MT4). When the programmed weight is reached, the vibrating elements are off, which stops dosing of raw materials. Over two-way conveyor T3 (M3 motor), the measured raw materials are transported to conveyor T4 (motor M4), which is used to insert the raw materials into cupola furnace. Conveyor T5 collects insubstantial parts of raw materials that are spilled during dosing.

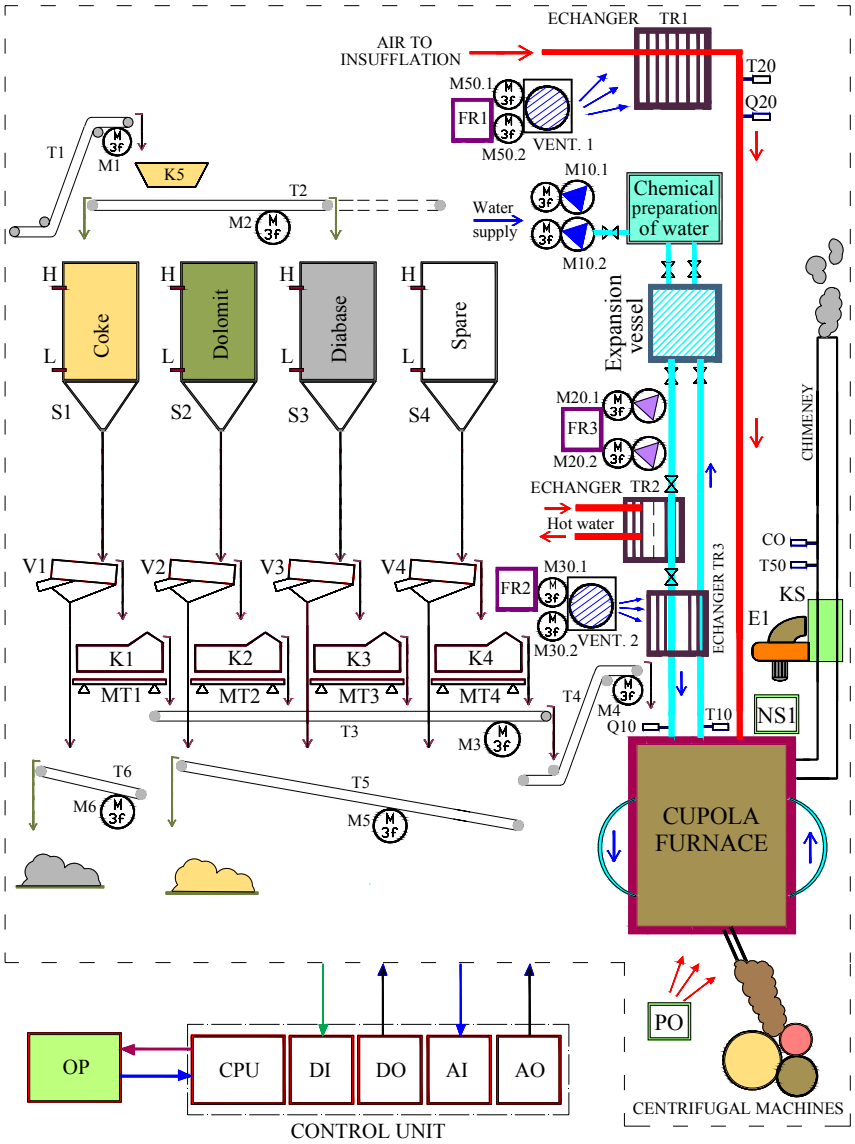

Fig. 2. *Scheme of cupola furnace with associated infrastructure, connected with control system*

This material is later transported to the raw materials storage. Scattered coke parts are collected by conveyor T6. The coke which melts the stone is burned by kindling of the inserted woods at the bottom of furnace, where the level and temperature of the melt are measured.

4. AIR HEATING FOR COMBUSTION

For the process of coke combustion and smelting of raw materials in cupola furnace, the air blowing is necessary. It is the ambient air, which is taken by frequently regulated fan M50.1 or M50.2 (Figure 2) and led to the recuperator TR (chamber for burning waste gases, which has the task of gas treatment by burning). Operation of frequency regulator takes place on the basis of a given air flow (meter Q20). The heated air, which can be measured by temperature sensor T20, is blown through a circular tube over the nozzles (Figure 3). The nozzles are built in the lower part of cupola furnace. Oxygen is periodically injected through the nozzles. It has an independent regulation from the storage facility to the insertion of measured quantities.

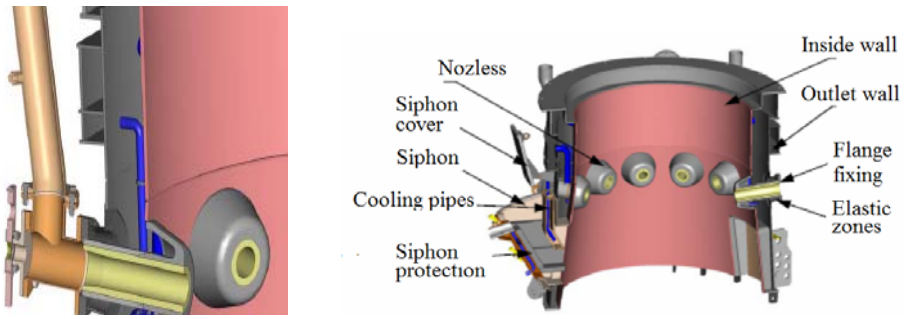

Fig. 3. *Installation for air blowing into the lower part of cupola furnace*

In technological terms, the lower part of the cupola furnace is its the most important element because the melting takes place there, and the result of this is releasing large amounts of heat release due to the process at high temperatures (for this cupola furnace melting temperature is 1,450 ÷ 1,480 °C). In this part the furnace suffers the greatest burden due to high temperatures and pressures what lead to friction of melting material and inside walls of furnace. During coke combustion and smelting of raw materials, flue gases are released in cupola furnace. These gases, generated during combustion of batches, come out through the exhaust system and they are taken to the preheater of blowing air. By this way, the energy of gases is used. Gases are burned with burner E1, which operates with oil or liquefied petroleum gas (LPG). This reduces the percentage of generated gases below permissible limits and adequates strict environmental standards.

5. COOLING OF CUPOLA FURNACE

During melting process, the furnace walls must be controlled cooled. It is done with water. The cooling system is circular with open tank and forced circulation (Figures 2 and 5). At first, water is supplied from the water system using the pumps M10.1, M10.2 (operating and backup) to the chemical treatment system, which is used for water softening. Using centrifugal circulation pumps M20.1, M20.2 (operating and backup) which are connected via frequency converter FR3, water goes in two serially

connected exchangers and continues to flow into the area which is located between the inner and external sheath of cupola furnace. The criterion for regulator FR3 operation is the assigned water flow for cooling cupola furnace. Temperature is measured here (Pt100 sensor - T10) as well as water pressure in pipeline (pressure sensor - P10) and water flow (meter Q10). The first exchanger is laminated and it heats the water in the primary circuit for the heating system that warms the manufacturing plant. The second is an air exchanger which is cooled by two fans driven by two frequency regulator FR2. The criterion for the operation of this regulator is maintaining the temperature of cooling water (about 75 °C).

6. CONTROL AND SUPERVISION

Cupola furnace, as facility mana-gement, is a multivariable system whose structural block scheme is given in Figure 4, which displays the input and output values as well as disorders. Operation of device and equipment is controlled by the control unit.

It is PLC Siemens S7 1200 with modular structure. Applicable PLC is capable of serial communication protocols via RS - 232 and RS - 485, using plug-ins. MODBUS protocol (via module RS - 485) and USS protocol (Universal Serial Interface Protocol) can be also used to communicate with the Simen frequency converters that support this protocol [4, 5, 6]. The control unit has a PROFINET (a kind of open-standard Ethernet) port that allows it to connect to the other elements of automation and systems with this connection. Due to this, it is possible to connect multiple PLCs and operator panels via communication protocols based on Ethernet and TCP/IP (Transmission Control Protocol/Internet Protocol) protocols. In project development, it is relatively easy and quick to configure PROFINET communication between PLCs - the operator panel. Creation and configuration of tags (symbolic names of input and output) are the same for PLC control program and supervision - control application of the operator panel [7, 8].

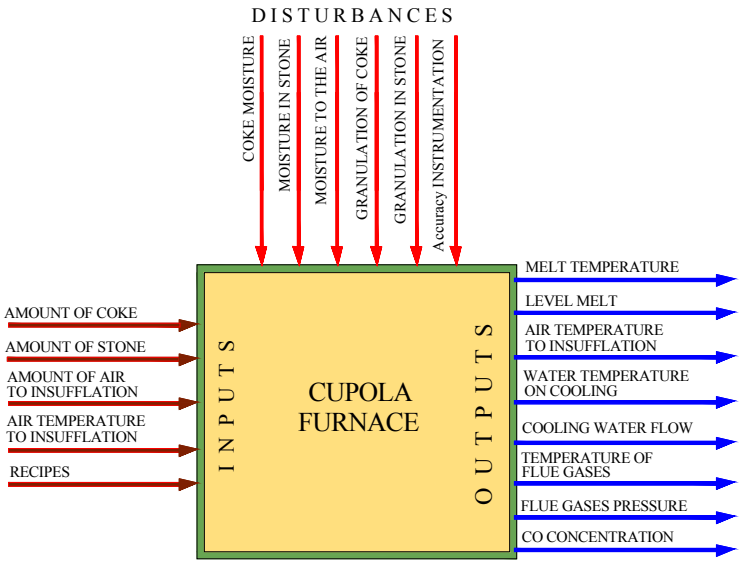

Fig. 4. *Structural scheme of the cupola furnace from control aspect*

Setting and viewing the parameters of cupola furnace and related equipment are performed on the operator color panel KTP 1000 which in connection to the PLC represents a control system under whose supervision are switching elements, sensors and actuators. Configuration and programming of unit S7 1200 and development of supervision - control program of operator panel are done using the software package *TIA Portal* that has the integrated STEP 7 Basic for controller and *WINCC* for visualization via KTP panel. Conception of control logic with S7-1200 is done connecting the different modules. On the Central Processing Unit (*CPU*), according to the requirements of the process which should be controled, different types of signaling and communication modules are added. Creation of the applications in the *TIA Portal* takes place in several steps: designing the project; planning PLC configuration, input, output and other modules, designing and configuring network connections between devices, writing a PLC control program, writing programs for the operator panel, loading of the written applications in PLC and panel, verification the operation and debugging the applications. After creating a new project, the option *Add new device* is selected in the *Devices & Networks* menu. In this way, properly PLC and operator panel are set in the project. If *SIMATIC PLC* is selected, the work with program *STEP 7 Basic* is continued, in which a control program develops. If operator panel is selected, the work is continued with the *WINCC* tools, where SCADA pages are created. Figure 5 shows a SCADA screen with technological scheme of the cupola furnace.

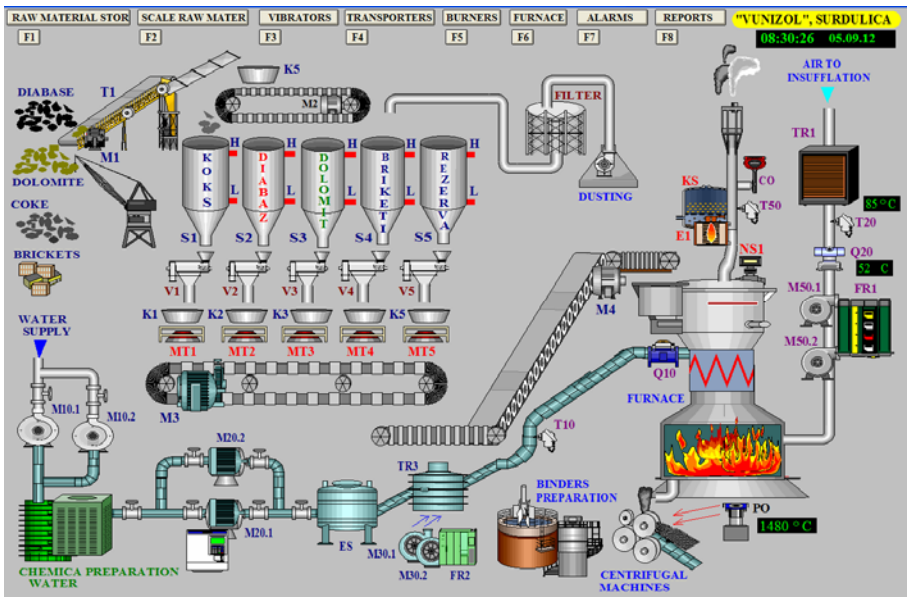

Fig. 5. *Technological scheme of tcupola furnace with supporting infrastructure (SCADA screen)*

Figure 6 shows a SCADA screen with a system for burning waste gases. At the mentioned figure, characteristic parameters of burner, when LPG is used as a fuel, are given. Processor of controller provides the user and system memory. User memory consists of memory to load (ROM - read only memory), which is nonvolatile memory and working memory (RAM - Random Access Memory), which is volatile because

of the erased data in the case of power failure [9, 10]. Application program and configuration parameters of controller are entered in the ROM memory, which is integrated into CPU (central processing unit). During the transition from the state of CPU in STOP to RUN, programs and data, which are necessary to carry out the program, are copied from ROM to RAM. Within the CPU is system memory that contains the address of variables. Memory address ranges are: inputs (I), outputs (Q), bit memory area (M), area for data blocks (DB) and local (temporary) memory (L).

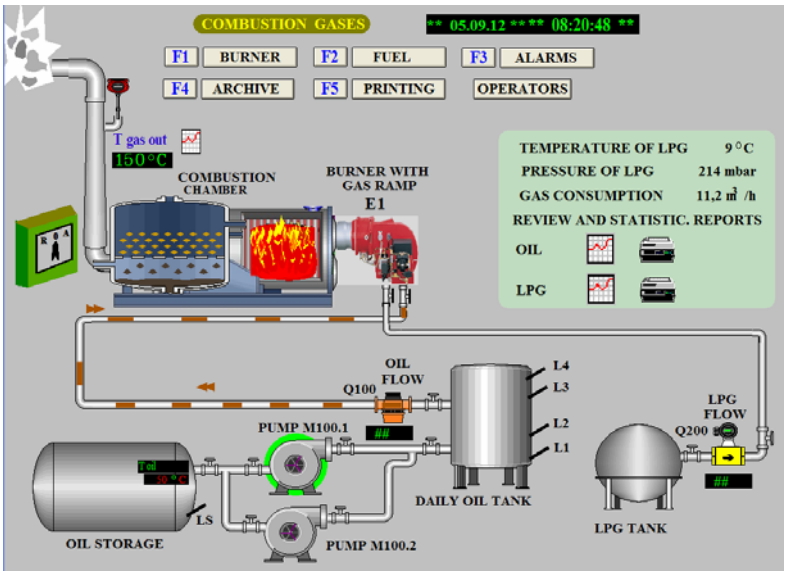

Fig. 6. *SCADA display of systems for combustion flue gases*

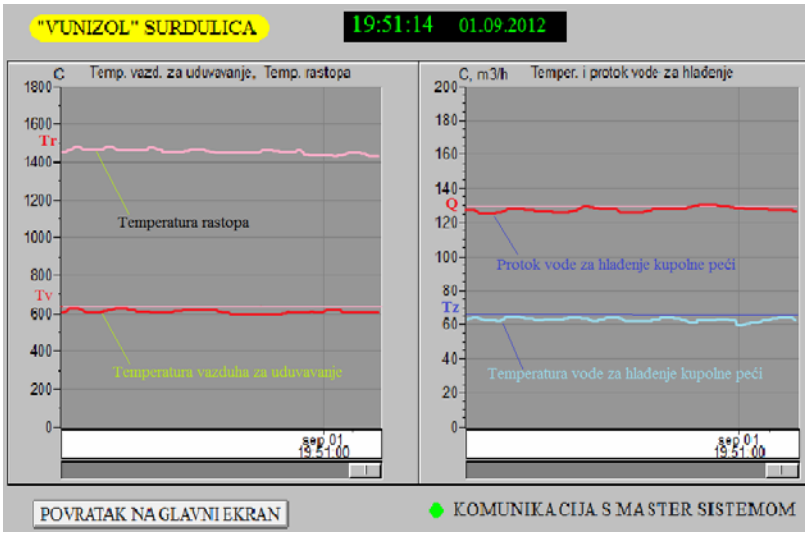

Fig. 7. *Trend graphs of characteristic values of cupola furnace*

Operator panel, as the interface to user, provides a visual representation the entire system, and provides setting and overview of typical values and parameters, and PLC executes regulation of cupola furnace.

Using trend graphs (Figure 7) or Tables, given and current values of relevant size of cupola furnace like melt temperature, air temperature and air flow for blow, temperature and cooling water flow rate, gas flow (oil) for burner operation by which the combustion of the flue gases is performed, used quantities of raw materials (stone, coke, briquettes and binders) for the specified period of time, can be monitored. Shift, daily and periodic reports are created and printed on demand. The status of fans, pumps, solenoid valves, motors of conveyors, systems for the chemical treatment of water are monitored. If certain sizes reach values which are outside this range, alarms with a description of the place and time of origin, with light and sound signaling, will generate. The corresponding text message and request the operator to verify alarms are printed on the operator panel. A list of possible causes of failure appears what makes work of maintenance service easier and reduces downtime.

7. CONCLUSION

Reconstruction of cupola furnace control system, based on PLC configuration in conjunction with display terminal, contributed to increase work efficiency of cupola furnace and in this way increase the efficiency and productivity of mineral wool production plant. Mineral wool is produced from raw materials situated in nature and/or from recycled raw materials, and their fibers are connected with ecological acceptable and biodegradable medium. Trash, which appears in production process or waste wool from site, are crashed and ground into granules. Adding sand and cement to the trash, the briquette is obtained, which is used as the raw material. Rock wool as isolation material is completely obtained from natural raw materials. During production process, from one cube meter raw material we can obtain much greater volume of isolation material with minimal energy sources consumption. Burning flue gasses results in reduction the harmful materials emission during production process and workers safety. SCADA system on display terminal has monitoring and control functions. Process monitoring and possible control correction in the case of specific circumstance are provided to the operator. Monitoring and control system directly measures technological variables and executive devices are controlled using the implemented algorithms. The system allows visualization of technological process and installed equipment, alarming in the case of failures emergence and achieving critical values of technological variables, archiving technological parameters, events and operator actions, automatic protection and device and equipment blocking in the case of critical situations. High rate of control and production organization are provided, plant downtime is decreased and maintenance service work is facilitated. Formed archive and appropriate interpretation of characteristic data for technological process, give necessary process information to the technologists and facilitating discovering the new technological solutions and improvement the existing ones.

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STATISTIČKA OBRADA REZULTATA MEĐULABORATORIJSKOG ISPITIVANJA GRANULOMETRIJSKOG SASTAVA PESKA I ŠLJUNKA IZ ZAPADNOG DELA KOSTOLAČKOG BASENA*****

Izvod

U radu su prikazani rezultati međulaboratorijskog ispitivanja granulometrijskog sastava peska i šljunka, na reprezentativnim uzorcima, sa lokaliteta zapadnog dela kostolačkog basena. Rezultati su statistički obrađeni na dva načina i to: ***Numeričkom metodom: Cochran-ov test preciznosti*** *i* ***Grafičkom interpretacijom: MANDEL-ova tehnika konzistentnosti*** *u skladu sa standardom* ***SRPS ISO 5725-2*** [1,2].

Izračunate su: Varijansa ponovljivosti Sr^2*; međulaboratorijska varijansa* S_L^2 *i varijansa obnovljivosti* S_R^2.

Uzorci su metodom deljenja dostavljeni svim laboratorijama učesnicama.

Ključne reči*: statistička obrada rezultata, međulaboratorijska ispitivanja, granulometrijski sastav, standard SRPS ISO 5725-2*

1. UVOD

U ovim ispitivanjima učestvovale su četiri akreditovane laboratorije. Međulaboratorijsko ispitivanje granulometrijskog sastava, rečnog peska i šljunka iz zapadnog dela kostolačkog basena, vršeno je u skladu sa standardom *SRPS U.B1.018:2005*.

Uzorkovanje i priprema uzorka izvršena je saglasno tački 3.1.3, gore navedenog standarda. Za svaku laboratoriju pripremljena su po tri reprezentativna uzorka peska i šljunka, u količini koji propisuje standard *SRPS U.B1.018:2005*[3]. Uzorci su na adekvatan način spakovani i isporučeni u ostale tri laboratorije.

Radi davanja uporedne analize ostvarenih rezultata, u obračun osnovnih i neo-

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***** *Rad je proizašao iz projekta TR 36028 „Razvoj i unapređenje metoda za analizu interakcije konstrukcije i tla na osnovu teorijskih i eksperimentalnih istraživanja“, koji finansira Ministarstvo za prosvetu, nauku i tehnološki razvoj Republike Srbije.*

phodnih parametara međulaboratorijskih ispitivanja, razmatrani su rezultati na sitima otvora, zajednička za sve laboratorije, a u skladu sa standardom.

Takođe su procenjene i varijanse ponovljivosti i obnovljivosti.

Ciljevi sprovođenja ovakvih ispitivanja, su između ostalog i :

- Provera ukupnog rada laboratorije;
- Provera osoblja laboratorija pri pojedinačnom ispitivanju;
- Uspostavljanje efikasnosti metode ispitivanja, a sve sa ciljem davanja tačnosti izlaznih rezultata korisnicima usluga laboratorija.

PRIKAZ REZULTATA MEĐULABORATORIJSKOG ISPITIVANJA

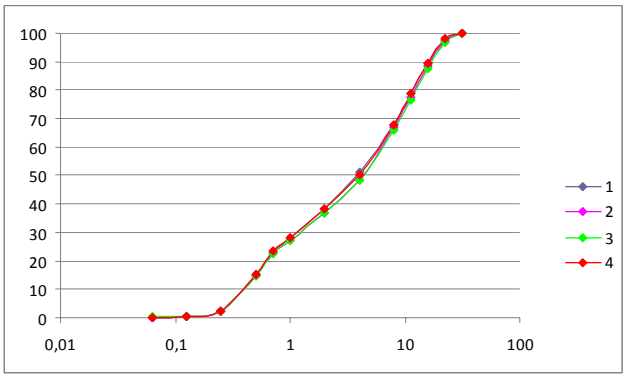
Tabela 1. *Rezultati ispitivanja granulometrijskog sastava peska i šljunka [5,6]*

Oznaka lab.	**1**			**2**			**3**			**4**		
Oznaka uzorka	Prva proba	Druga proba	Treća proba	Prva proba	Druga proba	Treća proba	Prva proba	Druga proba	Treća proba	Prva proba	Druga proba	Treća proba
Sita (mm)	***Prolaz kroz sito D(%)***											
0,063	0,18	0,19	0,20	0,20	0,20	0,20	0,27	0,27	0,30	0,20	0,20	0,20
0,125	0,56	0,56	0,55	0,70	0,66	0,66	0,60	0,69	0,68	0,50	0,50	0,60
0,25	2,32	2,34	2,26	2,40	2,42	2,37	2,34	2,56	2,37	2,30	2,30	2,30
0,5	14,93	15,76	15,23	14,40	14,50	14,65	14,06	15,49	14,97	14,80	15,20	15
0,71	22,36	23,77	23,21	22	22,56	22,55	21,18	23,51	22,84	22,80	23,90	23,20
1	27,08	29,16	28,27	26,60	27,69	27,45	25,78	28,34	27,66	27,30	28,50	29,10
2	36,92	39,49	38,68	36,40	37,43	37,43	34,99	38,25	37,64	36,70	38,50	39,70
4	49,45	52,03	51,75	47,50	48,08	49,74	45,92	49,70	49,67	50	50,10	50,90
8	65,38	68,78	68,97	66,70	64,71	69,10	63,03	66,18	68,41	65,20	68,70	68,70
11,2	77,61	79,22	79,41	76,60	75,87	79,48	73,83	76,31	79,35	77,90	79,40	79,80
16	89,15	89,36	89,20	87,10	90,26	87,80	84,70	88,80	88,87	89,10	89,70	89,90
22,4	97,03	97,27	98,33	97,70	97,18	96,72	96,66	96,49	97,33	97,60	98,50	98,60
31,5	100	100	100	100	100	100	100	100	100	100	100	100

Tabela 2. *Srednje vrednosti ćelija*

Oznaka lab. *j*	**1**	**2**	**3**	**4**	***Suma srednjih vrednosti***
Srednje vrednosti ćelija	$\overline{\overline{xij}}$				$= xij$
Sita (mm) *i*	$\overline{X}_{i1}$	$\overline{X}_{i2}$	$\overline{X}_{i3}$	$\overline{X}_{i4}$	$\Sigma\ \overline{xij}/4$
0,063	0,19	0,20	0,28	0,20	0,217
0,125	0,56	0,67	0,66	0,53	0,605
0,25	2,31	2,40	2,42	2,30	2,357
0,5	15,31	14,52	14,84	15	14,917
0,71	23,11	22,37	22,51	23,30	22,822
1	28,17	27,25	27,26	28,30	27,745
2	38,36	37,09	36,96	38,30	37,677
4	51,08	48,44	48,43	50,33	49,570
8	67,71	66,84	65,87	67,53	66,987
11,2	78,75	77,32	76,50	79,03	77,90
16	89,24	88,39	87,46	89,57	88,665
22,4	97,54	97,20	96,83	98,23	97,45
j-oznaka lab.(1-4) ***i-oznaka mreže sita(1-12)***					

Na slici 1, grafički su prikazane srednje vrednosti granulometrijskog sastava, određene iz rezultata triju prosejavanja, za svaku od četiri ispitnih laboratorija.



Sl. 1. *Srednje vrednosti granulometrijskog sastava*

Tabela 3. *Standardne devijacije -mere rasipanja ćelija*

Oznaka lab. *j*	1		2		3		4		*Suma kvadrata standar. devijacija*
Standardne devijacije	*sij*								
Sita (mm) *i*	s_{i1}	s_{i1}^2	s_{i2}	s_{i2}^2	s_{i3}	s_{i3}^2	s_{i4}	s_{i4}^2	Σs_{ij}^2
0,063	0,01	***0,0001≈0***	0,000	0,000	0,017	***0,0003≈0***	0,000	0,000	0
0,125	0,007	***0,000049≈0***	0,023	***0,0005≈0***	0,049	0,002	0,058	0,003	0,005
0,25	0,042	0,002	0,025	***0,000625≈0,001***	0,119	0,014	0,000	0,000	0,017
0,5	0,420	0,176	0,126	0,016	0,724	0,524	0,20	0,04	0,756
0,71	0,710	0,504	0,320	0,102	1,199	1,438	0,557	0,310	2,354
1	1,043	1,088	0,572	0,327	1,326	1,758	0,916	0,839	4,012
2	1,313	1,723	0,595	0,354	1,733	3,003	1,510	2,280	7,36
4	1,416	2,005	1,162	1,35	2,173	4,721	0,493	0,243	8,319
8	2,020	4,080	2,198	4,831	2,703	7,306	2,020	4,080	20,297
11,2	0,989	0,978	1,909	3,644	2,765	7,645	1,002	1,004	13,271
16	0,110	0,012	1,660	2,756	2,388	5,702	0,416	0,173	8,643
22,4	0,692	0,479	0,490	0,240	0,444	0,197	0,551	0,304	1,22

Napomena: *Standardna devijacija treba da se izrazi jednom cifrom više, u odnosu na date rezultate u tabelama 1 i 2, te je u skladu sa tom konstatacijom izvršeno i zaokruživanje na tri decimale prikazanih rezultata u tabeli 3. (tačka 7.2.10 -SRPS ISO 5725-2).*

REZULTATI COCHRANOVOG TESTA

Tabela 4. *Rezultati Cochranovog testa*

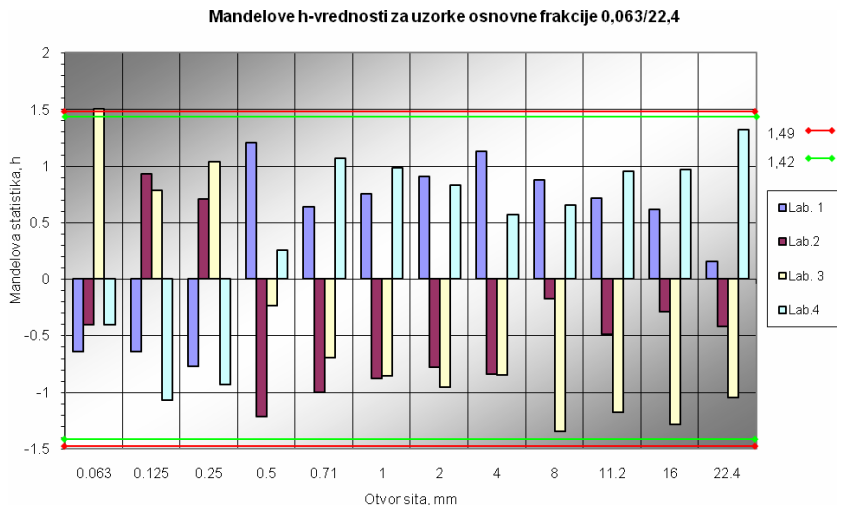
Sita (mm)	Lab.	Ispitna vrednost Sij_{max}^2	C vrednost	Kritične vrednosti		Komentar	Ocena
				1%	5%		
0,063	/	/	/	0,864	0,768	/	/
0,125	4	0,003	0,6			***C≤Ctab(5%)***	***Korektan***
0,25	3	0,014	0,823*			***C(1%)≥C≥(5%)***	***Zalutali (strag-glers)***
0,5	3	0,524	0,693			***C≤Ctab(5%)***	***Korektan***
0,71	3	1,438	0,611			***C≤Ctab(5%)***	***Korektan***
1	3	1,758	0,438			***C≤Ctab(5%)***	***Korektan***
2	3	3,003	0,408			***C≤Ctab(5%)***	***Korektan***
4	3	4,721	0,567			***C≤Ctab(5%)***	***Korektan***
8	3	7,306	0,360			***C≤Ctab(5%)***	***Korektan***
11,2	3	7,645	0,576			***C≤Ctab(5%)***	***Korektan***
16	3	5,702	0,66			***C≤Ctab(5%)***	***Korektan***
22,4	1	0,479	0,393			***C≤Ctab(5%)***	***Korektan***

REZULTATI MANDELOVE h I k STATISTIKE

Tabela 5. *Izračunate h vrednosti*

Oznaka lab. *j*	1	2	3	4	h indikator	
					1%	5%
Sita (mm) *i*	**Izračunate h vrednosti**					
0,063	-0,643	-0,405	1,5** *usamljena vrednost (outliers)*	-0,405		
0,125	-0,643	0,929	0,786	-1,071		
0,25	-0,770	0,705	1,033	-0,934		
0,5	1,202	-1,214	-0,235	0,254		
0,71	0,640	-1,004	-0,693	1,062		
1	0,752	-0,876	-0,858	0,982		
2	0,908	-0,781	-0,953	0,828		
4	1,128	-0,844	-0,851	0,567		
8	0,871	-0,177	-1,346	0,654	**1,49**	**1,42**
11,2	0,714	-0,487	-1,175	0,949		
16	0,612	-0,292	-1,282	0,963		
22,4	0,152	-0,422	-1,047	1,317		

Napomena: *Usamljene vrednosti (outliers) nisu uzete u proračun varijansi ponovljivosti i obnovljivosti, (tačka 7.1.6 -SRPS ISO 5725-1).*

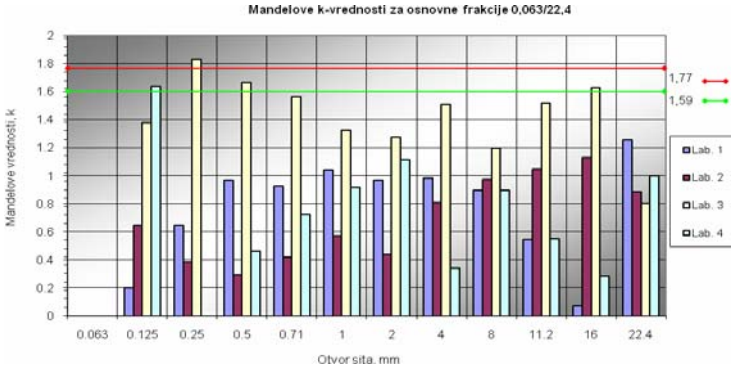


Sl. 2. *Grafik h vrednosti*

Tabela 6. *Izračunate k vrednosti*

Oznaka lab. *j*	1	2	3	4	k indikator	
					1%	5%
Sita (mm) *i*	**Izračunate k vrednosti**				**1,77**	**1,59**
0,063	0	0	0	0		
0,125	0,197	0,648	1,380	1,634* *Zalutala vrednost (stragglers)*		
0,25	0,646	0,385	1,831** *usamljena vrednost (outliers)*	0		
0,5	0,967	0,290	1,666* *Zalutala vrednost (stragglers)*	0,460		
0,71	0,926	0,417	1,563	0,726		
1	1,041	0,571	1,324	0,915		
2	0,968	0,439	1,277	1,113		
4	0,982	0,806	1,507	0,342		
8	0,897	0,976	1,2	0,897		
11,2	0,543	1,048	1,518	0,550		
16	0,075	1,129	1,624* *Zalutala vrednost (stragglers)*	0,283		
22,4	1,254	0,888	0,804	0,998		

Napomena: *Usamljene vrednosti (outliers) nisu uzete u proračun varijansi ponovljivosti i obnovljivosti, (tačka 7.1.6 -SRPS ISO 5725-1).*



Sl. 3. *Grafik k vrednosti*

Tabela 7. *Izračunate vrednosti varijansi*

Sita (mm) *i*	Sr^2	Sr	S_L^2	S_L	S_R^2	S_R
0,063	0,0000	0,0000	0,0374	0,1934	0,0374	0,1934
0,125	0,00125	0,0353	0,0049	0,0700	0,0061	0,0781
0,25	0,00425	0,0652	0,0016	0,0400	0,0058	0,0761
0,5	0,1890	0,4347	0,0448	0,2117	0,2338	0,4835
0,71	0,5885	0,7671	0,0081	0,0900	0,5966	0,7724
1	1,0030	1,0015	0,0000 (-0,0112)	0,0000	1,0030	1,0015
2	1,8400	1,3565	0,0000 (-0,0418)	0,0000	1,8400	1,3565
4	2,0797	1,4421	1,1069	1,0521	3,1866	1,7851
8	5,0742	2,2526	0,0000 (-0,9858)	0,0000	5,0742	2,2526
11,2	3,3177	1,8215	0,0304	0,1743	3,3481	1,8298
16	2,1607	1,4699	0,1705	0,4129	2,3312	1,5268
22,4	0,305	0,5523	0,2503	0,5002	0,5553	0,7452

Sr^2-Varijansa ponovljivosti
S_L^2-Međulaboratorijska varijansa
S_R^2- Varijansa obnovljivosti

Napomena: *Usled efekta slučajnosti, dobijene negativne vrednosti za S_L^2 smatraju se jednakim nuli (tačka 7.4.5.4- SRPS ISO 5725-2).*

ZAKLJUČAK

Svrha međulaboratorijskog ispitivanja, bila je ocena preciznosti ispitne metode i ocena sposobnosti ispitnih laboratorija, u skladu sa standardima SRPS ISO 5725-2 ISO/IEC Guide 43-1:1997 i SRPS 17025 [4,7].

Nakon statističke obrade rezultata, dvema statističkim metodama, grafičkom i analitičkom, može se izvesti sledeći zaključak: Rezultat laboratorije br.3, na situ otvora 0,250 mm, nakon statističke obrade Cochranovim testom može se smatrati zalutalim, dok se ostale ispitne vrednosti iste laboratorije i laboratorije br. 1 na situ 22,4 mm i laboratorije br.4 na situ od 0,125 mm, po osnovu Cochranovog kriterijuma kritičnih vrednosti, smatraju korektnim (tabela 4).

Rezultati laboratorije br.2 su zadovoljavajući i nisu ušli u ispitni opseg, Cochranovim testom.

Prema Mandelovoj h i k statistici, u laboratoriji br. 3 utvrđen je jedan neprihvatljiv rezultat (outliers) na situ od 0,063 mm i 0,250 mm, kao i tri zalutale vrednosti prema Mandelovoj k statistici : u laboratoriji br.3 na sitima od 0,5 i 16 mm i laboratoriji br.4 na situ od 0,125 mm.

U obzir treba uzeti i moguće uticajne faktore-efekte na krajnje rezultate ispitivanja:

1. uzorkovanje (homogenost);
2. priprema uzorka (efekat homogenizacije ili izuzimanje dela uzorka);
3. efekat izvršioca;
4. uticaj transporta.

Sveobuhvatnom analizom dobijenih rezultata, može se konstantovati dobra osposobljenost laboratorija za primenu ispitne standardne metode.

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STATISTICAL PROCESSING THE RESULTS OF INTERLABORATORY TESTING THE GRAIN-SIZE DISTRIBUTION OF SAND AND GRAVEL FROM THE WESTERN PART OF THE KOSTOLAC BASIN*****

Abstract

This paper presents the results of interlaboratory testing the grain-size distribution of sand and gravel on representative samples from the site of the western part of the Kostolac Basin. The results were statistically processed by two ways: Numerical method: the ***Cochran test*** *of accuracy and* ***Graphic interpretation****: the* ***MANDEL technique of consistency*** *in accordance with the Standard* ***SRPS ISO 5725-2*** *[1,2].*

The followings were calculated: repeatability variance Sr^2*; interlaboratory variance* S_L^2 *and reproducibility variance* S_R^2*.*

Samples were submitted by sharing method to all participating laboratories.

Keywords: *statistical data processing, interlaboratory testing, grain-size distribution, standard SRPS ISO 5725-2*

1. INTRODUCTION

Four accredited laboratories participated in these testing. Interlaboratory testing of grain-size distribution of river sand and gravel from the western part of the Kostolac Basin was carried out in accordance with the Standard *SRPS U.B1.018: 2005.*

Sampling and sample preparation were carried out in accordance with item 3.1.3 of the above standards. Three representa-tive samples of sand and gravel were prepared for each laboratory in the amount prescribed by the Standard *SRPS U.B1.018: 2005* [3]. The samples were properly packaged and submitted in three other laboratories.

In order to give a comparative analysis of the achieved results in calculation of basic

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and necessary parameters of interlaboratory tests, the results of sieve openings, common to all laboratories, and in accordance with the standard, were discussed

Variances of repeatability and reproducibility were also estimated.

The aims of conducting such tests, among other things, are the followings:

- Checking the total work of laboratory;
- Checking the laboratory staff at individual test;
- Establishing the efficiency of test method, with the goal of giving the accuracy of output results of laboratory services to the users.

REVIEW OF INTERLABORATORY TEST RESULTS

Table 1. *Test results the grain-size distribution of sand and gravel [5,6]*

Lab. designation	**1**			**2**			**3**			**4**		
Sample designation	First sample	Second sample	Third sample	First sample	Second sample	Third sample	First sample	Second sample	Third sample	First sample	Second sample	Third sample
Sieve (mm)	***Passage through sieve D(%)***											
0.063	0.18	0.19	0.20	0.20	0.20	0.20	0.27	0.27	0.30	0.20	0.20	0.20
0.125	0.56	0.56	0.55	0.70	0.66	0.66	0.60	0.69	0.68	0.50	0.50	0.60
0.25	2.32	2.34	2.26	2.40	2.42	2.37	2.34	2.56	2.37	2.30	2.30	2.30
0.5	14.93	15.76	15.23	14.40	14.50	14.65	14.06	15.49	14.97	14.80	15.20	15
0.71	22.36	23.77	23.21	22	22.56	22.55	21.18	23.51	22.84	22.80	23.90	23.20
1	27.08	29.16	28.27	26.60	27.69	27.45	25.78	28.34	27.66	27.30	28.50	29.10
2	36.92	39.49	38.68	36.40	37.43	37.43	34.99	38.25	37.64	36.70	38.50	39.70
4	49.45	52.03	51.75	47.50	48.08	49.74	45.92	49.70	49.67	50	50.10	50.90
8	65.38	68.78	68.97	66.70	64.71	69.10	63.03	66.18	68.41	65.20	68.70	68.70
11.2	77.61	79.22	79.41	76.60	75.87	79.48	73.83	76.31	79.35	77.90	79.40	79.80
16	89.15	89.36	89.20	87.10	90.26	87.80	84.70	88.80	88.87	89.10	89.70	89.90
22.4	97.03	97.27	98.33	97.70	97.18	96.72	96.66	96.49	97.33	97.60	98.50	98.60
31.5	100	100	100	100	100	100	100	100	100	100	100	100

Table 2. *Average values of cells*

Lab designation *j*	**1**	**2**	**3**	**4**	***Sum of average values***
Average values of cells	$\bar{x}ij$				$= xij$
Sieve (mm) *i*	$\bar{X}_{i1}$	$\bar{X}_{i2}$	$\bar{X}_{i3}$	$\bar{X}_{i4}$	$\Sigma\ \bar{x}ij/4$
0.063	0.19	0.20	0.28	0.20	0.217
0.125	0.56	0.67	0.66	0.53	0.605
0.25	2.31	2.40	2.42	2.30	2.357
0.5	15.31	14.52	14.84	15	14.917
0.71	23.11	22.37	22.51	23.30	22.822
1	28.17	27.25	27.26	28.30	27.745
2	38.36	37.09	36.96	38.30	37.677
4	51.08	48.44	48.43	50.33	49.570
8	67.71	66.84	65.87	67.53	66.987
11.2	78.75	77.32	76.50	79.03	77.90
16	89.24	88.39	87.46	89.57	88.665
22.4	97.54	97.20	96.83	98.23	97.45
j- lab designation(1-4) ***i-mesh size designation(1-12)***					

Figure 1 graphically shows the average values of grain-size distribution, determined from the results of three screening, for each of the four testing laboratories.

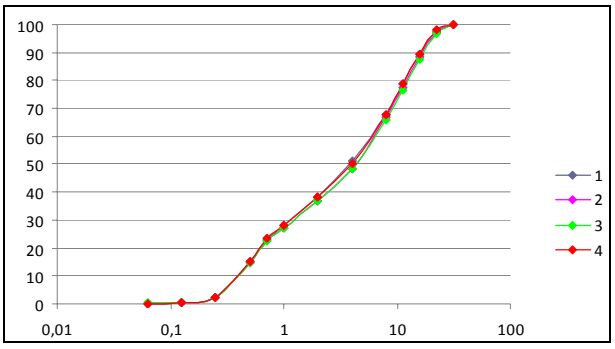

Fig. 1. *Average values of grain-size distribution*

Table 3. *Standard deviations – measures of cell dissipations*

Lab designation *j*	1		2		3		4		*Sum of squares of standard deviations*
Standard deviations	*sij*								
Sieve (mm) *i*	s_{i1}	s_{i1}^2	s_{i2}	s_{i2}^2	s_{i3}	s_{i3}^2	s_{i4}	s_{i4}^2	Σs_{ij}^2
0.063	0.01	***0.0001≈0***	0.000	0.000	0.017	***0.0003≈0***	0.000	0.000	0
0.125	0.007	***0.000049≈0***	0.023	***0.0005≈0***	0.049	0.002	0.058	0.003	0.005
0.25	0.042	0.002	0.025	***0.000625≈0.001***	0.119	0.014	0.000	0.000	0.017
0.5	0.420	0.176	0.126	0.016	0.724	0.524	0.20	0.04	0.756
0.71	0.710	0.504	0.320	0.102	1.199	1.438	0.557	0.310	2.354
1	1.043	1.088	0.572	0.327	1.326	1.758	0.916	0.839	4.012
2	1.313	1.723	0.595	0.354	1.733	3.003	1.510	2.280	7.36
4	1.416	2.005	1.162	1.35	2.173	4.721	0.493	0.243	8.319
8	2.020	4.080	2.198	4.831	2.703	7.306	2.020	4.080	20.297
11.2	0.989	0.978	1.909	3.644	2.765	7.645	1.002	1.004	13.271
16	0.110	0.012	1.660	2.756	2.388	5.702	0.416	0.173	8.643
22.4	0.692	0.479	0.490	0.240	0.444	0.197	0.551	0.304	1.22

Note: *Standard deviation should be expressed by one digit more, compared to the results given in Tables 1 and 2, and in accordance with this statement, a rounding was made to three decimals of shown results in Table 3 (item 7.2.10 -SRPS ISO 5725-2).*

THE COCHRAN TEST RESULTS

Table 4. *The Cochran test results*

Sieve (mm)	Lab	Test value Sij_{max}^2	C value	Critical values 1%	Critical values 5%	Comment	Evaluation
0.063	/	/	/	0.864	0.768	/	/
0.125	4	0.003	0.6			***C≤Ctab(5%)***	***Correct***
0.25	3	0.014	0.823*			***C(1%)≥C≥(5%)***	***Stragglers***
0.5	3	0.524	0.693			***C≤Ctab(5%)***	***Correct***
0.71	3	1.438	0.611			***C≤Ctab(5%)***	***Correct***
1	3	1.758	0.438			***C≤Ctab(5%)***	***Correct***
2	3	3.003	0.408			***C≤Ctab(5%)***	***Correct***
4	3	4.721	0.567			***C≤Ctab(5%)***	***Correct***
8	3	7.306	0.360			***C≤Ctab(5%)***	***Correct***
11.2	3	7.645	0.576			***C≤Ctab(5%)***	***Correct***
16	3	5.702	0.66			***C≤Ctab(5%)***	***Correct***
22.4	1	0.479	0.393			***C≤Ctab(5%)***	***Correct***

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Table 5. *Calculated h values*

Lab designation *j*	1	2	3	4	h indicator	
					1%	5%
Sieve (mm) *i*	**Calculated h values**				**1.49**	**1.42**
0.063	-0.643	-0.405	1.5** *Outliers*	-0.405		
0.125	-0.643	0.929	0.786	-1.071		
0.25	-0.770	0.705	1.033	-0.934		
0.5	1.202	-1.214	-0.235	0.254		
0.71	0.640	-1.004	-0.693	1.062		
1	0.752	-0.876	-0.858	0.982		
2	0.908	-0.781	-0.953	0.828		
4	1.128	-0.844	-0.851	0.567		
8	0.871	-0.177	-1.346	0.654		
11.2	0.714	-0.487	-1.175	0.949		
16	0.612	-0.292	-1.282	0.963		
22.4	0.152	-0.422	-1.047	1.317		

Note: *The outliers were not included in the calculation of repeatability and reproducibility variances, (item 7.1.6 -SRPS ISO 5725-1).*

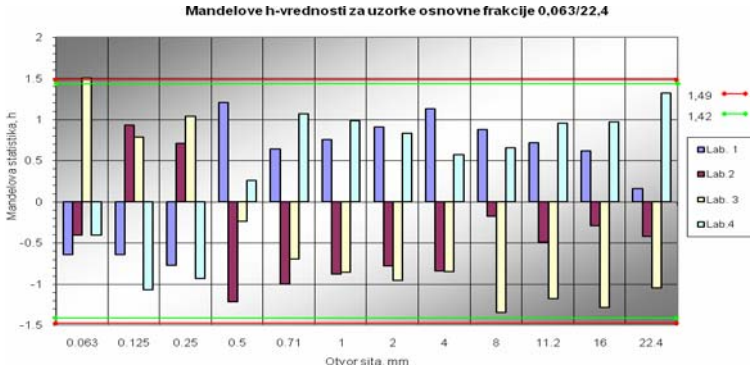

Fig. 2. *Graph of h values*

Table 6. *Calculated k values*

Lab designation *j*	1	2	3	4	k indicator	
					1%	5%
Sieve (mm) *i*	**Calculated k values**				**1.77**	**1.59**
0,063	0	0	0	0		
0.125	0.197	0.648	1.380	1.634* *Stragglers*		
0.25	0.646	0.385	1.831** *Outliers*	0		
0.5	0.967	0.290	1.666* *Stragglers*	0.460		
0.71	0.926	0.417	1.563	0.726		
1	1.041	0.571	1.324	0.915		
2	0.968	0.439	1.277	1.113		
4	0.982	0.806	1.507	0.342		
8	0.897	0.976	1.2	0.897		
11.2	0.543	1.048	1.518	0.550		
16	0.075	1.129	1.624* *Stragglers*	0.283		
22.4	1.254	0.888	0.804	0.998		

Note: *The outliers were not included in the calculation of repeatability and reproducibility variances, (item 7.1.6 -SRPS ISO 5725-1).*

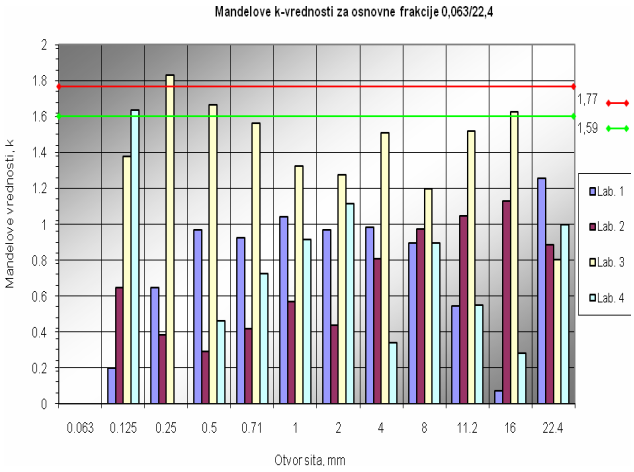

Fig. 3. *Graph of k values*

Table 7. *Calculated values of variances*

Sieve (mm) *i*	Sr^2	Sr	S_L^2	S_L	S_R^2	S_R
0.063	0.0000	0.0000	0.0374	0.1934	0.0374	0.1934
0.125	0.00125	0.0353	0.0049	0.0700	0.0061	0.0781
0.25	0.00425	0.0652	0.0016	0.0400	0.0058	0.0761
0.5	0.1890	0.4347	0.0448	0.2117	0.2338	0.4835
0.71	0.5885	0.7671	0.0081	0.0900	0.5966	0.7724
1	1.0030	1.0015	0.0000 (-0.0112)	0.0000	1.0030	1.0015
2	1.8400	1.3565	0.0000 (-0.0418)	0.0000	1.8400	1.3565
4	2.0797	1.4421	1.1069	1.0521	3.1866	1.7851
8	5.0742	2.2526	0.0000 (-0.9858)	0.0000	5.0742	2.2526
11.2	3.3177	1.8215	0.0304	0.1743	3.3481	1.8298
16	2.1607	1.4699	0.1705	0.4129	2.3312	1.5268
22.4	0.305	0.5523	0.2503	0.5002	0.5553	0.7452

Sr^2-Repeatability variance
S_L^2-Interlaboratory variance
S_R^2- Reproducibility variance

Note: *Due to the effect randomness, the obtained negative values for SL2 are considered equal to zero (item 7.4.5.4-ISO 5725-2).*

CONCLUSION

The purpose of interlaboratory testing was evaluation the test method precision and evaluation the capabilities of testing laboratories, in accordance with the Standards SRPS ISO 5725-2 ISO/IEC Guide 43-1:1997 i SRPS 17025 [4,7].

After statistical processing the results using two statistical methods, graphical

and analytical, the following conclusion can be made: the result of laboratory no.3, on the sieve of mesh size 0.250 mm, after statistical processing by the Cochran test can be considered as strayed, until all other test values of the same laboratory and laboratory no. 1 on the sieve of 22.4 mm and laboratory no. 4 on the sieve of 0.125 mm, based on the Cochran criteria of critical values, are considered as correct (Table 4).

The results of laboratory no.2 were satisfactory and did not include into test range by the Cochran test.

According to the Mandel h and k in laboratory no. 3, an unacceptable result (outliers) was determined on the sieve of 0.063 mm and 0.250 mm, and three stray values according to the Mandel k statistics: in the laboratory no.3 on the sieves of 0.5 and 16 mm and laboratory no. 4 on the sieve 0.125 mm.

Possible influencing factors-effects on the final results of testing should be also taken into consideration:

sample (homogeneity);
sample preparation (excluding the effect of homogenization or excluding a part of sample);
effect of performer,
impact of transport.

By comprehensive analysis the results, the good capability of laboratories can be stated for the use of standard test method.

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ANALIZA TEHNIČKO TEHNOLOŠKIH PARAMETARA SEKUNDARNE UDARNO ROTACIONE DROBILICE PRI PRERADI KAMENA KREČNJAKA

Izvod

U predmetnom radu obrađena je problematika proizvodnje kamena krečnjaka na postrojenju stabilne separacije na PK "Duboki potok - Bijela Rijeka". Pored toga istraživani su efekti proizvodnje različitih varijanti rada i tokova materijala. Istraživanja su sprovedena na stabilnom postrojenju separacije površinskog kopa krečnjaka „Duboki potok – bijela rijeka" u Dubokom potoku. Pozicije istražnih radova su se nalazile na sekundarnom dijelu separacije (udarno rotaciona drobilica, usmjerivači materijala, lijevci, gumeni transporteri, vibraciona sita itd). U toku rada korištene su metode mjerenja protoka materijala, obračuna kapaciteta transportera, laboratorijske metode utrđivanja granulometrijskog sastava dobijenog materijala i oblika zrna.

Rezultati istraživanja su iskazani:

- *u dijagramima granulometrijskog sastava dobijenog kamenog agregata sa najpovoljnijim pojasevima vijrednosti granulometrijskog sastava*
- *definisanju funkcionalne zavisnosti zazora udarne drobilice i strukture granulometrijskog sastava dobijenog materijala.*

Ključne riječi: *proces drobljenja, udarno-rotaciona drobilica, granulometrijska analiza, dijagram, zavisnost, zazor udarno rotacione drobilice, povoljna varijanta rada udarno rotacione drobilice.*

1. UVOD

Usitnjavanje je proces smanjenja krupnoće sirovine radi njene direktne upotrebe (pripreme mineralne sirovine) za proces koncentracije, drugi vid tehnološke prerade ili korištenja kao konačnog proizvoda[1].

Pored tehnološkog značaja koji se ogleda u smanjenju krupnoće i oslobađanju minerala, drobljenje ima i važan ekonomski značaj. Oko 4,5 – 5% od proizvedene električne energije u svijetu troši se na drobljenje. Drobljenje je veoma skup proces. Od ukupnih investicionih i eksploatacionih troškova postrojenja za pripremu i koncentraciju, 50 – 70% odnosi se na drobljenje mineralne sirovine. Stoga je veoma važno izvršiti optimizaciju procesa prerade mineralne sirovine tj. drobljenja mineralne sirovine, kako bi se u što većem procentu dobijeni rezultati približili zahtijevanim uslovima.

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1.1. Cilj naučnog rada i definisanje problema

Cilj ovog rada je egzaktno definisanje tehničko-tehnoloških parametara sekundarne udarno rotacione drobilice koji utiču na efekte drobljenja, kako bi se sa što manjim troškovima u procesu prerade kamena krečnjaka, te u skladu sa zahtjevima tržišta kvalitetno riješio problem dobijanja gotovih kamenih agregata odgovarajućeg granulometrijskog sastava zrna u potrebnom procentu kojeg zahtijeva tržište.

2. METODOLOGIJA RADA

Istraživanja su se bazirala na: postavljanju metodologije istraživanja, analizi rada sekundarne udarno rotacione drobilice, provođenje eksperimenata (usklađivanju tehničko-tehnoloških parametara sekundarne udarno rotacione drobilice i iskazivanju dijagrama granulometrijskog sastava dobijenog materijala.

Istraživanja su se sprovodila na lokalitetu PK „Duboki potok - Bijela rijeka“ tj. na postrojenju za preradu kamena krečnjaka na predmetnoj lokaciji[3].

Rezultati istraživanja su iskazani tabelarno (brojčane vrijednosti strukture granulometrijskog sastava dobijenog materijala pri određenoj vrijednosti zazora sekundarne udarno rotacione drobilice); grafički (grafikoni sa krivim granulometrijskog sastava dobijenog agregata pri određenoj vrijednosti zazora sekundarne udarno rotacione drobilice).

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

Strukturno model istraživanja se može podijeliti u sljedeće faze:

a) Laboratorijska ispitivanja granulometrijskog sastava materijala,
b) Terenska „in situ“ mjerenja ulaznih i izlaznih parametara,
c) Obrada dobijenih rezultata.

2.1. Laboratorijska ispitivanja

Kada je riječ o laboratorijskom ispitivanju granulometrijskog sastava ispitivanja suobavljena za dva slučaja i to:

1. Laboratorijsko ispitivanje granulometrijskog sastava ulaznog (doziranog) materijala u udarno rotacionu drobilicu,
2. Laboratorijsko ispitivanje granulometrijskog sastava izlaznog (drobljenog) materijala iz udarno rotacione drobilice.

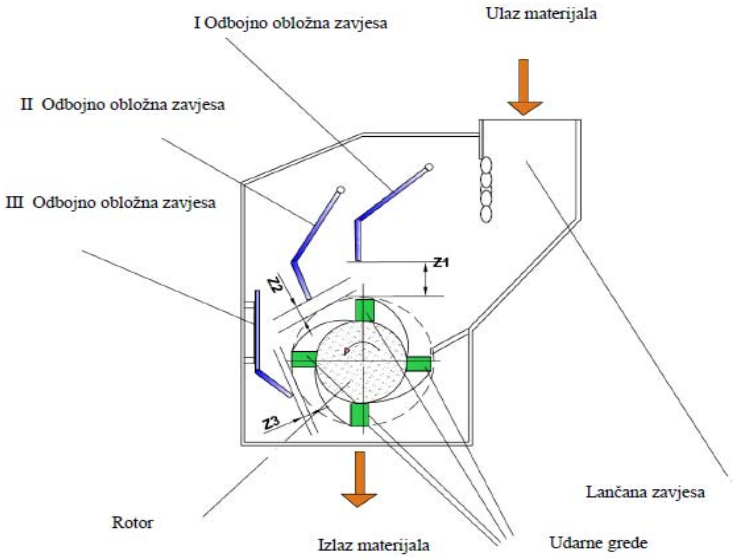
Uzorak je prosijavan na sitima otvora (mm): 31,5; 60; 90; 120; 200

Isptivanje je vršeno je za dvije varijante granulometrijskog sastava dozirnog (ulaznog u drobilicu) materijala i to:

1. Dozirni materijal u udarno rotacionu drobilicu čini sav materijal iz čeljusne drobilice 31,5/200 mm, a što se u daljnjem tekstu označava: režim doziranja „A“,
2. Dozirni materijal u udarno rotacionu drobilicu učini materijal 31,5/60 mm i 120/200 mm dobijen iz čeljusne drobilice. U ovoj dozirnoj granulometriji nedostaje granulacija 60/120 mm, koja se izdvaja kao gotov proizvod, režim doziranja „B“.

Sastav serije sita diktiraju građevinski standardi pa se primjenjuju sita sljedećih vrijednosti otvora (mm) [2]: 0,063; 0,09; 0,25; 0,5; 0,71; 1,00; 4,00; 8,00; 16,00; 31,5; 60,00; 90,00.

Postavljene su različite vrednosti ključnog parametra za granulometrijski sastav. Ukupno je postavljeno šest različitih varijanti, koje se karakterišu različitim veličinama zazora na sve tri udarno odbojne ploče statora udarne drobilice. Prilikom postavljanja vrijednosti veličine zazora za različite varijante, vođeno je računa o operativno neprihvatljivim vrijednostima navedenog parametra drobilice.



Sl. 1. Šema udarne drobilice sa četiri grede i tri zavjese odbojno obložnih ploča

U tabeli 1. date su vrijednosti zazora Z_1, Z_2 i Z_3 (slika 8.) za varijante pri kojima je analiziran granulometrijski sastav drobljenog kamenog agregata. Za varijante navedene u datoj tabeli vršena su ispitivanja strukture granulometrijskog sastava dobijenog materijala.

Tabela 1. *Parametri otvora drobilice za „in situ" istraživanje*

	vrijednosti zazora za sve tri zavjese		
varijante	Z_1, (mm)	Z_2, (mm)	Z_3,(mm)
varijanta I	140	40	22
varijanta II	160	50	25
varijanta III	170	60	30
varijanta IV	180	70	40
varijanta V	190	80	50
varijanta VI	200	90	55

2.2. Terenska „in-situ" ispitivanja

Pomenutim ispitivanjima obavljena su sljedeća mjerenja, odnosno radni postupci:

1. Mjerenja kapaciteta ulaznog materijala u udarno rotacionu drobilicu i kapacitetu izlaznog materijala iz udarno rotacione drobilice pri određenoj varijanti rada. Mjerenja su vršena na način da se sa gumenog transportera dužine jedan metar uzimao cjelokupan uzorak te pomoću obrazca (2.2) dobijao promatrani kapacitet:

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

gdje je:

Q - kapacitet (t/h),

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

v - brzina tračnog transportera (m/h)

2. Drobljenje kamenog materijala na udarno rotacionoj drobilici. U cilju dobijanja relevantnih uzoraka za laboratorijska istraživanja na postrojenju separacije, tj. na udarno rotacionoj drobilici vršeno je drobljenje kamenog materijala u šest različitih varijanti. Drobljenje u svih šest varijanti vršeno je pri dva režima dozirnog- ulaznog materijala.

2.3. Obrada dobijenih podataka

Obrada dobijenih podataka vršena je numeričkom analizom korištenjem Microsoft Office Excell 2007. Rezultati ispitivanja su uglavnom prikazani pomoću tabela i dijagramazbog što lakšeg i preglednijeg uočavanja zavisnosti istraživanih parametara.

3. REZULTATI ISTRAŽIVANJA

Rezultati sprovedenih istraživanja, dati su brojčanou tabelama, i to pri dva različita režima dozirno–ulaznog materijala u udarno-rotacionu drobilicu. Rezultati granulometrijskog sastava dobijenog materijala ispitivani su u šest različitih varijanti i to pri ranije navedenim zazorima odbojnih obloga udarne drobilice.

3.1. Granulometrijski sastav ulaznog, doziranog, materijalau sekundarnu drobilicu

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

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

gdje su :

X - aritmetička sredina mjerenja;

x_1, x_2, x_3.....x_n - pojedinačna mjerenja

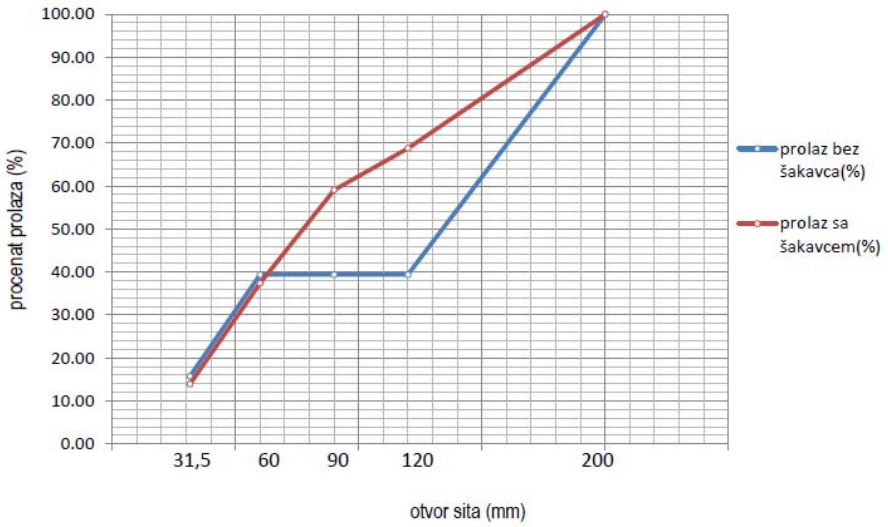
n – broj mjerenja.

U tabeli 2. dat je granulometrijski sastav ulaznog materijala u udarnu drobilicu sa procentima prosjeva na otvorima sita kako su dati u tabeli, za oba navedena režima doziranja. Primjetno je da je struktura ulaznog materijala bez kamenog agregata srednje granulacije 60/120 mm (šakavca) znatno drugačija.

Tabela 2. *Strukture granulometrijskog sastava dozirnog-ulaznog materijala, i to za režim doziranja „A“ i režim doziranja „B“*

Otvor sita, (mm)	31,50	60,00	90,00	120,00	200,00
Ulazni materijal bez kamenog agregata 60/120 mm (šakavca) u ulaznom materijalu, (%)	15,70	39,40	39,40	39,40	100,00
Ulazni materijal sa kamenim agregatom 60/120 mm (šakavcem) u ulaznom materijalu, (%)	13,90	37,40	59,10	68,80	100,00

Na slici 1. prikazane su krive granulometrijskog sastava ulaznog (doziranog) materijala, konstruisane na osnovu tabele 2.



Sl. 1. *Dijagram granulometrijskog sastava ulaznog, doziranog materijala*

Na slici 2. prikazane su dvije krive granulometrijskog sastava ulaznog (dozirnog) materijala, i to ulazni (dozirni) materijal sa šakavcem (kriva crvene boje), i ulazni (dozirni) materijal bez šakavca (kriva plave boje). Promatrajući krivu granulometrijskog sastava ulaznog (dozirnog) materijala bez šakavca (kriva plave boje), uočljivo je da se kod pomenutog ulaznog (dozirnog) materijala javlja nedostak kamenog agregata u intervalu 60-120 mm.

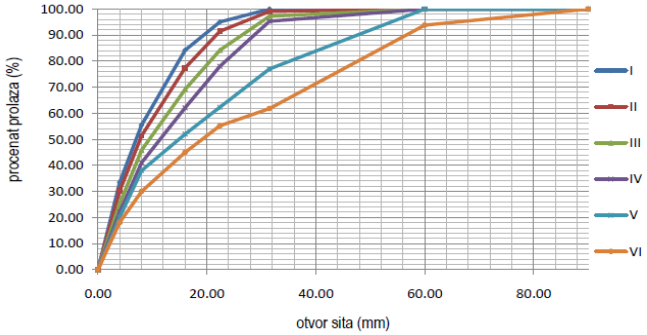
3.2. Zbirni prikaz rezultata granulometrijskih analiza +4 mm režim doziranja „A“

U tabeli 3. date su vrijednosti prolaza na sitima +4 mm za šest istraživanih varijanti rada udarno rotacione drobilice, režim doziranja „A“.

Tabela 3. *Vrijednosti prolaza materijala na sitima određenog otvora za šest istraživanih varijanti rada*

	OTVOR SITA (mm)						
VARIJANTA	4,00	8,00	16,00	22,40	31,50	60,00	90,00
I	33,50	55,50	84,20	95,00	100,00	100,00	100,00
II	30,20	51,40	77,40	91,50	99,10	100,00	100,00
III	25,40	45,80	69,20	84,20	97,20	100,00	100,00
IV	22,10	41,00	62,10	78,00	95,30	100,00	100,00
V	20,10	38,00	52,00	62,30	77,00	100,00	100,00
VI	18,10	30,00	45,00	55,20	61,80	93,80	100,00

Na slici 3. prikazane su krive granulometrijskog sastava dobijenog materijala +4 mm (procentualno učešće pojedinih frakcija) za šest istraživanih varijanti rada koje su konstruisane na osnovu tabele 3.)



Sl. 3. *Dijagram granulometrijskog sastava dobijenog materijala za šest istraživanih varijanti rada*

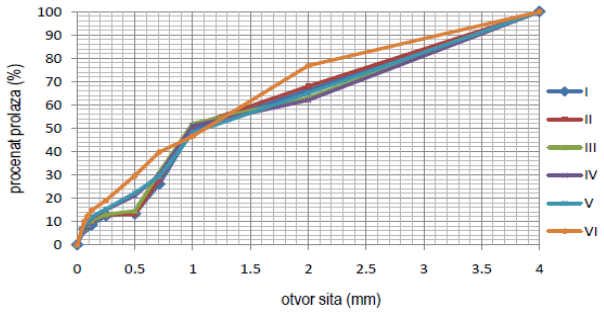
3.3. Zbirni prikaz rezultata granulometrijskih analiza za veličinu zrna 0/4 mm, režim doziranja „A“

U tabeli 4. date su vrijednosti prolaza na sitima -4 mm za šest istraživanih varijanti rada udarno rotacione drobilice, režim doziranja „A“.

Tabela 4. *Vrijednosti prolaza materijala na sitima određenog otvora pri šest varijanti rada*

	OTVOR SITA (mm)								
VARIJANTE	0.063	0.09	0.125	0.25	0.5	0.71	1	2	4
I	6.8	8.1	8.5	12.4	13.2	26	49.5	66.4	100
II	7.1	8.4	10.1	12.8	13.1	28	51	68	100
III	7	8.8	10.4	13	14.5	31	52	63	100
IV	7.2	9.2	11.5	15	21	30	51	62	100
V	8.5	9.8	12	15.3	22.2	29.3	48	65	100
VI	10	12.3	14.7	19	29.6	39.7	46.5	76.8	100

Na slici 4. prikazane su krive granulometrijskog sastava dobijenog materijala -4 mm (procentualno učešće pojedinih frakcija) za šest istraživanih varijanti rada koje su konstruisane na osnovu tabele 4.



Sl. 4. *Dijagram granulometrijskog sastava dobijenog materijala za šest istraživanih varijanti rada*

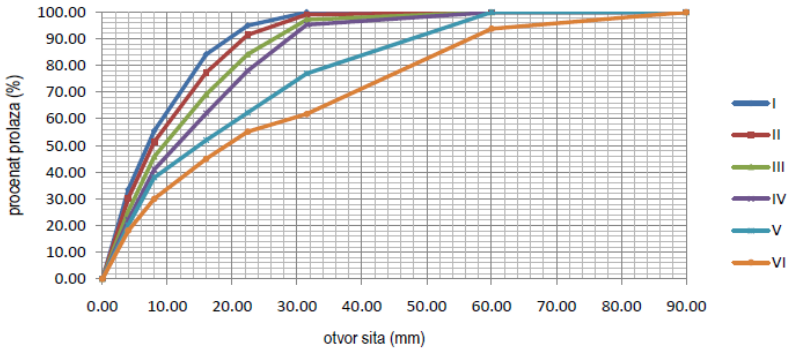
3.4. Zbirni prikaz rezultata granulometrijskih analiza 0/90 mm - režim doziranja „B“

U tabeli 5. date su vrijednosti prolaza na sitima +4 mm za šest istraživanih varijanti rada udarno rotacione drobilice, režim doziranja „B“.

Tabela 5. *Vrijednosti prolaza materijala na sitima određenog otvora pri šest varijanti rada*

	OTVOR SITA (mm)						
VARIJANTE	4.00	8.00	16.00	22.40	31.50	60.00	90.00
I	31.00	51.20	81.00	97.00	98.00	100.00	100.00
II	28.30	49.80	77.30	93.20	99.00	100.00	100.00
III	24.40	44.20	69.00	85.00	98.30	100.00	100.00
IV	21.00	39.80	67.80	79.20	97.00	100.00	100.00
V	19.20	37.10	51.80	63.00	78.40	98.00	100.00
VI	16.70	28.00	44.70	56.20	64.00	96.70	100.00

Na slici 5. prikazane su krive granulometrijskog sastava dobijenog materijala 0/90 mm (procentualno učešće pojedinih frakcija) za šest istraživanih varijanti rada koje su konstruisane na osnovu tabele 5., režim doziranja „B“



Sl. 5. *Dijagram granulometrijskog sastava dobijenog materijala za šest istraživanih varijanti rada*

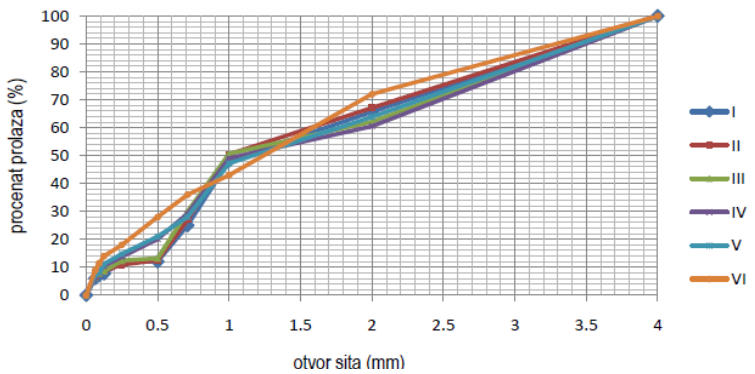
3.5. Zbirni prikaz rezultata granulometrijskih analiza 0/4 mm - režim doziranja „B“

U tabeli 6. date su vrednosti prolaza na sitima -4 mm za šest istraživanih varijanti rada, režim doziranja „B“.

Tabela 6. *Vrednosti prolaza materijala na sitima određenog otvora za šest istraživanih varijanti rada*

	OTVOR SITA (mm)								
VARIJANTE	0.063	0.09	0.125	0.25	0.5	0.71	1	2	4
I	6	7.1	7.7	11.9	12	25	48.1	65.7	100
II	6.8	7.5	8.7	10.9	12.5	27	50.5	67.1	100
III	6.4	7.9	8.6	12.4	13.2	29.9	50.6	62.1	100
IV	6.4	8.4	10.4	13.8	20.1	29.2	49	60.5	100
V	7.3	8	11.2	14.8	21	28	47.2	63.8	100
VI	9	11.4	14	18	28	36	43	72	100

Na slici 6. prikazane su krive granulometrijskog sastava dobijenog materijala -4 mm (procentualno učešće pojedinih frakcija) za šest istraživanih varijanti rada koje su konstruisane na osnovu tabele 6., i to za režim doziranja „B“.



Sl. 6. *Dijagram granulometrijskog sastava dobijenog materijala za šest istraživanih varijanti rada*

4. DISKUSIJA REZULTATA, IZBOR POVOLJNIH VARIJANTI RADA

Analizirajući tabelu 7. i sliku 6. može se zaključiti da se udarno rotaciona drobilica može efikasno koristiti u sekundarnom stepenu drobljenja kao završna drobillica pri proizvodnji tampona (kameni agregat 0-60 mm.), te pri proizvodnji kamenih agregata koji služe kao gradiva za spravljanje asfaltbetona i cementbetona.

Pri proizvodnji tržišno kategorisanog proizvoda tampon 0/60 mm. tj. kameni agregat 0/60 mm, karakteristično je da I, II, III i IV istraživana varijanta rada udarno rotacione drobilice tj. granulometrijski sastav dobijenog materijala pri tim varijantama rada udarno rotacione drobilice, se uklapa u pojas graničnih vrijednosti tampona 0/60 mm. – slika 6. i iste se mogu koristiti za dobijanje tampona 0/60 mm, pri čemu bi sa aspekta kapacitet bila najpovoljnija IV varijanta rada obzirom da se nalazi u pojasu gra-

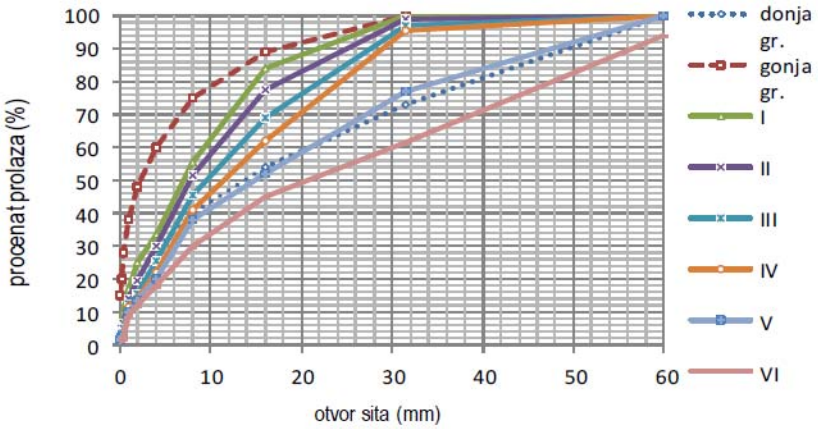
ničnih vrijednosti granulometrijskog sastava za tampon 0/60mm, a ima najveći kapacitet u odnosu navarijante rada koje se takođe nalaze u graničnom pojasu. V varijanta rada djelimično zadovoljava uslove granulometrijskog sastava tampona 0/60 mm, dok VI varijanta rada se gotovo u cjelosti nalazi van standardnih vrijednosti granulometrijskog sastava za tampon 0/60 mm.

Tabela 7. sadrži podatke standardnih graničnih vrijednosti prolaza na sitima za tampon 0/60 mm kao i vrijednosti prolaza na istim sitima kamenog materijala dobijenog pri šest istraživanih varijanti rada udarne drobilice, režim doziranja „A“.

Tabela 7. *Vrijednosti prolaza na situ (granične vrednosti) za tampon 0/60mm, za šest ispitivanih varijanti rada.*

			Varijanta rada (otvor drobilice Z_3(mm))					
otvor sita	donja gr.	gonja gr.	I	II	III	IV	V	VI
0,09	2	15	4,1	2,94	2,3	1,94	1,68	1,46
0,25	3	20	6,3	5	3,81	2,87	2,57	2,24
0,5	7	28	10	6,66	5,33	3,2	2,63	2,38
1	13	38	17,4	14,4	12,9	11,49	10,25	8,95
2	20	48	25	19,5	15,7	13,92	13,66	12,01
4	29	60	33,5	30,2	25,4	22,1	20,1	18,1
8	40	75	55,5	51,4	45,8	41	38	30
16	54	89	84,2	77,4	69,2	62,1	52	45
31,5	73	100	100	99,1	97,2	95,3	77	61,8
60	100	100	100	100	100	100	100	93,8

Na slici 7. prikazan je odnos krivih granulometrijskog sastava za šest istraživanih varijanti rada udarne drobilicei graničnih vrijednosti granulometrijskog sastava za tampon 0-60 mm.



Sl. 7. *Dijagram zavisnosti prolaza na situ gotovog proizvoda pri različitim varijantama rada udarne drobilice i graničnim krivimstandardnog granulometrijskog sastava tržišnog proizvoda tampona 0/60 mm*

5. ZAKLJUČCI

Na osnovu sprovedenih istraživanja koja su prezentovana u ovom radu i koja su data tekstualno, brojčano, tabelarno i grafički pomoću dijagrama, te utvrđenim zavisnostima i rezultatima istraživanja, nesporno je dokazano **da veličina zazora** sekundarne udarno rotacione drobilice **bitno utiče** na granulometrijski sastav kamenog agregata za potrebe tržišta.

Udarno rotaciona drobilica u sekundarnom stepenu drobljenja pri preradi krečnjaka predstavlja jedno od optimalnijih tehničkih rešenja pri odabiru opreme za realizaciju tehnološke šeme prerade krečnjačke stijenske mase obzirom na njene tehnološke mogućnosti .

Udarno rotaciona drobilica pri preradi krečnjaka omogućava proizvodnju agregata tehničkog kamena širokog spektra, različite strukture granulometrijskog sastava što u današnjim uslovima poslovanja predstavlja veoma bitan faktor rentabilnosti i uspješnosti poslovanja postrojenja za preradu tehničkog kamena.

Promjena varijante rada, tj promena veličine zazora na udarnim gredama sekundarne udarno rotacione drobilice pri preradi krečnjaka je relativno jednostavan i brz postupak imajući u vidu njene tehničke i konstrukcione karakterisike.

Promjena veličine zazora na udarno rotacionoj drobilici na vrijednosti koje su istraživane u predmetnom radu, omogućava se optimizacija procesa proizvodnje.

Za svaki trenutni zahtjev tržišta neophodno je izvršiti usporedbu tražene strukture i kapaciteta sa istraženim zavisnostima tj. podacima dobivenim za svaku varijantu rada, te na osnovu toga odabrati najpovoljniju varijantu rada udarne drobilice koja će davati strukturno najpribližnije vrijednosti u odnosu na zahtjev tržišta.

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ANALYSIS OF TECHNICAL-TECHNOLOGICAL PARAMETERS OF SECONDARY IMPACT ROTARY CRUSHER IN LIMESTONE PROCESSING

Abstract

This paper deals with the production of limestone at the stable plant separation of the open pit "Duboki potok-Bijela rijeka". Besides that, the effects of different levels of production and material flows were researched. Research was carried out in a fixed plant separation of the open pit limestone "Duboki potok-Bijela rijeka" in Duboki Potok. Positions of research were on the secondary part of separation (impact crusher, routers materials, funnels, rubber conveyors, vibrating screens, etc). In the course of using different methods of measuring material flow, calculating capacity conveyors, laboratory methods where used in measuring size and distribution obtained material, and particle shape.

The research results were reported in:

- *particle size distribution diagrams of the obtained aggregate stone with the best bands of particle size distribution*
- *defining the functional dependence of impact crusher gap size distribution and structure of the obtained materials.*

***Keyword**: crushing, impact crusher, grain-size distribution analysis, diagram dependency, clearance impact crusher, favorable variant of the impact crusher.*

1. INTRODUCTION

Crushing is the process of reduction the raw material for its direct use (mineral processing) for the concentration process, another aspect of technological treatment or use as the final product [1].

Besides the technological importance that is reflected in the reduction of grain size and liberation of minerals, crushing has significant economic importance. About 4.5 - 5% of the electricity produced in the world is spent on crushing. Crushing is a very expensive process. Crushing of raw material is 50-70% of the total investment and exploitation costs of facilities for the preparation and concentration. Therefore, it is important to perform the optimization processing of mineral raw materials, i.e. crushed minerals, to increase the percentage of the obtained results closer to the required conditions.

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1.1 The purpose of scientific research and problem definition

The aim of this paper is to exactly define the technical and technological parameters of the secondary impact crusher, which influenced the effects of crushing, to help with the lowering costs in the process of converting limestone, and in accordance with the requirements of the market solve the problem of obtaining high-quality finished aggregates corresponding grain size distribution in the percentage required by the market.

2. METHODOLOGY

The research was based on: setting the research methodology, analysis of the secondary impact rotary crusher, conducting experiments (harmonizing technical and technological parameters of the secondary impact crusher and presenting diagrams of particle size distribution of the obtained material.

Investigations are conducted over the site open pit "Duboki potok-Bijela rijeka", a plant for processing limestone at the location [3].

The research results are present in tables (numerical values of the structural grain size distribution of the obtained material at a given value of clearance secondary impact crusher) graphics (charts with the wrong size distribution of aggregates obtained at a given value of clearance of the secondary impact crusher).

Research model is structured by the type of research and set goal of research.

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

a) Laboratory tests of particle size distribution of materials,
b) Field "in situ" measurements of input and output parameters,
c) Processing of the obtained results.

2.1. Laboratory tests

The laboratory particle size distribution tests were carried out for two cases as follows:

1. Laboratory testing of the input size distribution (dosage) of material into the impact crusher,
2. Laboratory testing of particle size distribution of output (crushed) material from the impact crusher.

The sample was sieved on the sieves openings (mm): 31.5, 60, 90, 120, 200

Assays were done for two variants of particle size distribution dosing (input into the crusher) materials:

1. Dispense material into the impact crusher makes all the material from the jaw crusher 31.5 / 200 mm, which is below indicates: dosing regime : "A",
2. Dispense material into the impact crusher make material 31.5 / 60mm and 120/200 mm extracted from the jaw crusher. This dosing granulometry lacks grit 60/120 mm, which is set aside as a finished product, dosing regime "B".

Composition sifting dictate building standards and apply the following values sieve openings (mm) [2]: 0.063, 0.09, 0.25, 0.5, 0.71, 1.00, 4.00, 8.00, 16.00 , 31.5, 60.00, 90.00.

Different values of key parameters for the grain size distribution were set. Total of six different varieties, which are characterized by different sizes play in all three stator plate rebounding hammer impact crusher. When setting the size of the gap for different variants, account is taken of the operational values of this parameter unacceptable crusher.

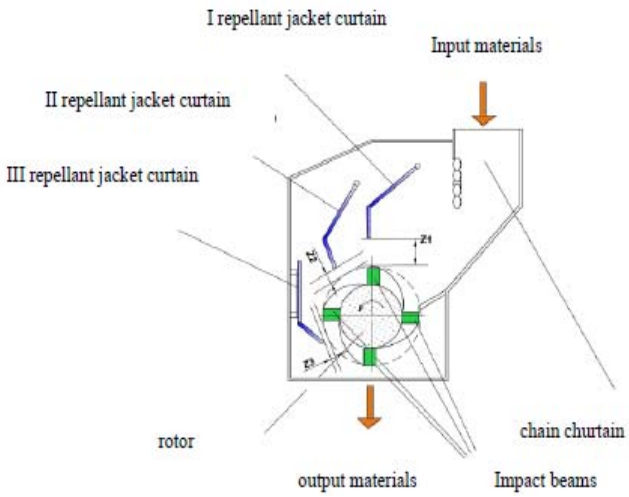

Fig. 1. *Scheme of impact crusher with four beams and three curtains os repulsive coating plates.*

Table 1 gives the values of gaps Z_1, Z_2 and Z_3 , for variants in which is analyzed the grain size distribution of crushed stone aggregate. For these variants in the given table, testing of structure the grain size distribution of the obtained material were carried out.

Table 1. *Parameters of crusher hole for the "in situ" research*

	clearance values for all three curtains		
variants	Z_1, (mm)	Z_2, (mm)	Z_3 ,(mm)
variant I	140	40	22
variant II	160	50	25
variant III	170	60	30
variant IV	180	70	40
variant V	190	80	50
variant VI	200	90	55

2.2. Field "in-situ" tests

The aforementioned studies, the following measurements or working procedures were done:

1. For measuring the input material impact crusher capacity and output material from the impact crusher with some variation work. 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

$$Q = q \cdot v \text{ (t/h)} \qquad (2.2.)$$

Where:

Q - volume (t / h)

q - weight material per meter of conveyor (t / m),

v - belt conveyor speed (m / h)

2. Crushing stone material to impact rotary crusher. In order to obtain the relevant samples for laboratory studies of plant separation, i.e. the crushing of stone material was done on impact rotary crusher in six different variants. Crushing in all six variants was conducted using two regimes of dosing-input material.

2.3. Processing the obtained data

Processing of the obtained data was done by numerical analysis using Microsoft Office Excel 2007. Results are generally present using tables and diagrams for their easier and clearly observing the dependence of research parameters.

3. RESEARCH RESULTS

The results of realized research are given numerically in tables, and at two different dosing regimes-input materials in the impact crusher. The results of particle size distribution of the obtained materials were studied in six different variants and the previously mentioned gaps repulsive lining impact crusher.

3.1. Grain size distribution of the feed, dosage, material in the secondary crusher

The results of research were tabulated as the arithmetic mean of a series of nine independent measurements and as such are presented numerically in the following form provided:

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

where:

X - mean measurement;

x_1 - x_2, x_3 ..... x_n - individual measurements

n - number of measurements.

Table 2 presents the grain size distribution of the feed material in the impact crusher with percentages of the average sieve openings that are given in the table for both the above regimes. It is notable that the structure of the input material without medium grit stone aggregate 60/120 mm is significantly different.

Table 2. *Structures of grain size distribution of dosage-input material for the dosing regimes "A" and "B"*

Sieve size, (mm)	31,5	60,0	90,0	120,0	200,0
Input material without stone aggregate 60/120 mm in the input (%)	15,7	39,4	39,4	39,40	100,0
Incoming material with stone aggregate 60/120 mm in the input (%)	13,9	37,4	59,1	68,80	100,0

Figure 1 shows the particle size distribution curve input (dosage) material, constructed on the basis of Table 2.

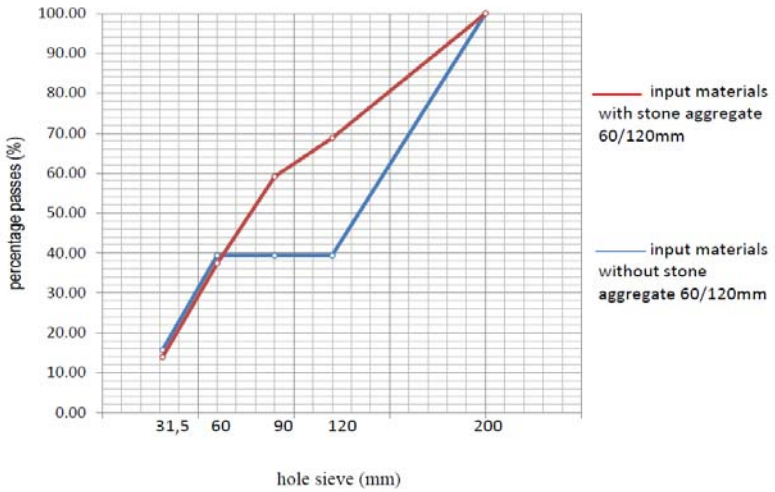

Fig. 1. *Diagram of grain size distribution of input, dosing material*

Figure 2 shows two curves of particle size distribution input (dosage) of materials, and input (dosing) material with aggregate (red curve), and input (dosing) material without aggregate 60-120 mm. (blue curve). Observing wrong grain size distribution of input (dosage) material without aggregate 60-120 mm (blue curve), it is notable that the aforementioned input (dosage) of material disadvantage occurs stone aggregate in the range 60-120 mm.

3.2. Cumulative review the results of grain size distribution analyses +4 mm dosing "A"

Table 3 values are given passes to +4 mm sieves for the six investigated variants of the impact crusher, dosage regime "A".

Table 3. *Values of the material passes the sieve openings for certain varieties of six research variant work*

	SIEV SIZE (mm)						
VARIANTS	4.00	8.00	16.00	22.40	31.50	60.00	90.00
I	33.50	55.50	84.20	95.00	100.00	100.00	100.00
II	30.20	51.40	77.40	91.50	99.10	100.00	100.00
III	25.40	45.80	69.20	84.20	97.20	100.00	100.00
IV	22.10	41.00	62.10	78.00	95.30	100.00	100.00
V	20.10	38.00	52.00	62.30	77.00	100.00	100.00
VI	18.10	30.00	45.00	55.20	61.80	93.80	100.00

Figure 3 shows the particle size distribution curves obtained material +4mm (proportional share individual fraction) for the six investigated variants of which were derived from Table 3.

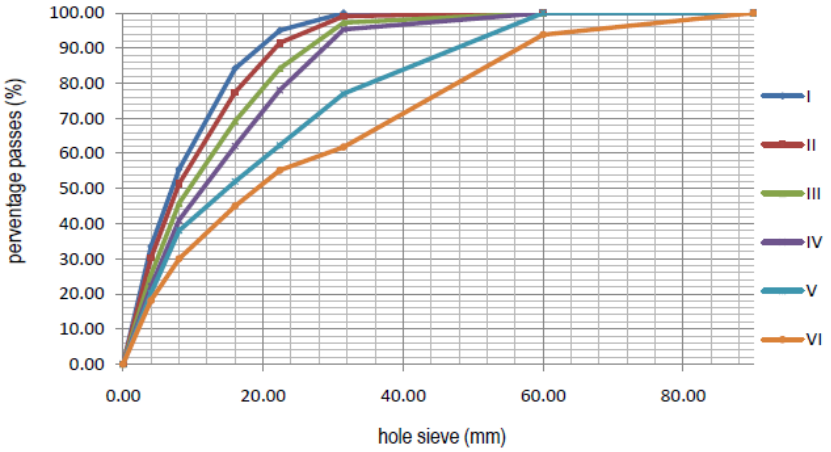

Fig. 3. *Diagram of particle size distribution obtained material for the six investigated variants of work*

3.3. Summary of analysis results for grain size 0/4 mm, dosing regime: "A"

In Table 4 values are given passes on screens for six -4 mm investigated variants of the impact crusher, dosage regimen "A".

Table 4. *The values of the material passes the sieve openings specified in six variants of sieve size (mm)*

	SIEVE SIZE (mm)								
VARIANTS	0.063	0.09	0.125	0.25	0.5	0.71	1	2	4
I	6.8	8.1	8.5	12.4	13.2	26	49.5	66.4	100
II	7.1	8.4	10.1	12.8	13.1	28	51	68	100
III	7	8.8	10.4	13	14.5	31	52	63	100
IV	7.2	9.2	11.5	15	21	30	51	62	100
V	8.5	9.8	12	15.3	22.2	29.3	48	65	100
VI	10	12.3	14.7	19	29.6	39.7	46.5	76.8	100

Figure 4 shows the particle size distribution curves obtained material -4 mm (proportional share individual fraction) for the six investigated variants of which were derived from Table 4.

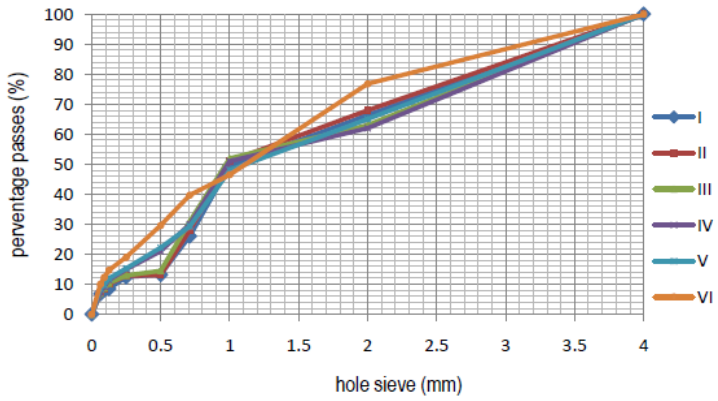

Fig. 4. *Diagram of particle size distribution obtained material for the six investigated variants of work*

3.4. Summary of analysis results of grain size 0/90 mm, dosing regime "B"

In Table 5 values are given passes to +4 mm sieves for the six investigated variants of the impact crusher, dosage regimen "B".

Table 5. *Values of the material passes the sieve openings specified in six variants of work*

	SIEVE SIZE (mm)						
VARIANTS	4.00	8.00	16.00	22.40	31.50	60.00	90.00
I	31.00	51.20	81.00	97.00	98.00	100.00	100.00
II	28.30	49.80	77.30	93.20	99.00	100.00	100.00
III	24.40	44.20	69.00	85.00	98.30	100.00	100.00
IV	21.00	39.80	67.80	79.20	97.00	100.00	100.00
V	19.20	37.10	51.80	63.00	78.40	98.00	100.00
VI	16.70	28.00	44.70	56.20	64.00	96.70	100.00

In Figure 5 shows the particle size distribution curves obtained material 0/90mm (percentage participation of each fraction) for the six investigated variants of which were derived from table 5, the dosage regimen "B".

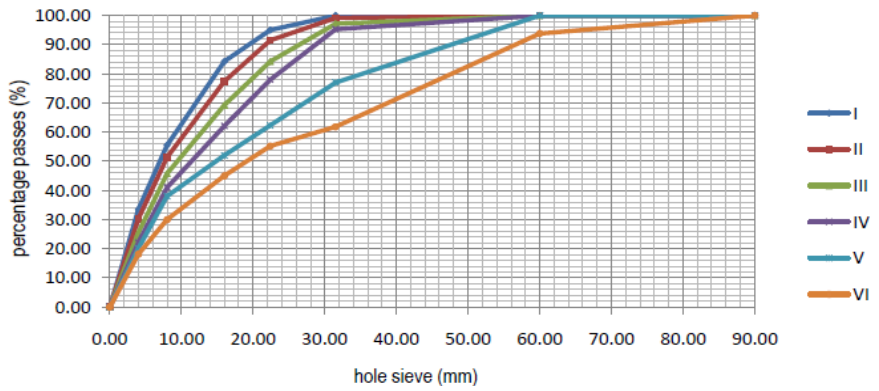

Fig. 5. *Diagram of particle size distribution obtained material for the six investigated variants of work*

3.5. Summary of analysis results of grain size 0/4 mm – dosing regime "B"

In Table 6 values are given passes on screens for six -4 mm investigated variants work, dosage regimen "B".

Table 6. *Values of the material passes the sieve openings specified for the six investigated variants of work*

	SIEVE SIZE (mm)								
VARIANTS	0.063	0.09	0.125	0.25	0.5	0.71	1	2	4
I	6	7.1	7.7	11.9	12	25	48.1	65.7	100
II	6.8	7.5	8.7	10.9	12.5	27	50.5	67.1	100
III	6.4	7.9	8.6	12.4	13.2	29.9	50.6	62.1	100
IV	6.4	8.4	10.4	13.8	20.1	29.2	49	60.5	100
V	7.3	8	11.2	14.8	21	28	47.2	63.8	100
VI	9	11.4	14	18	28	36	43	72	100

Figure 6 shows the particle size distribution curves obtained material -4 mm (percentage participation of each fraction) for the six investigated variants which were derived from Table 6 for the dosing regimen "B".

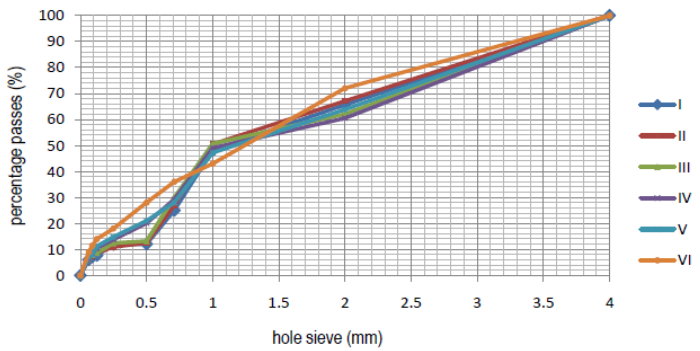

Fig. 6. *Diagram of the particle size distribution obtained material for the six investigated variants of work*

4. DISCUSSION OF RESULTS, CHOICE OF FAVORABLE VARIETIES OF OPERATION

Analyzing Table 7 and Figure 6, it can be concluded that the impact crusher can be used effectively in the secondary level as a final crushing the manufacture of tampons (stone aggregate 0-60 mm.), and the production of aggregates which serve as material for making asphalt concrete and cement concrete.

In the production of the product market categorized buffer 0/60 mm, i.e. stone aggregate 0/60mm, a characteristic that I, II, III and IV trials variants of the impact crusher that granulation of the material obtained in the variants of the impact crusher, belt fits the limits of tampons 0/60 mm. - Figure 6 and they may be used for obtaining tampons 0/60 mm, whereby the aspect of capacity was the best version of IV since it is in the zone limits of particle size distribution for the buffer 0/60 mm, and has the largest capacity in relation to the variations of which are also located in the border zone. V variant of partially satisfies the conditions of particle size distribution 0/60 mm tampons while you work variant is almost entirely located outside the standard value for the buffer size distribution 0/60 mm.

Table 7 contains data standard limits the passage of sieves to buffer 0/60 mm as well as the passage of the same sieves stone material obtained at six investigated variants of impact crushers, dosage regimen "A".

Table 7. *Passages in situ values (limits) for buffer 0/60 mm, for the six variants work*

hole sieve (mm)	lower limit	upper limit	Variant work (hole crusher Z_3 (mm))					
			I	II	III	IV	V	VI
0,09	2	15	4,1	2,94	2,3	1,94	1,68	1,46
0,25	3	20	6,3	5	3,81	2,87	2,57	2,24
0,5	7	28	10	6,66	5,33	3,2	2,63	2,38
1	13	38	17,4	14,4	12,9	11,49	10,25	8,95
2	20	48	25	19,5	15,7	13,92	13,66	12,01
4	29	60	33,5	30,2	25,4	22,1	20,1	18,1
8	40	75	55,5	51,4	45,8	41	38	30
16	54	89	84,2	77,4	69,2	62,1	52	45
31,5	73	100	100	99,1	97,2	95,3	77	61,8
60	100	100	100	100	100	100	100	93,8

Figure 7 indicates the relationship between particle size distribution curves for the six investigated variants of shock crusher limits of particle size distribution for the buffer 0-60 mm.

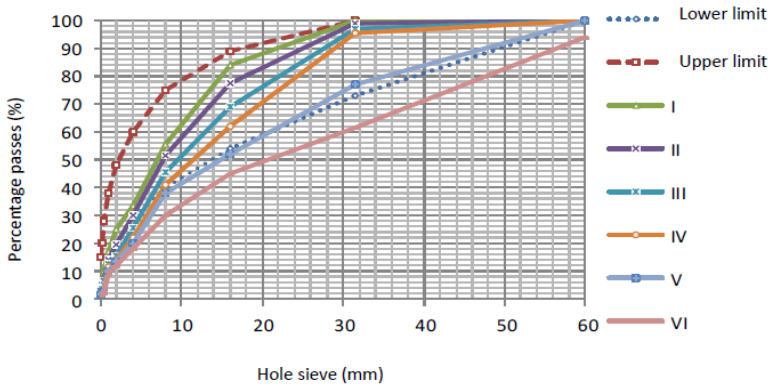

Fig. 7. *Diagram of passages in situ of the finished product at different variants of impact crusher and border size distribution of the product market tampons 0/60 mm*

5. CONCLUSIONS

Based on the conducted research are presented in this paper and are given a textual, numeric, tabular and graphical diagrams using, and set dependencies and research, has proven beyond doubt that the size of the gap secondary impact crusher significantly affects the grain size distribution of mineral aggregates for markets.

Hammer crusher in the secondary level in the limestone crushing is one of the optimal technical solutions in selecting equipment for the implementation of technological schemes of processing limestone rock mass due to its technological capabilities.

Hammer crusher in limestone processing allows the production of technical stone aggregates a wide spectrum of different structures in the particle size distribution business today is a very important factor in profitability and business performance processing plant technical stone.

Change of variants, resizing clearance on impact beams play in striking beams of secondary impact crusher in limestone processing is relatively simple and rapid procedure taking into account its technical and structural key advantages of it.

Change the size of the play in the rotary hammer crusher values, researched in the present work, allows the optimization of the production process.

For each current market demand it is necessary to compare the structure and the required capacity with dependencies explored with data ,obtained for each variants work, and based on selected the best variant of impact crusher that will give structurally closest value relative to themarket demand.

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Mirko Ivković, Mile Bugarin***

TEHNIČKO REŠENJE PODGRAĐIVANJA RUDARSKE PROSTORIJE U SLOŽENIM GEOTEHNIČKIM USLOVIMA

Izvod

U radu je prikazano tehničko rešenje podgrađivanja deonice rudarske prostorije „prekop k+45“, u jami „Strmosten“ Rudnika mrkog uglja „Rembas“, izrađene u nepovoljnoj sredini sa stanovišta osiguranja i podgrađivanja.

Tehničko rešenje rekonstrukcije zasnovano je na kombinovanom podgrađivanju prskanim betonom čeličnim okvirima i livenoj betonskoj oblozi.

Ključne reči: *rudnik, ugalj, rudarska prostorija, podgrađivanje*

1. UVOD

Podgrađivanje podzemnih rudarskih prostorija u radnoj sredini koja se kategoriše kao teška sa geotehničkog stanovišta je izuzetno složen zadatak. Svaka izrađena rudarska prostorija u jami treba da zadrži svoju funkcionalnost za predviđeni vek korišćenja, uz što manje troškove održavanja i rekonstrukcije.

Podgrada prostorije prima opterećenje okolnog masiva tako da kod pojačanih jamskih pritisaka nastupaju deformacije podgrade i suženja profila prostorije, koje ponekad može dovesti i do potpunog zatvarnja. Da bi se izbegle ove pojave vrše se rekonstrukcije prostorija, koje su sa tehničkog stanovišta teške i nesigurne, a sa ekonomskog stanovišta skupe, gotovo kao sama izrada.

Uzevši u obzir navedeno već kod projektovanja tehnologije rada, a kasnije kod izrade prostorija nastoji se izabrati takav sistem podgrađivanja i osiguranja kojim će se obezbediti stabilnost podgrade i funkcionalnost profila prostorije.

Poseban problem u rudarskoj praksi je izrada prostorija u glinovitim naslagama sa pojavama vode, kada usled izraženog svojstva bubrenja glina dolazi do pojačanog pritiska na podgradu. U takvim uslovima podgrada sa drvenim okvirima je krajnje nefunkcionalna a sa čeličnim okvirima takođe može biti neadekvatna za duži period korišćenja prostorije. U pojedinim slučajevima čak i kombinacija čelične podgrade i livenog betona je imala izražene deformacije, te se moraju tražiti i specifična rešenja.

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Jedno od takvih rešenja je i podgrađivanje denice prekopa k+45 u jami „Strmosten“ RMU „Rembas“-Resavica.

2. OSNOVNI PODACI O PREDMETNOJ RUDARSKOJ PROSTORIJI

Rudarska prostorija prekop +45 m izrađena u jami „Strmosten“ predstavlja kapitalnu rudarsku prostoriju, namenjenu za izvođenje glavne jamske vazdušne struje i dopremu repromaterijala po donjoj pruzi vagonetima sa lokomotivskom vučom.

Prostorija je izrađena na dubini od oko 400m ispod površine terena, pri čemu je dužina prostorije 1150 m, od čega je 750 m urađeno u krečnjačkim stenama, a 400 m kroz sivi i crveni peščar sa umetcima gline. Prostorija je izrađena klasičnom bušačko-minerskoj tehnologijom sa podgrađivanjem čeličnom lučnom podgradom od RI-profila na razmaku 1,0 m i zalaganjem sa rezanom hrastovom daskom. Nakon izrade prostorija je više puta rekonstruisana na deonicama u sivom i crvenom peščaru, pri čemu su ugrađeni čelični okviri od ojačanog zvonastog profila sa smanjenim razmakom podgrađenih okvira od 0,8 do 0,4 m.

I pored izmenjenog načina podgrađivanja nastupale su deformacije te je periodično vršena rekonstrukcija, a da bi se ovo izbeglo dato je novo tehničko rešenje podgrađivanja ugrožene deonice prostorije prekopa k+45 m.

Ovo tehničko rešenje zasniva se na rekonstrukciji prostorije u dužini od 400 m i ugradnji stalne podgrade (armirano-betonska obloga).

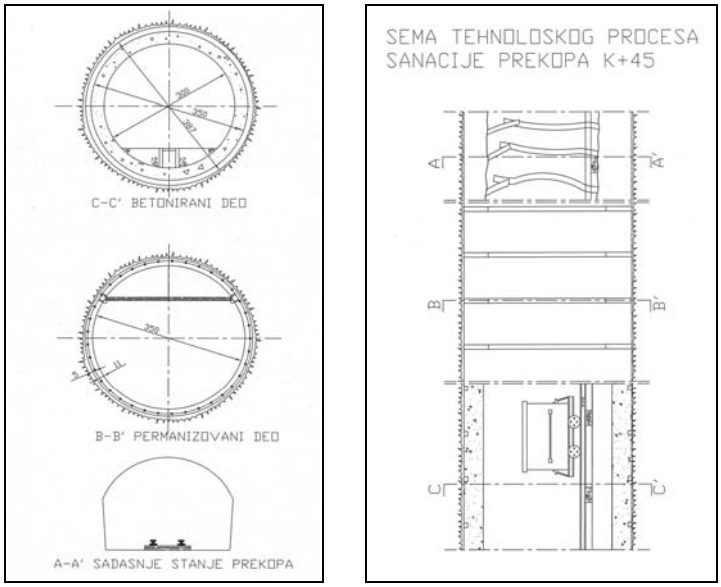
3. TEHNIČKO REŠENJE PODGRAĐIVANJA

Tehničko rešenje osiguranja i podgrađivanja deonice prostorije prekop k+45m zasniva se na realiz

aciji sledećih radova:

- rekonstrukcija, i
- podgrađivanje sa definitivnom betonskom oblogom

Na slici 1. dat je izgled deformisanog profila pre rekonstrukcije (manje od 4 mm^2) i šema procesa sanacije odnosno rekonstrukcije.



Sl.1.

Rekonstrukcija prostorije vrši se putem sledećih radnih operacija: vađenje deformisane podgrade, obrada profila do projektovane veličine, utovar iskopanog materijala, privremeno podgrađivanje i odvodnjavanje.

Izrada profila prostorije sastoji se u skidanju materijala iz stropa, pouzimanja bokova i podine sa ručnim rudarskim alatom i otkopnim čekićima, a u težim slučajevima i miniranjem. Utovar iskopa-nog materijala vrši se ručno i sa uto-varnom lopatom u jamske vagonete, koji se odvoze lokomotivom do glavne izvozne prostorije. Ove radove prati ugradnja privremenog koloseka i pomoćne preno-sne skretnice.

Nakon dovođenja profila prostorije u projektovano stanje, u cilju osiguranja iskopa i zadržavanja profila prostorije pre izrade definitivne armirano-betonske obloge, izrađuje se obloga od prskanog betona u dva sloja debljine 5 cm. Prskanje se izvodi sukcesivno sa radovima rekonstrukcije pri čemu dužina kampade koja se prska iznosi 1,0 m, a ono omogućava da se rad obavlja kontinuirano bez zastoja celom dužinom kampade.

Prskani beton ravnomerno se nanosi na obrađeni profil i na taj način obrazuje oblogu koja već nakon par sati posle nanošenja dostiže čvrstoću od 0,8 N/cm^2, što omogućava rad na podgrađivanju čeličnom podgradom. Čvrstoća prskanog betona dostiže i do 60 N/cm^2 a otpornost na zatezanje 5-15 N/cm^2.

Formiranje sloja prskanog betona vrši se stalnim udarcima zrnaca agregata iz mlaznice, te je nabijanje od sloja do sloja ravnomerno. U ovom slučaju, pošto je predviđen nabijanje dva sloja, upotrebljava se dodatak za brzo vezivanje prskanog betona. Za ugradnju prskanog betona od opreme se koristi pumpa za beton, mešalica za beton i priključci sa mlaznicom na komprimirani vazduh.

Na sveže ugrađeni prskani beton u dužini prostorije od 1,0 m postavlja se spoljna armaturna mreža Q 283, a onda montira okvir čelične podgrade prečnika 3,5 m po zadatim elementima.

S obzirom da je u prostoriji koja se rekonstruiše prisutna tekuća voda to se odvodnjavanje vrši tako što se u nekonstruisanom delu izradi privremeni vodosabirnik iz koga se voda pumpom izbacuje u vodosabirni kanal u rekonstruisanoj deonici.

Sama izrada deformisane podgrade od armirane betonske obloge vrši se sledećim radnim operacijama:

- postavljanje unutrašnje armaturne mreže Q 283,
- postavljanje i centriranje klizne oplate,
- spravljanje i ugradnja betonske mešavine u oblogu prostorije

S obzirom da je prečnik čeličnih lukova 3,5 m i da je svetli profil prostorije 3,0 m to debljina betonske obloge iznosi d=28 cm.

Betoniranje se vrši u kampadama dužine 4,0 m po fazama, na sledeći način:

- U prvoj fazi betoniraju se stope u dužini 8-12 m. Postavljanje oplate za betoniranje stopa vrši se uz strogu geodetsku kontrolu tako da se nakon betoniranja stopa dobiju površine koje prate nagib prostorije i koje služe kao oslonac za centriranje remenata za betoniranje gornjeg i podnožnog svoda potkopa.
- U drugoj fazi doprema se oplata i centrira na izbetonirane stope i betoniraju se bokovi i kalota kroz otvore na oplati.
- U trećoj fazi betonira se podnožni svod.
- U četvrtoj fazi betonira se kanal za vodu.

Spravljanje i ugradnja betona vrši se pomoću pneumatske kontinualne mašine za spravljanje i ugradnju betona, takozvanog „Spirokreta“.

Po završetku betonskih radova na podnožnom svodu i izrade kanala preostali

slobodni profil se nasipa tucanikom nakon čega se pristupa polaganju stalnog šinskog koloseka, pri čemu osovina koloseka prati podužnu osovinu prekopa.

4. ZAKLJUČAK

Po obrađenom tehničkom rešenju izvršena je rekonstrukcija i podgrađivanje deonice prostorije prekopa k+45 m u dužini od 400 m.

Praćenjem ponašanja prostorije nakon izvršenih radova nisu primećene deformacije podgrade i smanjenje profila, te se zaključuje da je dato rešenje adekvatno uslovima radne sredine.

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Mirko Ivkovic[*], *Mile Bugarin*[**]

TECHNICAL SOLUTION OF SUPPORTING THE MINING FACILITIES IN THE COMPLEX GEOTECHNICAL CONDITIONS

Abstract

This paper describes the technical solution of supporting a part of mining facility "dig κ+45", in the pit "Strmosten" of the Brown Coal Mine "Rembas", made in unfavorable area from the standpoint of security and supporting.

Technical solution of the reconstruction is based on the combined supporting using the sprayed concrete with steel frames and cast concrete lining.

Keywords: *mine, coal, mining room, supporting*

1. INTRODUCTION

Supporting the underground mining facilities in the workplace, categorized as difficult from the geotechnical point of view, is an extremely complex task. Each constructed mining facility in the pit has to retain its functionality for intended service life with the least costs of maintenance and reconstruction.

The support of facility receives the load of surrounding massive such as, under increased pit pressures, the support deformations occur and narrowing of facility profile, which can sometimes lead to a complete closing. To avoid this problem, the reconstruction of facilities is done, which are difficult from a technical standpoint and unsafe, and costly from an economic standpoint, almost like the construction.

Taking into account the above given, in the design of operation technology, and later in making facilities, it is tried to choose a system of supporting and security that will secure the stability of support and functionality of the facility profile.

A particular problem in mining practice is making the facilities in the clay layers with the occurrences of water and due to the pronounced swelling properties of clay, the increased pressure is on a support. In such conditions, the support with wooden frames is extremely dysfunctional and with steel frames it can also be inadequate for long-term use of facility. In some cases even a combination of steel support and cast concrete supports the pronounced deformations, and the specific solutions have to be looked for.

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One of these technical solutions is supporting a part of mining facility “dig κ+45“, in the pit "Strmosten" of the Brown Coal Mine "Rembas"- Resavica.

2. BASIC DATA ON THE SUBJECT OF MINING FACILITY

The mining facility “dig κ+45“, made in the pit "Strmosten", is a capital mining room intended to perform the main pit airflow and delivery of raw materials on lower rail with locomotive-drawn wagons.

The room was made at depth of about 400 m below the surface, where the length of room is 1150 m, out of which 750 m was done in the limestone rocks, and 400m through gray and red sandstone with clay inserts. The room was made using the classic drilling-blasting technology with supporting of steel arched supports of the RI-profiles at distance of 1.0 m and with the carved oak plank. After construction, the room was many times reconstructed on sections in gray and red sandstone, with built steel frames of reinforced bell profiles with reduced distance of supported frames of 0.8 to 0.4 m.

Although the support was changed, the deformations occurred and the reconstruction was periodically performed, and to avoid this, a new technical solution of supporting was given for threatened section of the dig k +45 m room.

This technical solution is based on the room reconstruction with length of 400 m and installation the permanent support (reinforced concrete lining).

3. TECHNICAL SOLUTION OF SUPPORTING

Technical solution of security and supporting a part of the dig k+45 m room is based on the realization of the following works:

- reconstruction, and
- supporting and with a definite concrete lining

Figure 1 gives a view of deformed profile before reconstruction (less than 4mm^2) and scheme of the rehabilitation and reconstruction process.

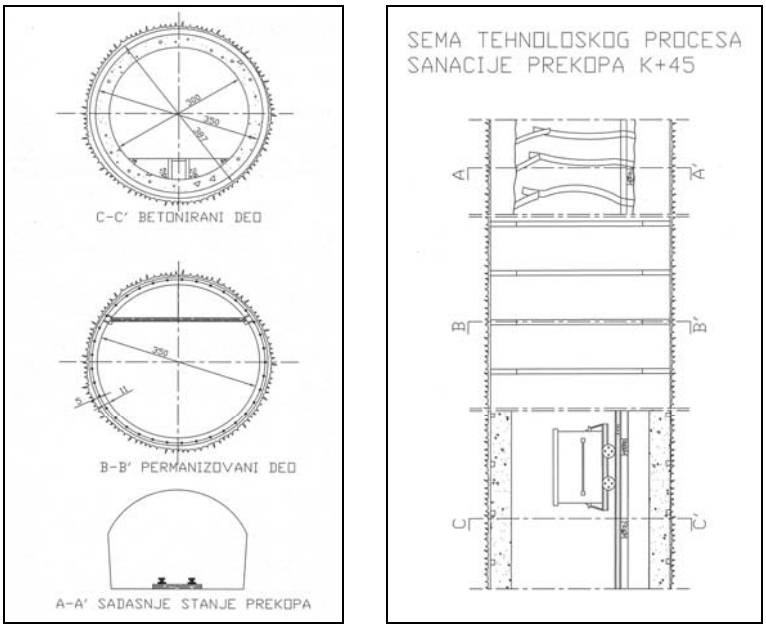

Fig. 1.

Reconstruction of the room is done through the following working operations: the extraction of deformed support, processing of profile to the designed size, loading of excavated material, and temporary supporting and dewatering.

Development of the room profile consists of material removal the ceiling, taking the sides and footwall with hand mining tools and excavation hammers and, in severe cases, by blasting. Loading of excavated material is carried out manually with a loading shovel into the pit wagons, which are transported by locomotive to the main export facilities. These works are followed by the installation of temporary tracks and auxiliary transmission switch.

After bringing the room profile in designed state, to ensure the excavation and retaining the room profile before development the final reinforced concrete lining, the lining is made of sprayed concrete in two layers, thickness of 5cm. Spraying is carried out successively with reconstruction works in which the sprayed section length is 1.0 m, and it allows continuous work without interruption along the whole section length.

Sprayed concrete is applied equally to the processed profile and thus form a coating that within a few hours after application reaches strength of 0.8 N/cm^2, allowing the supporting with steel support. The strength of sprayed concrete reaches up to 60 N/cm^2 and tensile strength of 5-15 N/cm^2.

Formation of sprayed concrete layer is carried out by permanent shocks of aggregate grains from nozzle, and the compaction of the layer to layer is equal. In this case, as compaction of two layers is predicted, the addition for quick bonding of sprayed concrete is used. Concrete pump, concrete mixer and connections with nozzle on compressed air are used for sprayed concrete.

On fresh installed sprayed concrete in room length of 1.0 m, the outer armature network Q 283 is set, and then the frame of steel support, diameter 3.5 m, is installed with the specified elements.

Since the liquid water is present in the room under reconstruction, drainage is done by construction a temporary water collector in unconstructed part from which water is discharged with pump into a water collector channel in the reconstructed section.

Development the deformed support of reinforced concrete lining is carried out by the following operations:

- Installation the internal armature network Q 283,
- Installation and alignment of slide plating,
- Preparation and installation of concrete mixture into the room lining.

Since diameter of steel arches is 3.5 m and light profile of the room is 3.0 m, then the concrete lining thickness is d = 28 cm.

Concreting is done in sections, length of 4.0 m in stages, as follows:

- In the first stage, the feet are concreted in length 8-12m. Setting of formwork for feet concreting is carried out with strict geodetic control so that the surfaces are obtained that follow the slope of the room and serve as a support for centering for concreting the top and invert arch of a dig.
- In the second stage, the formwork is delivered and centered on concreted feet and the blocks and spherical sections through the openings in the formwork.
- In the third stage, the foot arch is concreted.
- In the fourth stage, the channel for water is concreted.

Preparation and installation of concrete is done using the pneumatic continuous machines for making and installation of concrete, so-called "Spirokreta".

Upon completion of concrete works at the foot arch and development of the channel, the remaining free profile is filled

with gravel after which the permanent rail tracks are set, where the track axle follows the longitudinal axis of digs.

4. CONCLUSION

After processed technical solution, the reconstruction and supporting of a part the dig k+45 m room in length of 400m were done.

Observing the room behavior after carried out works did not point out support deformations and profile reduction, and it is concluded that the given solution is adequate to the conditions of working environment.

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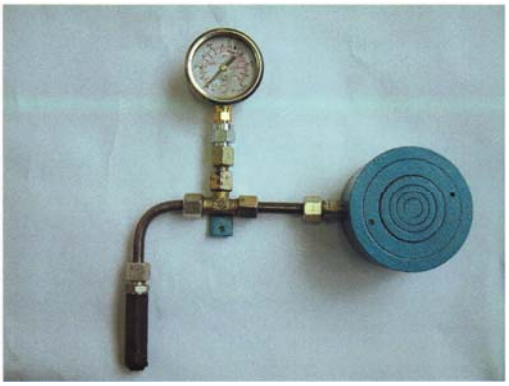

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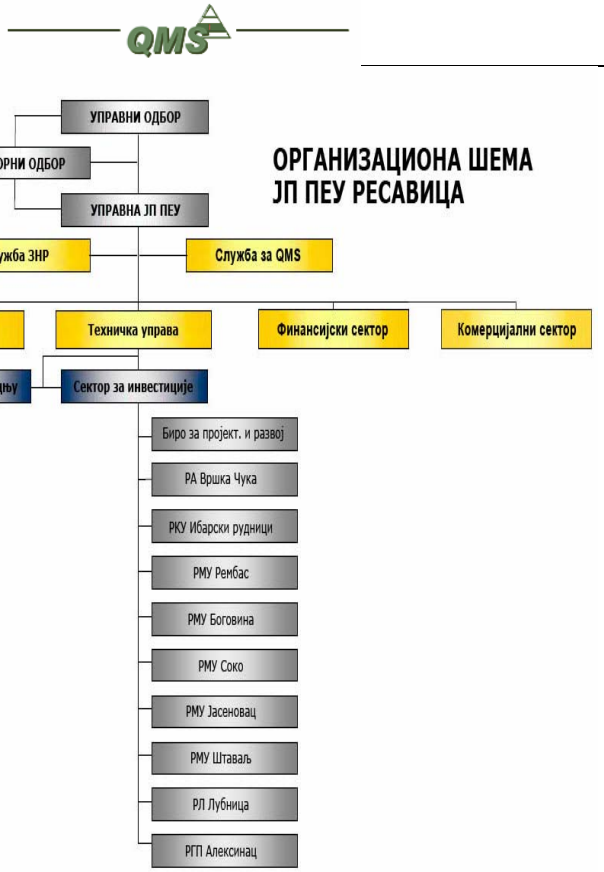

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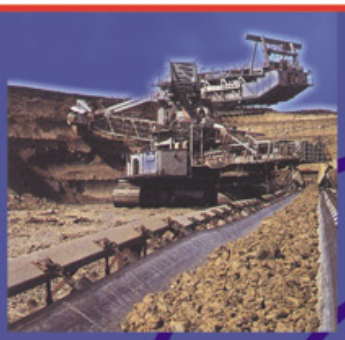

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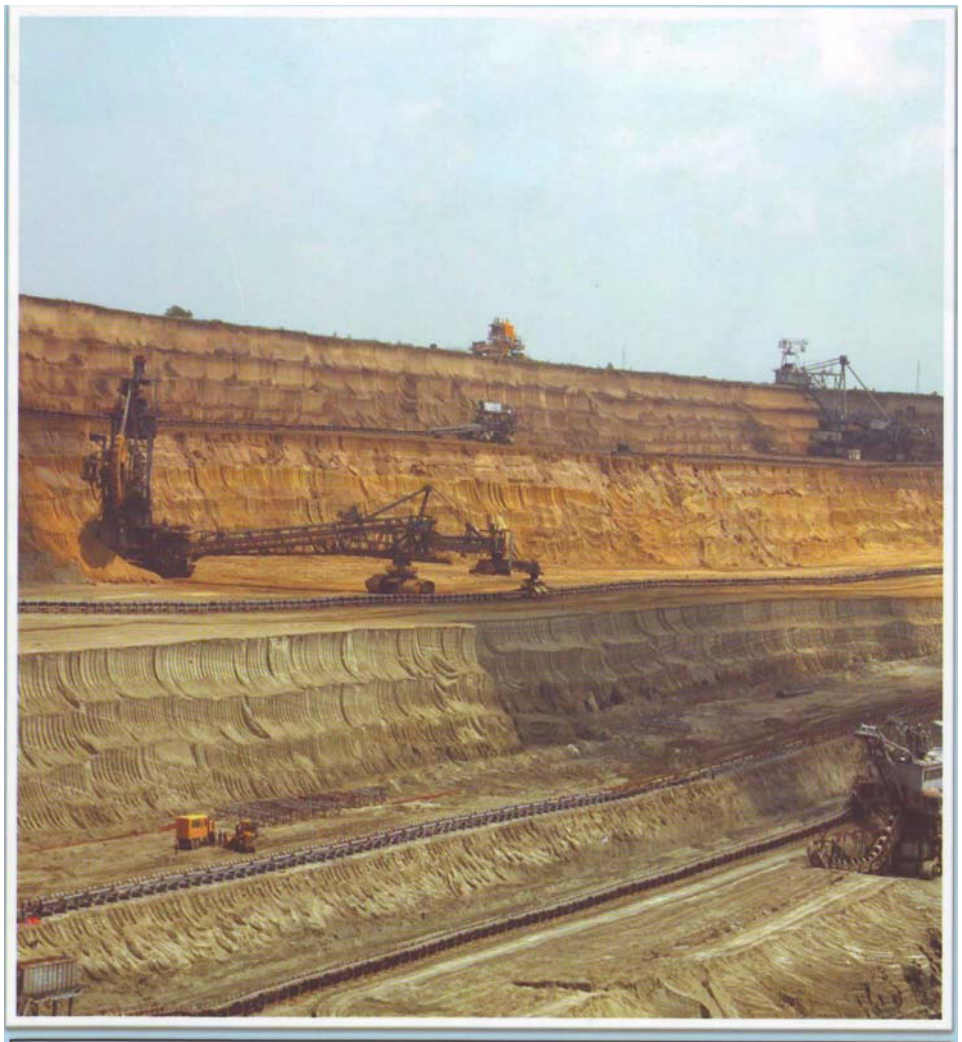

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