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CONTENS

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Dragan Ignjatović[*], Lidija Đurđevac Ignjatović[*], Milenko Ljubojev[*], Ivan Ivanov[**]

TESTING THE CARRYING CAPACITY OF ANCHOR IN THE ORE BODY "T1"[***]

Abstract

In order to secure the underground stope in the ore body, "T1", the supporting of excavated area is carried out. The supporting, in this case, is carried out by means of anchors of type SWELLEX and SN, M-20 in a combination with the resin LOKSET RESIN CAPSULES, and reinforcement mesh, which is applied with the layer of torkret concrete.

This work presents the results of testing the carrying capacity of anchors in a given ore body "T1"

Keywords: *excavated area, anchor, anchor carrying capacity, pull-out force*

1 INTRODUCTION

During underground mining, parallel with the ore exploitation, the supporting of excavated area is carried out. Supporting is carried out by means of anchors of type SWELLEX and SN, M-20 in a combination with the resin LOKSET RESIN CAPSULES. Supporting is preceded by drilling of boreholes for installation of anchors. Drilling is done using the drilling equipment BOOMER 282. Hole diameter is ∅ 33 mm.

After installation of anchors, their strain is performed, then the reinforcement mesh is installed and torkret concrete is applied.

After all above actions, testing of carrying capacity of anchors is carried out on a pull-out force using a hydraulic pump. Testing of carrying capacity of anchors is carried out according to the recommendations of the International Society for Rock Mechanics (ISRM).

In addition to the pull-out force, displacements of anchor head are also carried out. Pull-out force is applied gradually to achieve the set (working) or limit pull-out force.

The results of testing the carrying capacity of anchors are presented by graphic diagrams of movements in the function of pull-out force.

1.1 Analysis of test results

Measurements were performed twice (20.11.2013 and 23.01.2014) on 6 anchors, which are built on the specific places in the ore body T1.

Figures 1.1 a, b and c show a view of anchor testing in the ore body T1.

[*] *Mining and Metallurgy Institute Bor*
[**] *RBB "Jama" Bor*

[***] *This work is the results of the Project No. 33021 "Research and Monitoring the Changes of Stress Strain State of the Rock Mass "IN SITU" Around the Underground Rooms with Development of Model with the Special Reference to the Tunnel of the Krivelj River and the Underground Mine "Jama" Bor" funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia.*

a)

b)

c)

Figure 1.1 *a), b) and c) Testing of anchors - determining the pull-out force*

Table 1.1 gives the values of displacement in a function of pull-out force for tested anchors.

Table 1.1 *The values of displacement (Δl, [mm]) in the function of pull-out force – carrying capacity (F, [kN])*

Anchor – testing place					
Test 1, room side K-145		**Test 2, right side K-145**		**Test3, left side, K-145**	
Δl, [mm]	**F, [kN]**	**Δl, [mm]**	**F, [kN]**	**Δl, [mm]**	**F, [kN]**
4.30	18.64	7.00	18.64	1.00	9.32
8.80	46.60	-	-	2.60	18.64
10.00	55.92	-	-	3.30	37.28
11.30	65.24	-	-	4.20	46.60
12.60	74.56	-	-	4.80	55.92
14.20	83.88	-	-	5.00	65.24
15.70	82.30	-	-	5.80	74.56
-	-	-	-	7.00	83.88

Table 1.1 - *continued*

Anchor – testing place					
Test 1, right side K-123		**Test 2, right side K-123**		**Test 3, roof of room K-123**	
Δl, [mm]	**F, [kN]**	**Δl, [mm]**	**F, [kN]**	**Δl, [mm]**	**F, [kN]**
7.10	18.64	3.00	18.64	2.00	18.64
7.60	27.96	3.20	27.96	6.10	27.96
8.20	37.28	4.00	37.28	7.50	37.28
8.40	46.60	5.90	46.60	10.50	46.60
8.50	55.92	6.00	55.92	11.00	55.92
9.20	65.24	7.10	65.24	13.00	60.58
13.30	74.56	7.40	74.56	14.00	65.24
15.90	83.88	8.00	83.88	14.80	74.56
17.70	93.20	9.80	93.20	15.00	83.88
18.60	102.52	9.90	102.52	15.10	93.20
19.40	111.84	10.00	111.84	16.00	102.52
23.50	121.16	12.90	121.16	16.30	111.84
26.00	130.48	13.00	130.48	16.50	121.16
27.00	135.14	13.50	139.80	25.50	130.48
-	-	16.70	149.12	-	-
-	-	17.40	153.78	-	-

The results of measuring the pull-out force are graphically present in further text.

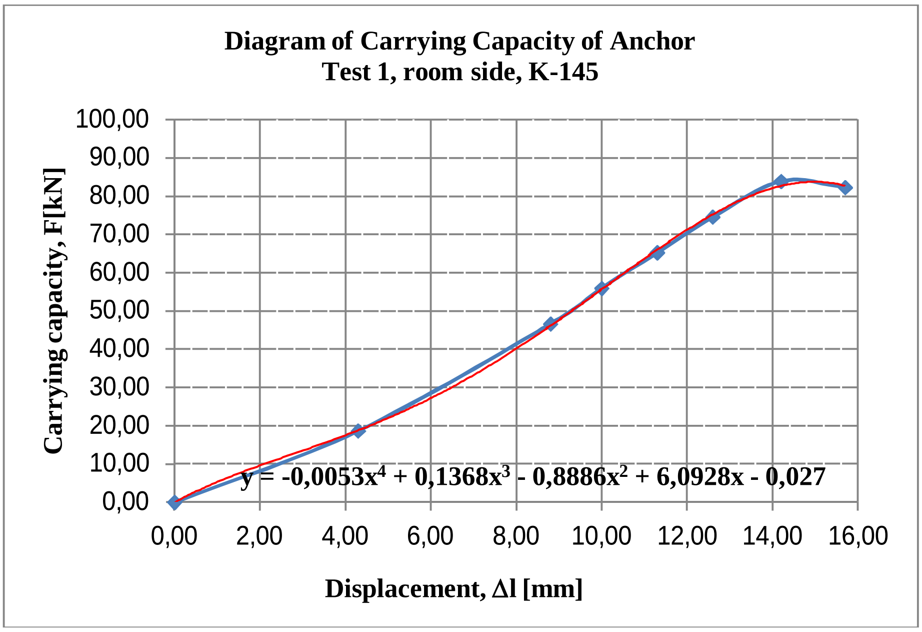

Figure 1.2 *Results of measuring the pull-out force of the first anchor of the first test series*

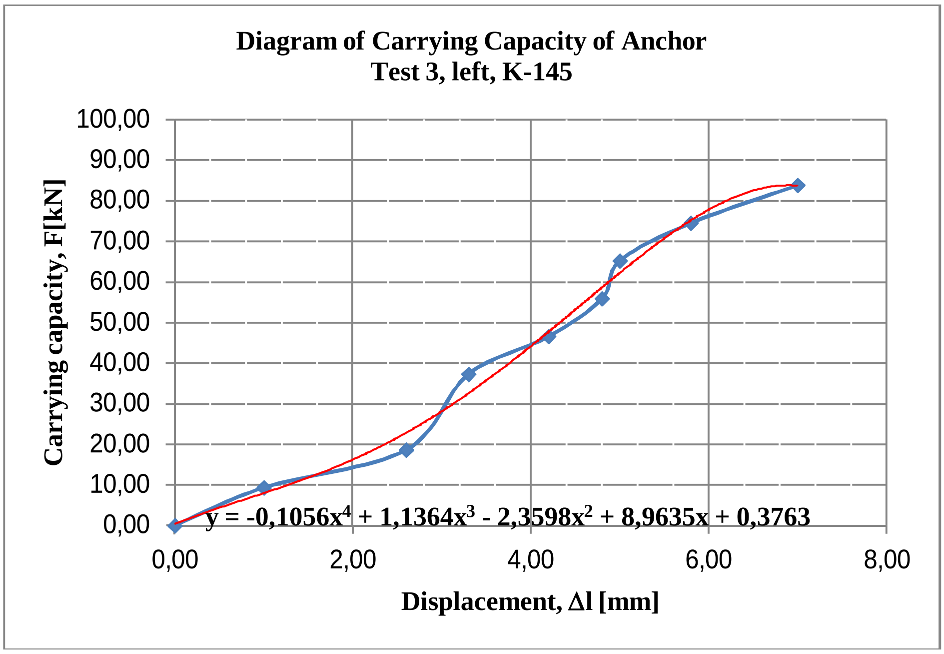

Figure 1.3 *Results of measuring the pull-out force of the third anchor of the first test series*

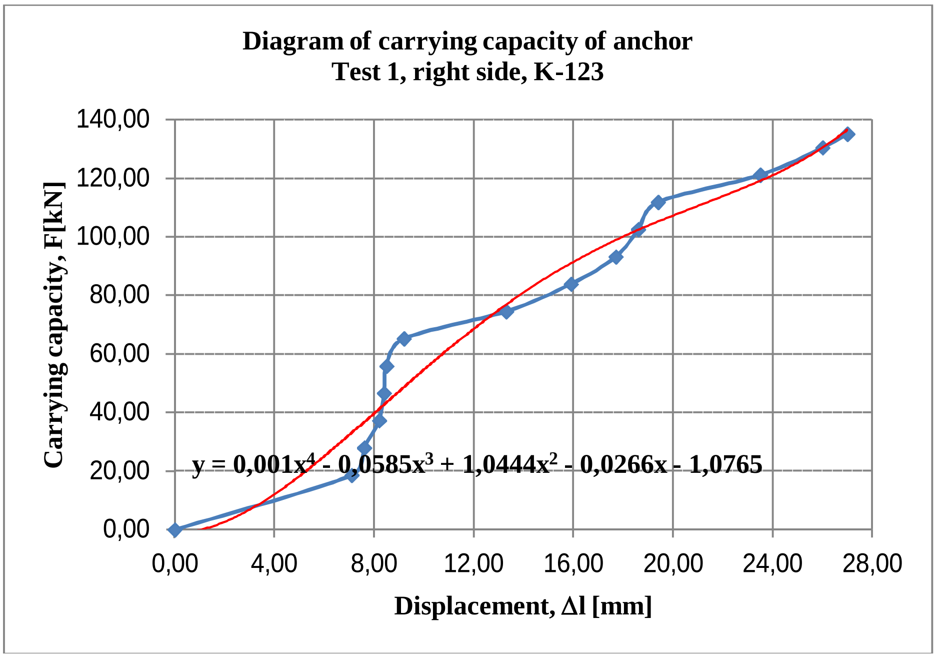

Figure 1.4 *Results of measuring the pull-out force of the first anchor of the second test series*

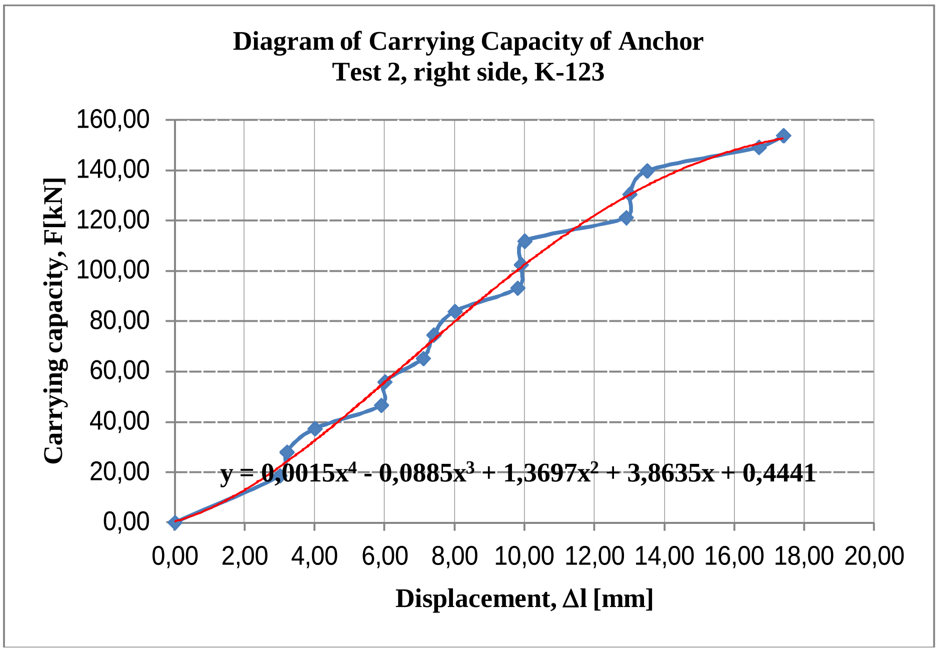

Figure 1.5 *Results of measuring the pull-out force of the second anchor of the second test series*

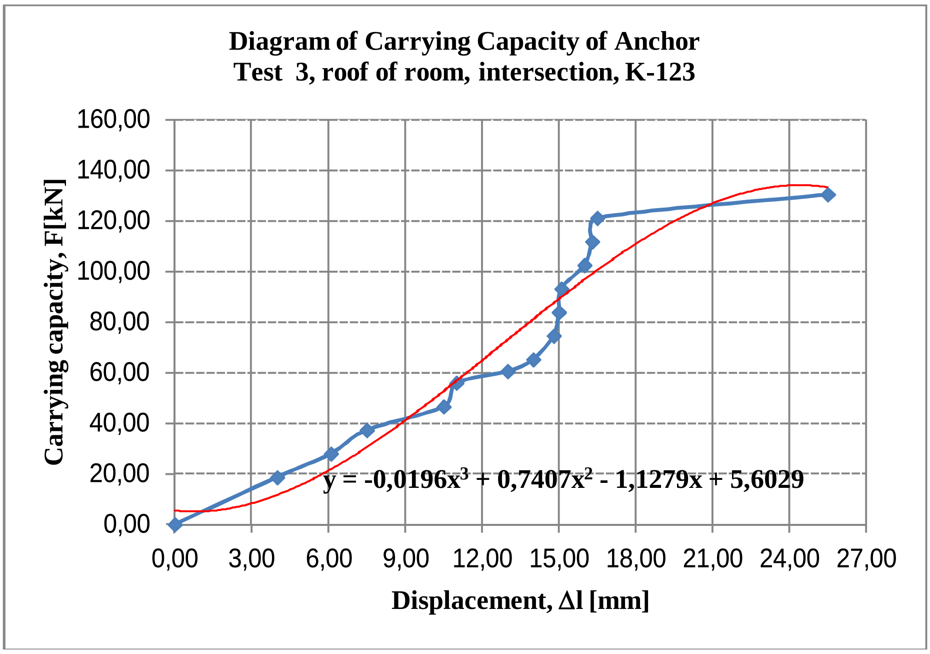

Figure 1.6 *Results of measuring the pull-out force of the third anchor of the second test series*

Values of pull-out forces of anchors were compared with the specification and attest given by the manufacturer, and it can be concluded that the anchors completely fulfill their functions.

2 CONCLUSION

In order to secure the underground stope in the ore body, "T1", the supporting of excavated area is carried out after finished exploitation. The supporting, in this case, is carried out by means of anchors of type SWELLEX and SN, M-20 in a combination with the resin LOKSET RESIN CAPSULES, and reinforcement mesh, which is applied with the layer of torkret concrete.

After tests, which were carried out in the field, it can be concluded that the tested anchors meet the prescribed quality according to the current standard and attest of manufacturer.

REFERENCES

[1] Quarterly Report on the Status of Works on the Ore Exploitation from the Ore Body "T1" in the “Jama” Bor, Mining and Metallurgy Institute Bor, Laboratory for Geomechanics, March 2014;

[2] M. Memić, E. Hadžić, S. Softić, Methodology of Design and Construction the Underground Rooms, Tuzla 1999;

[3] R. Popović, M. Ljubojev, L. Đurđevac Ignjatović, Deformability Parameters for Forming the Stress-strain State Models of Rock Massif, Mining and Metallurgy Engineering Bor, 3/2013, str. 1-6.

[4] V. Milić, I. Svrkota, D. Petrović, Analysis of Block Stability for Semi - Level Caving Method With Kateral Loading, Mining and Metallurgy Engineering Bor, 2/2013, pp. 21-26.

[5] S. Ćosić, M. Avdić, A. Sušić, M. Ljubojev, Finite Element Analysis of Deep Underground Salt, Mining and Metallurgy Engineering Bor, 3/2013, pp. 65-72.

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Dragan Ignjatović, Lidija Đurđevac Ignjatović*, Milenko Ljubojev*, Ivan Ivanov***

ISPITIVANJE NOSIVOSTI ANKERA U RUDNOM TELU „T1“***

Izvod

U cilju obezbeđenja podzemnog otkopa u rudnom telu „T1“, nakon izvršene eksploatacije se vrši podgrađivanje otkopnog prostora. Podgrađivanje se, u ovom slučaju, izvodi pomoću ankera SWELLEX i SN, M-20 u kombinaciji sa smolom LOKSET RESIN CAPSULES, i armaturnom mrežom, preko koje se nanosi sloj torkret betona.

U ovom radu su prikazani rezultati ispitivanja nosivosti ankera u datom rudnom telu „T1“

***Ključne reči:** otkopni prostor, anker, nosivost ankera, sila čupanja*

1. UVOD

U toku podzemnog otkopavanja, uporedo sa eksploatacijom rude, vršeno je podgrađivanje otkopnog prostora. Podgrađivanje se vrši ankerima tipa SWELLEX i SN, M-20 u kombinaciji sa smolom LOKSET RESIN CAPSULES. Podgrađivanju prethodi bušenje bušotina za ugradnju ankera. Bušenje se vrši bušaćom garniturom BOOMER 282. Prečnik bušotina je ∅ 33 mm.

Nakon ugradnje ankera, vršeno je njihovo naprezanje, zatim postavljanje armaturne mreže i nanošenje torkret betona.

Posle svih navedenih radnji vršena su ispitivanja nosivosti ankera na silu čupanja pomoću hidraulične pumpe. Ispitivanje nosivosti ankera je vršeno prema preporukama Međunarodnog društva za mehaniku stena (ISRM).

Pored sile čupanja registrovana su i pomeranja glave ankera. Sila čupanja se nanosi postepeno do dostizanja zadate (radne) ili granične sile čupanja.

Rezultati ispitivanja nosivosti ankera su prikazani grafički dijagramima pomeranja u funkciji sile čupanja.

1.1. Analiza rezultata ispitivanja

Merenja su izvršena u dva navrata (20.11.2013. i 23.01.2014. godine) na 6 ankera, koji su ugrađeni na karakterističnim mestima u rudnom telu T1.

Na slikama 1.1 a, b i c je prikazan izgled ispitivanja ankera u rudnom telu T1.

* *Institut za rudarstvo i metalurgiju Bor*
** *RBB „Jama“ Bor*
*** *Ovaj rad je proistekao iz Projekta nauke broj 33021 „Istraživanje i praćenje promena naponsko deformacionog stanja u stenskom masivu „IN SITU“ oko podzemnih prostorija sa izradom modela sa posebnim osvrtom na tunel Kriveljske reke i Jame Bor“, koga finansira Ministarstvo prosvete, nauke i tehnološkog razvoja Republike Srbije*

a)

b)

c)

Sl. 1.1 *a), b) i c). Ispitivanje ankera – određivanje sile čupanja*

U tabeli 1.1 date su vrednosti pomeranja u funkciji od sile čupanja za ispitane ankere.

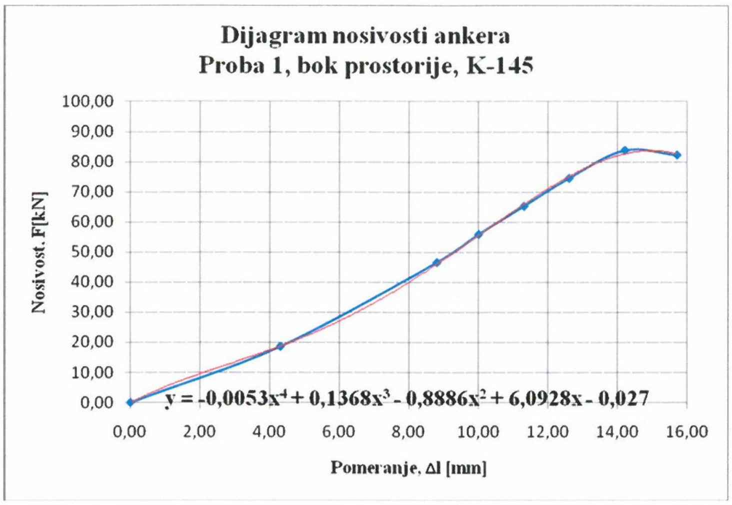
Tabela 1.1. *Vrednosti pomeranja (Δl, [mm]) u funkciji od sile čupanja – nosivosti (F, [kN])*

Anker – mesto ispitivanja					
Proba 1, bok prostorije K-145		**Proba 2, desni bok K-145**		**Proba 3, levi bok, K-145**	
Δl, [mm]	F, [kN]	Δl, [mm]	F, [kN]	Δl, [mm]	F, [kN]
4,30	18,64	7,00	18,64	1,00	9,32
8,80	46,60	-	-	2,60	18,64
10,00	55,92	-	-	3,30	37,28
11,30	65,24	-	-	4,20	46,60
12,60	74,56	-	-	4,80	55,92
14,20	83,88	-	-	5,00	65,24
15,70	82,30	-	-	5,80	74,56
-	-	-	-	7,00	83,88

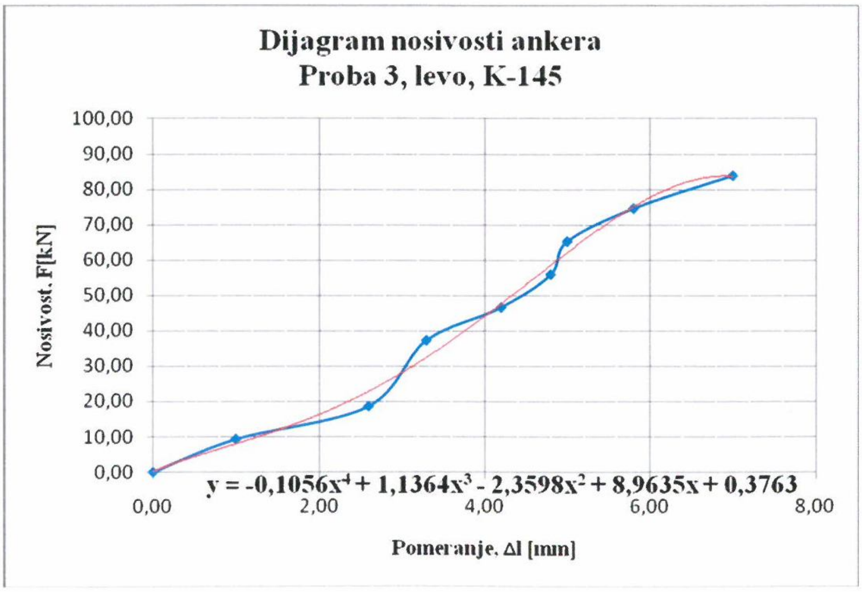
Nastavak tabele 1.1.

Anker – mesto ispitivanja					
Proba 1, desni bok K-123		**Proba 2, desni bok K-123**		**Proba 3, strop prostorije K-123**	
Δl, [mm]	**F, [kN]**	**Δl, [mm]**	**F, [kN]**	**Δl, [mm]**	**F, [kN]**
7,10	18,64	3,00	18,64	2,00	18,64
7,60	27,96	3,20	27,96	6,10	27,96
8,20	37,28	4,00	37,28	7,50	37,28
8,40	46,60	5,90	46,60	10,50	46,60
8,50	55,92	6,00	55,92	11,00	55,92
9,20	65,24	7,10	65,24	13,00	60,58
13,30	74,56	7,40	74,56	14,00	65,24
15,90	83,88	8,00	83,88	14,80	74,56
17,70	93,20	9,80	93,20	15,00	83,88
18,60	102,52	9,90	102,52	15,10	93,20
19,40	111,84	10,00	111,84	16,00	102,52
23,50	121,16	12,90	121,16	16,30	111,84
26,00	130,48	13,00	130,48	16,50	121,16
27,00	135,14	13,50	139,80	25,50	130,48
-	-	16,70	149,12	-	-
-	-	17,40	153,78	-	-

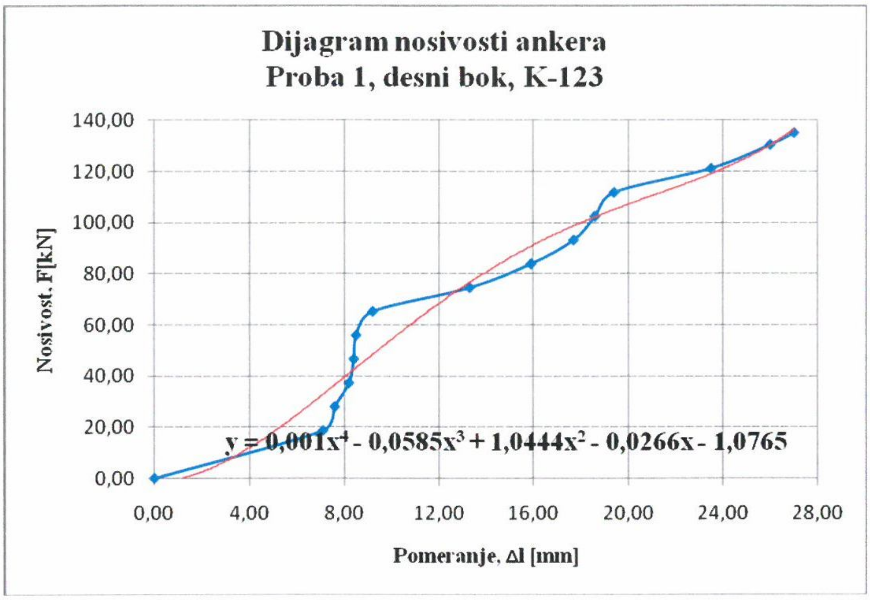
U daljem tekstu su grafički prikazi rezultata merenja sile čupanja.



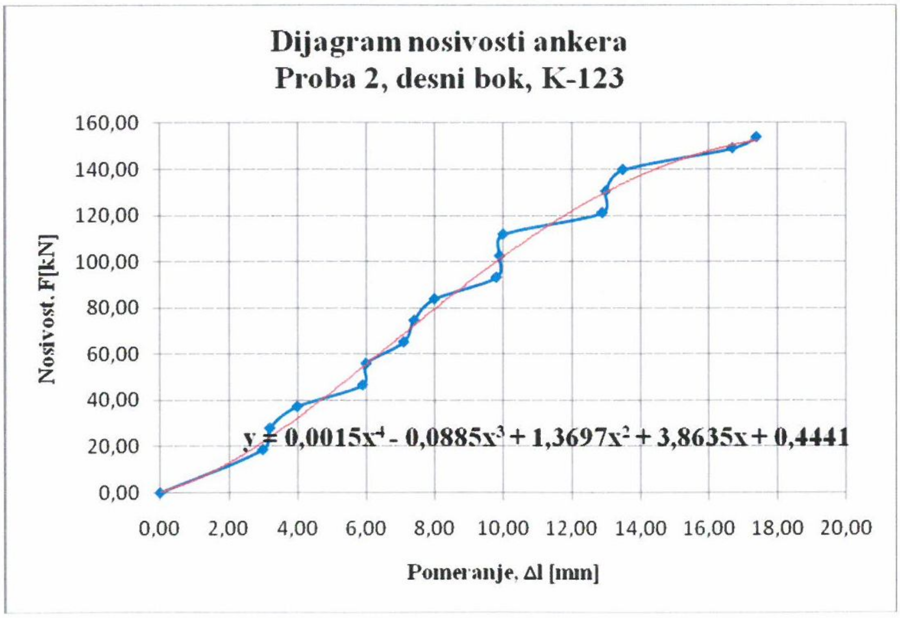
Sl. 1.2. *Rezultati merenja sile čupanja prvog ankera prve serije probe*



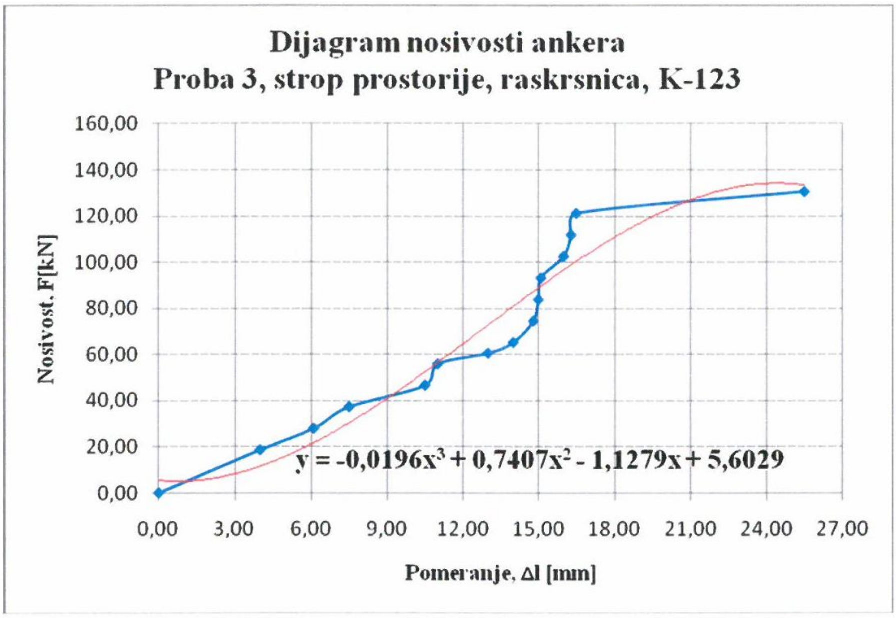
Sl. 1.3. *Rezultati merenja sile čupanja trećeg ankera prve serije probe*



Sl. 1.4. *Rezultati merenja sile čupanja prvog ankera druge serije probe*



Sl. 1.5. *Rezultati merenja sile čupanja drugog ankera* druge *serije probe*



Sl. 1.6. *Rezultati merenja sile čupanja trećeg ankera druge serije probe*

Vrednosti sila čupanja ankera su upoređene sa specifikacijom i atestom, koje je dao proizvođač, i može se zaključiti da ankeri u potpunosti ispunjavaju svoju funkciju.

2. ZAKLJUČAK

U cilju obezbeđenja podzemnog otkopa u rudnom telu „T1“, nakon izvršene eksploatacije se vrši podgrađivanje otkopnog prostora. Podgrađivanje se, u ovom slučaju, izvodi pomoću ankera SWELLEX i SN, M-20 u kombinaciji sa smolom LOKSET RESIN CAPSULES, i armaturnom mrežom, preko koje se nanosi sloj torkret betona.

Nakon ispitivanja, koja su izvršena na terenu, može se zaključiti da ispitani ankeri zadovoljavaju propisani kvalitet prema važećem standardu i atestu proizvođača.

LITERATURA

[1] Kvartalni izveštaj o stanju radova na eksploataciji rude iz rudnog tela „T1“ jame Bor, Institut za rudarstvo i metalurgiju Bor, Laboratorija za geomehaniku, mart, 2014.

[2] M. Memić, E. Hadžić, S. Softić, Metodologija projektovanja i izgradnje podzemnih prostorija, Tuzla 1999.

[3] R. Popović, M. Ljubojev, L. Đurđevac Ignjatović, Parametri deformabilnosti za formiranje modela naponsko-deformacijskog stanja stenskog maxsiva, Mining and Metallurgy Engineering Bor, 3/2013, str. 7-12.

[4] V. Milić, I. Svrkota, D. Petrović, Istraživanje stabilnosti dna otkopnog bloka za metodu poluetažnog prinudnog zarušavanja sa jednostranim bočnim utovarom rude, Mining and Metallurgy Engineering Bor, 2/2013, str. 27-32.

[5] S. Ćosić, M. Avdić, A. Sušić, M. Ljubojev, Naponsko - deformaciona analiza sonih komora metodom konačnih elemenata, Mining and Metallurgy Engineering Bor, 3/2013, pp. 73-80.

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Zoran Vaduvesković[*], Nenad Vušović[**], Daniel Kržanović[*]

ANALYSIS THE POSIBILITY OF IMPROVING THE ECONOMIC INDICATORS OF EXPLOITATION THE DEPOSIT CEMENTACIJA KRAKU BUGARESKU - ORE FIELD CEROVO[***]

Abstract

Cementacija - Kraku Bugaresku is a complex of ore bodies in the southeastern part of the deposit Cerovo. It contains a substantial portion of ore with high content of oxides regarding to the total copper in the ore, and with the existing processing technology in the current period, the modest results in metal recovery were achieved. This work, through an analysis, gives a discussion of possible combination of processing using the conventional flotation processing with pyrometallurgical treatment and heap leaching with the hydrometallurgical extraction of metal by SX -EW, in terms of the economic viability of such method. This work firstly made a comparison of optimization results of potential open pits in the ore deposit (Whittle Fx), in both cases for the same input techno-economic data. The obtained potential open pits in the optimization process (pit shells) for Revenue Factor 1 (i.e. the selling price of Cu cathode ton of 5,000 $) are differ from each other by about 8 million tons of ore in favor of the combined processing method and the amount of Cu in the ore to 16,502.44 t, while had grade in the case of method combination is higher for 3.27 %. Discounted cash flow is higher by as much as 61.94 %, which expressed in monetary units is 47,905,712 $.

Keywords: *heap leaching, SX -EW , optimization of open pits, discounted cash flow*

INTRODUCTION

The ore field Kraku Bugaresku (KB) - Cementacija is part of a complex of ore deposits at the site Cerovo Mali Krivelj, which is different from the rest of the deposit by the way of origin and type of mineralization. It is a cementation zone of secondary enrichment, and a portion of mineralization belongs to the oxide mineralization (about 40% of total geological reserves). It consists of the ore bodies Cementacija 1, 2, 3 and 4, out of which Cementacija 3 and 4 are distinguished by content of oxide ore to total reserves. According to the copper content, the complex belongs to the low-grade deposits whose economics of exploitation is very sensitive to some parameters such metal recovery in the process of enrichment, exploitation costs in technological chain from mining to metallurgical treatment, and even the sequence of mining the ore bodies (Push backs) within the cementation zone.

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[**] *University of Belgrade,Technical Faculty Bor*
[***] *This work is within the Projects of technological development TR33038 "Improving Technology of Exploitation and Processing of Copper Ore with Monitoring the Living and Working Environment in the RTB Bor Group" and TR34004 "The New Production Line for Copper Production by Solvent Extraction of Mine Water", funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia.*

Figure 1 shows the analysis of "Grade tonnage" for different cut-off grades, which is the characteristic of the deposit, where the ratio of amount RSULF and ROXD, i.e. amounts of both types of ore deposit.

The most common copper minerals in the upper part of the deposit, the oxidation zone, are cuprite, malachite and azurite, while in the zone of secondary sulphide enrichment, the most common are covellite and chalcocite.

CU Cut-off	ORSU tonne	OROX tonne	CUOX Ave grade	CUSU Ave grade
0.1	118000050	61458241	0.0186	0.1841
0.15	77644440	35989082	0.0217	0.2273
0.2	49637929	20080618	0.0249	0.2721
0.25	30505437	10594773	0.0282	0.3209
0.3	19244147	5625561	0.0312	0.3682
0.35	11857650	3321796	0.0351	0.4136
0.4	7065534	1939478	0.0402	0.4609
0.45	4448241	1231875	0.0443	0.5024
0.5	2869062	700313	0.0472	0.5425
0.55	1847175	371250	0.0501	0.5792
0.6	1168264	151875	0.0502	0.6191
0.65	645079	42188	0.052	0.6597
0.7	287078	25313	0.0605	0.7032
0.75	134847	8438	0.0599	0.7521
0.8	75938	8438	0.068	0.7663

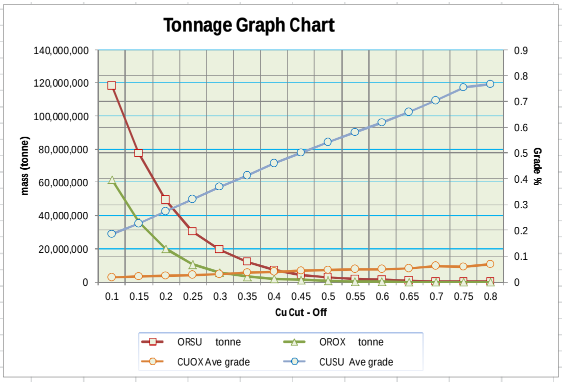

Figure 1 *"Grade tonnage"analysis for the copper ore deposit KB - Cementacija for different cut-off grades – Table and Graph*

The previous work applied to the mining of deposits Cementacija 1, which consisted of flotation processing of the entire amount of ore above the cut-off grade, without separation of oxide parties of ore from the sulphide, resulted in low copper recovery in the flotation plant, which ranged in the interval between 50 and 70%[1]. This has certainly a negative impact on the achieved economic results.

Due to these facts it is important to review and analyze the possibilities of increasing NPV, ie Cashflow in the exploitation of the complex ore bodies.

At the present level of technological development of exploitation and recovery of metals from oxide and sulphide ores, the importance is recently given to *leaching and solvent extraction of leaching solutions* from oxide ore, and even from sulphide ore (or concentrate).

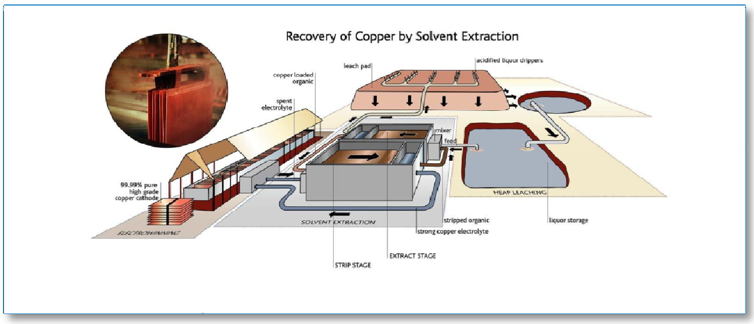

Figure 2 *Process Flow Diagram - heap leaching, solvent extraction and electro wining*

[1] *In the official Documents (Annual Technical Reports on Production of RBB, 1993. -2000.), the Production Results are not Presented Credible*

ANALYSIS IN SOFTWARE FOR STRATEGIC PLANNING WHITTLE FX

The input techno-economic data for carried out analysis in software for strategic planning Whittle Fx, for scenario 1 and 2, i.e. flotation of sulphide and oxide ores together, without selective mining with additional method of enrichment - heap leaching of the ore with more than 10% of oxides, are the following:

Table 1 *Input techno-economic parameters of exploitation for the optimization process (input)*

Parameter	Unit	Values
Capacity of excavation - excavations	t/year	12Mt from 3.year17 Mt
Capacity of flotation processing – Sulphide ore with max. 10% oxide	t/year	2.5Mt from 3. year 5.5 Mt
Capacity of heap leaching – Oxide ore with over 10% oxide content	t/year	2.5 Mt
Copper price	$/t cathode	5,000.00
Gold price	$/kg	40,000.00
Silver price	$/kg	500.00
Excavation costs	$/t	2.3
Flotation processing costs	$/t	4.00
Heap leaching costs	$/t ore	1.00
Metallurgical copper treatment costs	$/t cathode	450.00
Metallurgical gold treatment costs	$/kg	150.00
Metallurgical silver treatment costs	$/kg	15.00
Hydrometallurgical treatment costs (SXEW)	$/t cathode	100.0
Initial capital costs of leaching and SXEW	$	20,000,000
Total copper recovery (flotation and metal.)	%	0.788
Total gold recovery (flotation and metal.)	%	0.50
Silver recovery (flotation and metal.)	%	0.40
Copper recovery from oxide ore with over 10% oxide content	%	0.54
Discount rate	%	10.0

Analysis[2] was carried out for 3 scenarios, as follows:

1. Scenario 1 – processing method marked as "MILL", i.e. flotation ROXD and RSULF, i.e. two types of ore;
2. Scenario 2 – method "MILL" for ore with > 10% oxide, and method "LEAC" for ore with content > 10% oxide, wherein the leaching capacity is not limited;
3. Scenario 3 – same as Scenario 2, but with limited capacity of leaching to 2,500,000 t, and with the use of two types of stockpiles for ore less than 10% oxide ore and over 10% oxide (SP1 and SP2). Stockpiles were used as a "buffer" for addition of design capacity both in the flotation and leaching.

In further analysis for Scenarios 1 and 2, the results of optimization are presented in the tables type *Pit Pit By Garph,* i.e. the open pits from optimization with calculated cash flow and discounted cash flow for each of a set of nested open pit mines. Economic indicators are calculated for three possible cases – the *Best Case, Worst Case,* and *Specific Case,* i.e. for the mining bench by bench, and using pushbacks in mining. A key for the evaluation and selection of the optimal pit on the criterion of the optimal profit is *discounted cash flow* best case. This means that the selected pit (*Final pit*) is excavated in stages (Push backs).

In all three cases, a mining schedule is designed and calculated for mine life of selected open pit per the above criteria with the appropriate graphical views. Also, the calculated amounts per type of ore (as *Rock Type*) are presented in tables, with lower and higher oxide contents, or the realized capacities for the method "MILL" and method "LEAC" in Scenario 3 – with additional calculated amounts of ore that go to the stockpiles and from there into the process.

[2] *Beside the above given input data, the block model of deposit, so called "mod" file, is exported into software Whittle. In designing the mentioned "mod" file in the basic software, in this case Gemcom, the terrain topography is used, i.e. current mining lay out. In the case of this analysis, the mining lay out is at 10.08.2001, before reactivation of open pit, because the analysis was not carried out as a part of the Study or Project, but with the aim to point out the possibilities for increasing the economic effects of production, also initiating the important explorations aimed to extraction of Cu by hydrometallurgical method.*

SCENARIO 1 One Type of Processing MILL (Flotation) of Sulphide and Oxide Ore Together

Table 2 *Tabular presentation of optimization results per Scenario 1 with calculated cash flow*

PIT BY PIT GRAPH - SCENARIO 1

Final pit	Revenue factor for final pit	Open pit cashflow best $ disc	Open pit cashflow specified $ disc	Open pit cashflow worst $ disc	tonne input best	Waste best tonne	Mine life years best	Mine life years specified	Mine life years worst
1	0.32	1,257,649	1,257,649	1,257,649	64,520	9,407	0.03	0.03	0.03
2	0.34	2,340,019	2,340,019	2,340,019	127,897	9,971	0.05	0.05	0.05
3	0.36	3,265,188	3,265,188	3,265,188	188,088	10,150	0.08	0.08	0.08
4	0.38	4,415,908	4,415,908	4,415,908	272,142	14,544	0.11	0.11	0.11
5	0.4	5,121,194	5,121,194	5,121,194	326,594	28,340	0.13	0.13	0.13
6	0.42	6,782,948	6,782,948	6,782,948	475,371	39,226	0.19	0.19	0.19
7	0.44	8,622,922	8,622,922	8,622,922	654,558	64,086	0.26	0.26	0.26
8	0.46	10,525,070	10,525,070	10,525,070	868,580	85,685	0.35	0.35	0.35
9	0.48	13,053,414	13,053,414	13,053,414	1,188,709	111,857	0.48	0.48	0.48
10	0.5	15,071,636	15,071,636	15,071,636	1,480,565	120,560	0.59	0.59	0.59
11	0.52	15,737,824	15,737,824	15,737,824	1,589,257	128,947	0.64	0.64	0.64
12	0.54	18,383,286	18,383,286	18,383,286	2,040,985	229,016	0.82	0.82	0.82
13	0.56	20,388,697	20,388,697	20,388,697	2,429,329	299,806	0.97	0.97	0.97
14	0.58	21,534,215	21,532,415	21,532,415	2,663,808	335,688	1.07	1.07	1.07
15	0.6	48,788,934	47,538,914	47,538,914	7,875,043	5,582,314	2.52	2.52	2.52
16	0.62	55,146,867	53,508,008	53,508,008	9,599,654	6,485,167	2.84	2.84	2.84
17	0.64	63,570,562	60,902,078	60,902,078	11,991,784	7,986,686	3.27	3.27	3.27
18	0.66	67,546,940	64,308,942	64,308,942	13,194,047	8,727,104	3.49	3.49	3.49
19	0.68	76,251,473	71,761,565	71,761,565	16,394,020	10,505,786	4.07	4.07	4.07
20	0.7	79,816,489	74,837,962	74,837,962	17,911,544	11,034,033	4.35	4.35	4.35
21	0.72	84,775,931	78,120,000	78,120,000	20,275,932	12,509,270	4.78	4.78	4.78
22	0.74	87,297,954	79,729,295	79,729,295	21,721,280	13,173,614	5.04	5.04	5.04
23	0.76	99,408,000	82,884,123	82,884,123	28,647,492	19,642,382	6.30	6.55	6.55
24	0.78	102,648,142	83,151,343	83,151,343	31,079,978	21,409,083	6.74	7.05	7.05
25	0.8	105,911,193	82,932,523	82,932,523	33,864,262	24,482,200	7.25	7.62	7.62
26	0.82	107,796,516	83,166,000	83,166,000	36,026,740	25,479,248	7.64	8.02	8.02
27	0.84	109,864,961	82,857,682	82,857,682	38,690,541	27,906,217	8.13	8.52	8.52
28	0.86	112,055,441	81,155,078	81,155,078	41,754,095	31,007,667	8.68	9.10	9.10
29	0.88	113,121,606	80,039,265	80,039,265	43,695,298	33,065,173	9.04	9.46	9.46
30	0.9	115,083,888	75,541,273	75,541,273	48,341,430	37,235,782	9.88	10.32	10.32
31	0.92	115,955,763	71,519,775	71,519,775	50,942,253	40,014,353	10.35	10.89	10.89
32	0.94	116,329,206	69,437,935	69,437,935	52,691,741	42,144,430	10.67	11.24	11.24
33	0.96	116,577,596	67,166,852	67,166,852	54,558,738	44,257,231	11.01	11.62	11.62
34	0.98	116,812,522	63,546,156	63,546,156	56,940,722	47,520,092	11.44	12.10	12.10
35	1	116,822,322	62,763,271	62,763,271	57,462,570	48,143,878	11.54	12.20	12.20
36	1.02	116,733,132	60,247,593	60,247,593	59,523,326	50,336,326	11.91	12.60	12.60
37	1.04	116,570,305	57,088,898	57,088,898	61,004,701	52,645,714	12.18	12.91	12.91
38	1.06	116,246,697	53,548,340	53,548,340	62,679,665	55,723,640	12.49	13.27	13.27
39	1.08	116,104,201	52,612,974	52,612,974	63,285,683	56,807,448	12.60	13.38	13.38
40	1.1	115,890,094	51,230,325	51,230,325	63,973,933	57,909,775	12.72	13.51	13.51
41	1.12	114,776,583	41,519,881	41,519,881	67,492,199	62,846,779	13.36	14.34	14.34
42	1.14	114,282,584	37,924,212	37,924,212	68,822,070	65,024,645	13.60	14.65	14.65
43	1.16	114,198,024	37,513,600	37,513,600	69,049,326	65,188,415	13.65	14.69	14.69
44	1.18	113,547,212	35,394,348	35,394,348	70,505,451	68,088,287	13.91	14.96	14.96
45	1.2	113,180,094	34,216,439	34,216,439	71,313,473	69,376,637	14.06	15.11	15.11
46	1.22	112,692,740	31,159,282	31,159,282	72,264,584	71,233,186	14.23	15.34	15.34
47	1.24	112,393,820	29,204,421	29,204,421	72,820,099	72,285,894	14.33	15.48	15.48
48	1.26	110,665,910	18,407,558	18,407,558	75,656,596	79,276,775	14.86	16.25	16.25
49	1.28	109,992,003	16,490,497	16,490,497	76,759,211	81,937,428	15.15	16.46	16.46
50	1.3	109,028,005	11,329,090	11,329,090	78,333,172	85,123,865	15.43	16.80	16.80
51	1.32	108,936,513	10,951,659	10,951,659	78,476,259	85,430,456	15.46	16.83	16.83
52	1.34	108,604,954	9,631,895	9,631,895	78,947,606	86,580,421	15.54	16.93	16.93
53	1.36	108,528,079	9,319,586	9,319,586	79,090,693	86,744,802	15.57	16.96	16.96
54	1.38	107,646,094	6,399,243	6,399,243	80,168,057	89,781,653	15.77	17.17	17.17
55	1.4	106,959,546	4,034,446	4,034,446	81,102,333	92,015,091	15.94	17.35	17.35
56	1.42	106,704,144	3,213,701	3,213,701	81,439,009	92,833,624	16.00	17.41	17.41
57	1.44	106,461,667	2,659,448	2,659,448	81,716,767	93,627,441	16.06	17.47	17.47
58	1.46	106,136,964	1,975,632	1,975,632	82,087,111	94,621,529	16.14	17.53	17.53
59	1.48	106,087,512	1,742,133	1,742,133	82,154,446	94,741,304	16.15	17.55	17.55
60	1.5	105,680,501	702,770	702,770	82,533,207	96,158,579	16.25	17.62	17.62

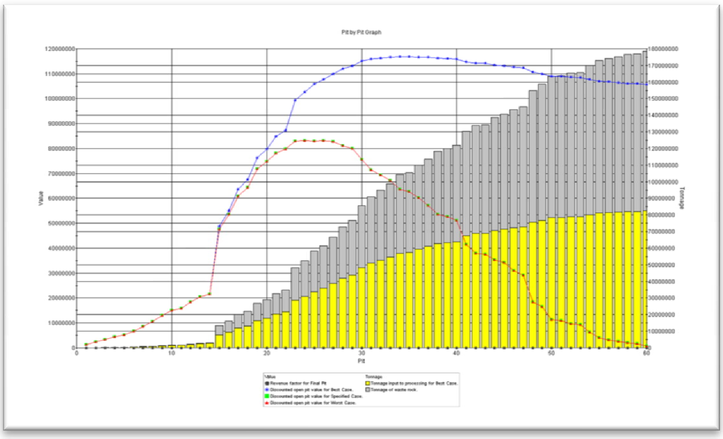

Figure 3 *Pit by Pit graph – Graph of optimization per Scenario 1*

Table 3 *Mining dynamics per Scenario 1*

					SCENARIO 1_ SHEDULE GRAPPH										
	PB: 19, 26,3														
Period	tonne input	Waste tonne	Strip ratio	tonne input RSUL	Units input RSUL CU	Grade input CUS	tonne input ROXD	Units input ROXD CU	Grade input CUOX	Grade input CU	Grade input PRCU	Grade input AU	Grade input AG	Open pit cashflow $	Open pit cashflow $ disc
					x 100			x100							
1	2,497,779	9,502,221	3.8	601,834	241,726	0.2449	1,895,945	462,625	0.0413	0.282	15.4797	0.0753	1.1065	-9,847,862	-8,952,602
2	2,499,693	9,500,307	3.8	917,321	451,536	0.3076	1,582,372	426,201	0.0484	0.3511	15.7806	0.0802	1.0753	-3,387,689	-2,799,743
3	5,495,999	11,504,001	2.09	1,769,556	816,733	0.2808	3,726,443	952,774	0.0458	0.322	16.0559	0.0718	1.0124	6,867,290	5,159,496
4	5,499,999	6,315,358	1.15	1,462,051	427,596	0.2038	4,037,947	887,950	0.0393	0.2392	16.1273	0.0693	1.1278	3,452,064	2,357,806
5	5,500,000	3,586,533	0.65	1,785,345	533,392	0.2303	3,714,655	929,696	0.0397	0.266	14.6026	0.0791	1.1537	15,477,799	9,610,495
6	5,500,000	2,599,697	0.47	2,570,586	823,796	0.2542	2,929,414	753,057	0.0361	0.2867	13.4667	0.0727	1.0313	20,814,587	11,749,292
7	5,500,000	1,403,682	0.26	3,146,090	1,044,249	0.2634	2,353,910	553,530	0.0301	0.2905	11.1239	0.0848	1.0792	28,194,533	14,468,253
8	5,499,999	1,557,531	0.28	4,021,808	1,109,667	0.2397	1,478,191	300,803	0.0186	0.2564	7.6091	0.0862	1.0487	23,064,615	10,759,813
9	5,500,000	1,263,215	0.23	5,082,426	1,282,422	0.2367	417,573	85,504	0.0133	0.2487	5.3879	0.0827	1.031	21,474,074	9,107,104
10	5,500,000	605,505	0.11	4,879,546	1,326,078	0.252	620,454	125,263	0.0133	0.2639	5.2266	0.0996	1.2105	27,995,708	10,793,557
11	5,500,000	271,792	0.05	5,017,944	1,395,811	0.2582	482,056	88,229	0.0129	0.2698	5.0344	0.0848	1.3015	28,542,461	10,003,959
12	2,969,102	34,036	0.01	2,916,661	803,531	0.2654	52,440	12,601	0.0105	0.2749	3.7942	0.0994	1.3529	17,194,580	5,724,357
	57,462,571	48,143,878		34,171,168			23,291,400							179,842,160	77,981,787

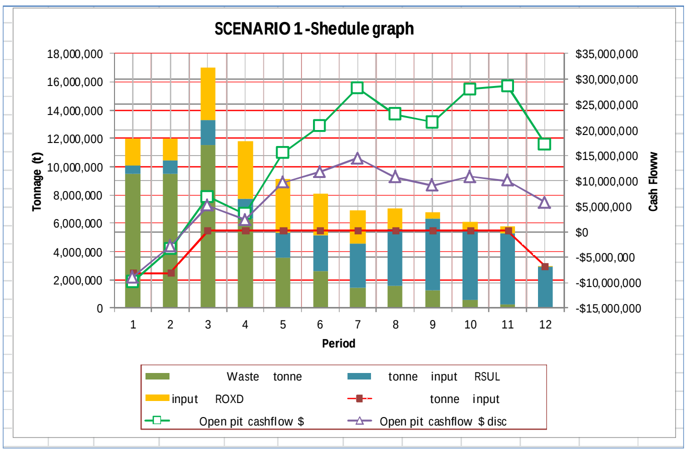

Figure 4 *Graphical view of mining dynamics per Scenario 1, with one processing method– MILL; total ore amounts without selective mining go to the flotation processing and concentrate to the pyrometallurgical method*

SCENARIO 2 Two Types of Processing
MILL (Flotation) and HEAP LEACHING

Table 4 *Tabular presentation of optimization results per Scenario with calculated cash flow*

PIT BY PIT GRAPH - SCENARIO 2

Final pit	Revenue factor for final pit	Open pit cashflow best $ disc	Open pit cashflow specified $ disc	Open pit cashflow worst $ disc	tonne input best	Waste best tonne	Mine life years best	Mine life years specified	Mine life years worst	Internal rate of return best %	Internal rate of return worst %
1	0.3	-19,672,238	-19,672,238	-19,672,238	26,916	67	0.00	0.00	0.00	0	0
2	0.32	-18,172,452	-18,172,452	-18,172,452	117,064	11,192	0.03	0.03	0.03	0	0
3	0.34	-16,598,225	-16,598,225	-16,598,225	236,298	14,400	0.05	0.05	0.05	0	0
4	0.36	-15,206,239	-15,206,239	-15,206,239	356,166	17,900	0.08	0.08	0.08	0	0
5	0.38	-13,815,237	-13,815,237	-13,815,237	471,549	24,595	0.11	0.11	0.11	0	0
6	0.4	-12,477,700	-12,477,700	-12,477,700	623,194	47,353	0.13	0.13	0.13	0	0
7	0.42	-10,006,388	-10,006,388	-10,006,388	879,677	89,393	0.20	0.20	0.20	0	0
8	0.44	244,677	244,677	244,677	2,221,015	757,403	0.29	0.29	0.29	4.03	4.03
9	0.46	2,673,733	2,673,733	2,673,733	2,552,183	830,394	0.36	0.36	0.36	17.29	17.29
10	0.48	8,658,819	8,658,819	8,658,819	3,431,323	1,262,659	0.48	0.48	0.48	50.03	50.03
11	0.5	17,861,713	17,861,713	17,861,713	5,020,490	2,005,231	0.69	0.69	0.69	102.2	102.2
12	0.52	56,166,769	54,806,665	54,806,665	11,373,660	7,933,596	2.07	2.19	2.19	174.16	136.69
13	0.54	72,345,544	68,906,902	68,906,902	14,459,921	10,464,136	2.36	2.49	2.49	183.73	116.43
14	0.56	78,651,502	74,683,218	74,683,218	15,955,469	11,180,073	2.49	2.64	2.64	187.33	116.22
15	0.58	89,657,379	83,964,252	83,964,252	18,628,312	12,656,334	2.74	2.97	2.97	193.51	112.76
16	0.6	94,177,326	88,262,713	88,262,713	19,906,020	13,491,902	2.86	3.11	3.11	196.05	110.79
17	0.62	102,041,906	94,967,147	94,967,147	22,306,910	14,818,353	3.20	3.44	3.44	198.55	103.31
18	0.64	107,825,197	99,135,151	99,135,151	24,190,047	15,786,074	3.44	3.72	3.72	199.57	98.3
19	0.66	115,263,766	104,855,424	104,855,424	26,963,760	17,384,509	3.78	4.11	4.11	200.93	92.92
20	0.68	119,827,401	109,467,857	108,368,981	28,858,724	18,643,233	4.03	4.36	4.39	201.72	87.95
21	0.7	131,018,438	119,070,774	114,123,936	33,311,000	23,050,589	4.59	4.92	5.07	202.39	74.82
22	0.72	133,849,985	121,691,295	115,646,776	34,870,282	24,119,422	4.77	5.10	5.35	202.58	71.9
23	0.74	146,289,750	134,152,102	117,198,533	42,640,316	31,908,409	5.74	5.84	6.58	202.61	54.6
24	0.76	151,869,938	139,491,522	117,668,350	46,568,407	35,916,783	6.18	6.24	7.17	202.7	49.49
25	0.78	153,176,720	140,648,407	117,997,340	47,586,853	36,658,979	6.32	6.38	7.36	202.71	48.83
26	0.8	155,346,218	141,567,411	116,920,205	49,572,609	38,908,109	6.48	6.75	7.70	202.73	46.22
27	0.82	157,052,532	143,038,162	116,146,307	51,466,413	40,623,250	6.70	6.96	8.01	202.75	44.61
28	0.84	158,467,534	144,384,440	115,089,056	53,107,709	42,556,953	6.92	7.18	8.32	202.76	42.8
29	0.86	159,647,264	145,337,729	114,353,244	54,648,002	44,289,647	7.13	7.40	8.59	202.76	41.68
30	0.88	160,916,422	146,339,541	112,147,672	56,769,062	46,725,984	7.39	7.65	8.95	202.76	39.53
31	0.9	161,913,154	146,964,713	109,851,681	58,780,703	49,642,105	7.63	7.89	9.28	202.77	37.45
32	0.92	162,816,991	147,314,004	104,105,169	61,768,704	53,527,893	8.03	8.11	9.82	202.77	33.85
33	0.94	163,095,472	147,660,882	103,368,020	62,694,563	54,471,675	8.16	8.24	9.98	202.77	33.5
34	0.96	163,321,340	147,887,443	101,824,917	63,822,428	56,193,108	8.31	8.39	10.19	202.77	32.62
35	0.98	163,417,237	147,538,011	98,291,386	65,463,725	58,731,018	8.53	8.61	10.49	202.77	30.92
36	**1.00**	163,413,866	147,208,895	95,534,405	66,860,931	61,005,204	8.75	8.81	10.74	202.77	29.78
37	1.02	163,350,325	146,984,292	93,855,435	67,618,452	62,402,200	8.88	8.92	10.90	202.77	29.17
38	1.04	162,990,167	146,391,624	88,142,664	69,621,676	66,530,279	9.24	9.10	11.32	202.77	26.95
39	1.06	162,687,631	146,011,943	84,136,112	70,825,293	69,012,059	9.45	9.22	11.61	202.77	25.54
40	1.08	162,418,596	145,687,328	81,941,941	71,675,400	70,757,066	9.61	9.32	11.78	202.77	24.91
41	1.1	161,958,663	145,239,954	77,022,384	73,114,691	73,794,528	9.87	9.43	12.01	202.77	23.38
42	1.12	161,715,486	144,974,952	76,337,965	73,754,376	74,761,151	9.97	9.54	12.12	202.77	23.23
43	1.14	161,282,789	144,524,440	74,139,095	74,713,903	76,282,487	10.12	9.66	12.28	202.77	22.64
44	1.16	160,393,985	143,478,731	70,610,743	76,271,030	79,628,190	10.40	9.93	12.63	202.77	21.87
45	1.18	160,009,540	143,005,599	68,802,935	76,927,549	80,809,058	10.51	10.05	12.77	202.77	21.46
46	1.2	159,750,944	142,701,727	67,614,646	77,306,309	81,529,923	10.57	10.12	12.87	202.77	21.21
47	1.22	159,499,447	142,341,707	66,256,070	77,676,653	82,319,161	10.64	10.17	12.96	202.77	20.91
48	1.24	159,295,897	142,113,953	65,799,438	77,945,994	82,837,707	10.69	10.22	13.02	202.77	20.84
49	1.26	158,015,015	139,922,517	62,328,616	79,410,535	86,639,495	11.00	10.79	13.35	202.77	20.18
50	1.28	157,863,368	139,693,840	61,865,282	79,595,707	86,985,252	11.03	10.85	13.39	202.77	20.09
51	1.3	157,367,328	139,021,808	60,337,557	80,134,389	88,212,094	11.13	11.01	13.52	202.77	19.79
52	1.32	157,072,032	138,672,839	59,388,993	80,428,981	88,960,379	11.19	11.11	13.59	202.77	19.61
53	1.34	156,925,269	138,858,175	58,867,463	80,580,485	89,306,146	11.22	11.15	13.63	202.77	19.51
54	1.36	155,676,400	136,824,618	55,643,325	81,582,097	92,525,863	11.47	11.45	13.85	202.77	18.95
55	1.38	155,395,291	136,336,916	54,535,636	81,851,438	93,245,125	11.53	11.51	13.91	202.77	18.73
56	1.4	154,835,151	135,675,444	53,218,993	82,339,618	94,564,453	11.64	11.64	14.02	202.77	18.52
57	1.42	154,365,417	135,440,033	51,467,525	82,785,714	95,738,141	11.73	11.70	14.11	202.77	18.15
58	1.44	154,006,200	134,626,269	50,782,641	83,063,472	96,541,596	11.79	11.76	14.17	202.77	18.05
59	1.46	153,778,993	134,710,293	50,099,768	83,248,644	97,114,026	11.84	11.79	14.22	202.77	17.92
60	1.48	153,362,897	133,681,893	48,817,500	83,534,819	98,184,577	11.92	11.84	14.30	202.77	17.69
61	1.5	152,867,204	133,127,020	47,673,571	83,863,078	99,432,262	12.03	11.90	14.39	202.77	17.49

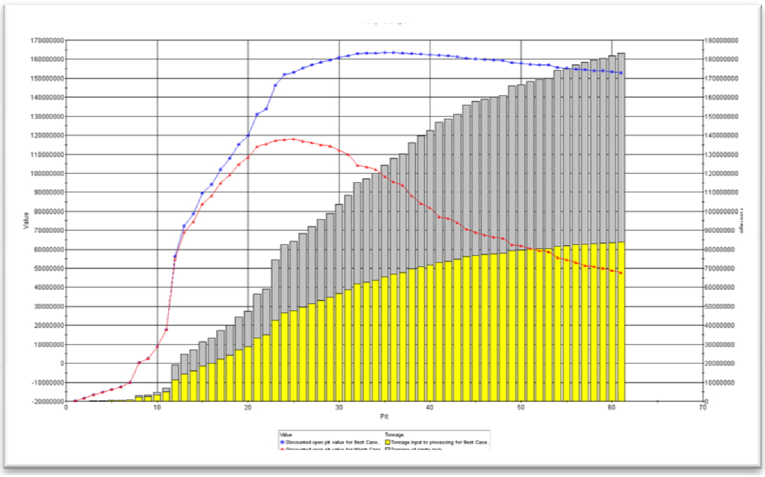

Figure 5 *Pit by Pit Graph optimization per Scenario 2 – output Whittle Fx*

Table 5 *Mining dynamics per Scenario 2*

SCENARIO 2 Shedule Graph PB: 19,25,35; Methods: MILL, LEAC,														
Period	Ore input tonne	Waste tonne	Strip ratio	input **MILL** **RSUL** tonne	Grade input CUS %	RSUL Units t	input **LECH** **ROXD** tonne	Grade input CUOX %	ROXD Units t	Grade input CU %	Grade input AU gram/t	Grade input AG gram/t	Open pit cashflow $	Open pit cashflow $ disc
1	1,483,848	10,516,152	7.09	95,351	0.1952	186	1,388,497	0.0364	505.4129	0.228	0.0641	1.0903	-16,257,162	-14,779,238
2	7,256,451	4,743,549	0.65	2,031,516	0.2616	5,314	5,224,935	0.0544	2842.365	0.3105	0.0678	1.0799	45,641,783	37,720,482
3	11,130,003	5,869,998	0.53	5,498,265	0.3002	16,506	5,631,737	0.0413	2325.907	0.3374	0.0851	1.0354	82,715,224	62,145,172
4	7,496,487	9,503,513	1.27	5,491,447	0.2717	14,920	2,005,040	0.0198	396.9979	0.2895	0.0896	1.2142	28,267,692	19,307,214
5	10,270,649	6,729,351	0.66	4,397,961	0.2189	9,627	5,872,689	0.0273	1603.244	0.2435	0.0814	1.1178	41,111,614	25,527,078
6	7,517,886	1,213,627	0.16	5,500,000	0.2387	13,129	2,017,886	0.0194	391.4699	0.2561	0.0751	1.0332	36,047,092	20,347,644
7	5,577,058	11,422,942	2.05	4,277,886	0.2268	9,702	1,299,172	0.0157	203.9700	0.2409	0.0944	1.2623	1,530,874	785,581
8	9,084,645	7,915,355	0.87	4,530,802	0.1891	8,568	4,553,843	0.0226	1029.169	0.2094	0.0663	1.1096	16,972,872	7,917,970
9	5,646,698	816,532	0.14	5,403,277	0.2183		243,421	0.0101	24.58552	0.2275	0.0884	1.1575	20,451,716	8,688,074
	65,463,725	58,731,019		**37,226,505**	0.2094	77,952	**28,237,220**	0.0330	9323.121				**256,481,705**	**167,659,977**

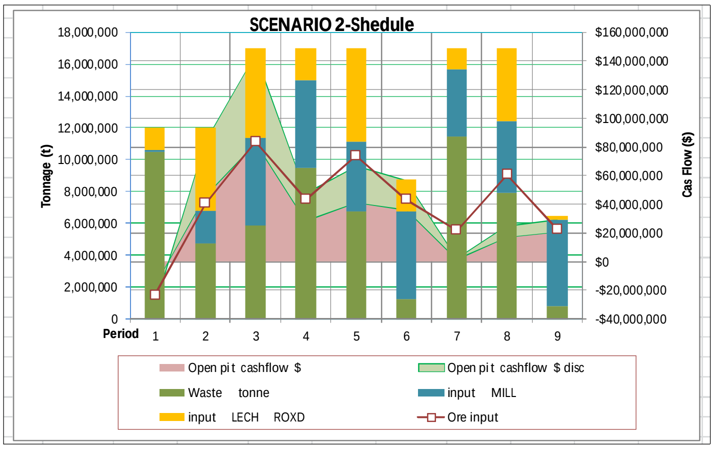

Figure 6 *Graphical view of mining dynamics per Scenariio 2, two processing methods MILL and LEAC; selective ore mining at the open pit*

SCENARIO 3 Two Types of Processing MILL (Flotation) and LEAC (Heap leaching) - Using Stock Pile

Table 6 *Mining dynamics per Scenario 3*

SCENARIO 3
Shedule graph, PB 19,26,35
METHODS: MILLS, LEAC,using STOCK PILE

Period	tonne input tonne	Waste tonne tonne	Grade input CU %	Strip ratio	tonne input MILL tonne	Grade input CUS %	**Total tonne RSUL input MILL Total tonne**	tonne input LECH tonne	**Total tonne ROXD input LEAC** Total tonne	Grade input CUOX %	to stockpile SP1-RSUL tonne	to stockpile SP2-ROXD tonne	from stockpile SP1-RSUL tonne	from stockpile SP2-ROXD tonne	Grade input AU gram/t	Grade input AG gram/t	Open pit cashflow $	Open pit cashflow $disc
1	4007473	12992527	0.248	4.73	466151	0.2103	**466,151**	2500000	**2,500,000**	0.042	285,841	755,480	0	0	0.0627	1.0459	-15,069,161	-13,699,237
2	11090720	5909280	0.3211	3.82	1024734	0.27	**1,310,575**	2500000	**2,500,000**	0.057	2,969,891	4,596,095	285,841	0	0.0697	1.1192	1,348,967	1,114,849
3	5854174	15145826	0.2866	2.59	3483203	0.2619	**5,500,000**	2370971	**2,500,000**	0.030	0	0	2,016,797	129,029	0.0985	1.0567	34,882,993	26,208,109
4	13715438	7284562	0.2878	1.97	4566208	0.2679	**5,500,000**	2500000	**2,500,000**	0.027	3,166,789	3,482,440	933,792	0	0.0919	1.2133	29,060,028	19,848,390
5	12774591	8225409	0.2487	3.36	2314153	0.2233	**5,500,000**	2500000	**2,500,000**	0.026	6,210,311	1,750,127	3,185,847	0	0.0749	1.0548	15,770,587	9,792,294
6	12525343	8474657	0.2297	2.52	3472467	0.2118	**5,500,000**	2500000	**2,500,000**	0.013	4,065,003	2,487,872	2,027,533	0	0.0862	1.3173	9,011,769	5,086,909
7	5442522	752221	0.2274	0.14	5201753	0.2183	**5,500,000**	240769	**2,500,000**	0.012	0	0	298,247	2,259,231	0.0891	1.166	39,699,894	20,372,323
8	0	0	0	999.99	0	0	**5,500,000**	0	**2,500,000**	0	0	0	5,500,000	2,500,000	0	0	55,009,671	25,662,417
9	0	0	0	999.99	0	0	**2,449,779**	0	**2,500,000**	0	0	0	2,449,779	2,500,000	0	0	35,498,778	15,054,947
10	0	0	0	999.99	0	0	**0**	0	**2,500,000**	0	0	0	0	2,500,000	0	0	19,828,642	7,644,800
11	0	0	0	999.99	0	0	**0**	0	**2,500,000**	0	0	0	0	2,500,000	0	0	19,828,642	6,949,818
12	0	0	0	999.99	0	0	**0**	0	**683,755**	0	0	0	0	683,755	0	0	5,423,171	1,851,880
	65,410,261	58,784,482					**37,226,505**		**28,183,755**		16,697,835	13,072,014	16,697,836	13,072,015			250,293,981	125,887,499

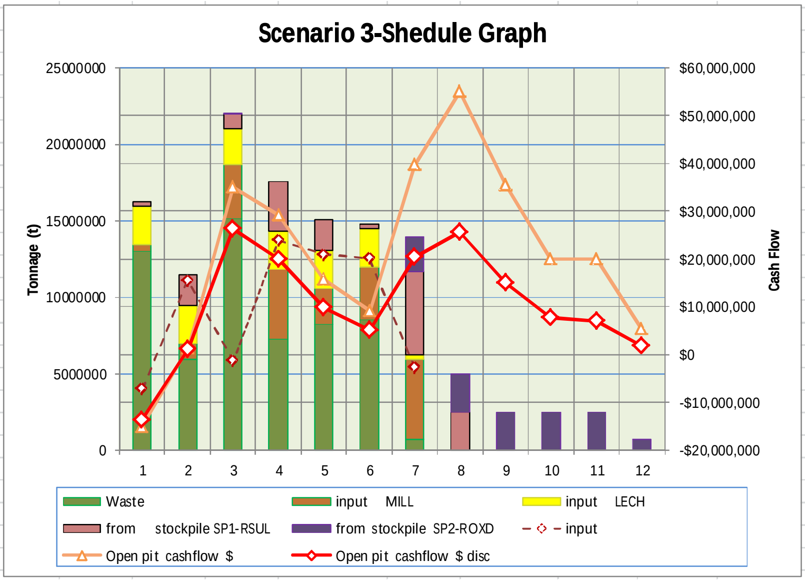

Figure 7 *Graphical view of mining dynamics per Scenario 3 – twp processing methods MILL and LEA, selective ore mining at the open pit*

CONCLUSION

The obtained possible open pits from the pit shells for *Revenu Factor 1*[3] *(*i.e. the selling price of a tone of Cu cathode of 5,000$*)*, are mutually different for about 8 million tons of ore in favor of combined method of processing, and the amounts of

[3] *Revenue Factor is a coefficient for multiplying the basic selling price of metal. In the case of this optimization the basic price is $ 5,000, and RevFtr is in the range 0.3 do 1.5.*

Cu in the ore for 16,502.44 t, while the had grade in the case of combination the processing method is higher for 3.27%. Discounted cash flow is higher for even 61.94%, as expressed in monetary units is 47,905,712 $.

These results of analysis, in addition to being a part of the input data related to leaching, solvent extraction and electrolysis - estimated on the basis of literature and experience in the world, and the degree of their accuracy is decreased, indicating in principle, to a significant improvement of economic results in the case of use the combined processing method. This suggests that it is needed to do more detailed tests (metallurgical test), which will increase the level of accuracy of the results to the level of relevance to business decision-making.

Table 7 *Comparative presentation of the cash flow for three scenarios of processing*

Period	Scenario 1		Scenario 2		Scenario 3	
	Open pit cashflow $	Open pit cashflow $disc	Open pit cashflow $	Open pit cashflow $disc	Open pit cashflow $	Open pit cashflow $disc
1	-9,847,862	-8,952,602	-16,257,162	-14,779,238	-15,069,161	-13,699,237
2	-3,387,689	-2,799,743	45,641,783	37,720,482	1,348,967	1,114,849
3	6,867,290	5,159,496	82,715,224	62,145,172	34,882,993	26,208,109
4	3,452,064	2,357,806	28,267,692	19,307,214	29,060,028	19,848,390
5	15,477,799	9,610,495	41,111,614	25,527,078	15,770,587	9,792,294
6	20,814,587	11,749,292	36,047,092	20,347,644	9,011,769	5,086,909
7	28,194,533	14,468,253	1,530,874	785,581	39,699,894	20,372,323
8	23,064,615	10,759,813	16,972,872	7,917,970	55,009,671	25,662,417
9	21,474,074	9,107,104	20,451,716	8,688,074	35,498,778	15,054,947
10	27,995,708	10,793,557	0	0	19,828,642	7,644,800
11	28,542,461	10,003,959	0	0	19,828,642	6,949,818
12	17,194,580	5,724,357	0	0	5,423,171	1,851,880
	179,842,160	77,981,787	256,481,705	167,659,977	250,293,981	125,887,499

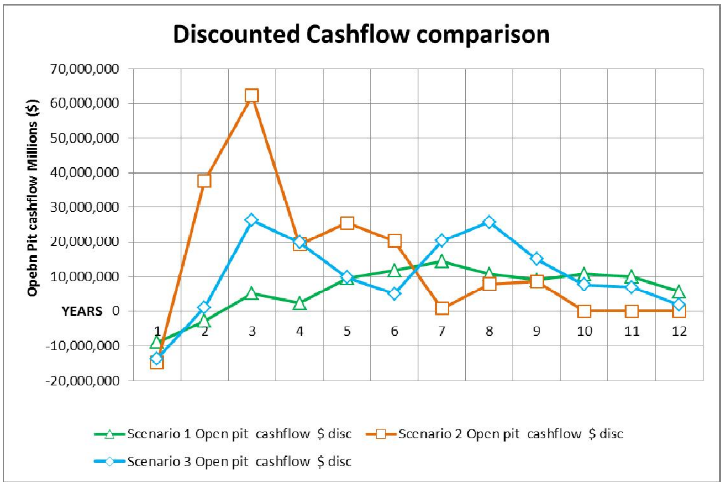

Figure 8 *Graph of comparative presentation of cash flow for all three scenarios of processing*

Difference in the discounted cash flow (total and incremental per year) between the analyzed Scenarios 1 and 2 is significant, while between 2 and 3 is not too large, even in favor of scenario without the use of stock piles, but it may be the result of insufficient knowledge of the actual techno - economic parameters of leaching process.

In this analysis mostly literature data on leaching have been used [1, 7], and partly based data on the assessed values of other's experiences and conclusions and comparisons with pyrometallurgical method of processing, where there is sufficient data. It is especially important for heap leaching to determine: recovery of basic and precious metals, as well as leaching time, also the costs of leaching pad preparation, consumption of acid, consumption of foil for substrate preparation, installation of distribution for acid (cyanide) and other normative materials as well as the costs of obtaining metals from leaching solutions in the metallurgical process of treatment. All of these costs should be kept to a ton of ore, ore a tone of the final product in the way defined by software Whittle and in the analysis of acceptance the input costs.

The authors of the paper work did not have the ambition to deal in this analysis with the technology of leaching (detailed technique and chemistry of the leaching process. They are of the other specialties, but to compare the economic effects of these cases of the applied methods of extraction the primary and associated precious metals, and based on that to make the certain conclusions presented in the paper.

The previous opinion of some experts as well as the inhabitants in the localities of ore deposits – Cerovo-Kraku Bugaresku, Ujova River and other current and potential localities, at which the deposits are located with similar characteristics, is that the leaching process is highly hazardous to the environment. Such opinion is denied in the world, inter alia, and because the total world production of copper, about 20%, is obtained by leaching. The most developed countries in the world do that because they take much more account of environmental protection than we do, and whose regulations in this area are far more stringent than ours (the United States, Chile, Canada, South Africa and others).

The purpose of this analysis is to highlight the potential alternative method which can increase the profit from the exploitation of deposits containing high contents of oxide minerals in the ore, which adversely affect the metal recovery in flotation method of enrichment. The analysis of this type, even it is the case of doubt whether even to exploit such deposits, i.e. whether the economics of exploitation is satisfactory, as there are conflicting opinions in the local professional community, can provide the adequate data for relevant qualified evaluation and decision.

It is important to note that it is the trend of leaching technology is also leaching of sulphide concentrates.

REFERENCES

[1] J. Peacey[1], G. Xian-Jian[1], E. Robles[2]: ,Copper Hydrometallurgy-Current Status, Preliminary Economics, Future Direction and Positioning Versus Smelting, J. Peacey[1], GUO Xian-Jian[1], E. Robles [2,1.]Hatch Associates Ltd., 2800 Speakman Drive, Mississauaga, Ontario L5K 2R7, Canada; [2]Hatch IngenierosyConsultores Ltda., San Sebastian 283, Piso 9, Los Condes, Santiago 6760226, Chile;

[2] J. F. Lupo: Design and Operation of Heap Leach Pads, By: John F. Lupo, Ph.D. Golder Asociates;

[3] C. Avendaño Varas: Review on Heap Leaching of Copper Ores, Carlos Avendaño Varas, Chemical Engenieer, Sociedad Terral S.A;

[4] R. Denis, M. Marcotte: 1,7 Million Square Meters PVC Heap Leach Pad Case History,Robert Denis, Solmax

International Inc., Varennes, Qc., Canada, Michel Marcotte, Genivar, Montreal, Qc., Canada, Draft paper submitted for publication GeoAfrica 2009;

[5] M. E. Orman, D. Romo, R. Tremayne: A Case Study of the Ocampo Phase 1 Heap Leach Expansion or Changing a Flat Pad to a Valley Fill, By: Marc E. Orman, David Romo, Russell Tremayne;

[6] Whittle Strategic Mine Planning, Gemcom Whittle™ Copyright © 2012 Gemcom Software International Inc.;

[7] G. Hovanec, Review of the Basic Economic Aspects of Copper Production Using the Method Acid Leaching, Mining Institute, Belgrade; (in Serbian)

[8] Z. Vaduvesković, M. Bugarin, D. Kržanović, Stripping Delaz Analysis in Relation to Designed Long-Term Plan of Excavation at the Open Pit Veliki Krivelj, Mining and Metallurgy Engineering Bor, 2/2013, pp.33-42.

[9] J. Vukašinović, J. Đorđević Boljanović, Mining Industry in the Knowledge Economy, Mining and Metallurgy Engineering Bor, 2/2013, pp. 117-126.

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ANALIZA MOGUĆNOSTI POBOLJŠANJA EKONOMSKIH POKAZATELJA EKSPLOATACIJE LEŽIŠTA CEMENTACIJA KRAKU BUGARESKU – RUDNO POLJE CEROVO***

Izvod

Cementacija Kraku Bugaresku je kompleks rudnih tela u jugoistočnom delu ležišta Cerovo. Sadrži znatan deo rude sa povećanim sadržajem oksida u odnosu na ukupan bakar u rudi, i sa postojećom tehnologijom prerade u dosadašnjem periodu postignutisu skromni rezultati u iskorišćenju metala.

Ovaj članak kroz analizu razmatra moguću kombinaciju metoda prerade klasičnom flotacijskom preradom sa pirometalurškom preradom i luženja na gomili sa hidrometalurškom ekstrakcijom metala postupkom SX-EW, sa aspekta ekonomske isplativosti takvog postupka. U članku je izvršeno najpre upoređenje rezultata optimizacije mogućih kopova na rudnom ležištu (Whittle Fx), u jednom i drugom slučaju za iste ulazne tehnoekonomske podatke. Dobijeni mogući kopovi iz procesa optimizacije (pit shells), za Revenu Factor 1 (tj. prodajnu cenu tone Cu katode od 5000 $), međusobno se razlikuju za oko 8 miliona tona rude u korist kombinovane metode prerade, a količine Cu u rudi za 16.502,44 t, dok je srednji sadržaj (had grade) u slučaju kombinacije metoda prerade veći za 3,27%. Diskontovani novčani tok (Cash Flow) je veći za čak 61,94%, što izraženo u novčanim jedinicama iznosi 47.905.712 $.

Keywords: *luženje na gomili, SX –EV, optimizacija kopova, diskontovani novčani tok.*

UVOD

Rudno polje Kraku Bugaresku (KB) Cementacija je deo kompleksa rudnih ležišta na lokalitetu Cerovo Mali Krivelj, koje se razlikuje od ostatka ležišta prema načinu nastanka i vrsti orudnjenja. To je cementaciona zona sekundarnog obogaćenja, i jedan deo orudnjenja spada u oksidne mineralizacije (oko 40% od ukupnih geoloških rezervi). Sastoji se od rudnih tela Cementacija 1, 2, 3 i 4 od kojih se prema sadržaju oksidne rude u odnosu na ukupne rezerve, izdvajaju cementacija 3 i 4. Prema sadržaju bakra, ovaj kompleks spada u siromašna ležišta čija je ekonomika eksploatacije vrlo osetljiva na pojedine parametre kao što su iskorišćenje metala u procesu obogaćenja, troškove eksploatacije u tehnološkom lancu od otkopavanja do metalurške prerade, pa čak i redosleda otkopavanja rudnih tela (Push backs) unutar cementacione zone.

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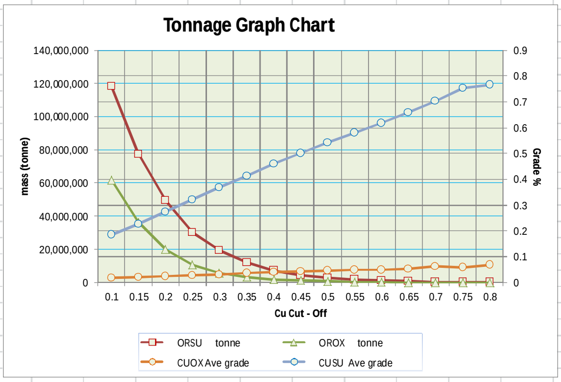
** *Univerzitet u Beogradu,Tehnički fakultet Bor*

*** *Članak je u sklopu projekata tehnološkog razvoja TR 33038 "Usavršavanje tehnologija eksploatacije i prerade rude bakra sa monitoringom životne i radne sredine u RTB Bor Grupa" i TR 34004 "Nova proizvodna linija za dobijanje bakra solventnom ekstrakcijom rudničkih voda", koji su finansirani od strane Ministarstva prosvete, nauke i tehnološkog razvoja.*

Na sl. 1. prikazana je analiza "Grade tonnage" za različite granične sadržaje (*Cut-off*), što predstavlja karakteristiku ležišta, odakle se vidi odnos količina RSULF i ROXD, tj. količine jedne i druge vrste rude u ležištu.

Najzastupljeniji minerali bakra u gornjem delu ležišta, oksidacionoj zoni su kuprit, malahit i azurit, dok su u zoni sekundarnog sulfidnog obogaćenja najzastupljeniji kovelin i halkozin.

CU Cut-off	ORSU tonne	OROX tonne	CUOX Ave grade	CUSU Ave grade
0.1	118000050	61458241	0.0186	0.1841
0.15	77644440	35989082	0.0217	0.2273
0.2	49637929	20080618	0.0249	0.2721
0.25	30505437	10594773	0.0282	0.3209
0.3	19244147	5625561	0.0312	0.3682
0.35	11857650	3321796	0.0351	0.4136
0.4	7065534	1939478	0.0402	0.4609
0.45	4448241	1231875	0.0443	0.5024
0.5	2869062	700313	0.0472	0.5425
0.55	1847175	371250	0.0501	0.5792
0.6	1168264	151875	0.0502	0.6191
0.65	645079	42188	0.052	0.6597
0.7	287078	25313	0.0605	0.7032
0.75	134847	8438	0.0599	0.7521
0.8	75938	8438	0.068	0.7663

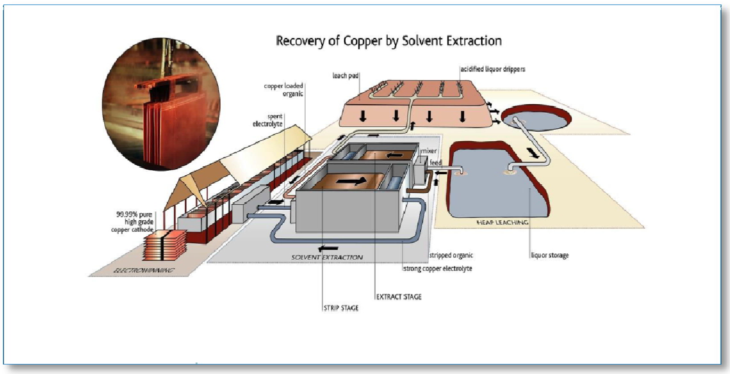


Sl. 1. *"Grade tonnage" analiza za ležište rude bakra KB Cementacija za različite granične sadržaje - tabela i grafik*

Dosadašnji način rada primenjen na eksploataciji ležišta Cementacija 1, koji se sastojao u flotacijskoj preradi celokupne količine rude iznad graničnog sadržaja, bez razdvajanja oksidnih partija rude od sulfidnih, rezultirao je niskim iskorišćenjem bakra u flotaciji koje se kretalo u intervalu između 50 i 70%[1]. To je svakako negativno uticalo i na ostvarene ekonomske rezultate.

Upravo zbog navedenih činjenica vrlo je značajno razmatranje i analiza mogućnosti povećanja NPV-a, odnosno Cashflow-a u eksploataciji ovog kompleksa rudnih tela.

Na sadašnjem nivou tehnološkog razvoja eksploatacije i iskorišćenja metala iz oksidnih i sulfidnih ruda, u poslednje vreme se značaj pridaje *luženju i solventnoj ekstrakciji lužnih* rastvora iz oksidnih ruda, pa čak i iz sulfidnih ruda (ili koncentrata).



Sl. 2. *Šematski Process Flow Diagram - Heap leach, Solvent Extraction and Electro Wining*

[1] *U zvaničnim dokumentima (Godišnji tehnički izveštaji proizvodnje RBB, 1993. -2000. godine) proizvodni rezultati nisu verodostojno prikazani*

ANALIZA U SOFTVERU ZA STRATEŠKO PLANIRANJE WHITTLE FX

Ulazni tehnoekonomski podaci za analizu vršenu u softveru za strateško planiranje Whittle Fx, za scenario 1. i 2., tj. flotiranje sulfidne i oksidne rude zajedno, bez selektivnog otkopavanja i selektivno otkopavanje sa dodatnom metodom metode obogaćivanja - luženjem na gomili rude sa preko 10% oksida, su sledeći:

Tabela 1. *Ulazni tehno-ekonomski parametri eksploatacije za proces optimizacije (input)*

Parametar	Jedinica	Vrednosti
Kapacitet otkopavanja - iskopine	t/god	12Mt od 3.godine 17 Mt
Kapacitet flotacijske prerade - Sulfidna ruda sa max. 10% oksidne	t/god	2,5Mt od 3. Godine 5,5 Mt
Kapacitet luženja na gomili – Oksidna ruda sa preko 10% sadržajem oksida	t/god	2.5 Mt
Cena bakra	$/tkatode	5,000.00
Cena zlata	$/kg	40,000.00
Cena srebra	$/kg	500.00
Troškovi otkopavanja	$/t	2,3.
Troškovi flotacijske prerade	$/t	4,00
Troškovi prerade luženjem na gomili	$/t rude	1.00
Troškovi metalurške prerade bakra	$/t katode	450.00
Troškovi metalurške prerade zlata	$/kg	150.00
Troškovi metalurške prerade srebra	$/kg	15.00
Troškovi hidrometalurške prerade (SXEW)	$/t katode	100.0
Inicijalni kapitalni troškovi luženja i SXEW	$	20,000,000
Ukupno iskorišćenje bakra (flot i metal)	%	0,788
Ukupno iskorišćenje zlata (flot i metal)	%	0,50
Iskorišćenje srebra (flot i metal)	%	0,40
Iskorišćenje bakra iz oksidne rude sa preko 10% sadržajem oksida	%	0,54
Diskontna stopa	%	10.0

Analiza[2] je vršena za 3 scenarija, i to:

1. Scenario 1 – metoda prerade označena sa „MILL“ tj. flotiranje ROXD i RSULF, odnosno dva tipa rude;
2. Scenario 2 – metoda „MILL“ za rudu sa > 10% oksida, i metoda „LEAC“ za rudu sa sadržajem > 10% oksida, pri čemu nije ograničen kapacitet luženja;
3. Scenario 3 – isti kao scenario 2, ali sa ograničenjem kapaciteta luženja na 2.500.000 t, i sa korišćenjem dve vrste skladišta (*Stock Piles*) za rudu do 10% oksida i rudu > 10% oksida (SP1 i SP2). Skladišta su korišćena kao "buffer" za dopunu projektovanog kapaciteta kako u flotaciji, tako i na luženju.

U daljoj analizi za SCENARIO 1 i 2 su tabelarno prikazani rezultati optimizacije u tabelama tipa *Pit By Pit Garph, tj.* kopovi iz optimizacije sa sračunatim novčanim tokom i diskontovanim novčanim tokom za svaki kop iz seta ugnježdenih kopova. Ekonomski pokazatelji su sračunati za tri moguća slučaja – *Best Case*, *Worst Case* i *Specific Case*, tj za radne uglove kosina na kopu jednakim 0^o, maksimalni radni ugao i specifičan (izabrani) kop. Merodavan za ocenu i izbor optimalnog kopa po kriterijumu optimalnog profita je diskontovani novčani tok (*cash flow)* za maksimalni radni ugao. To znači da se izabrani kop (*Final pit*) otkopava po fazama (*Push backs*).

Za sva tri slučaja je projektovana i sračunata dinamika otkopavanja za vek eksploatacije izabranog kopa po navedenom kriterijumu, sa odgovarajućim grafičkim prikazom. Takođe su u tabelama prikazane i obračunate količine po vrstama rude (kao *Rock Type*), sa manjim i većim sadržajem oksida, odnosno ostvarenim kapacitetima za metodu "MILL" i metodu"LEAC", u scenariju 3. - sa dodatnim obračunatim količinama rude koje idu na skladište i koje sa skladišta idu u procese.

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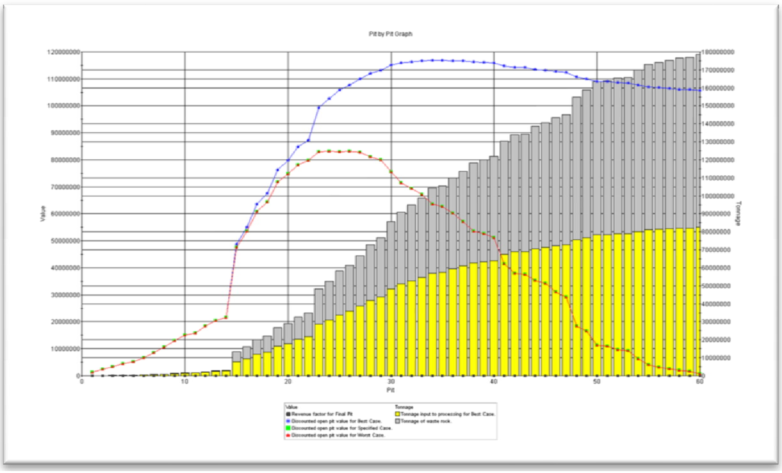
[2] *Pored napred navedenih ulaznih podataka, u softver Whittle se unosi i blok model ležišta, tzv. mod fajl. U kreiranju navedenog u osnovnom softveru, u ovom slučaju Gemcom, koristi se i topografija terena, odnosno stanje rudarskih radova na rudniku. U slučaju ove analize, stanje terena je 10.08.2001., tj. stanje pre ponovnog aktiviranja kopa, upravo zbog toga što analiza nije rađena u sklopu Studije ili projekta, nego je urađena sa svrhom da ukaže na mogućnosti povećanja ekonomskih efekata proizvodnje i pokrene značajnija istraživanja u pravcu extrakcije Cu i pratećih plemenitih metala hidrometalurškim postupkom.*

SCENARIO 1. Jedan tip prerade MILL (flotiranje) sulfidne i oksidne rude zajedno

Tabela 2. *Tabelarni prikaz rezultata optimizacije po Scenariju 1, sa obračunatim novčanog toka*

PIT BY PIT GRAPH - SCENARIO 1

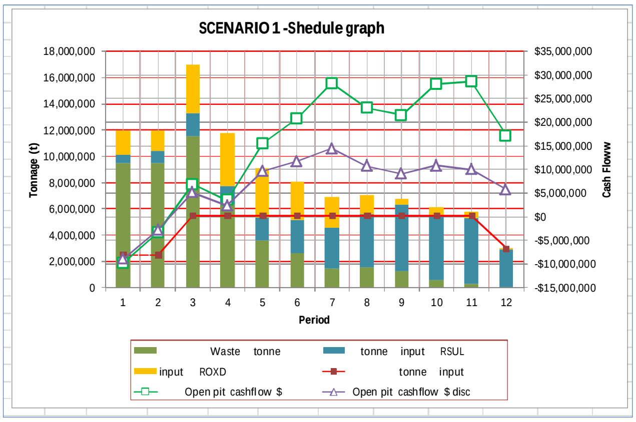
Final pit	Revenue factor for final pit	Open pit cashflow best $ disc	Open pit cashflow specified $ disc	Open pit cashflow worst $ disc	tonne input best	Waste best tonne	Mine life years best	Mine life years specified	Mine life years worst
1	0.32	1,257,649	1,257,649	1,257,649	64,520	9,407	0.03	0.03	0.03
2	0.34	2,340,019	2,340,019	2,340,019	127,897	9,971	0.05	0.05	0.05
3	0.36	3,265,188	3,265,188	3,265,188	188,088	10,150	0.08	0.08	0.08
4	0.38	4,415,908	4,415,908	4,415,908	272,142	14,544	0.11	0.11	0.11
5	0.4	5,121,194	5,121,194	5,121,194	326,594	28,340	0.13	0.13	0.13
6	0.42	6,782,948	6,782,948	6,782,948	475,371	39,226	0.19	0.19	0.19
7	0.44	8,622,922	8,622,922	8,622,922	654,558	64,086	0.26	0.26	0.26
8	0.46	10,525,070	10,525,070	10,525,070	868,580	85,685	0.35	0.35	0.35
9	0.48	13,053,414	13,053,414	13,053,414	1,188,709	111,857	0.48	0.48	0.48
10	0.5	15,071,636	15,071,636	15,071,636	1,480,565	120,560	0.59	0.59	0.59
11	0.52	15,737,824	15,737,824	15,737,824	1,589,257	128,947	0.64	0.64	0.64
12	0.54	18,383,286	18,383,286	18,383,286	2,040,985	229,016	0.82	0.82	0.82
13	0.56	20,388,697	20,388,697	20,388,697	2,429,329	299,806	0.97	0.97	0.97
14	0.58	21,534,215	21,532,415	21,532,415	2,663,808	335,688	1.07	1.07	1.07
15	0.6	48,788,934	47,538,914	47,538,914	7,875,043	5,582,314	2.52	2.52	2.52
16	0.62	55,146,867	53,508,008	53,508,008	9,599,654	6,485,167	2.84	2.84	2.84
17	0.64	63,570,562	60,902,078	60,902,078	11,991,784	7,986,686	3.27	3.27	3.27
18	0.66	67,546,940	64,308,942	64,308,942	13,194,047	8,727,104	3.49	3.49	3.49
19	0.68	76,251,473	71,761,565	71,761,565	16,394,020	10,505,786	4.07	4.07	4.07
20	0.7	79,816,489	74,837,962	74,837,962	17,911,544	11,034,033	4.35	4.35	4.35
21	0.72	84,775,931	78,120,000	78,120,000	20,275,932	12,509,270	4.78	4.78	4.78
22	0.74	87,297,954	79,729,295	79,729,295	21,721,280	13,173,614	5.04	5.04	5.04
23	0.76	99,408,000	82,884,123	82,884,123	28,647,492	19,642,382	6.30	6.55	6.55
24	0.78	102,648,142	83,151,343	83,151,343	31,079,978	21,409,083	6.74	7.05	7.05
25	0.8	105,911,193	82,932,523	82,932,523	33,864,262	24,482,200	7.25	7.62	7.62
26	0.82	107,796,516	83,166,000	83,166,000	36,026,740	25,479,248	7.64	8.02	8.02
27	0.84	109,864,961	82,857,682	82,857,682	38,690,541	27,906,217	8.13	8.52	8.52
28	0.86	112,055,441	81,155,078	81,155,078	41,754,095	31,007,667	8.68	9.10	9.10
29	0.88	113,121,606	80,039,265	80,039,265	43,695,298	33,065,173	9.04	9.46	9.46
30	0.9	115,083,888	75,541,273	75,541,273	48,341,430	37,235,782	9.88	10.32	10.32
31	0.92	115,955,763	71,519,775	71,519,775	50,942,253	40,014,353	10.35	10.89	10.89
32	0.94	116,329,206	69,437,935	69,437,935	52,691,741	42,144,430	10.67	11.24	11.24
33	0.96	116,577,596	67,166,852	67,166,852	54,558,738	44,257,231	11.01	11.62	11.62
34	0.98	116,812,522	63,546,156	63,546,156	56,940,722	47,520,092	11.44	12.10	12.10
35	1	116,822,322	62,763,271	62,763,271	57,462,570	48,143,878	11.54	12.20	12.20
36	1.02	116,733,132	60,247,593	60,247,593	59,523,326	50,336,326	11.91	12.60	12.60
37	1.04	116,570,305	57,088,898	57,088,898	61,004,701	52,645,714	12.18	12.91	12.91
38	1.06	116,246,697	53,548,340	53,548,340	62,679,665	55,723,640	12.49	13.27	13.27
39	1.08	116,104,201	52,612,974	52,612,974	63,285,683	56,807,448	12.60	13.38	13.38
40	1.1	115,890,094	51,230,325	51,230,325	63,973,933	57,909,775	12.72	13.51	13.51
41	1.12	114,776,583	41,519,881	41,519,881	67,492,199	62,846,779	13.36	14.34	14.34
42	1.14	114,282,584	37,924,212	37,924,212	68,822,070	65,024,645	13.60	14.65	14.65
43	1.16	114,198,024	37,513,600	37,513,600	69,049,326	65,188,415	13.65	14.69	14.69
44	1.18	113,547,212	35,394,348	35,394,348	70,505,451	68,088,287	13.91	14.96	14.96
45	1.2	113,180,094	34,216,439	34,216,439	71,313,473	69,376,637	14.06	15.11	15.11
46	1.22	112,692,740	31,159,282	31,159,282	72,264,584	71,233,186	14.23	15.34	15.34
47	1.24	112,393,820	29,204,421	29,204,421	72,820,099	72,285,894	14.33	15.48	15.48
48	1.26	110,665,910	18,407,558	18,407,558	75,656,596	79,276,775	14.86	16.25	16.25
49	1.28	109,992,003	16,490,497	16,490,497	76,759,211	81,937,428	15.15	16.46	16.46
50	1.3	109,028,005	11,329,090	11,329,090	78,333,172	85,123,865	15.43	16.80	16.80
51	1.32	108,936,513	10,951,659	10,951,659	78,476,259	85,430,456	15.46	16.83	16.83
52	1.34	108,604,954	9,631,895	9,631,895	78,947,606	86,580,421	15.54	16.93	16.93
53	1.36	108,528,079	9,319,586	9,319,586	79,090,693	86,744,802	15.57	16.96	16.96
54	1.38	107,646,094	6,399,243	6,399,243	80,168,057	89,781,653	15.77	17.17	17.17
55	1.4	106,959,546	4,034,446	4,034,446	81,102,333	92,015,091	15.94	17.35	17.35
56	1.42	106,704,144	3,213,701	3,213,701	81,439,009	92,833,624	16.00	17.41	17.41
57	1.44	106,461,667	2,659,448	2,659,448	81,716,767	93,627,441	16.06	17.47	17.47
58	1.46	106,136,964	1,975,632	1,975,632	82,087,111	94,621,529	16.14	17.53	17.53
59	1.48	106,087,512	1,742,133	1,742,133	82,154,446	94,741,304	16.15	17.55	17.55
60	1.5	105,680,501	702,770	702,770	82,533,207	96,158,579	16.25	17.62	17.62



Sl. 3. *Pit by Pit graph - Grafik optimizacije po Scenariju 1*

Tabela 3. *Dinamika otkopavanja po Scenariju 1*

					SCENARIO 1_ SHEDULE GRAPPH										
	PB: 19, 26,3														
Period	tonne input	Waste tonne	Strip ratio	tonne input RSUL	Units input RSUL CU	Grade input CUS	tonne input ROXD	Units input ROXD CU	Grade input CUOX	Grade input CU	Grade input PRCU	Grade input AU	Grade input AG	Open pit cashflow $	Open pit cashflow $ disc
					x 100			x100							
1	2,497,779	9,502,221	3.8	601,834	241,726	0.2449	1,895,945	462,625	0.0413	0.282	15.4797	0.0753	1.1065	-9,847,862	-8,952,602
2	2,499,693	9,500,307	3.8	917,321	451,536	0.3076	1,582,372	426,201	0.0484	0.3511	15.7806	0.0802	1.0753	-3,387,689	-2,799,743
3	5,495,999	11,504,001	2.09	1,769,556	816,733	0.2808	3,726,443	952,774	0.0458	0.322	16.0559	0.0718	1.0124	6,867,290	5,159,496
4	5,499,999	6,315,358	1.15	1,462,051	427,596	0.2038	4,037,947	887,950	0.0393	0.2392	16.1273	0.0693	1.1278	3,452,064	2,357,806
5	5,500,000	3,586,533	0.65	1,785,345	533,392	0.2303	3,714,655	929,696	0.0397	0.266	14.6026	0.0791	1.1537	15,477,799	9,610,495
6	5,500,000	2,599,697	0.47	2,570,586	823,796	0.2542	2,929,414	753,057	0.0361	0.2867	13.4667	0.0727	1.0313	20,814,587	11,749,292
7	5,500,000	1,403,682	0.26	3,146,090	1,044,249	0.2634	2,353,910	553,530	0.0301	0.2905	11.1239	0.0848	1.0792	28,194,533	14,468,253
8	5,499,999	1,557,531	0.28	4,021,808	1,109,667	0.2397	1,478,191	300,803	0.0186	0.2564	7.6091	0.0862	1.0487	23,064,615	10,759,813
9	5,500,000	1,263,215	0.23	5,082,426	1,282,422	0.2367	417,573	85,504	0.0133	0.2487	5.3879	0.0827	1.031	21,474,074	9,107,104
10	5,500,000	605,505	0.11	4,879,546	1,326,078	0.252	620,454	125,263	0.0133	0.2639	5.2266	0.0996	1.2105	27,995,708	10,793,557
11	5,500,000	271,792	0.05	5,017,944	1,395,811	0.2582	482,056	88,229	0.0129	0.2698	5.0344	0.0848	1.3015	28,542,461	10,003,959
12	2,969,102	34,036	0.01	2,916,661	803,531	0.2654	52,440	12,601	0.0105	0.2749	3.7942	0.0994	1.3529	17,194,580	5,724,357
	57,462,571	48,143,878		34,171,168			23,291,400							179,842,160	77,981,787

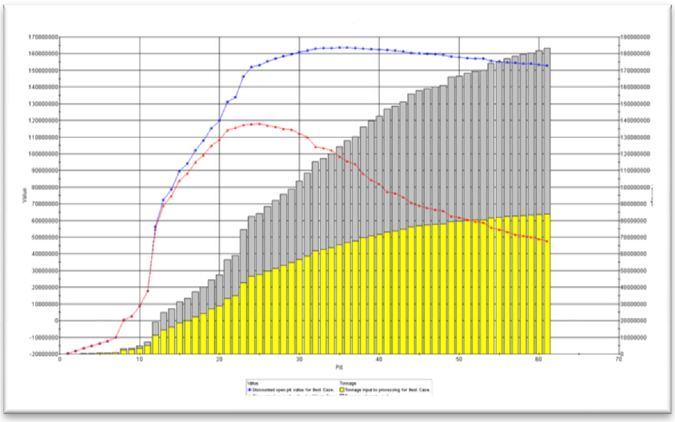


Sl. 4. *Grafički prikaz DINAMIKE otkopavanja po Scenariju 1, sa jednom metodom prerade – MILL; ukupne količine rude bez selektivnog otkopavanja idu u flotacijsku preradu i koncentrat na pirometalurški postupak*

SCENARIO 2. Dva tipa prerade MILL (flotiranje) i HEAP LEACHING (luženje na gomili)

Tabela 4. *Tabelarni prikaz rezultata optimizacije po Scenariju 2, sa obračunatim CashFlow*

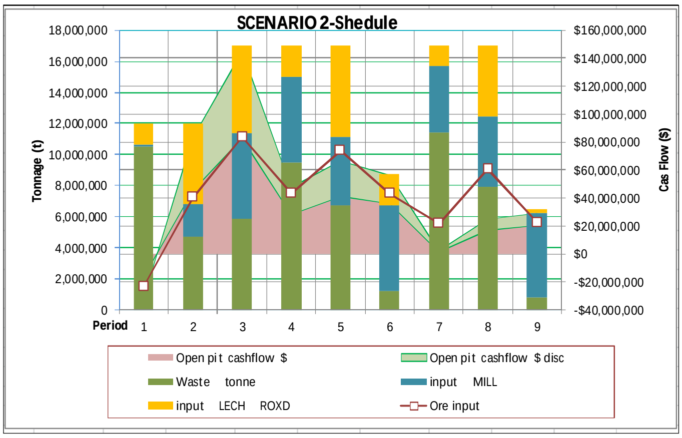
PIT BY PIT GRAPH - SCENARIO 2											
Final pit	Revenue factor for final pit	Open pit cashflow best $disc	Open pit cashflow specified $disc	Open pit cashflow worst $disc	tonne input best	Waste best tonne	Mine life years best	Mine life years specified	Mine life years worst	Internal rate of return best %	Internal rate of return worst %
1	0.3	-19,672,238	-19,672,238	-19,672,238	26,916	67	0.00	0.00	0.00	0	0
2	0.32	-18,172,452	-18,172,452	-18,172,452	117,064	11,192	0.03	0.03	0.03	0	0
3	0.34	-16,598,225	-16,598,225	-16,598,225	236,298	14,400	0.05	0.05	0.05	0	0
4	0.36	-15,206,239	-15,206,239	-15,206,239	356,166	17,900	0.08	0.08	0.08	0	0
5	0.38	-13,815,237	-13,815,237	-13,815,237	471,549	24,595	0.11	0.11	0.11	0	0
6	0.4	-12,477,700	-12,477,700	-12,477,700	623,194	47,353	0.13	0.13	0.13	0	0
7	0.42	-10,006,388	-10,006,388	-10,006,388	879,677	89,393	0.20	0.20	0.20	0	0
8	0.44	244,677	244,677	244,677	2,221,015	757,403	0.29	0.29	0.29	4.03	4.03
9	0.46	2,673,733	2,673,733	2,673,733	2,552,183	830,394	0.36	0.36	0.36	17.29	17.29
10	0.48	8,658,819	8,658,819	8,658,819	3,431,323	1,262,659	0.48	0.48	0.48	50.03	50.03
11	0.5	17,861,713	17,861,713	17,861,713	5,020,490	2,005,231	0.69	0.69	0.69	102.2	102.2
12	0.52	56,166,769	54,806,665	54,806,665	11,373,660	7,933,596	2.07	2.19	2.19	174.16	136.69
13	0.54	72,345,544	68,906,902	68,906,902	14,459,921	10,464,136	2.36	2.49	2.49	183.73	116.43
14	0.56	78,651,502	74,683,218	74,683,218	15,955,469	11,180,073	2.49	2.64	2.64	187.33	116.22
15	0.58	89,657,379	83,964,252	83,964,252	18,628,312	12,656,334	2.74	2.97	2.97	193.51	112.76
16	0.6	94,177,326	88,262,713	88,262,713	19,906,020	13,491,902	2.86	3.11	3.11	196.05	110.79
17	0.62	102,041,906	94,967,147	94,967,147	22,306,910	14,818,353	3.20	3.44	3.44	198.55	103.31
18	0.64	107,825,197	99,135,151	99,135,151	24,190,047	15,786,074	3.44	3.72	3.72	199.57	98.3
19	0.66	115,263,766	104,855,424	104,855,424	26,963,760	17,384,509	3.78	4.11	4.11	200.93	92.92
20	0.68	119,827,401	109,467,857	108,368,981	28,858,724	18,643,233	4.03	4.36	4.39	201.72	87.95
21	0.7	131,018,438	119,070,774	114,123,936	33,311,000	23,050,589	4.59	4.92	5.07	202.39	74.82
22	0.72	133,849,985	121,691,295	115,646,776	34,870,282	24,119,422	4.77	5.10	5.35	202.58	71.9
23	0.74	146,289,750	134,152,102	117,198,533	42,640,316	31,908,409	5.74	5.84	6.58	202.61	54.6
24	0.76	151,869,938	139,491,522	117,668,350	46,568,407	35,916,783	6.18	6.24	7.17	202.7	49.49
25	0.78	153,176,720	140,648,407	117,997,340	47,586,853	36,658,979	6.32	6.38	7.36	202.71	48.83
26	0.8	155,346,218	141,567,411	116,920,205	49,572,609	38,908,109	6.48	6.75	7.70	202.73	46.22
27	0.82	157,052,532	143,038,162	116,146,307	51,466,413	40,623,250	6.70	6.96	8.01	202.75	44.61
28	0.84	158,467,534	144,384,440	115,089,056	53,107,709	42,556,953	6.92	7.18	8.32	202.76	42.8
29	0.86	159,647,264	145,337,729	114,353,244	54,648,002	44,289,647	7.13	7.40	8.59	202.76	41.68
30	0.88	160,916,422	146,339,541	112,147,672	56,769,062	46,725,984	7.39	7.65	8.95	202.76	39.53
31	0.9	161,913,154	146,964,713	109,851,681	58,780,703	49,642,105	7.63	7.89	9.28	202.77	37.45
32	0.92	162,816,991	147,314,004	104,105,169	61,768,704	53,527,893	8.03	8.11	9.82	202.77	33.85
33	0.94	163,095,472	147,660,882	103,368,020	62,694,563	54,471,675	8.16	8.24	9.98	202.77	33.5
34	0.96	163,321,340	147,887,443	101,824,917	63,822,428	56,193,108	8.31	8.39	10.19	202.77	32.62
35	0.98	163,417,237	147,538,011	98,291,386	65,463,725	58,731,018	8.53	8.61	10.49	202.77	30.92
36	**1.00**	163,413,866	147,208,895	95,534,405	66,860,931	61,005,204	8.75	8.81	10.74	202.77	29.78
37	1.02	163,350,325	146,984,292	93,855,435	67,618,452	62,402,200	8.88	8.92	10.90	202.77	29.17
38	1.04	162,990,167	146,391,624	88,142,664	69,621,676	66,530,279	9.24	9.10	11.32	202.77	26.95
39	1.06	162,687,631	146,011,943	84,136,112	70,825,293	69,012,059	9.45	9.22	11.61	202.77	25.54
40	1.08	162,418,596	145,687,328	81,941,941	71,675,400	70,757,066	9.61	9.32	11.78	202.77	24.91
41	1.1	161,958,663	145,239,954	77,022,384	73,114,691	73,794,528	9.87	9.43	12.01	202.77	23.38
42	1.12	161,715,486	144,974,952	76,337,965	73,754,376	74,761,151	9.97	9.54	12.12	202.77	23.23
43	1.14	161,282,789	144,524,440	74,139,095	74,713,903	76,282,487	10.12	9.66	12.28	202.77	22.64
44	1.16	160,393,985	143,478,731	70,610,743	76,271,030	79,628,190	10.40	9.93	12.63	202.77	21.87
45	1.18	160,009,540	143,005,599	68,802,935	76,927,549	80,809,058	10.51	10.05	12.77	202.77	21.46
46	1.2	159,750,944	142,701,727	67,614,646	77,306,309	81,529,923	10.57	10.12	12.87	202.77	21.21
47	1.22	159,499,447	142,341,707	66,256,070	77,676,653	82,319,161	10.64	10.17	12.96	202.77	20.91
48	1.24	159,295,897	142,113,953	65,799,438	77,945,994	82,837,707	10.69	10.22	13.02	202.77	20.84
49	1.26	158,015,015	139,922,517	62,328,616	79,410,535	86,639,495	11.00	10.79	13.35	202.77	20.18
50	1.28	157,863,368	139,693,840	61,865,282	79,595,707	86,985,252	11.03	10.85	13.39	202.77	20.09
51	1.3	157,367,328	139,021,808	60,337,557	80,134,389	88,212,094	11.13	11.01	13.52	202.77	19.79
52	1.32	157,072,032	138,672,839	59,388,993	80,428,981	88,960,379	11.19	11.11	13.59	202.77	19.61
53	1.34	156,925,269	138,858,175	58,867,463	80,580,485	89,306,146	11.22	11.15	13.63	202.77	19.51
54	1.36	155,676,400	136,824,618	55,643,325	81,582,097	92,525,863	11.47	11.45	13.85	202.77	18.95
55	1.38	155,395,291	136,336,916	54,535,636	81,851,438	93,245,125	11.53	11.51	13.91	202.77	18.73
56	1.4	154,835,151	135,675,444	53,218,993	82,339,618	94,564,453	11.64	11.64	14.02	202.77	18.52
57	1.42	154,365,417	135,440,033	51,467,525	82,785,714	95,738,141	11.73	11.70	14.11	202.77	18.15
58	1.44	154,006,200	134,626,269	50,782,641	83,063,472	96,541,596	11.79	11.76	14.17	202.77	18.05
59	1.46	153,778,993	134,710,293	50,099,768	83,248,644	97,114,026	11.84	11.79	14.22	202.77	17.92
60	1.48	153,362,897	133,681,893	48,817,500	83,534,819	98,184,577	11.92	11.84	14.30	202.77	17.69
61	1.5	152,867,204	133,127,020	47,673,571	83,863,078	99,432,262	12.03	11.90	14.39	202.77	17.49



Sl. 5. *Pit by Pit Graph optimizacije po Scenariju 2. – output Whittle Fx*

Tabela 5. *Dinamika otkopavanja po Scenariju 2.*

							SCENARIO 2							
							Shedule Graph							
							PB: 19,25,35; Methods: MILL, LEAC,							
Period	Ore input tonne	Waste tonne	Strip ratio	input **MILL RSUL** tonne	Grade input CUS %	RSUL Units t	input **LECH ROXD** tonne	Grade input CUOX %	ROXD Units t	Grade input CU %	Grade input AU gram/t	Grade input AG gram/t	Open pit cashflow $	Open pit cashflow $disc
1	1,483,848	10,516,152	7.09	95,351	0.1952	186	1,388,497	0.0364	505.4129	0.228	0.0641	1.0903	-16,257,162	-14,779,238
2	7,256,451	4,743,549	0.65	2,031,516	0.2616	5,314	5,224,935	0.0544	2842.365	0.3105	0.0678	1.0799	45,641,783	37,720,482
3	11,130,003	5,869,998	0.53	5,498,265	0.3002	16,506	5,631,737	0.0413	2325.907	0.3374	0.0851	1.0354	82,715,224	62,145,172
4	7,496,487	9,503,513	1.27	5,491,447	0.2717	14,920	2,005,040	0.0198	396.9979	0.2895	0.0896	1.2142	28,267,692	19,307,214
5	10,270,649	6,729,351	0.66	4,397,961	0.2189	9,627	5,872,689	0.0273	1603.244	0.2435	0.0814	1.1178	41,111,614	25,527,078
6	7,517,886	1,213,627	0.16	5,500,000	0.2387	13,129	2,017,886	0.0194	391.4699	0.2561	0.0751	1.0332	36,047,092	20,347,644
7	5,577,058	11,422,942	2.05	4,277,886	0.2268	9,702	1,299,172	0.0157	203.9700	0.2409	0.0944	1.2623	1,530,874	785,581
8	9,084,645	7,915,355	0.87	4,530,802	0.1891	8,568	4,553,843	0.0226	1029.169	0.2094	0.0663	1.1096	16,972,872	7,917,970
9	5,646,698	816,532	0.14	5,403,277	0.2183		243,421	0.0101	24.58552	0.2275	0.0884	1.1575	20,451,716	8,688,074
	65,463,725	58,731,019		**37,226,505**	0.2094	77,952	**28,237,220**	0.0330	9323.121				**256,481,705**	**167,659,977**



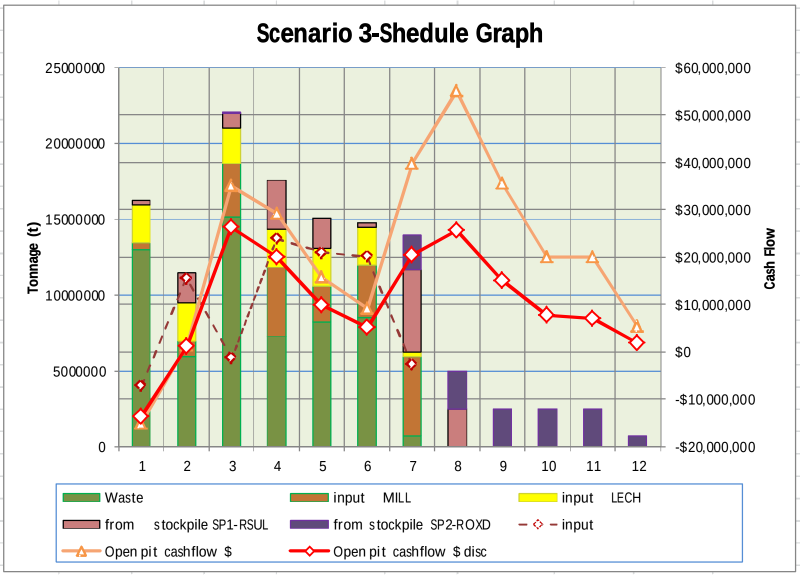
Sl. 6. *Grafik dinamike otkopavanja po Scenariju 2– dve metode prerade MILL i LEAC, selektivno otkopavanje rude na kopu;*

SCENARIO 3. Dva tipa prerade MILL (flotiranje) i LEAC (Heap leaching) – korišćenjem skladišta (Stock pile)

Tabela 6. *Dinamika otkopavanja po Scenariju 3*

SCENARIO 3
Shedule graph, PB 19,26,35
METHODS: MILLS, LEAC,using STOCK PILE

Period	tonne input	Waste tonne	Grade input CU	Strip ratio	tonne input MILL	Grade input CUS	**Total tonne RSUL input MILL**	tonne input LECH	**Total tonne ROXD input LEAC**	Grade input CUOX	to stockpile SP1-RSUL	to stockpile SP2-ROXD	from stockpile SP1-RSUL	from stockpile SP2-ROXD	Grade input AU	Grade input AG	Open pit cashflow $	Open pit cashflow $ disc
	tonne	tonne	%		tonne	%	**Total tonne**	tonne	Total tonne	%	tonne	tonne	tonne	tonne	gram/t	gram/t		
1	4007473	12992527	0.248	4.73	466151	0.2103	**466,151**	2500000	**2,500,000**	0.042	285,841	755,480	0	0	0.0627	1.0459	-15,069,161	-13,699,237
2	11090720	5909280	0.3211	3.82	1024734	0.27	**1,310,575**	2500000	**2,500,000**	0.057	2,969,891	4,596,095	285,841	0	0.0697	1.1192	1,348,967	1,114,849
3	5854174	15145826	0.2866	2.59	3483203	0.2619	**5,500,000**	2370971	**2,500,000**	0.030	0	0	2,016,797	129,029	0.0985	1.0567	34,882,993	26,208,109
4	13715438	7284562	0.2878	1.97	4566208	0.2679	**5,500,000**	2500000	**2,500,000**	0.027	3,166,789	3,482,440	933,792	0	0.0919	1.2133	29,060,028	19,848,390
5	12774591	8225409	0.2487	3.36	2314153	0.2233	**5,500,000**	2500000	**2,500,000**	0.026	6,210,311	1,750,127	3,185,847	0	0.0749	1.0548	15,770,587	9,792,294
6	12525343	8474657	0.2297	2.52	3472467	0.2118	**5,500,000**	2500000	**2,500,000**	0.013	4,065,003	2,487,872	2,027,533	0	0.0862	1.3173	9,011,769	5,086,909
7	5442522	752221	0.2274	0.14	5201753	0.2183	**5,500,000**	240769	**2,500,000**	0.012	0	0	298,247	2,259,231	0.0891	1.166	39,699,894	20,372,323
8	0	0	0	999.99	0	0	**5,500,000**	0	**2,500,000**	0	0	0	5,500,000	2,500,000	0	0	55,009,671	25,662,417
9	0	0	0	999.99	0	0	**2,449,779**	0	**2,500,000**	0	0	0	2,449,779	2,500,000	0	0	35,498,778	15,054,947
10	0	0	0	999.99	0	0	**0**	0	**2,500,000**	0	0	0	0	2,500,000	0	0	19,828,642	7,644,800
11	0	0	0	999.99	0	0	**0**	0	**2,500,000**	0	0	0	0	2,500,000	0	0	19,828,642	6,949,818
12	0	0	0	999.99	0	0	**0**	0	**683,755**	0	0	0	0	683,755	0	0	5,423,171	1,851,880
	65,410,261	58,784,482					**37,226,505**		**28,183,755**		16,697,835	13,072,014	16,697,836	13,072,015			250,293,981	125,887,499



Sl. 7. *Grafik Dinamike otkopavanja po Scenariju 3 - dve metode prerade MILL i LEAC, selektivno otkopavanje rude na kopu;*

ZAKLJUČAK

Dobijeni mogući kopovi iz procesa optimizacije (*pit shells*), za *Revenu Factor 1*[3] *(*tj. prodajnu cenu tone Cu katode od 5000$), međusobno se razlikuju za oko 8 miliona tona rude u korist kombinovane metode prerade, a količine Cu u rudi za 16,502. 44 t,

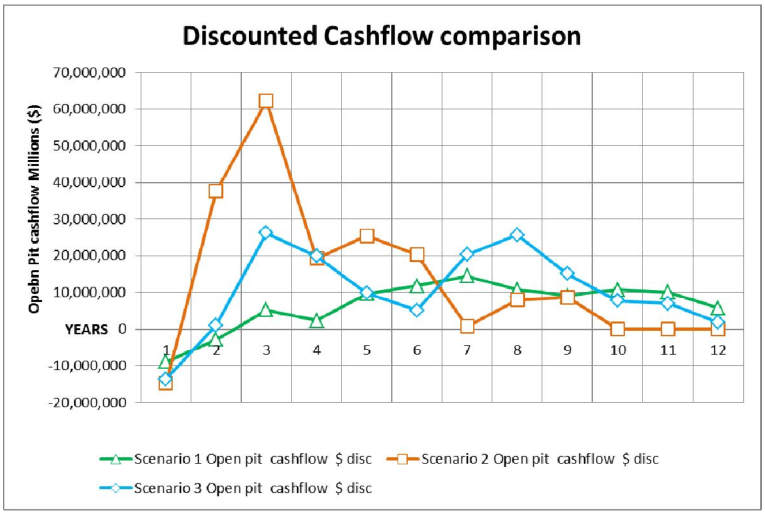
[3] *Revenue Factor je koeficijent kojim se množi bazna prodajna cena metala. U slučaju ove optimizacije bazna cena je $5000, a RevFtr se kreće od 0.3 do 1.5.*

dok je srednji sadržaj (*had grade*) u slučaju kombinacije metoda prerade veći za 3.27%. Diskontovani novčani tok (Cash Flow) je veći za čak 61.94%, što izraženo u novčanim jedinicama iznosi 47.905.712 $.

Navedeni rezultati analize, i pored toga što je deo ulaznih podataka vezanih za luženje, solventnu ekstrakciju i elektrolizu - procenjeno na osnovu literature i iskustava u svetu, pa je stepen njihove tačnosti smanjen, ukazuju, principijelno, na značajna poboljšanja tehno - ekonomskih rezultata u slučaju korišćenja kombinovane metode prerade. To upućuje nato da je potrebno uraditi detaljnija ispitivanja (*metallurgical test*), čime će se povećati stepen tačnosti rezultata do nivoa relevantnosti za donošenje poslovnih odluka.

Tabela 7. *Uporedni prikaz vrednosti novčanog toka (Cash Flow) za sva tri scenarija prerade*

Period	Scenario 1		Scenario 2		Scenario 3	
	Open pit cashflow $	Open pit cashflow $ disc	Open pit cashflow $	Open pit cashflow $ disc	Open pit cashflow $	Open pit cashflow $ disc
1	-9,847,862	-8,952,602	-16,257,162	-14,779,238	-15,069,161	-13,699,237
2	-3,387,689	-2,799,743	45,641,783	37,720,482	1,348,967	1,114,849
3	6,867,290	5,159,496	82,715,224	62,145,172	34,882,993	26,208,109
4	3,452,064	2,357,806	28,267,692	19,307,214	29,060,028	19,848,390
5	15,477,799	9,610,495	41,111,614	25,527,078	15,770,587	9,792,294
6	20,814,587	11,749,292	36,047,092	20,347,644	9,011,769	5,086,909
7	28,194,533	14,468,253	1,530,874	785,581	39,699,894	20,372,323
8	23,064,615	10,759,813	16,972,872	7,917,970	55,009,671	25,662,417
9	21,474,074	9,107,104	20,451,716	8,688,074	35,498,778	15,054,947
10	27,995,708	10,793,557	0	0	19,828,642	7,644,800
11	28,542,461	10,003,959	0	0	19,828,642	6,949,818
12	17,194,580	5,724,357	0	0	5,423,171	1,851,880
	179,842,160	77,981,787	256,481,705	167,659,977	250,293,981	125,887,499



Sl. 8. *Grafik uporednog prikaza Cash Flow za sva tri scenarija prerade*

Razlika u diskontovanom cashflow (zbirno i *incremental* po godinama) izmedju analiziranih scenarija 1. i 2. je značajna, dok između 2. i 3. nije prevelika, čak je u korist scenarija bez korišćenja stok pajlova, ali to može biti i posledica nedovoljnog poznavanja stvarnih tehno – ekonomskih parametara procesa luženja.

U ovoj analizi su korišćeni delom literaturni podaci o luženju [1,7], delom su vrednosti procenjene na osnovu drugih, tuđih iskustava ili zaključaka i poređenja sa pirometalurškim načinom prerade gde postoji dovoljno podataka. Naročito je bitno za luženje na gomili (*Heap Leaching*) utvrditi: iskorišćenja osnovnog i plemenitih metala, kao i vremena luženja, troškove same metode luženja od pripreme podloga za gomile rude koje će se tretirati, utroška kiseline, utroška folije za pripremu podloge, instalacije za razvod kiseline (cijanida) i drugih normativnih materijalakao i troškove dobijanja metala iz lužnih rastvora u metalurškom procesu prerade. Sve navedene troškove treba svesti na tonu rude, odnosno tonu finalnog proizvoda, na način kako softwer Whittle definiše i u analizi prihvata input troškova.

Autori članka nisu imali ambiciju da se u ovoj analizi bave samom tehnologijom luženja (detaljnom tehnikom i hemizmom procesa luženja) obzirom da su drugih specijalnosti, već da uporede ekonomske efekte za navedene slučajeve primenjenih metoda ekstrakcije osnovnog i pratećih plemenitih metala i na osnovu toga izvuku određene zaključke, prezentirane u radu.

Dosadašnje mišljenje dela stručne javnosti kao i stanovništva na lokalitetima rudnih ležišta - Cerovo Kraku Bugaresku, Ujova reka i drugih sadašnjih i potencijalnih lokaleta na kojima su ležišta sa sličnim karakteristikama, je da je postupak luženja vrlo rizičan po zaštitu životne sredine.Takvo mišljenje je demantovano u svetu, pored ostalog i time što se od ukupne svetske proizvodnje bakra, oko 20% dobija luženjem. To rade i najrazvijenije države u svetu, koje mnogo vise vode računa o zaštiti životne sredine nego mi, i čiji su propisi iz ove oblasti daleko stroživi od naših (SAD, Čile, Kanada, Južnoafrička Republika i dr.).

Svrha ove analize je da ukaže na potencijalnu, alternativnu metodu kojom se može uvećati dobit od eksploatacije ležišta koja sadrže povećani sadržaj oksidnih minerala u rudi koji negativno utiču na iskorišćenje metala pri flotacijskoj metodi obogaćivanja. Analiza ovog tipa čaki ako se radi o dilemi da li uopšte eksploatisati takva ležišta tj. da li je ekonomika eksploatacije zadovoljavajuća, o čemu postoje u ovdašnjoj stručnoj javnosti oprečna mišljenja, mogu dati odgovarajuće podatke za relevantnu kvalifikovanu ocenu i odluku.

Važno napomenuti i to da je trend tehnologije luženja – luženje i sulfidnih koncentrata.

LITERATURA

[1] J. Peacey[1], G. Xian-Jian[1], E. Robles[2]: ,Copper Hydrometallurgy-Current Status, Preliminary Economics, Future Direction and Positioning Versus Smelting, J. Peacey[1], GUO Xian-Jian[1], E. Robles [2,1.]Hatch Associates Ltd., 2800 Speakman Drive, Mississauaga, Ontario L5K 2R7, Canada; [2]Hatch IngenierosyConsultores Ltda., San Sebastian 283, Piso 9, Los Condes, Santiago 6760226, Chile;

[2] J. F. Lupo: Design and Operation of Heap Leach Pads, By: John F. Lupo, Ph.D. Golder Asociates;

[3] C. Avendaño Varas: Review on Heap Leaching of Copper Ores, Carlos Avendaño Varas, Chemical Engenieer, Sociedad Terral S.A;

[4] R. Denis, M. Marcotte: 1,7 Million Square Meters PVC Heap Leach Pad Case History,Robert Denis, Solmax International Inc., Varennes, Qc.,

Canada, Michel Marcotte, Genivar, Montreal, Qc., Canada, Draft paper submitted for publication GeoAfrica 2009;

[5] M. E. Orman, D. Romo, R. Tremayne: A Case Study of the Ocampo Phase 1 Heap Leach Expansion or Changing a Flat Pad to a Valley Fill, By: Marc E. Orman, David Romo, Russell Tremayne;

[6] Whittle Strategic Mine Planning, Gemcom Whittle™ Copyright © 2012 Gemcom Software International Inc.;

[7] G. Hovanec, Osvrt na osnovne ekonomske aspekte proizvodnje bakra primenom postupka kiselinskog luženja, Rudarski institut, Beograd;

[8] Z. Vaduvesković, M. Bugarin, D. Kržanović, Analiza kašnjenja u raskrivanju u odnosu na projektovani dugoročni plan otkopavanja na površinskom kopu Veliki Krivelj, Mining and Metallurgy Engineering Bor, 2/2013, str. 43-52.

[9] J. Vukašinović, J. Đorđević Boljanović, Rudarska industrija u ekonomiji znanja, Mining and Metallurgy Engineering Bor, 2/2013, str. 127-134..

UDK: 622.271/.68:622.73:681.325(045)=20 DOI:10.5937/MMEB1401037K

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SELECTION OF THE OPTIMUM LOCATION OF THE PRIMARY ORE CRUSHING AT THE OPEN PIT SOUTH MINING DISTRICT USING THE COMPARATIVE ANALYSIS OF SIMULATION RESULTS OF THE TRUCK TRANSPORT

Abstract

This work presents the procedure of transport simulation at the Open Pit South Mining District for two locations of the primary ore crushing and comparison of the achieved capacities and consumption of normative material, in order to determine the optimum location. Simulation was performed using the haulage and loading simulation software, Talpac.

Keywords: *simulation, Talpac, transport routes, location of primary crushing.*

INTRODUCTION

Copper deposit the South Mining District - Majdanpek is located close to the town of Majdanpek in the basin of the river Mali Pek. The open pit South Mining District, where the exploitation begun in 1959, is located within the copper deposit South Mining District – Majdanpek. The infrastructural facilities are situated in the immediate vicinity of the deposit that are used for ore processing as well as the truck waste landfills and flotation tailing dump. The open pit South Mining District is located at a distance of 0,5 km from the open pit North Mining District, which is also located near the town of Majdanpek (Figure 1).

The Feasibility Study has defined the dynamics of exploitation of the copper ore deposit South Mining District, with the annual capacity of ore mining of 8 500 000 t/year [1,2]. Dynamics of the Study has defined that only waste will be excavated in the first year in the operations *Andesite Finger* in the northwestern part of the open pit and the *East* in the eastern part of the open pit, while the ore will be excavated from the second year.

The primary ore crushing plant is located in the western side of the final contour of open pit, at elevation of K+375, while the waste will be transported primarily to the external landfills and after repairing the transport system for waste, to the crushing plant of this system TS-1 [1.3]. The fragmented waste is transported by the transport systems TS-1 to the landfill Ujevac.

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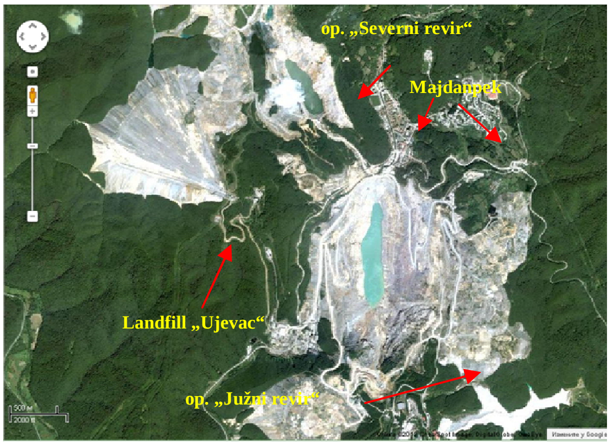


Figure 1 *Satellite image of mining facilities near the town of Majdanpek*

In addition to the above mentioned location of the ore crushing plant, there is a crushing plant located on the southern edge of the open pit North Mining District within the so-called Phase 2, at elevation of K+433 (Figure 2), which can be an alternative solution for ore crushing from the South Mining District.

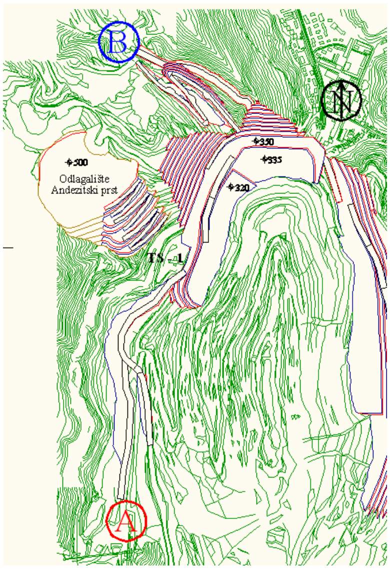


Figure 2 *North-western mining lay-out of the open pit South Mining District with locations of the primary crushing: A - location provided by the Feasibility Study; B - location of Phase 2 near the open pit North Mining District*

During mining operations in the *Andesite Finger* in the first year of excavation dynamics, disassembly of crusher was done in the western side of the open pit South Mining District and its relocation at the open pit Cerovo, in order to return the same on the study predicted location to the beginning of the second year of excavation dynamics.

However, due to a great possibility of delay in returning the crusher to the predicted location (A), an interim possible solution in such case is ore crushing on the crushing plant of "Phase 2" (B) in the North Mining District. The cost-effectiveness of such forced solution was also analyzed and by comparison of the operating costs of truck transportation of ore for two mentioned locations of the primary crushing.

For this purpose, the simulation of truck ore transport was done to the predicted location of the primary crushing (A) or to the location (B), i.e. Phase 2, using the haulage and loading simulation software Talpac and the results are presented for obtained exploitation capacities of truck, consumption of fuel, oil and greases and tires.

Description of the technological processes and transport routes at the Open Pit South Mining District

At the open pit South Mining District, a discontinuous mining technology is applied. Ore and overburden (waste) are prepared using the drilling-blasting works for loading with excavators whose bucket capacity is 15 m^3 (TEREX O&K - RH 120) and 22 m^3 (KOMATSU DEMAG PC4000-6). Transport of excavated material is done by trucks, whose payloads are 136 t (BELAZ 7513), 150 t (KOMATSU HD 1500-5) and 220 k (BELAZ 75306B). Transport routes, both at the open pit and external, are designed with maximum gradient not exceeding 8%, due to the technical characteristics of the truck fleet [2,4].

Figure 2 shows the mining layout of the north-western part of the open pit South Mining District (Andesite Finger) at the end of the second year of exploitation with a view of the primary crushing location. Label A represents the location of primary crushing that is provided by the Feasibility Study. Crushing plant at this location is at elevation K+375. The average length of transport routes from the center of mass at the site is 2.06 km in the second year and 2.91 km in the third year. Label B represents the location of crushing plant on the southern edge of the open pit North Mining District, so called Phase 2. Crushing plant at this location is at elevation K+433. The average length of transport routes from the site at the open pit South Mining District is 1.92 km in the second year and 2.57 km in the third year of exploitation.

Comparing the transport routes for the given locations, it can be seen that the transport routes have less length in the case of ore transport to the location B (Phase 2), but it is also evident that the height of lifting is greater (K+433) than it is the case with the location of A (K+375). This can be seen in more detail in the following figures (Figures 3 and 4).

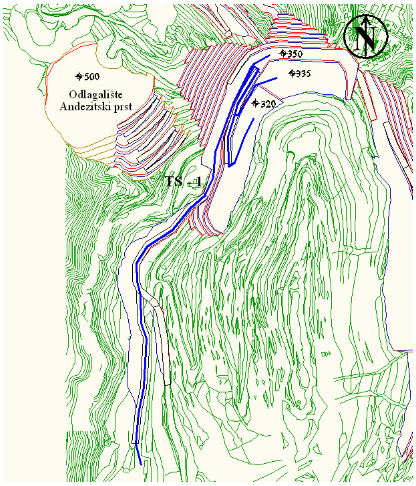


Figure 3 *Mining layout of open pit South Mining District at the end of the second year with the presented transport route to the crushing plant (location A)*

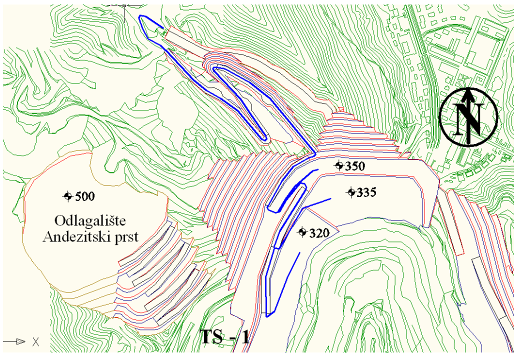


Figure 4 *Mining layout of open pit South Mining District at the end of the second year with the presented transport route to the crushing plant Phase 2 (location B)*

Description of the database structure of input data, simulation types of transport systems and methods of calculation of the fuel consumption in the software Talpac

Optimization of transport that is carried out in Talpac allows that changing of input parameters such as the type of material, organization of work, type of loading and transport equipment and characteristics of transport routes, can determine the optimal solution for transport system at the open pit the mine in terms of achievement of the lowest costs of this technological phase. This is achieved through the selection of appropriate equipment and transport routes which allow higher capacity, and hence smaller truck fleet and lower costs of consumables, out of which the most important is the fuel.

The structure of the input database of software Talpac defining loading-transport cycle is shown in the following diagram (Figure 5) [5,6].

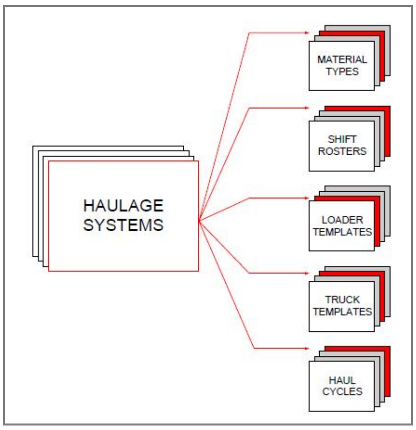


Figure 5 *Structure of the database of software Talpac*

There are two types of simulation in Talpac, as follows: *Full Simulation* and *Quick Estimate.*

Full simulation is a stochastic model that takes into account variability of data used in calculation, such as: time of loading and transport cycle, unloading time of the truck, coefficient of filling the excavator bucket and truck load capacity. Variation of these data in transport cycle, through a certain number of shifts, results into possible loss of time due to the truck waiting in line for loading or inactivity of the excavator due to the truck waiting, which finally affects the productivity of loading-transport system.

In contrast to the Full Simulation, the *Quick Estimate* is a deterministic model that does not take into account the variability of the above-mentioned data and therefore the obtained result is for the ideal case.

In the case of transport simulation at the open pit South Mining District, the method of *Full Simulation* was used.

Calculation of fuel consumption in Talpac is carried out over the trucks engine load (*rimpull* – traction force) that occurs in a particular segment of the transport cycle, depending on the speed of truck movement in this segment (Figure 6). This load depends on the material weight that is transported and the roads grade.

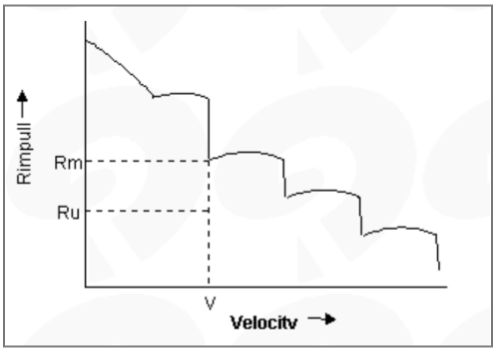


Figure 6 *Ratio of traction force ("rimpull") and speed of truck movement: R_m - maximum possible traction force for the achieved speed of movement in a particular segment; R_U - generated traction force for the achieved speed of movement in a particular segment; v - speed of truck movement*

Fuel consumption on a particular segment is calculated using the formula [7]:

$$\Delta f = \left[\frac{R_U}{R_m} \times \frac{(F_{100} - F_0)}{60} \right] \times \Delta t$$

where:

- Δf – spent fuel on a particular segment (l),
- R_U/R_m – ratio of generated and maximum traction force for the achieved speed at a particular segment,
- F_{100} – fuel consumption at 100% utilization of engine power (l/h),
- F_0 – fuel consumption when operating "at idle", exp. truck waiting to be loaded (l/h),
- Δt – time of truck movement in a particular segment.

Fuel consumption in each segment, cumulatively represents total fuel consumption for transport route. The average hourly fuel consumption is given by the following formula [7]:

$$F = (f_t \times N_{trips}) + \left[60 - (N_{trips} \times T_{travei}) \times \frac{F_0}{60} \right]$$

where:

F - average hourly fuel consumption (l/h),

f_t - total fuel consumption for transport route (l),

N_{trips} - number of transport cycles per hour,

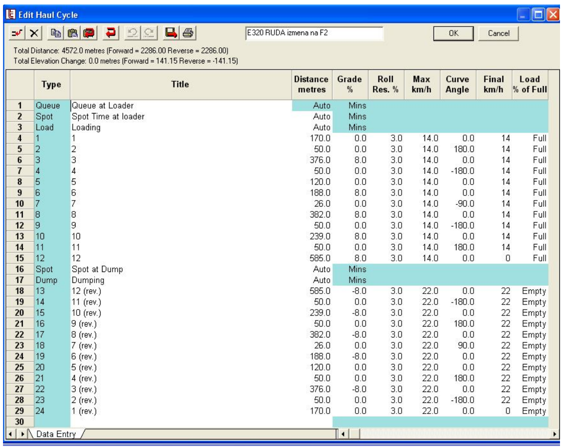
T_{travel} – time of transport cycle (min).

Simulation of truck transport depending on the location of primary crushing

Simulation of truck transport is carried out using the software Talpac for the first two years of ore excavation, i.e. for the second and third year according to the defined dynamics of ore excavation.

Simulation was performed with the following input data:

- data for the ore are taken for material, i.e. density of 2.65 t/m^3,
- 5,688 h/year is taken for the working time at the open pit *(Roster)*, i.e. 5,206 h/year for transport mechanization,
- transport route *(Haul Cycle)* is defined by entering the segments of appropriate lengths, slope, curve turns and the average speed of truck at the open pit (Figure 7),
- TEREX O&K - RH 120 excavator with bucket volume of 15 m^3 was chosen as a loading mechanization for ore in these years,
- BELAZ 7513 trucks, loading capacity of 136 t, KOMATSU HD 1500-5, loa-ding capacity of 150 t and BELAZ 75306B, loading capacity of 220 t, were chosen as a transport mechanization.


Edit Haul Cycle

E320 RUDA izmena na F2

OK | Cancel

Total Distance: 4572.0 metres (Forward = 2286.00 Reverse = 2286.00)
Total Elevation Change: 0.0 metres (Forward = 141.15 Reverse = -141.15)

	Type	Title	Distance metres	Grade %	Roll Res. %	Max km/h	Curve Angle	Final km/h	Load % of Full
1	Queue	Queue at Loader	Auto	Mins					
2	Spot	Spot Time at loader	Auto	Mins					
3	Load	Loading	Auto	Mins					
4	1	1	170.0	0.0	3.0	14.0	0.0	14	Full
5	2	2	50.0	0.0	3.0	14.0	180.0	14	Full
6	3	3	376.0	8.0	3.0	14.0	0.0	14	Full
7	4	4	50.0	0.0	3.0	14.0	-180.0	14	Full
8	5	5	120.0	0.0	3.0	14.0	0.0	14	Full
9	6	6	188.0	8.0	3.0	14.0	0.0	14	Full
10	7	7	26.0	0.0	3.0	14.0	-90.0	14	Full
11	8	8	382.0	8.0	3.0	14.0	0.0	14	Full
12	9	9	50.0	0.0	3.0	14.0	-180.0	14	Full
13	10	10	239.0	8.0	3.0	14.0	0.0	14	Full
14	11	11	50.0	0.0	3.0	14.0	180.0	14	Full
15	12	12	585.0	8.0	3.0	14.0	0.0	0	Full
16	Spot	Spot at Dump	Auto	Mins					
17	Dump	Dumping	Auto	Mins					
18	13	12 (rev.)	585.0	-8.0	3.0	22.0	0.0	22	Empty
19	14	11 (rev.)	50.0	0.0	3.0	22.0	-180.0	22	Empty
20	15	10 (rev.)	239.0	-8.0	3.0	22.0	0.0	22	Empty
21	16	9 (rev.)	50.0	0.0	3.0	22.0	180.0	22	Empty
22	17	8 (rev.)	382.0	-8.0	3.0	22.0	0.0	22	Empty
23	18	7 (rev.)	26.0	0.0	3.0	22.0	90.0	22	Empty
24	19	6 (rev.)	188.0	-8.0	3.0	22.0	0.0	22	Empty
25	20	5 (rev.)	120.0	0.0	3.0	22.0	0.0	22	Empty
26	21	4 (rev.)	50.0	0.0	3.0	22.0	180.0	22	Empty
27	22	3 (rev.)	376.0	-8.0	3.0	22.0	0.0	22	Empty
28	23	2 (rev.)	50.0	0.0	3.0	22.0	-180.0	22	Empty
29	24	1 (rev.)	170.0	0.0	3.0	22.0	0.0	0	Empty
30									

Data Entry

Figure 7 *Entering the segments of a transport route for level E320*

Figure 7 shows the transport cycle (*Haul Cycle*) for level E320 which consists of a loading cycle, a cycle of driving the full truck and unloading cycle, and also in the opposite direction to the movement of the empty truck, at the transport route which is incorporated in segments.

The result of calculation is significantly affected by exploitation-technical characteristics of selected equipment. These characteristics are a part of the standard database in Talpac that are used by the program in calculation. Talpac has a database of a large number of trucks that are in use, and if the truck is not in the database, there is a possibility of addition for new mechanization.

Figure 8 shows a diagram of ratio of the traction forces that are created during the truck movement and speed of movement in the case of a truck KOMATSU HD 1500-5, loading capacity 150 t. Diagram (taken from the Talpac database) shows a logical trend of decreasing the speed of truck movement with the increase of load in movement. Through these data, the pro gram determines achievable truck speeds in the segments of transport routes that are uphill, what ultimately affects the exploitation capacity of truck.

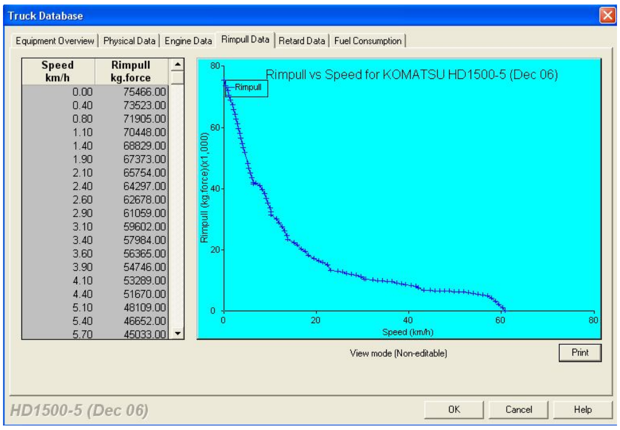


Figure 8 *Ratio of traction forces and movement speeds for KOMATSU HD 1500-5 truck*

Figure 9 shows a graph showing the dependence of fuel consumption on the loads in truck movement. Fuel consumption is calculated by the specific fuel consumption, which is taken from the manufacturer and recorded in the table (the upper left corner of Figure 9), taking into account the engine load of truck in movement, i.e. uphill vs. downhill movement.

As it can be seen from the diagram in Figure 9, the fuel consumption decreases during deceleration (downhill movement), or increases in acceleration of truck (uphill movement).

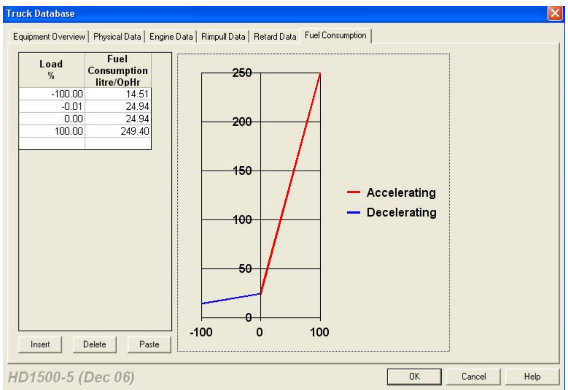
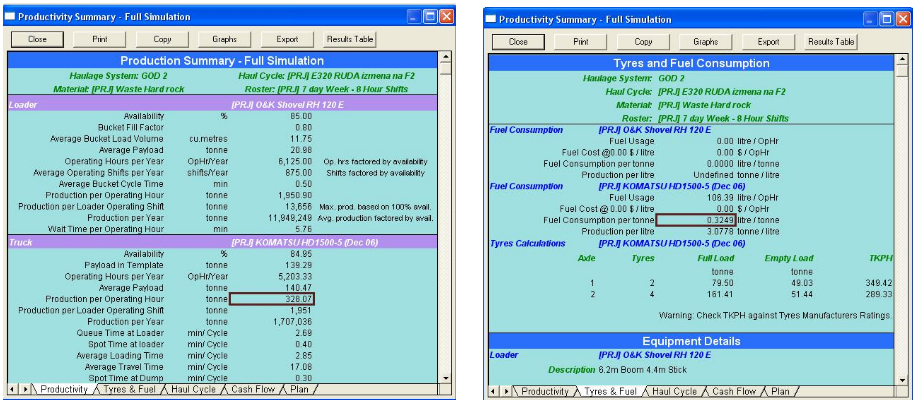


Figure 9 *"Window" for data entering on fuel consumption*

Based on the entered data on fuel consumption in a particular operation mode of truck engine, the program calculates the fuel consumption for the considered route.

Simulation results

Figure 10 shows the results of simulations for specific level (in this case the level E320), i.e. the exploitation capacity of truck and fuel consumption for this transport route. Consumption of oil and grease is adopted as 10% of fuel consumption, while the consumption of tires is calculated depending on the resulting exploitation capacity and lifetime of the tires, which is adopted as 4,800 Mh.



a) *b)*

Figure 10 *Simulation results : a) – exploitation capacity, b) – fuel consumption*

Table 1 shows an example of transport calculation for the second year of operation, in the case of ore transport to the crushing plant of Phase 2 (location B). The operational capacity and consumables are calculated for each route (level) separately, while for the final results of this year, the average weighted values are taken. The required number of trucks is obtained by dividing the planned annual production of ore and the annual capacity of one truck.

In the second year, due to lower volumes of ore, the simulation is only performed for trucks KOMATSU, loading capacity of 150 t. The Copper Mine Majdanpek (RBM) has 2 trucks of this type which satisfies the required number of trucks obtained by calculation.

In the third year occur large amounts of ore, and therefore require a large number of trucks. Simulation for this year was made taking into account the known number of trucks that RBM has, i.e. 2 trucks KOMATSU, loading capacity 150 t, and 3 trucks BELAZ, loading capacity 136 t, where the unknown (necessary) number of trucks BELAZ, loading capacity 220 t, is added which is required to meet the designed capacity. The result of calculation has shown that in addition to the known number of trucks, loading capacities 136 t and 150 t, another one truck, loading capacity 220 t, is required in order to achieve the planned capacity of transport, i.e. the total number of required trucks is 6. Method of calculation for the third year in the case of ore transport to Phase 2, is shown in Table 2. Exploitation capacity and consumables per levels, shown in Table 2, represent the average weighted values of the obtained results for individual trucks.

Method of calculation for the second location of crushing (location A) in the second and third year is the same to the shown one in Tables 1 and 2, so there is no need for a table view for this location, however the final results for this location will be shown in Table 3.

Table 3 presents the comparative results for the second and third year of the excavation dynamics for the locations of primary crushing A and B. Due to the shorter transport routes for location B (Phase 2), a slightly higher exploitation capacity is obtained and thus lower consumption of tires. On the other hand, due to the need for dealing with a large elevation difference for this location, the fuel consumption is increased. The required number of trucks in these two cases, for these two years, has not changed.

Table 1 *Results of calculation for the SECOND year for ore transport to Phase 2 (location B)*

Feedback	*Year*	*Level*	*Ore t*	*t/h*	*h/year*	*No. of trucks*	*Route length km*	*tkm*	*Oil, l/t*	*Oil & grease, l/t*	*Tires, tires/t*
1	2	3	4	5	6	7	8	9	10	11	12
Excavator 15m³ - Truck 150 t	**2.**	E380	27 732	*464.94	5 206	0.01	1.441	39 961	0.2157	0.02157	0,0000021
		E365	551 537	478.78	5 206	0.2	1.368	754 503	0.2103	0.02103	0,0000020
		E350	1 104 511	398.96	5 206	0.5	1.735	1 916 327	0.2536	0.02536	0,0000024
		E335	1 526 107	339.97	5 206	0.9	2.128	3 247 555	0.2994	0.02994	0,0000028
		E320	575 510	327.44	5 206	0.3	2.286	1 315 616	0.3250	0.0325	0,0000029
	Total		**3 785 397**	**376,418**	**5 206**	**1.9**	**1.9216**	**7 273 963**	**0.2763**	**0.02763**	**0.0000026**

Table 2 *Results of calculation for the THIRD year for ore transport to Phase 2 (location B)*

Feedback	*Year*	*Level*	*Ore t*	*t/h*	*h/year*	*No. of trucks*	*Route length km*	*tkm*	*Oil, l/t*	*Oil & grease, l/t*	*Tires, tires/t*
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Excavator 15m³ – Trucks 136 t, 150 t and 220 t	**3.**	E320	1 022 074	313.637	5 206	0.5	2.511	2 566 428	0.3071	0.03071	0.0000031
		E305	1 607 407	276.520	5 206	1.1	2.874	4 619 689	0.3532	0.03532	0.0000035
		E290	1 665 957	276.153	5 206	1.2	2.847	4 742 979	0.3640	0.03639	0.0000035
		E275	1 691 960	269.713	5 206	1.2	2.89	4 889 765	0.3857	0.03856	0.0000036
		E260	1 672 198	254.543	5 206	1.3	3.103	5 188 831	0.4192	0.04192	0.0000038
		E245	875 609	244.910	5 206	0.7	3.261	2 855.362	0.4492	0.04491	0.0000039
	Total		**8 535 206**	**271,995**	**5 206**	**6.0**	**2.91**	**24 863 055**	**0.3790**	**0.03790**	**0.0000035**

Table 3 *Comparative review of the results for both locations of primary ore crushing for various types of trucks*

Year / period	*Loading-transport feedback*	*Location of the crushing plant*	*Average length of route, km*	*Average hourly exploitation, capacity, t/h*	*Fuel consump. l/t*	*Oil and grease consump. l/t*	*Tire consump., tires/t*	*Required Number of trucks*
Year 2.	**Excavator 15m³ - Trucks150 t**	**A**	2.06	359.23	0.2082	0.02082	0.0000027	2
		B	1.92	376.42	0.2763	0.02763	0.0000026	2
Year 3.	**Excavator 15m³ – Trucks 136 t, 150 t and 220 t**	**A**	2.91	271.95	0.3790	0.03790	0.0000035	6
		B	2.57	280.25	0.3927	0.03927	0.0000034	6

* *In Tables 1 and 2, in columns 5 and 10 – exploitation capacity (t/h) and fuel consumption (l/t) for the route on the certain level, the results are given from the analysis in Talpac, while the other data are partly input (ore quantities), and partly derived by weighting and calculated on the basis of the results from the simulation in Talpac. For example: number of trucks for a certain level is calculated as a multiplication of columns 5 and 6, divided by column 4, i.e. (5 * 6) / 4.*

CONCLUSION

Applying the classical calculation method of transport, which does not take into account the characteristics of transport routes, for short transport route higher exploitation capacities would also be obtained but, on the other hand, also smaller values of consumables which is not the case here.

Using the haulage and loading simulation software, in this case the software Talpac, it is possible to make a decision based on more accurate obtained results than it is the case in using the conventional method of calculation. Also, once a simulation can be performed, it can be recalculated many times by changing the input parameters such as the type of loading and transport equipment, transport routes, speed of truck movement and planned organization of work.

On the other hand, to exploit the possibility of obtaining more precise simulation results, it is necessary to process the transport routes in detail, i.e. to enter into segments for each uphill, downhill and turn. This increases the time required for the calculation of transport compared to the classical method in which this is usually not done.

REFERENCES

[1] D. Kržanović et al.: Feasibility Study on Mining the South Mining District Deposit in the Copper Mine Majdanpek, Mining and Metallurgy Institute Bor, 2011;

[2] D. Kržanović, M. Žikić, N. Vušović, R. Pantović, S. Stojadinović: Optimum Development of the Open pit South Mining District in Majdanpek for Annual Capacity of Copper Ore Mining of 8 500 000 t, 44rd International October Conference on Mining and Metallurgy, Hotel Albo Bor, 1-3 October 2012; pp. 225-228

[3] D. Kržanović, M. Žikić, R. Pantović: Important Improvement of Utilization the Available Geological Reserves of the South Mining District Deposit in Majdanpek in the New Defined Optimum Contour of the Open Pit Using the Whittle and Gemcom Software, Mining Engineering, 1/2012, pp. 29-36;

[4] D. Kržanović, M. Žikić, S. Stojadinović: Analysis of the Realized and Catalog Fuel Consumption of Trucks Belaz 7530b in the First Year of Exploitation at the Open Pit Veliki Krivelj Serbia, Integrated International Symposium Tiorir, '11, Proceedings, Volume 1, Zlatibor, Serbia, 11-15 September 2011, pp. 60-64;

[5] V. Malbašić, J. Hamović: Economic Evaluation of Haulage System Shovel - Truck at the Open Pit Mines, The International Journal of Transport and Logistics, Issue 7, pp. 17-31, 2004;

[6] R. Janković, Lj. Savić: Simulation of Truck Haulage at the Open Pit Mine Majdanpek, Transport and Logistics, Issue 11, pp. 96-103, 2006;

[7] Talpac Manual: TALPAC Truck and Loader Productivity Analysis, Release 9, 2007.

[8] S. Mašić, M. Brčaninović, Analysis the Operating Parameters of БелАЗ Truck at the Open Pits of the Brown Coal Mine “Banovici” Based on Processor Data, Mining and Metallurgy Institute Bor, 4/2013, pp. 29-38.

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IZBOR OPTIMALNE LOKACIJE PRIMARNOG DROBLJENJA RUDE NA POVRŠINSKOM KOPU JUŽNI REVIR UPOREDNOM ANALIZOM REZULTATA SIMULACIJE KAMIONSKOG TRANSPORTA

Izvod

Ovim radom je prikazan postupak simulacije transporta na površinskom kopu Južni revir za dve lokacije primarnog drobljenja rude i upoređivanje postignutih kapaciteta i potrošnje normativnog materijala, u cilju određivanja optimalne lokacije. Simulacija je izvršena softverom za simulaciju utovarno - transportnih sprega Talpac.

Ključne reči: *simulacija, Talpac, transportna relacija, lokacija primarnog drobljenja.*

UVOD

Ležište bakra Južni revir – Majdanpek nalazi se u neposrednoj blizini grada Majdanpekau slivu reke Mali Pek. U okviru ležišta bakra Južni revir – Majdanpek nalazi se površinski kop Južni revir, u kome je eksploatacija počela 1959. godine. U neposrednoj okolini ležišta nalaze se infrastrukturni objekti koji se koriste za preradu rude, kao i kamionska odlagališta jalovine i flotacijsko odlagalište. Od površinskog kopa Severni revir, koji se takođe nalazi u blizini grada Majdanpeka, površinski kop Južni revir udaljen je oko 0,5 km (slika 1).

Studijom izvodljivosti definisana je dinamika eksploatacije ležišta rude bakra Južni revir, sa godišnjim kapacitetom otkopavanja na rudi od 8.500.000 t/god [1,2]. Dinamikom Studije je definisano da će se u prvoj godini otkopavati isključivo jalovina u zahvatima *Andezitski prst* u severozapadnom delu kopa i *Istok* u istočnom delu kopa, dok će se ruda otkopavati počev od druge godine.

Postrojenje primarnog drobljenja za rudu je locirano u zapadnom boku završne konture kopa, na koti K+375, dok će se jalovina transportovati najpre na spoljna odlagališta i nakon reparacije transportnog sistema za jalovinu, do drobiličnog postrojenja ovog sistema TS-1 [1,3]. Transportnim sistemom TS-1 usitnjena jalovina se transportuje na odlagalište Ujevac.

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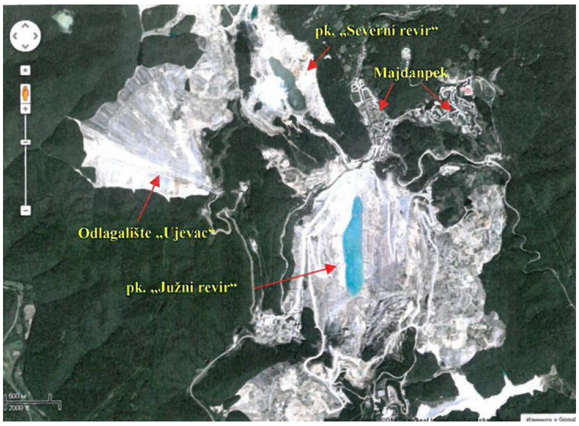
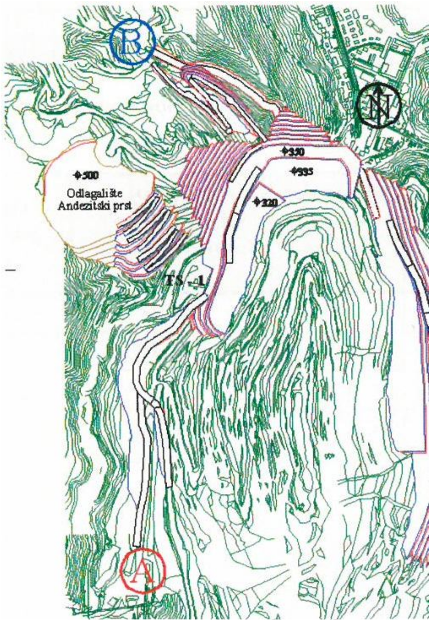


Sl. 1. *Satelitski snimak rudarskih objekata u blizini grada Majdanpeka*

Pored pomenute lokacije drobljenja rude, postoji i drobilično postrojenje koje se nalazi na južnom obodu površinskog kopa Severni revir u sklopu tzv. Faze 2, na koti K+433 (slika 2) koje može biti alternativno rešenje i za drobljenje rude sa Južnog revira.



Sl. 2. *Severo-zapadni zahvat kopa Južni revir sa lokacijama primarnog drobljenja: A - lokacija predviđena Studijom izvodljivosti; B - lokacija Faze 2 u blizini p. k. Severni revir*

Za vreme odvijanja rudarskih radova na Andezitskom prstu u toku prve godine dinamike otkopavanja, izvršena je demontaža drobilice u zapadnom boku p. k. Južni revir i njeno izmeštanje na p. k. Cerovo, sa ciljem da se ista vrati na Studijom predviđenu lokaciju do početka druge godine dinamike otkopavanja.

Međutim, zbog postojanja velike mogućnosti kašnjenja sa vraćanjem drobilice na predviđenu lokaciju (A), moguće prelazno rešenje u takvom slučaju je drobljenje rude na drobiličnom postrojenju „Faze 2“ (B) na Severnom reviru. Isplativost ovakvog iznuđenog rešenja analizirana je i upoređenjem eksploatacionih troškova kamionskog transporta na rudi za pomenute dve lokacije primarnog drobljenja.

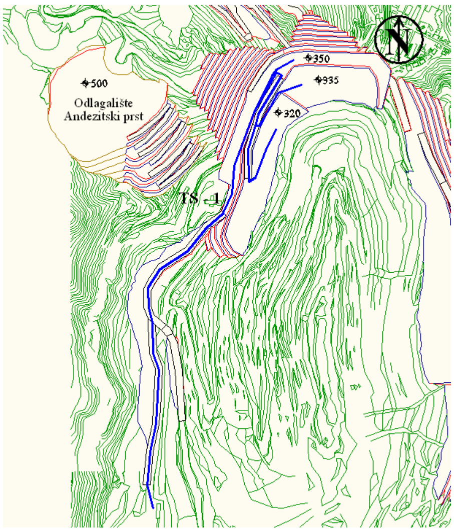
U tu svrhu izvršena je simulacija kamionskog transporta rude do predviđene lokacije primarnog drobljenja (A), odnosno do lokacije (B), tj. Faze 2, primenom softvera za simulaciju utovarno-transportnih sprega *Talpac* i prikazani su rezultati dobijenih eksploatacionih kapaciteta kamiona, potrošnje goriva, ulja i maziva i guma.

Opis tehnoloških procesa i transportnih relacija na površinskom kopu Južni revir

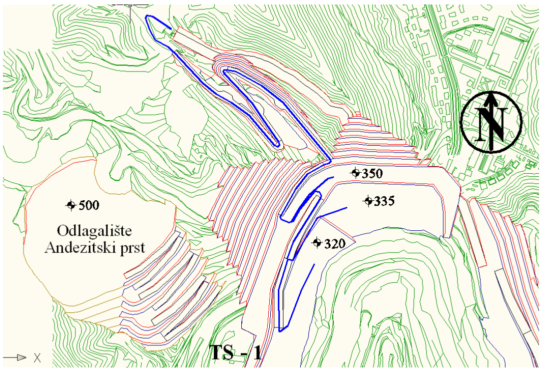
Na površinskom kopu Južni revir primenjuje se diskontinualna tehnologija otkopavanja. Ruda i raskrivka (jalovina) se bušačko-minerskim radovima priprema za utovar bagerima čije su zapremine kašika 15 m^3 (TEREX O&K - RH 120) i 22 m^3 (KOMATSU DEMAG PC4000-6). Transport iskopina se vrši kamionima nosivosti 136 t (BELAZ 7513), 150 t (KOMATSU HD 1500-5) i 220 t (BELAZ 75306B). Transportni putevi, kako u kopu tako i spoljni, su projektovani sa maksimalnim nagibom koji ne prelazi 8%, zbog tehničkih karakteristika dela kamionske flote [2,4].

Na slici 2 data je situacija u severnozapadnom delu površinskog kopa Južni revir (Andezitski prst) na kraju druge godine eksploatacije sa prikazom lokacija primarnog drobljenja. Oznaka A predstavlja lokaciju primarnog drobljenja koja je predviđena Studijom izvodljivosti. Drobilično postrojenje na ovoj lokaciji se nalazi na koti K+375. Prosečna dužina transportnih relacija od centra masa na radilištu je 2,06 km u drugoj godini i 2,91 km u trećoj godini. Oznaka B predstavlja lokaciju drobiličnog postrojenja na južnom obodu površinskog kopa Severni revir, tzv. Faza 2. Drobilično postrojenje na ovoj lokaciji se nalazi na koti K+433. Prosečna dužina transportnih relacija od radilišta na kopu Južni revir je 1,92 km u drugoj godini i 2,57 km u trećoj godini eksploatacije.

Upoređenjem transportnih relacija za navedene lokacije, vidi se da transportne relacije imaju manju dužinu u slučaju transporta rude prema lokaciji B (Faza 2), ali je takođe uočljivo da je visina dizanja veća (K+433) nego što je to slučaj sa lokacijom A (K+375). Ovo se može detaljnije videti na narednim slikama (slike 3 i 4).



Sl. 3. *Prikaz površinskog kopa „Južni revir“ na kraju druge godine sa prikazanom transportnom relacijom do drobiličnog postrojenja (lokacija A)*

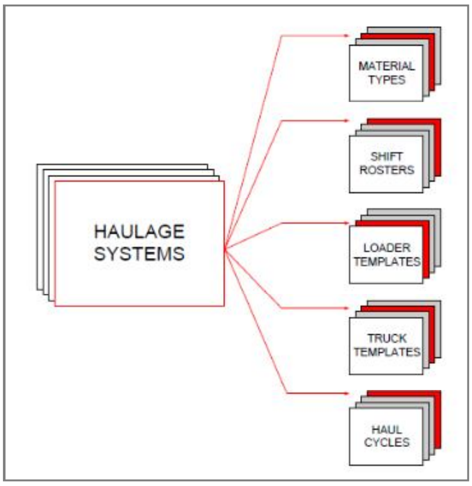


Sl. 4. *Prikaz površinskog kopa „Južni revir“ na kraju druge godine sa prikazanom relacijom do drobiličnog postrojenja „Faza 2“ (lokacija B)*

Opis strukture baze ulaznih podataka, tipova simulacije transportnih sistema i načina proračuna potrošnje goriva u softveru Talpac

Optimizacija transporta koja se izvodi u Talpaku omogućuje da se promenom ulaznih parametara poput vrste materijala, organizacije rada, vrste utovarne i transportne opreme i karakteristika transportne relacije, odredi optimalno rešenje za transportni sistem na kopu u smislu postiznja najnižih troškova ove tehnološke faze. Ovo se postiže kroz izbor adekvatne opreme i transportnih relacija koje omogućuju veći kapacitet, a time i manju kamionsku flotu i niže troškove normativnog materijala, od kojih je najznačajnije gorivo.

Struktura baze ulaznih podataka softvera Talpac kojom se definiše utovarno – transportni ciklus je prikazana na sledećoj šemi (slika 5) [5,6].



Sl. 5. *Struktura baze podataka sofvera Talpac*

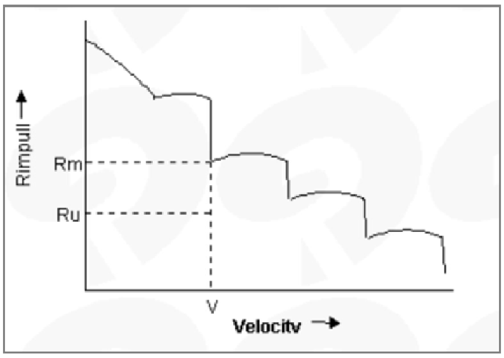
U Talpaku postoje dva tipa simulacije i to: *Full Simulation* (potpuna simulacija) i *Quick Estimate* (brza procena).

Potpuna simulacija predstavlja stohastički model i uzima u obzir varijabilnost podataka koji se koriste u proračunu, poput: vremena utovarnog i transportnog ciklusa, vreme istovara kamiona, koeficijent punjenja bagerske kašike i nosivost kamiona. Varijacija ovih podataka u transportnom ciklusu, kroz određeni broj smena, dovodi do mogućeg gubitka vremena zbog čekanja kamiona u redu na utovar ili neaktivnost bagera zbog čekanja na kamion, što konačno utiče na produktivnost utovarno – transportnog sistema.

Za razliku od potpune simulacije, simulacija *Quick Estimate* predstavlja deterministički model koji ne uzima u obzir varijabilnost pomenutih podataka i samim tim dobijeni rezultat je za idealni slučaj.

U slučaju simulacije transporta na površinskom kopu Južni revir korišćena je metoda *Full Simulation.*

Proračun potrošnje goriva se u Talpaku izvodi preko optrerećenja motora kamiona (*rimpull* – vučna sila) koje se javlja na određenom segmentu transportnog ciklusa u zavisnosti od brzine kretanja kamiona na tom segmentu (slika 6). Ovo opterećenje zavisi od težine materijala koji se prevozi i od nagiba puta.



Sl. 6. *Odnos vučnih sila („rimpull") i brzina kretanja kamiona: Rm-maksimalno moguća vučna sila za postignutu brzinu kretanja na određenom segmentu; Ru-ostvarena vučna sila zapostignutu brzinu kretanja na određenom segmentu; v-brzina kretanja kamiona*

Potrošnja goriva na određenom segmentu se računa preko formule: [7]

$$\Delta f = \left[\frac{R_U}{R_m} \times \frac{(F_{100} - F_0)}{60} \right] \times \Delta t$$

gde je:

- Δf – gorivo koje je potrošeno na određenom segmentu (l),
- R_U/Rm – odnos ostvarene i maksimalne vučne sile za postignutu brzinu kretanja na određenom segmentu,
- F_{100} – potrošnja goriva kod 100% iskorišćenja snage motora (l/h),
- F_0 – potrošnja goriva pri radu „u prazno", prim. čekanje kamiona na utovar (l/h),
- Δt – vreme kretanja kamiona na određenom segmentu.

Potrošnja goriva na svakom segmentu, kumulativno predstavlja ukupnu potrošnju goriva za transportnu relaciju. Prosečna časovna potrošnja goriva je data sledećom formulom: [7]

$$F = \left(f_t \times N_{trips}\right) + \left[60 - \left(N_{trips} \times T_{travei}\right) \times \frac{F_0}{60}\right]$$

Gde je:

F – prosečna časovna potrošnja goriva (l/h),

f_t – ukupna potrošnja goriva za transportnu relaciju (l),

N_{trips} – broj transportnih ciklusa na sat,

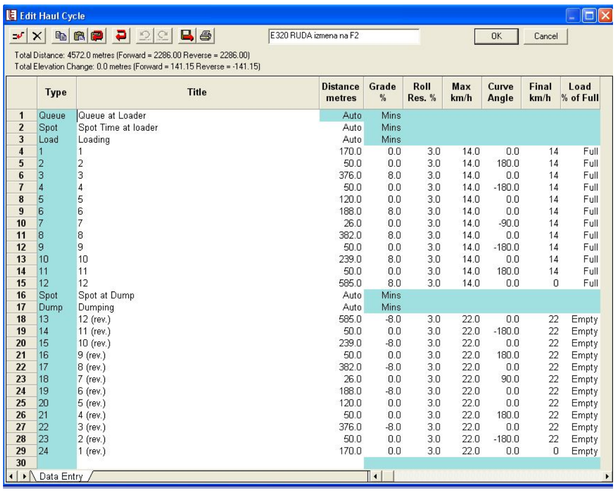
T_{travel} – vreme transportnog ciklusa (min).

Simulacija kamionskog transporta u zavisnosti od lokacije primarnog drobljenja

Simulacija kamionskog transporta je izvršena primenom softvera Talpac za prve dve godine u kojima se vrši otkopavanje rude, tj. za *drugu* i *treću* godinu prema projektovanoj dinamici otkopavanja.

Simulacija je izvršena sa sledećim ulaznim podacima:

- za materijal su uzeti podaci za rudu, tj. zapreminska masa od 2,65 t/m^3,
- za radno vreme na kopu (*Roster*) uzeto je 5.688 h/god, odnosno 5.206 h/god za transportnu mehanizaciju,
- transportna relacija (*Haul Cycle*) je definisana unošenjem segmenata odgovarajućih dužina, nagiba, krivina skretanja i prosečnih brzina kretanja kamiona na kopu (slika 7),
- za utovarnu mehanizaciju na rudi u ovim godinama izabran je bager TEREX O&K - RH 120 zapremine kašike 15 m^3,
- za transportnu mehanizaciju izabrani su kamioni BELAZ 7513 nosivosti 136 t, KOMATSU HD 1500-5 nosivosti 150 t i BELAZ 75306B nosivosti 220 t.



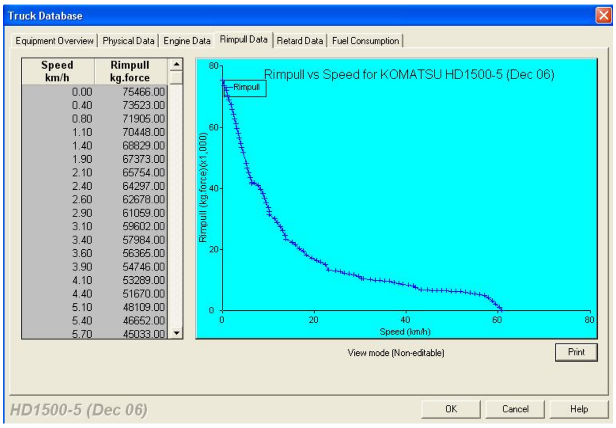
	Type	Title	Distance metres	Grade %	Roll Res. %	Max km/h	Curve Angle	Final km/h	Load % of Full
1	Queue	Queue at Loader	Auto	Mins					
2	Spot	Spot Time at loader	Auto	Mins					
3	Load	Loading	Auto	Mins					
4	1	1	170.0	0.0	3.0	14.0	0.0	14	Full
5	2	2	50.0	0.0	3.0	14.0	180.0	14	Full
6	3	3	376.0	8.0	3.0	14.0	0.0	14	Full
7	4	4	50.0	0.0	3.0	14.0	-180.0	14	Full
8	5	5	120.0	0.0	3.0	14.0	0.0	14	Full
9	6	6	188.0	8.0	3.0	14.0	0.0	14	Full
10	7	7	26.0	0.0	3.0	14.0	-90.0	14	Full
11	8	8	382.0	8.0	3.0	14.0	0.0	14	Full
12	9	9	50.0	0.0	3.0	14.0	-180.0	14	Full
13	10	10	239.0	8.0	3.0	14.0	0.0	14	Full
14	11	11	50.0	0.0	3.0	14.0	180.0	14	Full
15	12	12	585.0	8.0	3.0	14.0	0.0	0	Full
16	Spot	Spot at Dump	Auto	Mins					
17	Dump	Dumping	Auto	Mins					
18	13	12 (rev.)	585.0	-8.0	3.0	22.0	0.0	22	Empty
19	14	11 (rev.)	50.0	0.0	3.0	22.0	-180.0	22	Empty
20	15	10 (rev.)	239.0	-8.0	3.0	22.0	0.0	22	Empty
21	16	9 (rev.)	50.0	0.0	3.0	22.0	180.0	22	Empty
22	17	8 (rev.)	382.0	-8.0	3.0	22.0	0.0	22	Empty
23	18	7 (rev.)	26.0	0.0	3.0	22.0	90.0	22	Empty
24	19	6 (rev.)	188.0	-8.0	3.0	22.0	0.0	22	Empty
25	20	5 (rev.)	120.0	0.0	3.0	22.0	0.0	22	Empty
26	21	4 (rev.)	50.0	0.0	3.0	22.0	180.0	22	Empty
27	22	3 (rev.)	376.0	-8.0	3.0	22.0	0.0	22	Empty
28	23	2 (rev.)	50.0	0.0	3.0	22.0	-180.0	22	Empty
29	24	1 (rev.)	170.0	0.0	3.0	22.0	0.0	0	Empty
30									

Sl. 7. *Unos segmenata transportne relacije za etažu E320*

Na slici 7. prikazan je transportni ciklus (*Haul Cycle*) za etažu E320 koji se sastoji od ciklusa utovara, ciklusa vožnje punog kamiona i ciklusa istovara, takođe i u suprotnom smeru za kretanje praznog kamiona, na transportnoj relaciji koja je uneta u segmentima.

Na rezultat proračuna bitno utiču i eksploataciono - tehničke karakteristike izabrane opreme. Ove karakteristike su deo standardne baze podataka u Talpaku koju program koristi prilikom proračuna. Talpac poseduje bazu podataka o većem broju kamiona koji su u primeni, a u slučaju da se kamion ne nalazi u bazi, postoji mogućnost dopune za novu mehanizaciju.

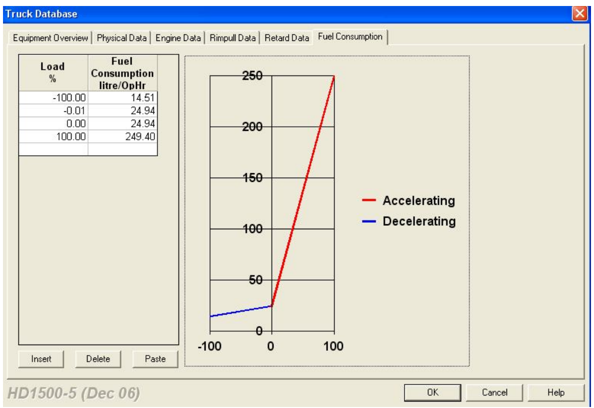
Na slici 8. je prikazan dijagram odnosa opterećenja (*vučnih sila*) koja se stvaraju prilikom kretanja kamiona i brzina kretanja za slučaj kamiona KOMATSU HD 1500-5, nosivosti 150 t. Dijagram (preuzet iz baze podataka Talpaka) pokazuje logičan trend opadanja brzine kretanja kamiona sa porastom opterećenja pri kretanju. Preko ovih podataka program određuje brzine kretanja kamiona koje je moguće ostvariti na segmentima transportnih relacija koje su pod usponom, što konačno utiče na eksploatacioni kapacitet kamiona.



Sl. 8. *Odnos vučnih sila i brzina kretanja kamiona KOMATSU HD 1500-5*

Na slici 9 prikazan je grafik koji pokazuje zavisnost potrošnje goriva od opterećenja prilikom kretanja kamiona. Potrošnja goriva je proračunata preko specifične potrošnje goriva, koja je preuzeta od proizvođača i uneta u tabelu (gornji levi ugao slike 9), uzimajući u obzir i opterećenje motora kamiona pri kretanju, tj. kretanje pri usponu, odnosno padu.

Kako se to može videti sa dijagrama na slici 9, potrošnja goriva opada pri usporavanju (kretanju po padu), odnosno povećava se pri ubrzanju kamiona (kretanju po usponu).

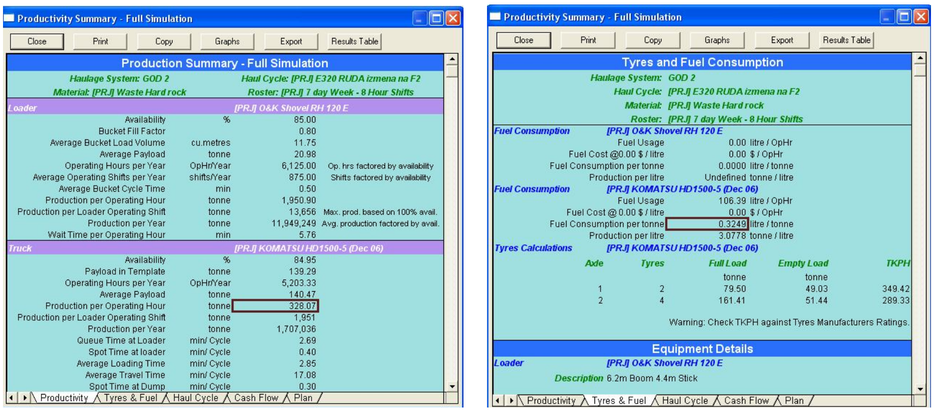


Sl. 9. *„Prozor“ za unos podataka o potrošnji goriva*

Na bazi unetih podataka o potrošnji goriva pri određenom režimu rada motora kamiona, program izračunava normativ potrošnje goriva za razmatranu relaciju.

Rezultati simulacije

Na slici 10 su prikazani rezultati simulacije za određenu etažu (u ovom slučaju etaža E320), tj. eksploatacioni kapacitet kamiona i potrošnja goriva za tu transportnu relaciju. Normativ ulja i maziva usvojen je kao 10% od potrošnje goriva, dok je normativ guma proračunat u zavisnosti od dobijenog eksploatacionog kapaciteta i veka trajanja guma koji je usvojen na 4.800 Mh.



a. *b.*

Sl. 10. *Rezultat simulacije (a. - eksploatacioni kapacitet, b. - normativ goriva)*

U tabeli 1 je prikazan primer proračuna transporta za drugu godinu eksploatacije, za slučaj transporta rude prema drobiličnom postrojenju Faze 2 (lokacija B). Eksploatacioni kapaciteti i normativi potrošnog materijala su proračunati za svaku relaciju (etažu) posebno, dok su za konačne rezultate za ovu godinu uzete srednje ponderisane vrednosti. Potreban broj kamiona je dobijen kao količnik planirane godišnje proizvodnje na rudi i godišnjeg kapaciteta jednog kamiona.

U drugoj godini, zbog manjih količina na rudi, simulacija je izvršena samo za kamione KOMATSU nosivosti 150 t. Rudnik bakra Majdanpek (RBM) poseduje 2 kamiona ovog tipa što zadovoljava proračunom dobijen potreban broj kamiona.

U trećoj godini se javljaju veće količine rude, a samim tim je potreban i veći broj kamiona. Simulacija za ovu godinu je izvršena uzimajući u obzir poznat broj kamiona koje RBM poseduje, tj. 2 kamiona KOMATSU, nosivosti 150 t i 3 kamiona BELAZ, nosivosti 136 t, kojima je dodat nepoznat (traženi) broj kamiona BELAZ, nosivosti 220 t, koji je potreban za zadovoljenje projektovanog kapaciteta. Rezultat proračuna je pokazao da je pored poznatog broja kamiona nosivosti 136 t i 150 t, potreban još jedan kamion nosivosti 220 t da bi se ostvario planirani kapacitet na transportu, tj. ukupno potreban broj kamiona je 6. Postupak proračuna za treću godinu, za slučaj transporta rude do Faze 2, prikazan je u tabeli 2. Eksploatacioni kapaciteti i normativi potrošnog materijala po etažama, koji su prikazani u tabeli 2, predstavljaju srednje ponderisane vrednosti dobijenih rezultata za pojedinačne kamione.

Postupak proračuna za drugu lokaciju drobljenja (lokacija A) u drugoj i trećoj godini je identičan prikazanom u tabelama 1 i 2, tako da nema potrebe za prikazom tabela za ovu lokaciju, već će konačni rezultati za tu lokaciju biti prikazani u tabeli 3.

U tabeli 3. uporedno su prikazani rezultati za drugu i treću godinu dinamike otkopavanja za lokacije primarnog drobljenja A i B. Zbog kraćih transportnih relacija za lokaciju B (Faza 2) dobija se nešto veći eksploatacioni kapacitet, a time i manji normativ na gumama. Sa druge strane, zbog potrebe savlađivanja većeg uspona za ovu lokaciju povećana je potrošnja goriva. Potreban broj kamiona u ova dva slučaja, za ove dve godine, nije promenjen.

Tabela 1. *Rezultati proračuna za DRUGU godinu za transport rude do Faze 2 (lokacija B)*

Sprega	*God*	*Etaža*	*Ruda t*	*t/h*	*h/god*	*Br. kamiona*	*Relacija km*	*tkm*	*Nafta l/t*	*Ulja i maziva l/t*	*Gume kom/t*
1	2	3	4	5	6	7	8	9	10	11	12
Bager 15m³ - Kamion 150 t	**2.**	E380	27 732	*464,94	5 206	0,01	1,441	39 961	0,2157	0,02157	0,0000021
		E365	551 537	478,78	5 206	0,2	1,368	754 503	0,2103	0,02103	0,0000020
		E350	1 104 511	398,96	5 206	0,5	1,735	1 916 327	0,2536	0,02536	0,0000024
		E335	1 526 107	339,97	5 206	0,9	2,128	3 247 555	0,2994	0,02994	0,0000028
		E320	575 510	327,44	5 206	0,3	2,286	1 315 616	0,3250	0,0325	0,0000029
	Total		**3 785 397**	**376,418**	**5 206**	**1,9**	**1,9216**	**7 273 963**	**0,2763**	**0,02763**	**0,0000026**

Tabela 2. *Rezultati proračuna za TREĆU godinu za transport rude do Faze 2 (lokacija B)*

Sprega	*God*	*Etaža*	*Ruda t*	*t/h*	*h/god*	*Br. kamiona*	*Relacija km*	*tkm*	*Nafta l/t*	*Ulja i maziva l/t*	*Gume kom/t*
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Bager 15m³ - Kamioni 136 t, 150 t i 220 t	**3.**	E320	1 022 074	313,637	5 206	0,5	2,511	2 566 428	0,3071	0,03071	0,0000031
		E305	1 607 407	276,520	5 206	1,1	2,874	4 619 689	0,3532	0,03532	0,0000035
		E290	1 665 957	276,153	5 206	1,2	2,847	4 742 979	0,3640	0,03639	0,0000035
		E275	1 691 960	269,713	5 206	1,2	2,89	4 889 765	0,3857	0,03856	0,0000036
		E260	1 672 198	254,543	5 206	1,3	3,103	5 188 831	0,4192	0,04192	0,0000038
		E245	875 609	244,910	5 206	0,7	3,261	2 855,362	0,4492	0,04491	0,0000039
	Total		**8 535 206**	**271,995**	**5 206**	**6,0**	**2,91**	**24 863 055**	**0,3790**	**0,03790**	**0,0000035**

Tabela 3. *Uporedni prikaz rezultata za obe lokacije primarnog drobljenja rude za različite tipove kamiona*

Godina / Period	*Utovarno-transportna sprega*	*Lokacija drobiličnog postrojenja*	*Prosečna dužina relacije, km*	*Prosečni eksploatacioni časovni kapacitet, t/h*	*Normativ goriva, l/t*	*Normativ ulja i maziva, l/t*	*Normativ guma, kom/t*	*Potreban broj kamiona*
God. 2.	**Bager 15m³ - Kamioni 150 t**	**A**	2,06	359,23	0,2082	0,02082	0,0000027	2
		B	1,92	376,42	0,2763	0,02763	0,0000026	2
God. 3.	**Bager 15m³ - Kamioni 136 t, 150 t i 220 t**	**A**	2,91	271,95	0,3790	0,03790	0,0000035	6
		B	2,57	280,25	0,3927	0,03927	0,0000034	6

* *U tabelama 1 i 2, u kolonama 5. i 10. – eksploatacioni kapacitet (t/h) i normativ potrošnje nafte (l/t) za relaciju na određenoj etaži, dati su rezultati iz analize u Talpac-u, dok su ostali podaci delom ulazni (količine rude), a delom izvedeni ponderisanjem i sračunati na osnovu rezultata iz simulacije u Talpac-u. Npr. broj kamiona za određenu etažu sračunat je kao količnik proizvoda kolona 5. i 6. i kolone broj 4., tj (5 * 6) / 4.*

ZAKLJUČAK

Primenom klasične metode proračuna transporta, u kojoj se ne uzimaju u obzir karakteristike transportnih relacija, za kraće transportne relacije bi se takođe dobili veći eksploatacioni kapaciteti ali, sa druge strane, i manje vrednosti normativa što ovde nije slučaj.

Primenom softvera za simulaciju utovarno-transportnih sprega, u ovom slučaju softvera Talpac, moguće je doneti odluku na bazi preciznije dobijenih rezultata nego što je to slučaj kod primene klasične metode proračuna. Takođe, jednom urađena simulacija se može više puta preračunati, izmenom ulaznih parametara poput vrste utovarne i transportne opreme, transportnih relacija, brzina kretanja kamiona i planirane organizacije rada.

Sa druge strane, da bi se iskoristila mogućnost dobijanja što preciznijih rezultata simulacije, potrebno je da se transportna relacija detaljnije obradi, tj. unese u segmentima za svaki uspon, pad i skretanje. Ovim se povećava vreme potrebno za proračun transporta u odnosu na klasičnu metodu u kojoj se ovo obično ne radi.

LITERATURA

[1] D. Kržanović i dr.: Studija izvodljivosti eksploatacije ležišta Južni revir u rudniku bakra Majdanpek, Institut za rudarstvo i metalurgiju Bor, 2011

[2] D. Kržanović, M. Žikić, N. Vušović, R. Pantović, S. Stojadinović: Optimum Development of the Open Pit South Mining District in Majdanpek for Annual Capacity of Copper Ore Mining of 8 500 000 t, The 44rd International October Conference on Mining and Metallurgy, Hotel Albo Bor, 1-3 oktobra 2012, str. 225-228

[3] D. Kržanović, M. Žikić, R. Pantović: Bitno poboljšanje iskorišćenja raspoloživih geoloških rezervi ležišta Južni revir Majdanpek u novo definisanoj optimalnoj konturi kopa primenom softverskih paketa Whittle i Gemcom, Rudarski radovi 1/2012, str. 21-28

[4] D. Kržanović, M. Žikić, S. Stojadinović: Analiza ostvarene i kataloške potrošnje goriva kamiona Belaz 7530b u prvoj godini eksploatacije na površinskom kopu Veliki Krivelj, Integrated International Symposium Tiorir '11, Proceedings, Volume 1, Zlatibor, Srbija, 11-15 septembra 2011, str. 60-64

[5] V. Malbašić, J. Hamović: Economic Evaluation of Haulage System Shovel - truck on the Open Pit Mines, The International Journal of Transport and Logistics, iss. 7, pp. 17-31, 2004

[6] R. Janković, Lj. Savić: Simulation of Truck Haulage at the Open Pit Mine Majdanpek, Transport i logistika, iss. 11, pp. 96-103, 2006

[7] Talpac Manual: TALPAC Truck and Loader Productivity Analysis, Release 9, 2007

[8] S. Mašić, M. Brčaninović, Analiza parametara rada kamiona БелАЗ na površinskim kopovima RMU "Banovići" na osnovu podataka sa procesora, Mining and Metallurgy Institute Bor, 4/2013, str. 39-48

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APPLICATION OF LIME IN THE POLYVINYL CHLORIDE INDUSTRY**

Abstract

This paper presents the importance of limestone in a variety of industries with a special focus on the use of limestone as filler in the industry of polyvinyl chloride (PVC). Of Out of all fillers, used in the industry of PVC processing, calcium carbonate type of fillers are 80%. Fillers are used in order to improve various mechanical properties of polymer such as tensile and breaking properties, density, bending strength, hardness, thermal stability, viscosity and more. Latest trends of industrial development and demands of the processing industry for high quality carbonate fillers influenced the implementation process of surface modification limestone and calcite, which is the main constituent of fine micronized limestone in order to enhance its performance.

Keywords*: limestone, calcite, filler, PVC*

INTRODUCTION

Limestone is used in a large number of industries including the industry for processing of polyvinyl chloride (PVC). The largest application of limestone is found in the construction industry where it is used to make plaster, concrete mixtures, in manufacturing various types of cement, lime and directly in the form of various sized crushed stone. Another important user of limestone is metallurgy, where limestone used in agglomeration, in blast furnaces and the Besemer smelting process. Chemical industry also uses a significant amount of raw materials in the industrial production of nitrogen compounds, pulp, paper, soda, chlorine lime, carbide, rubber and others. In agricultural, limestone is used for neutralization of acid soils, and as a feed additive. Significant amounts of limestone are used in the sugar industry, glass and ceramic industries. In many cases, particular industries have established the general standards of quality limestone, although some users set their own internal requirements.

The quality of limestone (defined chemical composition) refers to the smallest content of CaO, or $CaCO_3$, and maximum content of impurities and harmful components, such as Fe_2O_3, SiO_2, Al_2O_3, MgO, P_2O_5, TiO_2, MnO, Cr_2O_3 content of alkali, cement and others. The group of physical properties that determine the quality of limestone are: grain size distribution, fortress, capacity, porosity, colour, etc. Limestone, used as filler in a

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variety of industries, must be of high quality finely divided materials. In the products, based on limestone, the most important qualitative properties are colour (whiteness) and shine. Also, the physical structure of mineral and rock mass is an important factor, especially when considering the ability of grinding the mineral raw materials. Within these requirements, and for each purpose, or users, the appropriate standards are identified. Procedures for preparation the mineral raw materials are processed to a number of Ca-carbonate raw materials with different chemical and mineral composition, in order to obtain a large number of products for various industries. In literature, the Ca-carbonate mineral deposits are commonly classified as the industrial mineral resources, while the geologists classify them into dolomite and limestone, [1].

LIMESTONE-FILLER FOR POLYVINYL CHLORIDE

Among many different additives that are necessary to polyvinyl chloride (PVC) in order to obtain a definitive quality product, a significant place have special additives under the name fillers for PVC. The term filler in PVC processing technology includes generally very inexpensive inorganic material, resulting in the first task, which is to reduce the cost of overall mixture, or the finished product [2]. Mineral fillers, which also include limestone, with their largest application in the industry, are just thermoplastics, especially in PVC. Industry for the production of PVC sets certain requirements in terms of quality that apply to all fillers, including the limestone: to withstand heat, pressure and mechanical stresses with no changes that accompany the processing of PVC, should be well dispersed in PVC, more white, free of impurities and foreign matter, must not act abrasive, must not contain more than 0.4% moisture, if PVC are inactive, the fillers should be emphasized, however the need for their inertness and compatibility with all additives present in the mixture.

Limestone, as well as other inorganic fillers are added to the PVC is always in the form of fine, dry powder and in the mixing step of PVC with other additives, with the aim of better and more complete homogenisation. The latest trends of industry development and requirements of manufacturing industry for high quality carbonate fillers were directed towards finding the test procedures to improve properties of limestone as filler. Filler in order to get that power will improve the mechanical properties of PVC products is done by modifying the surface of calcite, which is the main constituent of fine micronized limestone. The most commonly used reagents for modification are fatty acid salts of various fatty acids, various oils, etc., [2-5]. Limestone with surface-modified mineral calcite can be very easily dispersed in the polymer giving a homogeneous mixture. Moreover, limestone modified in any area calcite shows more improved properties as compared to lime which was not modified with the calcite namely: limestone becomes highly hydrophobic and thus water repellent and moisture which is very important for each filler; calcite surface modification significantly reduces the abrasive effect of limestone; these fillers show the improved rheological properties, higher impact resistance and better electrical properties; the use of this type of filler gets significantly better surface finished products, given the smoothness, gloss and its appearance [6]. It should be noted that all of the fillers, used in the industrial processing of PVC, 80% of total consumption are calcium carbonate type fillers.

POLIVINIL CHLORIDE (PVC)

Polyvinyl chloride (PVC) is more than 70 years one of the most important polymers whose production capacity of about 20% of the total world production of polymers. By the procedure of polymerization vinyl chloride is obtained powder from which further processing produces two types of PVC and rigid and PVC soft (flexible) PVC. Rigid PVC is obtained by processing the polymer powder without special additives. Sheer is a tough, tough and hard to process, but very stable on the impact of atmospheric precipitation, humidity and chemicals. It is used for example for making window frames, ca-sings, etc. Soft PVC is obtained by processing the polymer powder with the addition of plasticizers. At the same time a thick paste was obtained, which is converted by heating into a homogeneous gel. Properties of soft PVC depend on the proportion of plasticizer. It has weaker mechanical properties, less resistant to the action of heat, chemical and atmospheric precipitations in relation to the rigid PVC, but pliable and easily processed. It is used for making insulators for cables, medical instruments, disposable tubes, gloves, etc. A transparent, soft PVC, and can be used for making transparent films, and bottles. In general, it can be said that the properties of polymer are determined by their internal material, and some of their properties are similar to the properties of solid crystalline bodies, while the other are similar to the properties of liquids. Physical and mechanical properties of rigid and soft PVC are shown in Table 1 [7].

Table 1 *Physical and mechanical properties of PVC*

Property	Unit	Rigid PVC	Soft PVC
Density	g / cm^3	1.38 to 1.55	1.16 to 1.35
Tensile Strength	MPa	40-60	10-25
Extension in breaking	%	30-70	250-450
Compressive strength	MPa	55-90	6-12
Hardness per Shore	-	D 65-85	A 40-100
Specific heat capacity	J / K g	0.8-1.1	1.3-2
Thermal Conductivity	W / K m	(15-20) x10^{-4}	(13-17) x10^{-4}
Coefficient of thermal expansion	1 / K	(5-10) x10^{-5}	(7-25) x10^{-5}
Temperature of constant use	^{o}C	65-85	50-70

PVC is produced nowadays in large quantities due to good mechanical and physical properties, as well as a diverse range of applications. PVC is non-flammable, burning in the presence of flame and chemically inert. It is compatible with many additives, including fillers plasticisers, stabilisers, lubricants and other polymers. Figure 1 shows the proportion of certain additives of polyvinyl chloride [8].

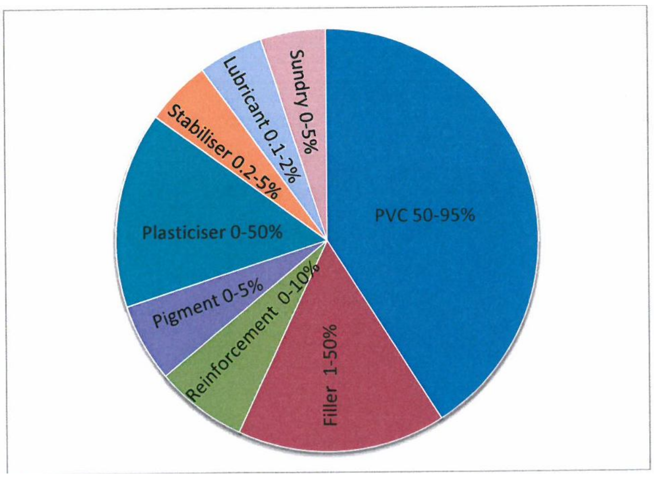

Figure 1 *Content of certain adittives in the PVC mixture*

These additives allow polymer to be more easily processed by various techniques, and to obtain the stable products in degradation of certain mechanical properties.

PLASTICS

Plastics are defined polymeric materials in the process of refining. Wherein it means that the polymeric material is everything that is processed, i.e. what the final product is made. Also, the plastic masses are materials obtained on the basis of polymer, having plasticity in some condition (high-temperature conditions), and which is completely or partially lost during transition to the other temperature conditions (low temperature). Plasticity of these materials allows them to obtain the necessary forms using the methods based on plastic deformation. Plastics are characterized that their mechanical properties are a combination of properties of solids and liquids. In the other words, they are solid materials which can be subjected to high mechanical deformations reflux [9]. Therefore, plastics today are very widely used in various industries as well as in everyday life. In particular, the increased production and use of synthetic thermo-plastics - thermoplastic (high temperature is easy to shape and retain that shape by cooling), which include PVC, as well as their use. Figure 2 shows the consumption of PVC in various industries [10].

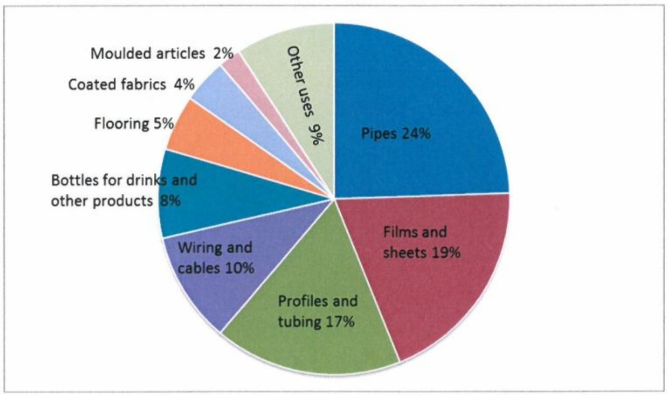

Figure 2 *Consumption of PVC in various industries*

Plastics can be composed only of polymer. However, in most cases the plastics are multicomponent systems (so-called polymer blends) the composition of which, in addition to the polymer, includes the following components: binder, hardener or catalyst, filler, plasticiser and colorant. Plastic material consisting of polymer with filler is the simplest kind of polymer compound, consisting of a polymer matrix (matrices) as the continuous phase and inorganic filler dispersed in the matrix. Fillers are used in order to modify various properties of polymer such as tensile properties (tensile strength and the elongation tension); breaking properties (tensile strength and elongation), the density increases, the modulus of elasticity and flexural strength; it reduces the coefficient of thermal expansion and creep, increases the hardness and thermal stability, improves the surface quality of the finished product, and modifies the thermal conductivity changing the flow properties increasing the viscosity and reducing the swelling of extrudate, and it reduces the combustibility and improves the possibility of colouring plastics.

Mechanical properties of plastics are of great importance to the process of refining and defining the quality of finished products. When plastics are usually static testing of mechanical properties determined: tensile strength and elongation tension, tensile strength and elongation. Tensile properties are of primary importance, because they provide information on maximum allowable load to failure plastics and final rupture. The plastic mass that makes unfilled polymer, the fracture occurs at the point where the structure is the weakest, or at the point of creating the highest stress as the result of deformation. Local crack further expands throughout the material. In the example of polyvinyl chloride-free polymer as the filler, Figure 3 shows the Van der Waals bonds between two chains of PVC under the force of elongation [2].

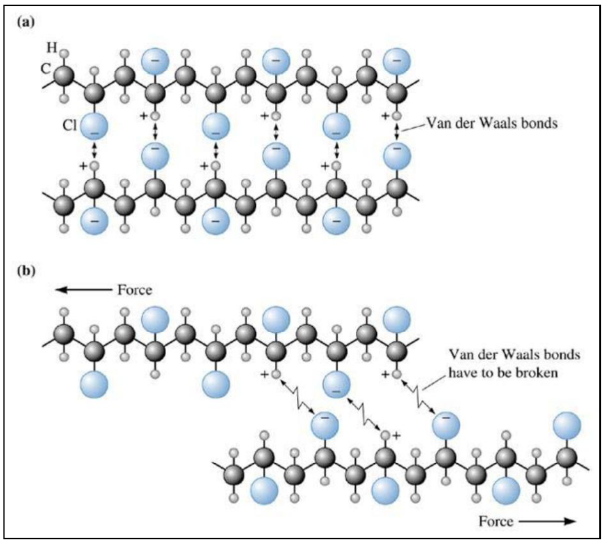

Figure 3 *Scheme of molecular connections in polyvinyl chloride (PVC): a) Van der Waals connections between two PVC chains; b) Breaking of the Van der Waals connections between two PVC chains under the effect of tension force*

In the plastic mass consisting of a polymer with filler, the fracture may begin in a matrix itself at the interface polymer/filler, or within the agglomerates formed in the filler. Tensile stress of the polymer mixture depends on its microstructure, including the interfacial border of the structure in polymer / filler, since the load is transferred from one stage to another. Also, the properties of polymer blends are determined by the certain shape and size of the filler particles and their spatial distribution in the matrix, i.e. polymer. Generally, it can be said that a filler-type calcium carbonate with their presence contributes to stronger interaction between the PVC chains. Addition of lime in the calcite which, as the dominant mineral is modified with stearic acid and mixture of the polymer provides an even stronger interaction in the system of limestone or calcite - PVC-stearic acid which results in improvement the mechanical properties of the final product [2, 6]. Table 2 contains the values of some mechanical properties of the blend of PVC containing pure limestone (C) as the filler (PVC+C) and the modified limestone (PVC+CW-1.5, and PVC+CD-3). Designation W refers to the "wet" modification process, D to the "dry" method, and the number represents the concentration of stearic acid which is used for modifying, expressed in %. Those concentrations are taken in both processes at which there was a full coverage of minerals with stearic acid.

Table 2 *Mechanical properties of PVC blends*

Mechanical properties	Unit	PVC+C	PVC+CW-1.5	PVC+CD-3
Tensile strength	MPa	52.70	54.20	53.20
Breaking strength	MPa	36.50	38.20	37.90
Tensile elongation	%	4.30	4.35	4.46

As it is seen in Table 2, the tensile and breaking strength and tension elongation have higher values of PVC blends containing calcite modified with stearic acid and compared to the values in PVC blends containing the unmodified calcite.

CONCLUSION

Limestone is used in different stages of technological process of a large number of industries including PVC industry. PVC blend containing limestone as filler is easily processed by different techniques and final products have superior mechanical properties, especially tensile and breaking strength and tensile elongation. The quality of limestone as filler in PVC industry may be improved modifying its primary mineral calcite with stearic acid. Namely, the modification method provides stronger interaction in the system limestone, i.e. calcite-stearic acid-PVC, as compared to the interaction between two chains of PVC, which does not contain modified filler.

REFERENCES

[1] J. Pavlica, D. Draškić, Preparation of Nonmetallic Metal Mineral Resources, Faculty of Mining and Geology, Belgrade, 1997;

[2] S. R. Mihajlović, Physico-chemical Moodification of Calcite with Stearic Acid, Doctoral Dissertation, Faculty of Mining and Geology, University of Belgrade, 2011;

[3] S. R. Mihajlović, D. D. Vučinić. Ž. T. Sekulić, S. Z. Milićević, B. M. Kolonja, Mechanism of Stearic Acid Adsorption to Calcite, Powder Technol. 245 (2013), pp. 208-216;

[4] S. Mihajlović, Ž. Sekulić, A. Daković, D. Vučinić, V. Jovanović, J. Stojanović, Surface Properties of Natural Calcite Filler Treated with Stearic Acid, Ceram. Silik. 53 (4) (2009), pp. 268-275;

[5] S. R. Mihajlović, A. S. Daković, Ž. T. Sekulić, D. A. Ileš, M. M. Kragović, Surface Adsorption of Stearic Acid on Natural Calcite, Hem. Ind. 63 (2) (2009), pp. 101-106;

[6] S. R. Mihajlović, Ž. T. Sekulić, D. R. Vučinić, V. D. Jovanović, B. M. Kolonja, Testing the Mechanical Properties of Polyvinyl-chloride with Addition of Modified Calcite as Filler, Hem. Ind. 66 (5) (2012), pp. 787–794;

[7] Technical Encyclopedia, Yugoslav Lexicographical Institute "Miroslav Krleža", Zagreb, 1976;

[8] http://withfriendship.com/user/kalaikumar/polyvinyl-chloride.php

[9] T. Kovačić, Structure and Characteristics of Polymers, University of Split, Faculty of Chemistry and Technology, 2010;

[10] http:// www.essentialchemicalindustry.org

[11] I. Jovanović, M. Bugarin, S. Magdalinović, Review of Contemporary World Studies on Characteristics of Fly Ash as a Secondary Mineral Resource: Part 1, Mining and Metallurgy Engineering Bor 2/2013, pp. 147-156

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PRIMENA KREČNJAKA U INDUSTRIJI POLIVINIL-HLORIDA**

Izvod

U radu je prikazan značaj krečnjaka u različitim industrijskim granama sa posebnim osvrtom na upotrebu krečnjaka kao punioca u industriji polivinil-hlorida (PVC). Od svih punilaca koja se koriste u industriji prerade PVC-a, 80 % su punioci tipa kalcijum karbonata. Punioci se koriste sa ciljem da se poboljšaju različite mehaničke osobine polimera kao što su: zatezna i prekidna svojstva, gustina, tvrdoća, toplotna postojanost, viskozitet i drugo. Najnoviji pravci industrijskog razvoja kao i zahtevi prerađivačke industrije za što kvalitetnijim karbonatnim puniocima uticali su na uvođenje postupka površinskog modifikovanja krečnjaka odnosno kalcita, koji je osnovni konstituent fino mikroniziranog krečnjaka kako bi se poboljšale njegove osobine.

***Ključne reči**: krečnjak, kalcit, punilac, PVC.*

UVOD

Krečnjak se koristi u velikom broju industrijskih grana uključujući i industriju za preradu polivinil hlorida (PVC). Veliku primenu krečnjak je našao u građevinarstvu gde se koristi za pravljenje maltera, betonskih mešavina, u proizvodnji raznih vrsta cementa, kreča i direktno u vidu drobljenog kamena različite krupnoće. Značajan korisnik krečnjaka je metalurgija, gde se krečnjak koristi u aglomeraciji, u visokim pećima i kod Besemerovog postupka topljenja. Hemijska industrija, takođe, koristi značajne količine ove sirovine u industrijskoj proizvodnji azotnih jedinjenja, celuloze, papira, sode, hlornog kreča, karbida, gume i dr. U poljoprivredi krečnjak se koristi za neutralizaciju kiselih zemljišta i kao dodatak stočnoj hrani. Značajne količine krečnjaka koriste industrija šećera, staklarska i keramička industrija. U velikom broju slučajeva pojedine industrijske grane su utvrdile opšte standarde kvaliteta krečnjaka, mada ima slučajeva da korisnici određuju svoje interne zahteve.

Kvalitet krečnjaka (definisan hemijskim sastavom) odnosi se na najmanji sadržaj CaO, odnosno $CaCO_3$ i najveći dozvoljeni sadržaj nečistoća i štetnih komponenti, kao što su: Fe_2O_3, SiO_2, Al_2O_3, MgO, P_2O_5, TiO_2, MnO, Cr_2O_3, sadržaj alkalija, gipsa i dr. U grupu fizičkih svojstava koje određuju kvalitet krečnjaka spadaju: granulometrijski sastav, tvrdina, nosivost, poroznost, boja i dr. Krečnjak koji se koristi kao punilac u različitim industrijskim granama mora da bude visokokvalitetna fino usitnjena sirovina. Kod proizvoda na bazi krečnjaka

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najvažnija kvalitativna svojstva su boja (belina) i sjaj. Takođe, fizička struktura mineralne i stenske mase predstavljaju značajan faktor, posebno kada se razmatra sposobnost usitnjavanja ove mineralne sirovine. U okviru ovih zahteva, a za svaku pojedinačnu namenu, odnosno korisnika, utvrđeni su odgovarajući standardi. Postupcima pripreme mineralnih sirovina prerađuju se brojne Ca-karbonatne sirovine, različitog hemijskog i mineralnog sastava, sa ciljem dobijanja velikog broja proizvoda za različite industrijske grane. U literaturi se Ca-karbonatne mineralne sirovine najčešće svrstavaju u industrijske mineralne sirovine, dok ih geolozi razvrstavaju u dolomite i krečnjake, [1].

KREČNJAK - PUNILAC ZA POLIVINIL-HLORID

Među velikim brojem različitih dodataka koji su neophodni polivinil-hloridu (PVC) kako bi se dobio kvalitetniji definetivni proizvod značajno mesto zauzima skup posebnih dodataka pod zajedničkim nazivom punioci za PVC. Pod pojmom punilac u tehnologiji prerade PVC-a podrazumeva se uglavnom vrlo jeftin neorganski materijal, iz čega proizilazi i prvi zadatak, a to je smanjenje cene sveukupne mešavine, odnosno gotovog proizvoda [2]. Mineralni punioci, među koje spada i krečnjak, svoju najveću primenu nalaze upravo u industriji termoplastičnih masa, a posebno kod PVC-a. Industrija za proizvodnju PVC-a postavlja određene zahteve po pitanju kvaliteta koji važe za sve punioce, pa tako i za krečnjak, a to su: da bez ikakvih promena izdrže temperaturu, pritisak i mehaničko naprezanje koji prate preradu PVC-a, neophodno je da se dobro disperguje u PVC-u, da budu što više bele boje, bez nečistoća i stranih materija, ne sme da deluju abrazivno, ne sme da ima više od 0,4 % vlage i ako su punioci za PVC neaktivni potrebno je ipak naglasiti potrebu za njihovom inertnošću i kompatibilnošću sa svim dodacima prisutnim u smesi.

Krečnjak, kao i ostali neorganski punioci, dodaju se PVC-u uvek u formi finog, suvog praha i to u fazi mešanja PVC-a sa svim ostalim dodacima, sa ciljem što bolje i potpunije homogenizacije. Najnoviji pravci industrijskog razvoja kao i zahtevi prerađivačke industrije za što kvalitetnijim karbonatnim puniocima usmerili su ispitivanja ka iznalaženju postupaka kojima se poboljšavaju osobine krečnjaka kao punioca. U cilju dobijanja punioca koji može da poboljša mehaničke osobine PVC proizvoda vrši se površinsko modifikovanje kalcita, koji je osnovni konstituent fino mikroniziranog krečnjaka. Najčešće se od reagenasa za modifikovanje koriste masne kiseline, različite soli masnih kiselina, različita ulja i dr. [2-5]. Krečnjak kod kog je mineral kalcita površinski modifikovan veoma lako se disperguje u polimeru pri čemu se dobija homogena mešavina. Osim toga, krečnjak kod kog je modifikovana površina kalcita pokazuje još neka bolja svojstva u odnosu na krečnjak kod kojih nije modifikovan kalcit, a to su: krečnjak postaje izrazito hidrofoban i tako odbija vodu i vlagu što je posebno važno za svaki punilac; površinskim modifikovanjem kalcita znatno se smanjuje abrazivno dejstvo krečnjaka; ovakvi punioci pokazuju bolja reološka svojstva, veću otpornost na udarac i bolja električna svojstva; upotrebom ovakve vrste punioca dobija se znatno kvalitetnija površina gotovog proizvoda, s obzirom na glatkost, sjaj i njegov izgled. [6]. Treba naglasiti da od svih punioca koja se koriste u industriji prerade PVC-a 80 % od ukupne potrošnje su punioci tipa kalcijum karbonata.

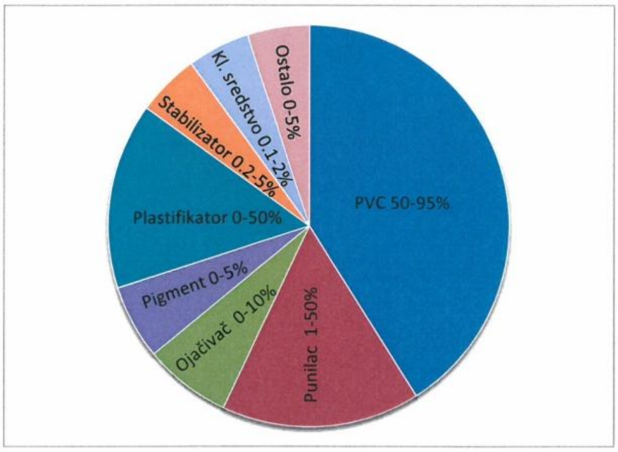
POLIVINIL-HLORID (PVC)

Polivinil-hlorid (PVC) je više od 70 godina jedan od najvažnijih polimera, čiji je kapacitet proizvodnje oko 20 % ukupne svetske proizvodnje polimera. Postupkom polimerizacije vinil-hlorida dobija se prah od kojeg se daljom preradom proizvode dve vrste PVC-a i to: tvrdi (kruti) PVC i meki (fleksibilni) PVC. Tvrdi PVC se dobija preradom polimernog praha bez posebnih dodataka. Providan je, tvrd, žilav i težak za preradu, ali vrlo stabilan na uticaj atmosferskih padavina, vlage i hemikalija. Koristi se npr. za izradu okvira za prozore, kućišta i sl. Meki PVC se dobija preradom polimernog praha uz dodatak plastifikatora. Pri tome se dobija gusta pasta, koja se zagrevanjem pretvara u homogeni gel. Osobine mekog PVC-a zavise od udela plastifikatora. Slabijih je mehaničkih svojstava, manje otporan prema delovanju toplote, atmosferskih padavina i hemikalija u odnosu na tvrdi PVC, ali je savitljiviji, rastegljiviji i lako se prerađuje. Koristi se za izradu izolatora za kablove, medicinskih instrumenata za jednokratnu upotrebu, cevi, rukavica i dr). Meki PVC je providan, pa može da se koristi za pravljenje providnih boca i folija. Generalno se može reći da su osobine polimera uslovljene njihovom unutrašnjom građom, pa su neke njihove osobine slične osobinama čvrstih kristalnih tela, dok su neke slične osobinama tečnosti. Fizičke i mehaničke osobine tvrdog i mekog PVC-a prikazane su u tabeli 1. [7].

Tabela 1. *Fizičke i mehaničke osobine PVC-a*

Osobina	Jedinica	Tvrdi PVC	Meki PVC
Gustina	g/cm^3	1,38-1,55	1,16-1,35
Zatezna čvrstoća	MPa	40-60	10-25
Produženje pri kidanju	%	30-70	250-450
Čvrstoća na pritisak	MPa	55-90	6-12
Tvrdoća po Shore-u	-	D 65-85	A 40-100
Specifični toplotni kapacitet	J/K g	0,8-1,1	1,3-2
Toplotna provodljivost	W/Kcm	$(15\text{-}20)x10^{-4}$	$(13\text{-}17)x10^{-4}$
Koeficijent toplotnog širenja	1/K	$(5\text{-}10)x10^{-5}$	$(7\text{-}25)x10^{-5}$
Temperatura stalne upotrebe	^oC	65-85	50-70

PVC se danas proizvodi u velikim količinama zbog dobrih mehaničkih i fizičkih svojstava, kao i vrlo raznovrsnih mogućnosti primene. PVC je nezapaljiv, gori samo u prisustvu plamena i hemijski je inertan. Kompatibilan je sa mnogim aditivima, uključujući punioce, plastifikatore, stabilizatore, klizna sredstva, pigmente, kao i druge polimere. Na slici 1 je prikazan udeo pojedinih dodataka polivinil hloridu [8].

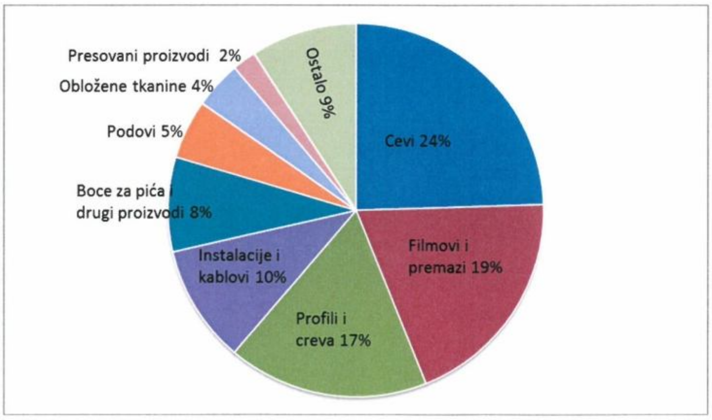


Sl. 1. *Udeo pojedinih dodataka u PVC mešavini*

Ovi dodaci omogućavaju da se polivinil hlorid lakše prerađuje različitim tehnikama i da se dobiju proizvodi sa što boljim mehaničkim svojstvima.

PLASTIČNE MASE

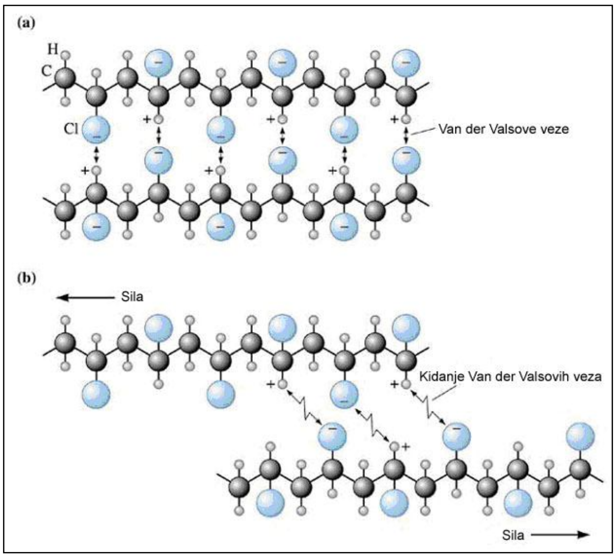
Plastične mase su polimerni materijali u postupku prerade. Pri tome se podrazumeva da je polimerni materijal sve ono što se prerađuje, tj. ono od čega je izrađen gotov proizvod. Takođe, plastičnim masama se nazivaju materijali dobijeni na bazi polimera, koji imaju u nekom stanju plastičnost (uslovi visoke temperature), a koja se potpuno ili delimično gubi pri prelasku u druge temperaturne uslove (niže temperature). Plastičnost tih materijala omogućava da se od njih dobiju proizvodi potrebnog oblika primenom metoda baziranih na plastičnoj deformaciji. Plastične mase se odlikuju time što njihove mehaničke osobine predstavljaju kombinaciju osobina čvrstih tela i tečnosti. Drugim rečima to su čvrsti materijali koji mogu da podležu velikim mehaničkim povratnim deformacijama [9]. Zbog toga plastične mase danas imaju izuzetno veliku primenu u različitim industrijskim granama, kao i u svakodnevnom životu. Posebno je porasla upotreba i proizvodnja sintetičkih termoplastičnih masa – termoplasta (na visokim temperaturama se lako oblikuju, a hlađenjem zadržavaju taj oblik), u koje spada i PVC, kao i njihova upotreba. Na slici 2 je prikazana potrošnja PVC-a u različitim industrijama [10].



Sl. 2. *Potrošnja PVC u različitim industrijama*

Plastične mase mogu da se sastoje samo od polimera. Međutim, u najvećem broju slučajeva plastične mase predstavljaju višekomponentne sisteme (tzv. polimerne mešavine) u čiji sastav, pored polimera, ulaze sledeće komponente: vezivo, katalizator ili očvršćivač, punilac, plastifikator, bojilo i dr. Plastična masa koju čine samo polimer sa puniocem su najjednostavnija vrsta polimerne mešavine, koja se sastoji iz polimerne osnove (matrice) kao kontinuirane faze i neorganskog punioca dispergovanog u matrici. Punioci se koriste sa ciljem da se modifikuju različite osobine polimera kao što su: zatezna svojstva (zatezna čvrstoća i zatezno izduženje); prekidna svojstva (prekidna čvrstoća i prekidno izduženje); povećava gustinu, modul elastičnosti i savojnu čvrstoću; smanjuje koeficijent toplotnog širenja i puzanje; povećava tvrdoću i toplotnu postojanost; poboljšava kvalitet površine gotovog proizvoda; modifikuje toplotnu i električnu provodljivost; menja svojstva tečenja tako što povećava viskozitet i smanjuje bubrenje ekstrudata; smanjuje zapaljivost i poboljšava mogućnost bojenja plastike.

Mehaničke osobine plastičnih masa imaju veliki značaj kako u procesu prerade tako i za definisanje kvaliteta gotovih proizvoda. Kod plastičnih masa najčešće se statičkim ispitivanjima mehaničkih osobina određuju: zatezna čvrstoća i zatezno izduženje; prekidna čvrstoća i prekidno izduženje. Osobine pri zatezanju su od primarne važnosti, jer daju informacije o maksimumu dozvoljenog opterećenja do loma plastične mase i konačnog pucanja. U plastičnoj masi koju čini polimer bez punioca lom nastaje na mestu na kom je struktura najslabija, odnosno na mestu stvaranja najvećeg naprezanja kao posledice procesa deformacije. Lokalna pukotina se dalje širi kroz ceo materija. Na slici 3 su prikazani lanci polivinil hlorida koji su međusobno povezani Van der Valsovim vezama koje se kidaju pri delovanju sile istezanja na plastičnu masu [2].



Sl. 3. *Šematski prikaz međumolekulskih veza kod PVC-a: a) Van der Valsove veze između dva lanca PVC-a; b) kidanje Van der Valsovih veza između dva lanca PVC-a pod dejstvom sile istezanja*

U plastičnoj masi koju čini polimer sa puniocem lom može da započne u samoj matrici, na međupovršini polimer/punilac ili unutar aglomerata formiranih u puniocu. Zatezno naprezanje polimerne mešavine zavisi od njene mikrostrukture, uključujući međupovršinsku strukturu na granici polimer/punilac, pošto se opterećenje prenosi sa jedne faze na drugu. Takođe, osobine polimerne mešavine pri naprezanju su određene oblikom i veličinom čestica punioca, kao i njihovim prostornim rasporedom u matrici, tj. polimeru. Generalno se može reći da punilac tipa kalcijum karbonata svojim prisustvom doprinosi jačoj interakciji između dva lanca PVC-a. Ali dodatkom krečnjaka kod kog je kalcit, kao dominantni mineral, modifikovan stearinskom kiselinom polimernoj mešavini, obezbeđuje se još jača interakcija u sistemu krečnjak odnosno kalcit-stearinska kiselina - PVC što kao rezultat ima poboljšanje mehaničkih osobina gotovog proizvoda [2, 6]. U tabeli 2 su date vrednosti nekih od mehaničkih osobina PVC mešavina koje sadrže čist krečnjak (K) kao punilac (PVC+K) i modifikovani krečnjak (PVC+KM-1.5 i PVC+KS-3). Oznaka M se odnosi na „mokri“ postupak modifikovanja kalcita, S na „suvi“ postupak, dok broj predstavlja koncentraciju stearinske kiseline koja je upotrebljena za modifikovanje izraženu u %. Kod oba postupka su uzete one koncentracije pri kojima je ostvarena potpuna pokrivenost minerala stearinskom kiselinom.

Tabela 2. *Mehaničke osobine PVC mešavina*

Mehaničke osobine	Jedinica	PVC+K	PVC+KM-1.5	PVC+KS-3
Zatezna čvrstoća	MPa	52,70	54,20	53,20
Prekidna čvrstoća	MPa	36,50	38,20	37,90
Zatezno izduženje	%	4,30	4,35	4,46

Kao što se vidi u tabeli 2 zatezna i prekidna čvrstoća i zatezno izduženje imaju veće vrednosti kod PVC mešavine koja sadrži kalcit modifikovan stearinskom kiselinom u odnosu na vrednosti kod PVC mešavine koja sadrži nemodifikovani kalcit.

ZAKLJUČAK

Krečnjak se koristi u različitim fazama tehnološkog procesa velikog broja industrijskih grana uključujući i industriju PVC-a. PVC mešavina koja sadrži krečnjak kao punilac se lakše prerađuje različitim tehnikama i gotovi proizvodi imaju bolja mehanička svojstva prvenstveno zateznu i prekidnu čvrstoću i zatezno izduženje. Kvalitet krečnjaka kao punioca u industriji PVC-a se može poboljšati postupkom modifikovanja njegovog osnovnog minerala kalcita stearinskom kiselinom. Naime, postupkom modifikovanja se obezbeđuje jača interakcija u sistemu krečnjak odnosno kalcit-stearinska kiselina - PVC, u odnosu na interakciju između dva lanca PVC-a koji ne sadrži modifikovani punilac.

LITERATURA

[1] J. Pavlica, D. Draškić, Priprema nemetaličnih mineralnih sirovina, Rudarsko-geološki fakultet, Beograd, 1997.

[2] S. R. Mihajlović, Fizičko-hemijsko modifikovanje kalcita stearinskom kiselinom, Doktorska disertacija, Rudarsko-geološki fakultet Univerziteta u Beogradu, 2011.

[3] S. R. Mihajlović, D. D. Vučinić. Ž. T. Sekulić, S. Z. Milićević, B. M. Kolonja, Mechanism of stearic acid adsorption to calcite, Powder Technol. 245 (2013), str. 208-216.

[4] S. Mihajlović, Ž. Sekulić, A. Daković, D. Vučinić, V. Jovanović, J. Stojanović, Surface properties of natural calcite filler treated with stearic acid, Ceram. Silik. 53 (4) (2009), str. 268-275.

[5] S. R. Mihajlović, A. S. Daković, Ž. T. Sekulić, D. A. Ileš, M. M. Kragović, Površinska adsorpcija stearinske kiseline na prirodnom kalcitu, Hem. Ind. 63 (2) (2009), str. 101-106.

[6] S. R. Mihajlović, Ž. T. Sekulić, D. R. Vučinić, V. D. Jovanović, B. M. Kolonja, Ispitivanje mehaničkih osobina polivinil-hlorida sa dodatkom modifikovanog kalcita kao punioca, Hem. Ind. 66 (5) (2012), str. 787–794

[7] Tehnička enciklopedija, Jugoslovenski leksikografski zavod „Miroslav Krleža“, Zagreb, 1976.

[8] http://withfriendship.com/user/kalaikumar/polyvinyl-chloride.php

[9] T. Kovačić, Struktura i svojstva polimera, Sveučilište u Splitu, Kemijsko-tehnološki fakultet, 2010.

[10] http://www.essentialchemicalindustry.org

[11] I. Jovanović, M. Bugarin, S. Magdalinović, Pregled savremenih svetskih istraživanja o karakteristikama letećeg pepela kao sekundarne mineralne sirovine; Deo 1, Mining and Metallurgy Engineering Bor 2/2013, str. 157-166

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MODELING THE BATCH POWER OF MILL[**]

Abstract

This paper presents a new method of modeling the batch power of mill on the basis of dimensional analysis and criterion equations. The grinding batch is represented by the grinding bodies, material and medium that is used to provide the flow of raw material through the mill, and most commonly water or air. The rate of energy consumption in the mill is regulated by the charge density and it presents the charge density. The feed power is dependent on the type of media milling body and prior to the treatment of mineral raw materials. Approximate power mill defined engine power is the power of batch mill highest charge density. In the work is varied density in batch laboratory mills and defined a model of batch power mill which we used in the adaptation of the mill plants in new industrial plant.The present model of the feed mill power is checked on industrial exploitation of quartz raw materials in Lukic polje near Milici. The process of mechano-chemical treatment defines as venture milling with longer residence time of material in the mill and small batch densities, all with the aim to reduce the force with which the batch effect on grain mineral resources. Radicality of fragmentation varies with the density of charge so that the densities obtained with smaller sized features special milling products with a narrower range of narrow size class and thus increased the specific surface area and reactivity.

Keywords: *batch strength, charge density, mechano-chemical treatment, reactivity*

INTRODUCTION

Modeling the batch strength of mill, shown in the work was done on the basis of theoretical considerations and dimensional analysis using the criterion equations. The paper uses a laboratory model and dimensional analysis, based on the similarity of dynamic invariants developed a model of mechano-chemical treatment in an industrial mill. The paper describes the process flow of physical modeling and determination of engine power for lower density batch mill $\rho_{š}$, given that the grinding is done with silex balls and not with the metal balls. Thus developed model provides answers to the question of the necessary batch strength of quartz sand grinding at the converted facility for so-called unconventional conditions of grinding or mechano-chemical treatment.

THEORETICAL CONSIDERATIONS

Theoretical considerations are related to the model of flow in the mill as a streaming media through the pipe with the certain characteristics. The required parameters that describe this process are:

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- Hydrodynamic *size:* υ , p , g
- Fluid properties: ρ , μ , σ

wherein:

υ - speed, $L \cdot t^{-1}$;
p - pressure of fluid, $M \cdot L^{-1} \cdot t^{-2}$;
g - gravitational acceleration, $L \cdot t^{-2}$;
ρ - density, $M \cdot L^{-3}$;
μ - dynamic viscosity, $M \cdot L^{-1} \cdot t^{-1}$;
σ - surface tension, $M \cdot t^{-2}$,
N - power, $M \cdot L^{2} \cdot t^{-3}$,
L - length, L,
M - mass, M,
t - time, t,

of these values is performed by a mechanical force acting, F_i force of inertia, F_g strength by weight, F_p pressure force, F_{tr} friction force, F_σ force of surface tension, F_q heat diffusion forces, F_m force mass diffusion. Putting the ratio of these two forces, the invariants or similarity criteria are obtained [1]. Figure 1 shows a cylindrical ball mill which can be seen as a pipe for streaming media with the characteristic sizes and parameters of grinding process and mechanochemical treatment.

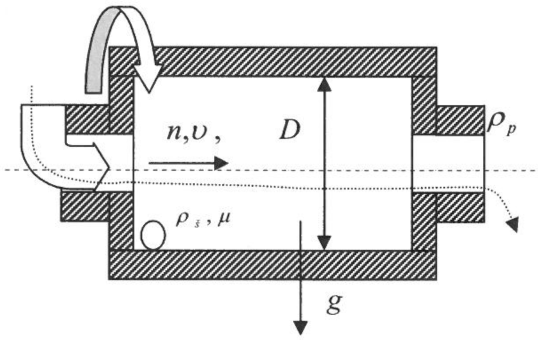

Figure 1 *Tube for media streaming, animation of mill*

Buckingham's theorem similarities

According to the Buckingham π theorem, each equation containing n related physical quantities (υ , ρ , μ etc.), between which m sizes are independent dimensions (M, L, t), may be converted to an equation which has n to m dimensionless criteria and simplex, composed of those values. As the criterion for simplex or taken tag P , then the above theorem can be written:

$$f(P_1, P_2, P_3, \ldots) = 0 \qquad (1)$$

$$P_1 = f(P_2, P_3, \ldots) \qquad (2)$$

This theorem is of great importance in the experimental and theoretical work. The relationship could be found between the dimensionless expression, and thereby the number of unknown reduced number of basic units of measure at least 3 conditions that significantly simplifies the experimentation and finding legality of interrelated physical size [1,2]. Criteria similarities are encountered practically in solving any problems from chemical engineering, particularly in problems magnification (scale-up). From the Annunciation-Stokes's equations of motion of viscous fluids, the following is got:

$$F_i = -F_g - F_p + F_{tr} \qquad (3)$$

Or the balance of the forces of inertia, forces of weight, thrust force and friction force.

If the left side of the equation is shared with some members of the right side of the equation, the following is got:

$$\frac{\rho \cdot \frac{\upsilon^2}{l}}{\rho \cdot g} = \left[\frac{\upsilon^2}{l \cdot g} \right] = Fr \qquad (4)$$

$$\frac{\rho \cdot \frac{\upsilon^2}{l}}{\frac{p}{l}} = \left[\frac{\rho \cdot \upsilon^2}{p} \right] = Eu^{-1} \qquad (5)$$

$$\frac{\rho \frac{\upsilon^2}{l}}{\mu \cdot \frac{\upsilon}{l^2}} = \left[\frac{l \cdot \upsilon \cdot \rho}{\mu} \right] = \mathrm{Re} \qquad (6)$$

As the raw material in mill moves and mixes, the substantial inertial force of the gravitational force and frictional force are important. Gravity criterion, criterion of strength and flow criteria therefore should not be ignored. According to the above, the following is got:

$$E_U = f(\mathrm{Re}, Fr). \qquad (7)$$

MATERIALS AND METHODS

The experiment in which the grinding is performed has the characteristics of fluid flow through the tube. Fluid flow through tube is supported by mixing that is achieved by milling bodies because the mantle of mill is moved. In many experimental investigations, it was observed that the grinding process and mechano-chemical treatment will most affect the following parameters: the density of batch, $\rho_š$, speed of mill mantle *n*, diameter of mill mantle *D*, viscosity μ and, gravitational acceleration, *g*. All these parameters are included in a model of grinding development using specific criteria (Euler, Reynolds and Frude). Test conditions set so that we are in the first series of experiments, consisting of three experiments, experiments carried out in a single device when the criterion Frude was immutable, and when it is changed during the mechano-chemical treatment, or the flow rate of raw material through the mill, which is such a change had implications Reynolds criteria. This experiment would not have been feasible if we changed the type of grinding the batch so silex alum and steel grinding body were used. The measured density and viscosity of the pulp were constant for the first series of experiments.

In another series of experiments, which also consists of three experiments, the conditions set by Frude criterion were investigated s changing and this was achieved using mills of various sizes. The Reynolds criterion in this series of experiments was maintained so as constant used milling different types of bodies and they have had a different feedstock residence time in the mill, and wherein the density and viscosity of the pulp have a constant value. This was achieved when the mill with the largest dimensions of the used silex balls, then at the mill medium dimensions of alumino used balls, and at the end of the mill with the smallest dimensions of the used steel balls.

Density and viscosity of the pulp within a single batch is maintained constant, and vary between batches, so that the two series were actually derived values of the two densities and viscosity of two values.

Dimensional Analysis and Criterion Equations

The formation of dimensionless numbers for a particular problem is most easily achieved using dimensional matrix. Dimensional matrix consists of a square and the remaining matrix. Rows of the matrix form the basis of size, and it will form a rank r matrix. The columns of the matrix represent the physical size or influential parameters. Sizes of squares elementary matrices appear in all the dimensionless numbers, while each element of the residual matrix appears in only one dimensionless number. For this reason, the remain-ning matrix should be comprised of the most important variables.

Table 1 *Basic dimensional matrix*

	ρ	D	n	N	μ	g
Mass, M	1.	0	0	1.	1.	0
Length, L	-3	1.	0	2	-1	1.
Time, t	0	0	-1	-3	-1	-2
	Basic matrix			Remaining matrix		

Rearrange matrix (linear transformation) is done by the core matrix becomes a common matrix. After the creation of a common matrix, dimensionless numbers arise in the following way. Each element of the remaining matrix, which is in the numerator is divided by the square matrix of the parameters that were graded under the number of the remaining elements of the matrix as shown in the example. Dimensional matrix for this case has the form.

Table 2 *Renovated dimensional matrix*

	ρ	D	n	N	μ	g
M	1	0	0	1	1	0
3M+L	0	1	0	5	2	1
-t	0	0	1	3	1	2
	Basic matrix			Remaining matrix		

$$\frac{N}{\rho^1 \cdot n^3 \cdot D^2} = \frac{N}{\rho \cdot n^3 \cdot D^5} \equiv Np$$

criterion power mill

Strength criterion and sometimes referred to as modified Euler expression (Euler) (Eu_M) because:

$$\left[\frac{\rho \cdot \upsilon^2}{p}\right] = Eu^{-1}$$

And

$$Eu_M = Eu^{-1} \equiv \left[\frac{\rho \cdot \upsilon^2 \cdot \frac{l^3}{t}}{p \cdot \frac{l^3}{t}}\right] \equiv \qquad (8)$$

$$\equiv \frac{\rho \cdot n^3 \cdot D^5}{N} \equiv Np^{-1}$$

wherein:

$$Q = \frac{l^3}{t}$$ - flow of pulp

$$\frac{\mu}{\rho^1 \cdot n^1 \cdot D^2} = \frac{\mu}{\rho \cdot n \cdot D^2} \equiv \mathrm{Re}^{-1}$$

- dimensionless Reynolds number for mixing process

$$\frac{g}{\rho^0 \cdot D^1 \cdot n^2} = \frac{g}{D \cdot n^2} \equiv Fr^{-1}$$ -

Froude's dimensionless number for mixing

Under the certain experimental conditions in the laboratory, it was attempted to reach a solution of the equation 7 and to find the coefficient k and exponents a and b

Its new analytical form has the appearance shown by equation 9

$$Eu_M = k \cdot \mathrm{Re}^a \cdot Fr^b \qquad (9)$$

By logarithms the criterion equation 9, the following is got:

$$\log Eu_M = \log k + a \cdot \log \mathrm{Re} + b \cdot \log Fr \quad (10)$$

It is necessary to determine experimentally the function Eu_M and one of the criteria, but the second criterion is kept constant in this series of experiments.

If the equation 9

$$k \cdot Fr^b = konst. = B \quad (11)$$

Obtained criterion equations:

$$\log Eu_M = a \cdot \log \mathrm{Re} + \log B \quad (12)$$

Thus the form:

$$y = a \cdot x + b$$

Dynamic viscosity μ and pulp density ρ_p in a laboratory mill can be adjusted so that their ratio is constant. Measuring viscosity is on the Brookfield viscometer. The equipment with rotating cylinders was used which allows determination of the viscosity over a wide range of consistency. The pulp density is measured in the mining pycnometer (to be used in flotation), and a scale to measure the density. Thanks to the use of different types of batch milling bodies (steel, alumino silicate spheres) the grinding times were different but the fineness of each of these experiments was the same.

Change the Reynolds Re-Criterion, which is required for the formation of models, is achieved by changing the residence time in the mill, the raw material, the table 3. Change the value of Euler's criterion Eu_M is calculated according to equation 8, and the analytical expressions of equality and shows that all parameters are known ($N, \rho_{up}, n^3 i\ D^5$). Force N measure with the electric meter, or device that is connected to the engine laboratory mill. The density of the charge $\rho_{š}$ is a linear function of the density of the pulp ρ_p where the coefficient of direction and the intercept on the ordinate are dependent on the type of body that is milling ρ_{vk} and ρ_{sk} as can be seen from Equation 13: [3, 4, 5]

$$\rho_{š} = \rho_{vk} + 1{,}15 \cdot (1 - \frac{\rho_{vk}}{\rho_{sk}}) \cdot \rho_p \left[kg \cdot m^{-3}\right] \quad (13)$$

Where:

ρ_{vk} - *density of balls in bulk density in kg/m³,*

ρ_{sk} - *density of the material from which the ball is made, in kg / m³,*

ρ_p - *pulp density in kg / m³.*

The material from which it was made, ball, cast

Fe - ρ_{sk} = 7800 kgm^{-3},

Al_2O_3 - ρ_{sk} = *4800* kgm^{-3}

Silicate - ρ_{sk} = 2600 kgm^{-3}.

Density of balls in bulk density,

Fe cast - ρ_{vk} = 4100 to 4200 kgm^{-3},

Al_2O_3-pressed ρ_{vk} =2500 to 2700 kgm^{-3}

Silicate - ρ_{vk} = 1800 to1900 kgm^{-3}.

Frude constancy criteria in this series is achieved by the use of a mill of the same size for all of the individual experiments. When the data in the table shows the diagram it is evident that the points that represent the coordinates of individual experiments are approximately straight line. Figure 2 shows that the $tg\alpha = a =$ 0,6259, Or a the exponent of criteria Re, and cut-outs on the axes $\log Eu_M$ represents the value of $\log B$, and is $\log B = -1{,}8261$ and then B = 0,014924507.

In order to determine the coefficient of k from equation 9 is required to carry out another series of experiments in which to set the conditions of the experiment that the Reynolds number is constant. Thus, after the first series of experiments, the model is performed a second series of experiments, in which the criterion value is maintained constant Re, and from equation 9:

$$k \cdot \mathrm{Re}^a = konst. = C \tag{14}$$

It follows from this criterion equation:

$$\log Eu_M = b \cdot \log Fr + \log C \tag{15}$$

So, again, the straight line equation as a functional dependence Eu_M of changes Fr .

In order to remain constant the Reynolds criterion, it is necessary to be changed during the treatment so that the greater the mill is longer retention time of the raw material in the mill, the smaller shorter retention time of raw materials. The above experimental conditions were achieved by reducing the speed of medium and large, when the mill is decreased, and the efficiency of grinding by increasing the number of mill rotation when higher efficiency is achieved by grinding. To achieve the above conditions milling time except change the number of rotation of the mill was also necessary that the largest mill uses less density fed-batch (batch of sileks balls) in the medium mill, medium density fed-batch (batch of alumino-Ball), and the smallest mill, the largest batch density (batch of steel balls). Finally, in order to maintain the constant Reynolds criterion, it was necessary to perform several preliminary experiments to determine the pulp density

Table 3 *Experimental data for the power criterion when the Frude number is not changed*

Viscosity of pulp	Grinding time	Diameter of sheath	Speed pulp	Pulp density	Reynolds number		Speed	Frude number		Measured power mill	Milling body types	Density of charged balls	Material density	Charge density	Euler number Eu_M	
					Re	*LogRe*		*Fr*	*logFr*						Eu_M	$logEu_M$
μ, Pas	t, s	D, m	υ, ms $^{-1}$	kgm^{-3}			ns $^{-1}$			N, W		kgm^{-3}	kgm^{-3}	kgm^{-3}		
0.416	600	0.305	0.000510	1226	0.458	-0.3387	1.04	0.0329	-1.482	760	Si	1800	2600	2234	0.008726	-2.05917
0.416	400	0.305	0.000763	1226	0.686	-0.1637	1.04	0.0329	-1.482	760	Al	2600	4800	3246	0.012681	-1.89684
0.416	180	0.305	0.001694	1226	1.523	0.1826	1.04	0.0329	-1.482	760	Fe	4200	7800	4851	0.018949	-1.72241

Table 4 *Experimental data for the power criterion when the Reynolds number is not changed*

Viscosity of pulp	Grinding time	Diameter of sheath	Speed pulp	Pulp density	Reynolds number		Speed	Frude number		Measured power mill	Milling body types	Density of charged balls	Material density	Charge density	Euler number Eu_M	
					Re	*LogRe*		*Fr*	*logFr*						Eu_M	$logEu_M$
μ, Pas	t, s	D, m	υ, ms $^{-1}$	kgm^{-3}			n,s^{-1}			N, W		kgm^{-3}	kgm^{-3}	kgm^{-3}		
0.17	417	0.150	0.00036	1066	0.338612	-0.4703	1.6	0.0384	-1.415668	70	Fe	4200	7800	4766	0.02117649	-1.67415
0.17	898	0.220	0.000245	1066	0.337985	-0.4711	0.8	0.0141	-1.851397	250	Al	2600	4800	3162	0.00333724	-2.47661
0.17	1713	0.305	0.000178	1066	0.34043	-0.4679	0.5	0.0076	-2.117760	760	Si	1800	2600	2177	0.00094513	-3.02451

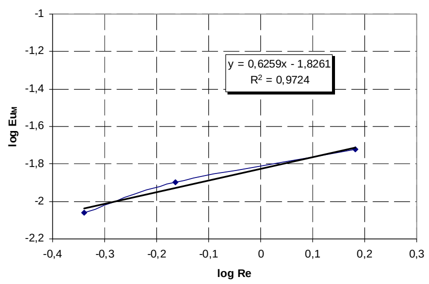

Figure 2 *Function* $\log Eu_M$ *and* $\log \mathrm{Re}$

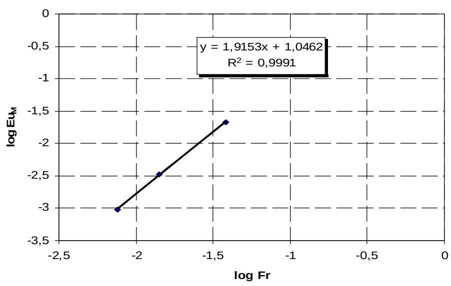

Figure 3 *Function* $\log Eu_M$ *and* $\log Fr$

Table 4 presents the experimental data for the second series of experiments, when the data in the table shows in graphical form to an almost straight line, Figure 3. Analogous conclusion of the earlier shows that $tg\beta = b = 1{,}9153$ and the intercept on the ordinate $\log Eu_M$ value $\log C = 1{,}0462$ and then $C = 11{,}12243817$ as the two series of experiments determined criteria exponent $\mathrm{Re}(a)$ and exponent of criteria $Fr(b)$, Constant k can be calculated from:

$$k = \frac{B}{Fr^b} = \frac{0.015}{Fr^{1.92}} = 10.27 \text{, apropos}$$

$$k = \frac{C}{\mathrm{Re}^a} = \frac{11.12}{\mathrm{Re}^{0.63}} = 21.91 \qquad (16)$$

To afford the median:

$$k_{sr} = \frac{\sum_1^2 k}{2} = \frac{k_1 + k_2}{2} = = \frac{10.27 + 21.91}{2} = 16.1 \qquad (17)$$

Given that the system is interrogated for this constant k and exponents a and b constant values can be obtained for the experimental combination of criteria Re *and* Fr calculated value Eu_M.

$$Eu_M = k \cdot \mathrm{Re}^a \cdot Fr^b = = 16.1 \cdot 0{,}338612^{0.63} \cdot 0.032989^{1.92} = = 0.011869 \qquad (18)$$

Given that: $\frac{\rho_{up} \cdot n^3 \cdot D^5}{N} = Eu_M$ and $Eu_M = k \cdot \mathrm{Re}^a \cdot Fr^b$ it is seen that the use of laboratory tests occurred criterion equation batch power mill in treatment of silicate materials that can be used to check the mill batch strength in the accelerated conditions.

$$N = \frac{\rho_{š} \cdot n^3 \cdot D^5}{16.1 \cdot \mathrm{Re}^{0.63} \cdot Fr^{1.92}} \qquad (19)$$

Checking the Mill Batch Strength

Checking the mill batch strength adapted to the treatment of quartz sand in Lukic field near Milici was performed to check the batch loop power that has value $N = 280000$ W. $\rho_{š} = 2177\ kgm^{-3}$ - The density of the charge (ball + water + material), $D = 2{,}2\ m$ - Inner diameter of the mill, $n = 0.3\ s^{-1}$ - Speed of the mill,

$$N = \frac{\rho_{up} \cdot n^3 \cdot D^5}{16.1 \cdot \mathrm{Re}^{0.63} \cdot Fr^{1.92}} = = \frac{2177 \cdot 0.3^3 \cdot 2.2^5}{0.012} = 255256W$$

As seen criterion equation model gives good results, because the calculated batch mill power less than the power the mill frame and engine power.

CONCLUSION

The importance of the present method of finding the criterion equation model batch mill power is great because the model can be used generally for all mineral materials [6,7]. Criterion equation model is possibly to apply to the industrial mills, because the laboratory conditions have been altered in all the relevant parameters that affect the process in the industry conditions.

REFERENCES

[1] E. Beer, Manual for Sizing the Devices of Chemical Processing Industry SKTH / Chemistry in the Industry, Zagreb, 1985, p.491;

[2] N. Magdalinović, Comminution and Classification of Mineral Raw Materials, Technical Faculty in Bor, Bor 1985, p. 70;

[3] M. Petrov et al., Technical-technological Solution, "Development of Software Systems for Grinding the Quartz Sand from the Deposit Skočić for the Needs of Chemical I of the Birač - Zvornik Silica Plant Obtained Using the Criterion of Equation Modeling", ITNMS Belgrade, 2012;

[4] M. Petrov et al., Technical-technological Solution, "The New Technology of Wet Grinding of Quartz Sand in Boksit a.d. Milici and Determination the Specific Capacity of Mill with Silex Balls." ITNMS Belgrade, 2012;

[5] S. Rozgaj, Processing Apparatus and Devices, IGKRO "Svjetlost", Sarajevo, 1980, p. 63;

[6] M. Grbović, N. Magdalinović, Processing Equipment for Crushing and Grinding of Mineral Raw Materials, "Copper", Bor, 1980, p. 88;

[7] S. Puštrić, Selection and Calculation of Machinery and Equipment for Crushing, Screening and Grinding of Mineral Raw Materials, Mining and Geology, Belgrade 1974, p. 48.

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MODELOVANJE ŠARŽNE SNAGE MLINA**

Izvod

U radu je prikazana nova metoda modelovanja šaržne snage mlina na bazi dimenzione analize i kriterijumskih jednačina. Šaržu predstavljaju meljuća tela materijal i medijum koji se koristi ba bi se obezbedijo protok sirovine kroz mlin, a najčešće je to voda ili vazduh. Brzina trošenja energije u mlinu se reguliše gustinom šarže i predstavlja šaržnu snagu. Šaržna snaga zavisi od vrste meljućih tela i medija u kojem se vrši tretman mineralne sirovine. Okvirna snaga mlina definisana snagom motora predstavlja šaržnu snagu mlina za najveću gustinu šarže. U radu je varirana gustina šarže u laboratorijskim mlinovima i definisan model šaržne snage mlina kojeg smo primenili kod adaptacije mlinskog postrojenja u novi industrijski pogon. Prikazani model šaržne snage mlina proveren je u industrijskim uslovima ekspoloatacije kvarcne sirovine u Lukića polju kod Milića. Proces mehano-hemijskog tretmana definše se kao poduhvat mlevenja sa dužim vremenom boravka materijala u mlinu i manjim šaržnim gustinama, a sve sa ciljem da se smanji sila kojom šarža deluje na zrna mineralne sirovine. Radikalnost usitnjavanja se menja sa promenom gustine šarže tako što se sa manjim gustinama dobijaju posebne karakteristike krupnoće proizvoda mlevenja sa užim dijapazonom uskih klasa krupnoće i time uvećanom specifičnom površinom i reaktivnošću.

Ključne reči: *šaržna snaga, gustina šarže, mehanohemijski tretman, reaktivnost*

UVOD

Modelovanje šaržne snage mlina prikazano u radu urađeno je na osnovu teorijskih razmatranja i pomoću dimenzione analize kriterijumskih jednačina. U radu je korišćen laboratorijski model i dimenziona analiza, a na osnovi invarijante dinamičke sličnosti razvien je model mehanohemijskog tretmana u industrijskom mlinu. U radu je prikazan tok procesa fizičkog modelovanja i određivanja snage motora za manju gustinu šarže mlina $\rho_{š}$ s obzirom da se mlevenje vrši sa sileks kuglama a ne sa metalnim kuglama. Ovako razvijen model daje odgovore na pitanje potrebne šaržne snage mlevenja kvarcnog peska u adaptiranom postrojenju za takozvane nekonvencionalne uslove mlevenja odnosno mehanohemijski tretman.

TEORIJSKA RAZMATRANJA

Teorijska razmatranja vezuju se za model strujanja u mlinu kao strujanje nekog medija kroz cev sa određenim ka-

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rakteristikama. Potrebni parametri koji opisuju ovaj proces su:

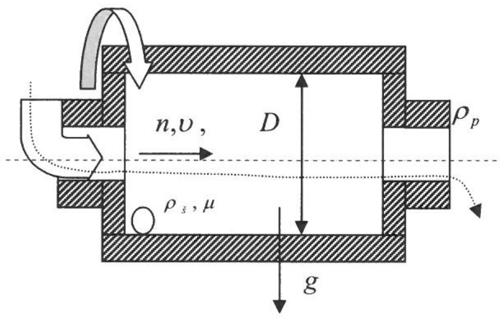
- hidrodinamičke veličine: υ, p, g
- svojstva fluida: ρ, μ, σ

gde je:

υ - brzina, $L \cdot t^{-1}$;
p - pritisak fluida, $M \cdot L^{-1} \cdot t^{-2}$;
g - gravitaciono ubrzanje, $L \cdot t^{-2}$;
ρ - gustina, $M \cdot L^{-3}$;
μ - dinamički viskozitet, $M \cdot L^{-1} \cdot t^{-1}$;
σ - površinski napon, $M \cdot t^{-2}$;
N - snaga, $M \cdot L^{2} \cdot t^{-3}$;
L - dužina, L;
M - masa, M;
- t - vreme, t.

Iz ovih veličina izvode se delujuće mehaničke sile, F_i sila inercije, F_g sila težine, F_p sila pritiska, F_{tr} sila trenja, F_σ sila površinskog napona, F_q sila difuzije toplote, F_m sila difuzije mase.

Stavljajući u količnički odnos po dve od navedenih sila, dobijamo invarijante ili kriterijume sličnosti [1]. Na slici 1 je prikazan cilindrični mlin sa kuglama koji se može posmatrati kao cev za strujanje medija sa karakterističnim veličinama odnosno parametrima procesa mlevenja i mehanohemijskog tretmana.



Sl. 1. *Cev za strujanje medija, animacija mlina*

Bakingem-ova teorema sličnosti

Prema Buckinghamovom π teoremi svaka jednačina koja sadrži n povezanih fizičkih veličina (υ, ρ, μ itd.), između kojih m veličine imaju nezavisne dimenzije (M, L, t), može biti prevedena u jednačinu koja ima n do m bezdimenzionih kriterijuma i simpleksa, sastavljenih iz tih veličina. Pošto je za simpleks ili kriterijum uzeta oznaka P, onda se gornja teorema može napisati:

$$f(P_1, P_2, P_3, ...) = 0 \qquad (1)$$

odnosno:

$$P_1 = f(P_2, P_3, ...) \qquad (2)$$

Ova teorema ima veliki značaj u eksperimentalnom i teorijskom radu. Nalazimo vezu između bezdimenzionih izraza, a pri tome je broj nepoznatih sveden na broj osnovnih jedinica mere najmanje 3 što veoma pojednostavljuje uslove eksperimentisanja i nalaženje zakonitosti o međusobnom odnosu fizičkih veličina [1,2]. Kriterijumi sličnosti se susreću praktično kod rešavanja svakog problema iz hemijskog inženjerstva, a posebno kod problema uvećanja (scale-up). Iz Navje-Štoks-ove jednačine kretanja viskozne tečnosti dobijamo da je:

$$F_i = -F_g - F_p + F_{tr} \qquad (3)$$

Odnosno ravnotežu sila inercije, sila težine, sila pritiska i sila trenja.

Ako se leva strana jednačine deli sa pojedinim članovima desne strane jednačine dobijamo:

$$\frac{\rho \cdot \frac{\upsilon^2}{l}}{\rho \cdot g} = \left[\frac{\upsilon^2}{l \cdot g}\right] = Fr \qquad (4)$$

$$\frac{\rho \cdot \frac{\upsilon^2}{l}}{\frac{p}{l}} = \left[\frac{\rho \cdot \upsilon^2}{p}\right] = Eu^{-1} \qquad (5)$$

$$\frac{\rho \frac{\upsilon^2}{l}}{\mu \cdot \frac{\upsilon}{l^2}} = \left[\frac{l \cdot \upsilon \cdot \rho}{\mu}\right] = \mathrm{Re} \qquad (6)$$

S obzirom da se u mlinu sirovina kreće i meša značajne su inercione sile gravitacione sile i sile trenja. Gravitacioni kriterijum, kriterijum snage i kriterijum strujanja stoga ne smeju biti zanemareni. Prema prethodnom imamo:

$$E_U = f(\mathrm{Re}, Fr). \qquad (7)$$

MATERIJAL I METODE

Eksperiment u kojem se vrši mlevenje ima karakteristike strujanja fluida kroz cev. Strujanje fluida kroz cev potpomognuto je mešanjem koje se ostvaruje pomoću meljućih tela jer se plašt mlina obrće. U mnogim eksperimentalnim istraživanjima primećeno je da na proces mlevenja i mehanohemijskog tretmana najviše utiču sledeći parametri: gustina šarže, $\rho_š$, broj obrtaja plašta mlina, *n*, prečmik plašta mlina, *D*, viskozitet μ i gravitaciono ubrzanje, *g*. Sve navedene parametre uključili smo u razvoj modela mlevenja pomoću određenih kriterijuma (Ojlera, Rejnoldsa i Frudea). Uslove ispitivanja podesili smo tako da smo u prvoj seriji opita, koja se sastoji od tri opita, eksperimente vršili u jednom istom uređaju kada je kriterijum Frude bio nepromenljiv, a pri tome se menjalo vreme mehanohemijskog tretmana, odnosno brzina proticanja sirovine kroz mlin, što je kao implikaciju imalo promenu Rejnoldsovog kriterijuma. Ovakav eksperiment ne bi bio izvodljiv ukoliko ne bismo menjali vrstu meljuće šarže pa smo koristili sileks, alumo i čelična meljuća tela. Izmerene gustine i viskoziteti pulpe su bili konstantni za prvu seriju opita.

U drugoj seriji opita, koja se takođe sastoji od tri opita, uslove ispitivanja podesili smo tako da Frudeov kriterijum bude promenljiv a to je bilo moguće postići upotrebom mlinova različitih veličina. Rejnoldsov kriterijum u ovoj seriji opita održavan je konstantantnim tako što su korišćene različite vrste meljućih tela i što smo imali različito vremena boravka sirovine u mlinu, a da pri tome gustine i viskoziteti pulpe imaju stalne vrednosti. Ovo je bilo moguće postići kada su u mlinu sa najvećim gabaritnim dimenzijama korišćene sileks kugle, zatim u mlinu sa srednjim gabaritnim dimenzijama korišćene alumo kugle, i na kraju u mlinu sa najmanjim gabaritnim dimenzijama korišćene čelične kugle.

Gustine i viskoziteti pulpe unutar pojedinačne serije se održavaju konstantnim, a između serija se razlikuju, tako da su u dve izvedene serije bile zapravo dve vrednosti gustine i dve vrednosti viskoziteta.

Dimenziona analiza i kriterijumske jednačine

Formiranje bezdimenzionih brojeva za određeni problem najlakše se postiže upotrebom dimenzionih matrica. Dimenziona matrica sastoji se od kvadratne i preostale matrice. Redovi matrica formiraju bazu dimenzija, i ona će formirati rang r matrice. Kolone matrice predstavljaju uticajne fizičke veličine ili parametre. Veličina kvadrata osnovne matrice pojavljuju se u svim bezdimenzionim brojevima, dok će se svaki elemenat preostale matrice pojavit samo u jednom bezdimenzionom broju. Iz ovog razloga preostala matrica bi trebalo da bude sastavljena od najvažnijih promenljivih veličina.

Tabela 1. *Osnovna dimenziona matrica*

	ρ	D	n	N	μ	g
Masa M	1	0	0	1	1	0
Dužina L	-3	1	0	2	-1	1
Vreme t	0	0	-1	-3	-1	-2
	Osnovna matrica			Preostala matrica		

Preuređivanje matrice (linearna transformacija) vrši se tako što jezgro matrice prelazi u zajedničku matricu. Nakon stvaranja zajedničke matrice bezdimenzioni brojevi nastaju na sledeći način. Svaki element preostale matrice koji stoji u brojiocu deli se sa parametrima kvadratne matrice koji su stepenovani brojem ispod elementa preostale matrice kao što je dato u primeru. Dimenziona matrica za naš slučaj ima oblik:

Tabela 2. *Preuređena dimenziona matrica*

	ρ	D	n	N	μ	g
M	1	0	0	1	1	0
3M+L	0	1	0	5	2	1
-t	0	0	1	3	1	2
	Osnovna matrica			Preostala matrica		

$$\frac{N}{\rho^1 \cdot n^3 \cdot D^2} = \frac{N}{\rho \cdot n^3 \cdot D^5} \equiv Np$$

- kriterijum snage mlina

Kriterijum snage se katkada naziva i modifikovani izraz Ojlera (Euler) (Eu_M) jer je:

$$\left[\frac{\rho \cdot \upsilon^2}{p}\right] = Eu^{-1}$$

a,

$$Eu_M = Eu^{-1} \equiv \left[\frac{\rho \cdot \upsilon^2 \cdot \frac{l^3}{t}}{p \cdot \frac{l^3}{t}}\right] \equiv$$

$$\equiv \frac{\rho \cdot n^3 \cdot D^5}{N} \equiv Np^{-1} \tag{8}$$

gde je:

$Q = \frac{l^3}{t}$ - protok pulpe

$$\frac{\mu}{\rho^1 \cdot n^1 \cdot D^2} = \frac{\mu}{\rho \cdot n \cdot D^2} \equiv \mathrm{Re}^{-1}$$

- Rejnoldsov bezdimenzioni broj za proces mešanja

$$\frac{g}{\rho^0 \cdot D^1 \cdot n^2} = \frac{g}{D \cdot n^2} \equiv Fr^{-1}$$

- Froudeov bezdimenzioni broj za mešanje

Uz određene uslove eksperimenta u laboratorijskim uslovima pokušalo se je da se dođe do rešenja jednačine 7 i do pronalaženja koeficijenta k i eksponenata a i b.

Njen novi analitički oblik ima izgled prikazan jednačinom 9:

$$Eu_M = k \cdot \mathrm{Re}^a \cdot Fr^b \qquad (9)$$

Logaritmujući kriterijumsku jednačinu 9 dobijamo:

$$\log Eu_M = \log k + a \cdot \log \mathrm{Re} + b \cdot \log Fr \qquad (10)$$

Potrebno je eksperimentalno odrediti funkciju Eu_M i jedan od kriterijuma, s tim da se drugi kriterijum održava konstantnim u tom nizu eksperimenata.

Ako je iz jednačine 9:

$$k \cdot Fr^b = konst. = B \qquad (11)$$

Dobija se kriterijumska jednačina:

$$\log Eu_M = a \cdot \log \mathrm{Re} + \log B \qquad (12)$$

Dakle oblik:

$y = a \cdot x + b$.

Dinamički viskozitet μ i gustine pulpe ρ_p se u laboratorijskom mlinu mogu podesiti tako da njihov odnos bude konstanta. Merenje viskoziteta vršeno je viskozimetrom po Brukfildu. Korišćen je pribor sa rotirajućim cilindrima koji omogućava određivanje viskoznosti u širokom intervalu konzistencije. Gustina pulpe meri se rudarskim piknometrom (koji se upotrebljava u flotacijama) i vagom za merenje gustine. Zahvaljujući koriščenju različitih vrsta šarže meljućih tela (čelične, alumo i silikatne kugle) vremena mlevenja su se razlikovala ali je finoća mlevenja u svakom od pomenutih opita bila ista.

Promena Rejnoldsovog Re - kriterijuma, koja je potrebna za formiranje modela, postiže se menjanjem vremena boravka sirovine u mlinu, tabela 3. Promena vrednosti Ojlerovog kriterijuma Eu_M računa se prema jednačini 8, a iz analitičkog izraza te jednakosti se vidi da su poznati svi parametri $(N, \rho_{up}, n^3 i\ D^5)$. Snagu N merimo pomoću električnog brojila, odnosno uređaja na koji je priključen motor laboratorijskog mlina. Gustina šarže $\rho_š$ je linearna funkcija gustine pulpe ρ_p gde koeficijent pravca i odsečak na ordinati zavise od vrste meljućih tela odnosno ρ_{vk} i ρ_{sk} kao što se vidi iz jednačine 13:[3, 4, 5]

$$\rho_š = \rho_{vk} + 1{,}15 \cdot (1 - \frac{\rho_{vk}}{\rho_{sk}}) \cdot \rho_p \ \frac{kg}{m^3} \qquad (13)$$

gde je:

ρ_{vk} - gustina kugli u nasutom stanju, u kg/m^3;

ρ_{sk} - gustina materijala od kog je sačinjena kugla, u kg/m^3;

ρ_p - gustina pulpe, u kg/m^3.

Gustina materijala od kog je sačinjena kugla:

Fe livene - ρ_{sk} = 7800 kgm^{-3},

Al_2O_3 - ρ_{sk} = *4800* kgm^{-3},

Silikatne - ρ_{sk} = 2600 kgm^{-3}.

Gustina kugli u nasutom stanju:

Fe livene - ρ_{vk} = 4100 do 4200 kgm^{-3},

Al_2O_3 presovane - ρ_{vk} = 2500 do 2700 kgm^{-3},

Silikatne - ρ_{vk} = 1800 do 1900 kgm^{-3}.

Konstantnost Frudeovog kriterijuma u ovoj seriji postiže se upotrebom mlina istih dimenzija za sve pojedinačne opite. Kada se podaci iz tabele predstave dijagramom vidljivo je da se tačke koje predstavljaju koordinate pojedinih opita nalaze na približno pravoj liniji.

Na slici 2 je vidljivo da je $tg\alpha = a = 0{,}6259$, odnosno a je eksponent kriterijuma Re, a odsečak na osi $\log Eu_M$ predstavlja vrednost $\log B$, pa je $\log B = -1{,}8261$, a tada je B =0,014924507.

Da bi utvrdili koeficijent k iz jednačine 9 potrebno je da izvršimo još jednu seriju eksperimenata u kojoj će se podesiti uslovi eksperimenta da Rejnoldsov broj bude konstanta. Dakle, nakon prve serije eksperimenata na modelu se izvodi druga serija eksperimenata, u kojoj se održava konstantnim vrednost kriterijuma Re, odnosno iz jednačine 9:

$$k \cdot \mathrm{Re}^{a} = konst. = C \qquad (14)$$

Iz ovoga sledi kriterijumska jednačina:

$$\log Eu_{M} = b \cdot \log Fr + \log C \qquad (15)$$

Dakle opet jednačina prave linije kao funkcionalna zavisnost Eu_M od promene Fr.

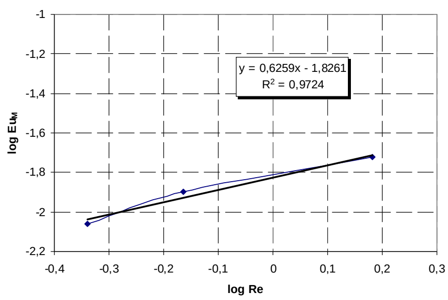
Da bi Rejnoldsov kriterijum ostao konstanta potrebno je bilo menjati vreme tretmana na način da u većem mlinu bude duže vreme zadržavanja sirovine, a u manjem mlinu kraće vreme zadržavanja sirovine. Navedene eksperimentalne uslove postigli smo sa smanjenjem broja obrtaja srednjeg i velikog mlina kada je efikasnost mlevenja manja i povećanjem broja obrtanja malog mlina kada je postignuta veća efikasnost mlevenja.

Tabela 3. *Eksperimentalni podaci za kriterijum snage kada se ne menja Frudeov broj*

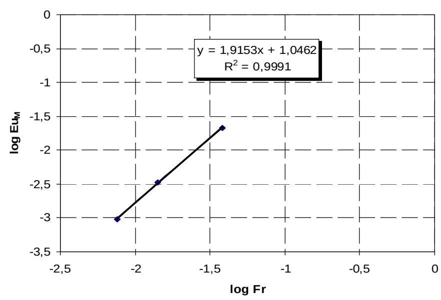
Viskozitet pulpe	Vreme mlevenja	Prečnik plašta	Brzina pulpe	Gustina pulpe	Rejnoldsov broj		Broj obrtaja	Frudeov broj		Merena snaga mlina	Vrsta meljućih tela	Gustina nasutih kugli	Gustina materijala	Gustina šarže	Ojlerov broj Eu_M	
					Re	*logRe*		*Fr*	*logFr*						Eu_M	$logEu_M$
μ,Pas	t, *s*	D,m	υ,ms^{-1}	*kgm*$^{-3}$			ns^{-1}			N,W		*kgm*$^{-3}$	*kgm*$^{-3}$	*kgm*$^{-3}$		
0,416	600	0,305	0,000510	1226	0,458	-0,3387	1,04	0,0329	-1,482	760	Si	1800	2600	2234	0,008726	-2,05917
0,416	400	0,305	0,000763	1226	0,686	-0,1637	1,04	0,0329	-1,482	760	Al	2600	4800	3246	0,012681	-1,89684
0,416	180	0,305	0,001694	1226	1,523	0,1826	1,04	0,0329	-1,482	760	Fe	4200	7800	4851	0,018949	-1,72241

Tabela 4. *Eksperimentalni podaci za kriterijum snage kada se ne menja Rejnoldsov broj*

Viskozitet pulpe	Vreme mlevenja	Prečnik plašta	Brzina pulpe	Gustina pulpe	Rejnoldsov broj		Broj obrtaja	Frudeov broj		Merena snaga mlina	Vrsta meljućih tela	Gustina nasutih kugli	Gustina materijala	Gustina šarže	Ojlerov broj Eu_M	
					Re	*logRe*		*Fr*	*logFr*						Eu_M	$logEu_M$
μ,Pas	t, *s*	D,m	υ,ms^{-1}	*kgm*$^{-3}$			n,s^{-1}			N,W		*kgm*$^{-3}$	*kgm*$^{-3}$	*kgm*$^{-3}$		
0,17	417	0,150	0,00036	1066	0,338612	-0,4703	1,6	0,0384	-1,415668	70	Fe	4200	7800	4766	0,02117649	-1,67415
0,17	898	0,220	0,000245	1066	0,337985	-0,4711	0,8	0,0141	-1,851397	250	Al	2600	4800	3162	0,00333724	-2,47661
0,17	1713	0,305	0,000178	1066	0,34043	-0,4679	0,5	0,0076	-2,117760	760	Si	1800	2600	2177	0,00094513	-3,02451



Sl. 2. *Funkcija* $\log Eu_M$ *i* $\log \mathrm{Re}$



Sl. 3. *Funkcija* $\log Eu_M$ *i* $\log Fr$

Da bi postigli pomenute uslove vremena mlevenja osim promene broja obrtanja mlina takođe je bilo potrebno da se u najvećem mlinu koristi manja šaržna gustina (šarža od sileks kugli), u srednjem mlinu srednja šaržna gustina (šarža od alumo kugli), a u najmanjem mlinu najveća šaržna gustina (šarža od čeličnih kugli). Na kraju, da bi Rejnoldsov kriterijum ostao konstantan bilo je potrebno izvršiti više preliminarnih opita da bi se utvrdila i gustina pulpe. U tabeli 4 su prikazani eksperimentalni podaci za drugu seriju opita, a kada se podaci iz tabele predstave u grafičkom obliku dobijamo skoro pravu liniju, slika 3. Analogno ranijim zaključivanjima vidi se da je $tg\beta = b = 1{,}9153$ i odsečak na ordinati $\log Eu_M$ je vrednost $\log C = 1{,}0462$, a tada je C=11,12243817. Pošto je u dva niza eksperimenata određen eksponent kriterijuma $\mathrm{Re}(a)$ i eksponent kriterijuma $Fr(b)$, konstanta k se može izračunati iz:

$$k = \frac{B}{Fr^b} = \frac{0{,}015}{Fr^{1{,}92}} = 10{,}27\,,$$

odnosno

$$k = \frac{C}{\mathrm{Re}^a} = \frac{11{,}12}{\mathrm{Re}^{0{,}63}} = 21{,}91 \qquad (16)$$

Pa se dobija srednja vrednost:

$$k_{sr} = \frac{\sum_1^2 k}{2} = \frac{k_1 + k_2}{2} = \frac{10{,}27 + 21{,}91}{2} = 16{,}1 \qquad (17)$$

Uzevši da su za ovakav ispitivani sistem konstanta k i eksponenti $a\,i\,b$ konstantne vrednosti može se za eksperimentalno dobijenu kombinaciju kriterijuma Re $i\,Fr$ izračunati vrednost Eu_M.

$$Eu_M = k \cdot \mathrm{Re}^a \cdot Fr^b = 16{,}1 \cdot 0{,}338612^{0{,}63} \cdot 0{,}032989^{1{,}92} = 0{,}011869 \qquad (18)$$

Obzirom da je: $\dfrac{\rho_{up} \cdot n^3 \cdot D^5}{N} = Eu_M$ i $Eu_M = k \cdot \mathrm{Re}^a \cdot Fr^b$ vidimo da se primenom laboratorijskih ispitivanja došlo do kriterijumske jednačine šaržne snage mlina u tretmanu silikatne sirovine koji može biti upotrebljena za proveru šaržne snage mlina u uvećanim uslovima.

$$N = \frac{\rho_{š} \cdot n^3 \cdot D^5}{16{,}1 \cdot \mathrm{Re}^{0{,}63} \cdot Fr^{1{,}92}} \qquad (19)$$

Provera šaržne snage mlina

Provera šaržne snage mlina za adaptirane uslove tretmana kvarcnog peska u Lukića polju kod Milića vršena je da bi se proverila okvirna šaržna snaga koja ima vrednost $N = 280.000$ W.

$\rho_{š} = 2177\ kgm^{-3}$ - gustina šarže (kugle+voda+materijal)

$D = 2{,}2\,m$ - unutrašnji prečnik mlina,

$n = 0{,}3\ s^{-1}$ - broj obrtaja mlina,

$$N = \frac{\rho_{up} \cdot n^3 \cdot D^5}{16{,}1 \cdot \mathrm{Re}^{0{,}63} \cdot Fr^{1{,}92}} = \frac{2177 \cdot 0{,}3^3 \cdot 2{,}2^5}{0{,}012} = 255.256\,W$$

Kao što se vidi kriterijumska jednačina modela daje dobre rezultate, jer je izračunata šaržna snaga mlina manja od okvirne snage mlina odnosno snage motora.

ZAKLJUČAK

Značaj prikazanog postupka iznalaženja kriterijumskih jednačina modela šaržne snage mlina je velik jer se model može koristiti uopšteno za sve mineralne sirovine [6,7]. Kriterijumske jednačina modela moguće je primeniti i na industrijskim mlinovima zato što su u laboratorijskim uslovima menjani svi relevantni parametri koji utiču na proces i u industrijskim uslovima.

LITERATURA

[1] E. Beer, Priručnik za dimenzioniranje uređaja kemijske procesne industrije SKTH/kemija u industriji, Zagreb 1985, str. 491.

[2] N. Magdalinović, Usitnjavanje i klasiranje mineralnih sirovina, Tehnički fakultet u Boru, 1985, Bor, str. 70.

[3] M. Petrov i ostali autori Tehničko tehnološkog rešenje: "Razvoj programskog sistema mlevenja kvarcnog peska ležišta Skočić za potrebe hemijske industrije fabrike glinice Birač - Zvornik dobijen korišćenjem kriterijumskih jednačina modeliranja", ITNMS Beograd, 2012.

[4] M. Petrov i ostali autori Tehničko tehnološkog rešenje: "Nova tehnologija mokrog mlevenja kvarcnog peska u Ad-Boksit Milići i određivanje specifičnog kapaciteta mlina sa sileks kuglama", ITNMS Beograd, 2012.

[5] S. Rozgaj, Procesni aparati i uređaji, IGKRO "Svjetlost", Sarajevo, 1980, str. 63.

[6] M. Grbović, N. Magdalinović, Procesna oprema drobljenja i mlevenja mineralnih sirovina, "Bakar", Bor, 1980, str. 88.

[7] S. Puštrić, Izbor i proračun mašina i uređaja za drobljenje prosejavanje i mlevenje mineralnih sirovina, RGF, Beograd, 1974, str. 48.

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RECYCLING IN THE FUNCTION OF SAVINGS AND GREEN ECONOMY OF MINERAL RESOURCES

Abstract

Recycling means the separation of materials from waste and reusing the same. It involves the collection, separation, processing and manufacturing the new products from already used parts. This work will provide the basic concepts of recycling in the function of savings the mineral resources. Savings of mineral resources, in this way, present one of the goals of green economy and the green economy implies the widespread use of renewable energy sources with as less as possible emission or occurrence and production of harmful substances into the environment. Savings of metallic mineral resources are mostly achieved by recycling, and therefore the recycling is a priority for achievement the sustainable development.

***Key words**: recycling, savings, mineral resources, green economy*

INTRODUCTION

Recycling is a term which describes the process "waste" converting into raw materials from which the new products are formed. As such, it is a part of an integrated waste management system, and it is on the third place in the hierarchy of waste management. System of management and recycling the various types of waste is not only the environmental issue, but also became a part of the economic and energy potential of a country. Recycling has the economic, environmental, but also the social importance because it affects the raising of environmental awareness, helping the prevention in environmental pollution, saving the natural resources, consuming less energy in waste processing, from energy that is consumed for obtaining the products from raw materials, and at the end, the amount of waste is reduced by recycling. The most widespread distribution of waste includes the two cate gories: the industrial waste, generated in the industrial processes, and municipal waste, generated in households. Besides the harmful effects of waste on the environment, it is also very important the secondary source of metals as well as the other products, obtained by recycling. Statistical indicators of recycling in the world are different, ranging from Japan, which recycles 80-90% of waste, across the EU, which recycles 30-40% of waste, to small Serbia. which has the present recycling of waste, only 6-8%. Based on the above data, it can be concluded that Serbia is still far from establishing an environmentally safe and efficient management system with certain types of waste.

This especially refers to the municipal waste, considering that today in Serbia almost a half of the amount of generated waste from households ends on the illegal landfills, what is a constant source of soil,

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air and water pollution. Therefore, it is necessary for Serbia to make more effort for achieving better waste management as well as more efforts to introduce the new technologies that would enable this management. In terms of recycling, and technologies related to recycling, there is the concept of green technologies. The concept of green technology, which is a part of the green economy concept, has shown a sudden growth in recent years. In general, the "green trends" in 2012 has resulted into reduction of waste, recycling and reusing of processed products. Trend of sustainable development is present in the world for a long time as the trend of sustainable economy, ecology, i.e. social development. At the global level, the green economy is seen as the economy in which the economic solutions and innovations allows the society to use efficiently the resources, improving the welfare of people by the inclusive way with preserving the natural systems that sustain the awareness and mankind (UNEP, United Nations Environment Program, 2010).

WASTE CLASSIFICATION

Waste characterization is the process of testing which determines the physicochemical, chemical and biological properties and composition of t waste, i.e. determines whether the waste contains or does not contain one or more hazardous characteristics. Waste classification is the process of classifying the waste into one or more waste lists, which are regulated by separate regulations, and according to its origin, composition, and further purpose; (Waste Catalogue, 2010). The Act on Waste Management requires that the waste would be described in a way that allows the safe handling and waste management, as well as any change of ownership of waste would be accompanied by appropriate documentation that necessarily include the waste index number. The waste is classified according to the Waste Catalogue that is consistent with the European Waste Catalogue (European List of Waste/European Waste Catalogue). Within the Catalogue, the waste is systematized primarily according to the activities within which it is generated, but also according to the type of waste, materials or processes. The Waste Catalogue includes systematically more than 800 types of waste, divided into 20 groups, which are indicated by two-digit numbers and divided as follows:

1. Waste generated from exploration, exploration from mines or quarries and physical and chemical treatment of minerals;
2. Waste generated from agriculture, horticulture, forestry, hunting and fishing, food preparation and processing;
3. Waste generated from wood processing and production of paper, cardboard, pulp, panels and furniture;
4. Waste generated from leather, fur and textile industries;
5. Waste generated from petroleum refining, natural gas purification and pyrolytic treatment of coal;
6. Waste generated from inorganic chemical processing;
7. Waste generated from organic chemical processing;
8. Waste generated from manufacturing, supplying and use of coatings (paints, varnishes and vitreous enamels), adhesives, seals and printing inks);
9. Waste generated from photographic industry;
10. Waste generated from thermal processes;
11. Waste generated from chemical surface treatment and coating of metals and other materials; hydrometallurgy of ferrous metals;
12. Waste generated from shaping the physical and mechanical surface treatment of metals and plastics;

13. Waste generated from oil and residues of liquid fuels (except edible oils);
14. Waste generated from organic substances used as solvents, coolants as well as propellant gases;
15. Waste generated from packaging;
16. Waste not otherwise specified in the Catalogue;
17. Construction waste and demolition waste (including soil from contaminated sites);
18. Waste from health care of people and animals from system-related research;
19. Waste from the waste treatment plants for waste water treatment, off-site production and water treatment intended for human consumption and water for industrial usage;
20. Municipal waste (household waste and similar commercial, industrial and institutional waste) including separately collecting fractions.

From the above mentioned categories of waste, the next following sub-groups are separated: plastic, metal, wood, organic waste, paper, electronics, rubber, glass and waste oil. Listed wastes represent the secondary raw material for the new products. Solid waste is important in the recycling of waste. The solid waste is municipal, industrial and commercial, packaging and construction waste. Industrial and commercial waste are the most desirable, also the most wanted type of waste in the market. Without this kind of waste, the operators of private sector cannot survive. Items and devices of metals that have lost their value in use, often end up on landfill, and so actively pollute the environment. This type of waste is the secondary raw material for metal obtaining, because the new products are obtained by collecting and returning into recycling and, at the same time, the primary resources are saved and thus extending the life of the primary reserves of raw materials. The environmental pollution is reduced by this way. For example, it is estimated that 15% is lost of the total amount of produced copper, while the remaining amount is built into items and objects that serve to reusing. It is similar to steel, which is illustrated by data that nearly 75% of is nowadays obtained by recycling. The fact that total amount of municipal waste in the world has reached a worryingly high level, indicates the urgent taking of actions that lead to the waste reduction.

It can be noted, that the amount of waste is directly related to the production volume, and also development of the country. Developed countries produce more waste, due to higher production, but, on the other hand, these countries lead in development of technologies for waste suppression. In these countries, municipal waste is treated in the plant for sorting. For example, in the EU, the total amount of municipal waste that is burnt is 33%. After such treatment, the remainder of waste is quantitatively less, so it is easier to deposit it. Considering all presented facts regarding to the waste, hereinafter, the importance of including the external costs will be present, which are directly related to the exploitation of mineral resources. It will be further clarify the importance of recycling to reduce the costs of metal obtaining and its economic justification.

IMPORTANCE OF INCLUDING THE EXTERNAL COSTS IN THE EXPLOITATION OF MINERAL RESOURCES

Externalities are the effects of positive or negative character, arising from the certain activities, while at the same they are not the result of acting the price mechanism. The term "external effect" was first used by the theorist of welfare economics, AS Pigou (1912), who set the foundations for the standard theory of externalities. Starting from market failures, Pigou made a setting on necessity of state intervention, which should ensure that market prices reflect the full social cost. Viewed from a theoretical point of view, in order to avoid transmitting of external costs to the entire community, their internalization is necessary, or inclusion the pollution costs into the price of products that cause pollution (Ilic et al., 2013). In the economic theory and practice, there are two groups of measures for regulation the externalities (Stanic, 2012):

1. Command-control (standards or constraints), and
2. Market measures (taxes and transferable licenses).

It should be noted that the external positive effects may exist both in production and consumption, and that they can be positive and negative. *Positive externalities* are benefits to the third parties and they are not included in the price of product. In the case of external effects in consumption, a subject of brings benefits to any person by his consumption, in order that it happens without creating the additional costs for this second person. Hence, he is not ready to recognize them in the price of goods that he buys for consumption purposes.

On the other hand with the positive externalities in production, a manufacturer provides benefits to the third party with its activity, but not to the people whom he sales his goods, so he does not charge any fees from the third parties for this activity (Ilic-Popov, 2000). An example of positive externalities is education. *Negative externalities* mean the costs of legal entity or individual causes, i.e. imposed by the other members of society, who are not included in the product price. Due to the scale of the negative external effects of their larger and more far-reaching consequences, this type of external effects is paid much more attention.

Sustainable management of mineral resources has indicated that the price of metal is one of the main instruments for achieving this sustainability. If the classical economic model of supply and demand is taken into consideration, it can be concluded that the same includes a supply and demand curve, which defines the marginal costs of labor and capital. However, metal production from primary mineral resources results into costs incurred by direct or indirect damage and pollution of natural environment, but which the manufacturer does not include that in his forms of costs. If those costs are omitted, it certainly will not be the real and fair view of the state of modern human activity and in the action that costs arise. Therefore, the classical model of supply and demand has to include externalities, or external costs, which are expressed in the monetary or financial value of environmental pollution. But, how the environmental damage has to be determined? This question is imposed due to a reason of impossible accurately determining the damages caused by the environmental pollution. If the relief or air quality is violated, it is difficult to estimate the amount of losses as compared to the potential benefits of these natural conditions. It is easier to estimate the amount of loss on degradation the certain area of soil, on the basis of lost potential profit from the yield of crops grown or could be grown on them. The costs incurred due to the health problems of population can be also easier monetary expressed and displayed. Viewed both from environmental and financial side, certainly that no damages to the environment are desirable. But these damages are real and really exist, except that some damages cannot be removed, while some can be remediated. If the environmental pollutions do not have any value and as such do not appear in the economic model of supply and demand, it might be practical and their market value is zero. No matter how hard it is to determine the values of these damages, in order to protect life, and therefore the survival of human society, the externalities must be taken into consideration of modern economic analysis. The function of costs, incurred by pollution of natural conditions and environment in the economic analysis model, growing in a proportion with the increase in production and, for the purposes of this study, it can be assumed that these costs are directly proportional to the production of metals (Magdalinović et al., 2011).

On a global scale, mining and metallurgy are the biggest polluters of the environment, with cumulative and far-reaching consequences for the environment and climate change. The most obvious and most direct consequences of pollution are manifested through the air pollution by harmful gases (sulfur, carbon and nitrogen), mineral dust particles and heavy metals (lead, arsenic, manganese, cadmium, mercury) which have the alarming adverse effects on human health. Considering that the modern industry, including the mining industry, mostly pollutes the environment, the above mentioned analysis can be applied to any of its branch.

Figure 1 shows a simple way of introducing the external costs in the analysis of metal supply and demand. The costs of metal production, labor and capital can be seen on the graph. Market equilibrium **R_1,** determined by the intersection of supply and demand graph, is equivalent to **Q1** and price **C_1.** If the estimated external costs (environmental damage) are involved into the production costs, a new higher graph of supply is obtained that represents the sum of production and external costs, and which can be called the social costs. In introduction the external costs, the balance point **R_1** is moved to point **R_2,** which represents the social optimum. If the supply **Q_2** is lower and **C_2** price is higher, it is easier to achieve the social optimum. Such approach of introduction the costs in the analysis of supply and demand has a justified meaning. Namely, the costs really exist and they slow down the depletion of primary metal reserves in the new equilibrium (Magdalinović-Kalinović, 2010).

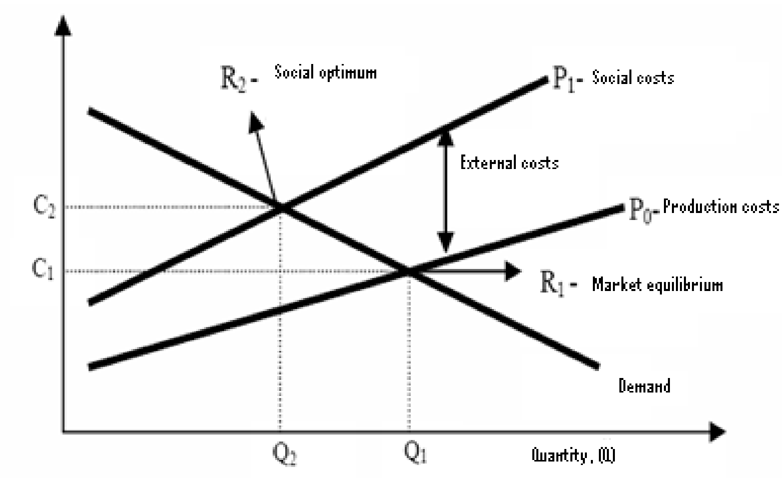

Figure 1 *Model of supply and demand with external costs*

The new equilibrium **R_2** causes the price increase **C_2**, while the sold quantity **Q_1** is reduced to **Q_2**. The effect of economic efficiency is good notwithstanding that the consumers would protest due to the price increase (the price is only the result of the real costs of production). If the sale is less, the production is also reduced and such production will reduce the environmental damage. On the other hand, the saving will be on the primary metal resources because their depletion will result into reduction. Such approach, i.e. the obtained new graphic, is approximate to the efficient equilibrium, i.e. the social optimum of metal production (from the primary reserves). Introducing the externalities into the classical model of supply and demand can be done in different ways, depending both on mineral resources and the way in which the same pollutes the environment. Tax on pollution presents one of the ways of introducing the external costs, which affect not only filling the state cash register, but also the awareness of producers on the natural environment, is really polluted. With higher tax on pollution, the supply of raw materials in the market is lower and higher raw material prices. This situation corresponds to the ecologists, because it is in favor of reduced environmental pollution, as the producers, in this manner, would be forced to produce less. However, the question may be freely asked about what the highest metal price to which the producers can go or that consumers can accept and pay. This is because the amount of pollution is associated with the technology that has to be changed and improved. If it is left the unchanged, the tax will only have a role in reduced supply and higher prices.

Recycling may be the answer to this and similar questions. If the metal price in the market achieves the upper critical level, the consumers will search for the new ways to substitute the same, i.e. they will turn to recycling. The metal is obtained from recycling process with less costs, and also lower pollution of the environment. From the standpoint of sustainable development, this is the most favorable option since it extends the life time of primary reserves for metal production at the same time reducing bad effects on the environment.

Therefore, it can be said that it is necessary to find the optimal level of pollution and harmonize the tax rates to that level. However, is the optimal pollution that which does not exist? The paradox is to use the word optimal when talking about pollution, considering the real awareness that optimal pollution is zero pollution. But, if it is taken into account that every, even the smallest production causes it, from an economic point of view, it is necessary that the production is zero, i.e. that does not exist. The society in any case has to decide what level of pollution is ready to accept. If the certain level of optimality is established, it is necessary to strive also the reduction of these "optimal" harmful effects. Such reduction can only be achieved applying the new technologies.

It can be stated that as long as there is production, there will be a level of pollution. To determine the optimal level, the economists have introduced into analysis a comparison the marginal costs of pollution **BCP,** with the marginal costs of damage from pollution, which in this case will be marked with **BCD.** Figure 2 shows curves of these costs, and it can be concluded that the reduction of pollution is profitable while the costs of pollution control are less than benefits obtained from reduced damage.

The point $\mathbf{Q_{max}}$**,** as maximum level of pollution, is the amount of pollution which has not been controlled. If, the pollution is reduced by taking the measures, the marginal costs of environmental damage will be decreased too. However, the less each pollution unit, the greater unit of control costs, that is, the marginal control costs are increased. In the convergence point of the graphic of the marginal pollution costs and marginal control costs, there is the point of optimum level of pollution, $\mathbf{Q_{OZ}}$**.** This point determines the amount of tax **-** *p* on pollution (Figure 2) (Magdalinović-Kalinović, 2010).

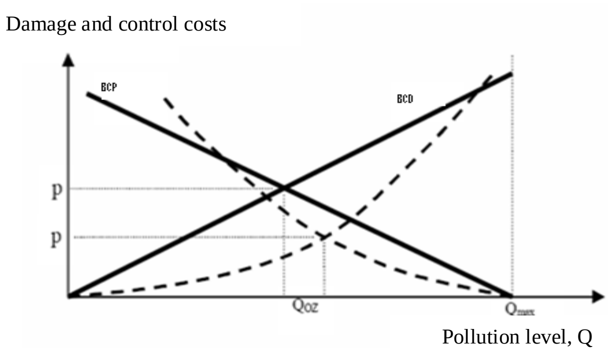

Figure 2 *Marginal costs of damage and control*

Although this analysis can be related to the certain obstacles in practice, such as some kinds of pollution expressed in monetary value, particularly when it is either cumulative pollution or esthetic damage of the relief, it is the only model to explain and comprehend the way on which the politics of pollution control affects producers to change the method of metal production and in that way to improve the awareness on the environment pollution. Recycling is the only efficient way to extend lifetime of the primary metal reserves. Figure 3 shows the profitability of recycling, represented by marginal production costs of metals from the primary sources and by recycling. The *x* axis shows the portion of metal production by recycling, while the *y* axis shows the marginal costs. As high as the portion of metals obtained from recycling, the marginal costs of metal production from recycling are higher, marked as **TR**. The costs of metal production by recycling first increase linearly, then along the graphic of exponential function. For the needs of work, it can be supposed that the marginal costs of metal production from the primary reserves, **TPR,** decline linearly. If the costs of the environmental damage are added to the costs of metal production from the primary reserves, the total costs of metal production from the primary reserves, **UTPR,** are obtained. The point of intersection the marginal costs and total costs of metal production, involving the sum of costs of metals obtained from the primary reserves and recycling costs, defines the optimum portion of metals obtained by recycling. Total costs are minimum; therefore, the portion of metal obtained by recycling is marked as optimum.

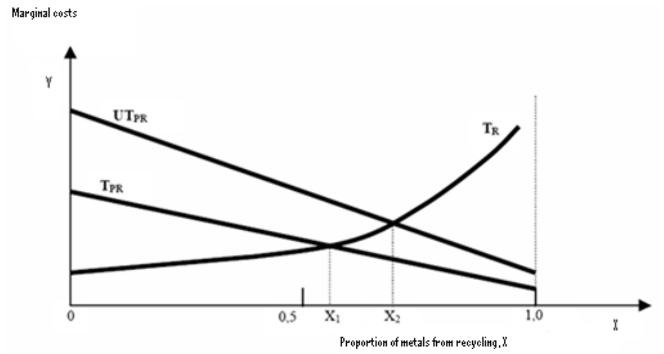

Figure 3 *Marginal cost of metal production from the primary reserves and recycling*

However, including the external values into this analysis, it results into increase the optimum portion of metal production by recycling, from the point X_1 to the point X_2. It is necessary to point out that beyond this point of the optimum portion of metals obtained by recycling (X_2), the costs of metals obtained by recycling increase rapidly. According to the graphic, it can be concluded that total recycling is both expensive and difficult; therefore, it is not justifiable. The amount of metal obtained by recycling is conditioned by development of a certain country. However, development is not the only condition but also estimated reserves, or natural wealth of metal reserves, as well as the economic profitability of obtaining the raw materials from the primary reserves. Since the West European countries have a lack of the primary raw materials for metal production, it is a good example to obtain considerable amounts of metals by recycling. South America, rich in copper, compared to the average values of the world, records two times less participation of cooper obtained by recycling than from the primary reserves. Tables 1 and 2 show data on the obtained copper by recycling, both per regions and per type of metal mostly obtained by recycling (Magdalinović et al., 2007).

Table 1 *Share of recycled copper in total copper consumption in the world (%)*

Year / **Region**	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*
Asia	30.9	30.0	31.7	33.1	37.7	34.2	34.0
Europe	44.4	41.6	41.2	41.5	41.0	41.3	42.7
North America	32.4	31.5	30.5	31.1	33.2	34.1	33.0
Rest of the world	16.3	14.0	14.6	16.6	17.1	18.8	16.3
All/ world	34.6	33.0	33.4	34.2	36.8	35.3	35.1

Source: International Copper Study Group, Copper Bulletin, 2010

Table 2 *Metals obtained from recycling in the world, 2006*

Metal	**Lead**	**Zinc**	**Copper**	**Nickel**	**Gold**	**Aluminum**	**Silver**	**Chrome**
% from recycling	72	26	37	35	43	49	16	25

Source: http://home.clara.net/darvill/altenerg/wave.htm

Index of Sustainability

Sustainable development and its postulates on coordination of ecology, economics and society are closely related to the concept of green economy. Green economy is any economic activity involving profit, which, however, takes into account the environment, therefore, coordinating, at the same time, both factors. Strong sustainability includes the fact that the growth of economy must not be accomplished at the cost of exhausting non-renewable resources. The main indicators of sustainable development and the economy as well are the intergeneration righteousness and righteousness among the equals. The intergeneration righteousness means the amount of consumed natural resources that cannot be regenerated by human community that must not exceed the limit of utilization because this limit leads to the ecologic debt. Each ecologic debt is left to future generations to be paid. The achievements of the concept of sustainable development are observed by the certain indicators, based on modern ecologic postulates which identify the causal and consequential connections between the economic politics and politics of environmental protection and improvement. Realiable indicator warns to the problem before it becomes too serious, directing to the measures that are nece-ssary to be undertaken so that the problem can be solved. The indicators of sustai-nable development point to the weakness of causal and consequential connections between economy, the environment and society. Although they have some common properties, characteristic for their efficiency, they differ among themselves. Sustainable development defines the idea of the sustainability index in exploitation the mineral resources as the rate of production and consumption of metals, and it is determined in relation to the consumption of the primary reserves. Strategy of sustainable development means a continued, longterm reduction of consumption the primary reserves of metals with simultaneous increase of metal production by recycling. Hence, it leads to the rate of metal production by recycling and their consumption. The index of sustainable development, defined in this way, can range within the interval from 0 to 1. The higher index value, that is, closer to 1, the better conditions for realization the sustainable development. Higher index of sustainability matches the positive contribution of the environment protection, since in the case of recycling, the amount of municipal waste is reduced and also the metal production from the primary, non-renewable, sources. The index of sustainable development can be 0 if obtaining of metals by recycling is 0. The index can have the highest value, 1, if the metal production by recycling is equal to its consumption. Regardless the fact that the index of sustainable development is defined in relation to the preservation of primary reserves, it points out the level of negative effect of metal production on the environment. The higher the index, the stronger sustainability, i.e., greater savings of primary reserves and, therefore, better protection of the environment.

CONCLUSION

Taking into consideration the fact that population growth worldwide causes increase the amount of produced waste, the mankind is forced to pay the greatest possible attention to solving the problem of proper waste management. Rapid development of industrial production has caused increasingly greater consumption of the primary sources of raw materials for obtaining energy. Metals are consumed rapidly, and, if such rate is going to continue, the primary reserves will be consumed in a relatively short time. To bring down the consumption at the optimum level, and aiming to reduce the pollution of the environment, which has been considerably damaged by rapid industrialization, it is necessary to include the category of external costs in the conventional model of offer and demand of metals. These costs somehow express and evaluate the pollution of the environment. That is the way to establish the socially optimum balance on trade, resulting thus with higher price and less offer of metals from the primary reserves. Less production of metals from the primary reserves is positive from the point of view of sustainable development because it extends life time of the primary reserves and reduces the environmental pollution. Higher price of metals, as consequence of involvement the external costs, encourages producers to turn to higher metal production by recycling, the process from which they are obtained with significantly lower costs of production. Higher metal production by recycling leads to reduction of metal production from the primary reserves and in that way extends their existence. Recycling contributes to reduction of waste, resulting in reduction of environmental pollution. Reduction the environmental pollution is a positive, so-called “green“trend, involving the concept of “green economy“.

REFERENCES

[1] Ilić B., Stojanović D., Simeonović N. (2013): Trade of Transferable Permits in the Stock Market in the Function of Improvement the Environmental, Journal of Economics Niš, No. 4, pp. 172-185; (in Serbian)

[2] Ilić-Popov, G.: Environmental Taxes, Faculty of Law, University of Belgrade (2000), pp. 36; (in Serbian)

[3] Waste Catalogue Ministry of Environment and Spatial Planning, Agency for Environmental Protection of Serbia, Belgrade; (2010), (in Serbian)

[4] Magdalinović-Kalinović M.,: Magistarski rad, Technical Faculty Bor (2010); (in Serbian)

[5] Magdalinović-Kalinović M., Magdalinović N., Economic Model of Metal Recyclling, 5th Symposium on Recycling Technology and Sustainable Development, Soko Banja (2010); pp. 106-117 (in Serbian)

[6] Magdalinović N., Magdalinović-Kalinović M., Mihajlović D.: An Addition to the Definition of the Sustainable Development Index in the Field of Metal Raw Materials, 3rd International Conference on Sustainable Development Indicators in the Mining Industry, Milos Island, Greece (2007); pp. 97-107.

[7] Magdalinović N., Magdalinović- Kalinović M., Popović G.: Facts and Principles for Establishing the Management of Mineral Resources of Metals, 3-13. The First Symposium on Management the Mineral Resources with International Participation, Faculty of Management, Zaječar; (2011), pp. 3-15. (in Serbian)

[8] Stanić M., Public Measures and Instruments in the Environmental Policy, 10th International Symposium Synergy, Bijeljina; (2012), pp. 413-420 (in Serbian)

[9] http://home.clara.net/darvill/altenerg/wave.htm. Report of the U.S. Geological Society for 2007.

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RECIKLAŽA U FUNKCIJI ŠTEDNJE I ODRŽIVE EKONOMIJE MINERALNIH SIROVINA

Izvod

Pod reciklažom se podrazumeva izdvajanje materijala iz otpada i ponovno korišćenje istog. Ona podrazumeva sakupljanje, izdvajanje, preradu i izradu novih proizvoda od već korišćenih delova. U radu će se dati osnovni pojmovi reciklaže u funkciji štednje mineralnih sirovina. Štednja mineralnih sirovina, na ovaj način predstavlja jedan od ciljeva zelene ekonomije, a zelena ekonomija podrazumeva široko korišćenje obnovljivih izvora energije uz što manju emisiju, odnosno pojavu i proizvodnju štetnih materija u prirodnu sredinu. Štednja metaličnih mineralnih resursa najviše se ostvaruje reciklažom, a samim tim predstavlja prioritet za ostvarenje održivog razvoja.

Ključne reči: *reciklaža, štednja, mineralne sirovine, zelena ekonomija*

UVOD

Reciklaža je pojam kojim se može opisati proces pretvaranja „otpada“ u sirovine od kojih nastaju novi proizvodi. Kao takva, predstavlja deo integralnog sistema upravljanja otpadom, te se nalazi na trećem mestu u hijerariji upravljanja otpadom. Sistem upravljanja i recikliranja različitih vrsta otpada nije samo ekološko pitanje, već ujedno ulazi u sastav ekonomskog i energetskog potencijala jedne zemlje. Reciklaža ima ekonomski, ekološki, ali i društveni značaj jer utiče na podizanje ekološke svesti, pomaže u sprečavanju zegađenja prirodne sredine, štedi prirodne resurse, troši manje energije prilikom prerade otpada, od energije koja se utroši za dobijanje proizvoda od sirovina, na kraju, recikliranjem se smanjuje i količina otpada. Najrasprostranjenija podela, ubraja dve kategorije otpada i to industrijski, koji nastaje u industrijskim procesima i komunalni, koji nastaje u domaćinstvu. Otpad je pored svoje štetnosti, koju ima na prirodnu sredinu, vrlo značajan sekundarni izvor metala, kao i drugih proizvoda koji se dobijaju reciklažom. Statistički pokazatelji reciklaže u svetu su različiti, te idu od Japana koji reciklira 80-90% otpada, preko zemalja EU koja reciklira 30-40% otpada, sve do male Srbije koja ima zastupljenu reciklažu otpada, svega 6-8%. Na osnovu iznetih podataka može se zaključiti da je Srbija još uvek daleko od uspostavljanja ekološki bezbednog i efikasnog sistema upravljanja određenim vrstama otpada.

Ovo se posebno odnosi na komunalni otpad, obzirom da danas u Srbiji skoro upola količine prozvedenog otpada iz domaćinstva, završava na divljim deponijama, gde predstavljaju konstantni izvor zagađenja zemlje, vazduha i vode. Uputno bi bilo za Srbiju, da je potrebno da uloži više napora u postizanju boljeg upravljanju otpadom, te i više napora za uvođenje novih tehnologija

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koje bi to upravljanje i omogućile. U smislu recikliranja i tehnologija koje su vezane za reciklažu, nastao je i koncept zelenih tehnologija. Koncept zelena tehnologija, koji predstavlja deo koncepta zelene ekonomije, pokazao je nagli rast tokom proteklih godina. Uopšteno gledajući, „zeleni trendovi“ u 2012. godini uticali su na smanjenje otpada, reciklažu i ponovno korišćenje prerađenih proizvoda. Trend održivog razvoja već duže vreme je prisutan u svetu, kao trend održive ekonomije, ekologije, odnosno društvenog razvoja. Na globalnom nivou, zelena ekonomija posmatra se kao ekonomija u kojoj ekonomska rešenja i inovacije omogućavaju društvu da efikasno koristi resurse, poboljšavajući dobrobit ljudi na inkluzivan način, uz očuvanje prirodnih sistema koji održavaju svet i čovečanstvo (UNEP, United Nations Enviroment Programme, 2010).

KLASIFIKACIJA OTPADA

Karakterizacija otpada predstavlja postupak ispitivanja kojim se utvrđuju fizičko - hemijske, hemijske i biološke osobine i sastav otpada, odnosno određuje se da li otpad sadrži ili ne sadrži jednu ili više opasnih karakteristika. *Klasifikacija otpada* predstavlja postupak svrstavanja otpada na jednu ili više lista otpada koje su utvrđene posebnim propisom, a prema njegovom poreklu, sastavu i daljoj nameni; (Katalog otpada, 2010) Zakon o upravljanju otpadom zahteva da otpad bude opisan na način koji omogućava sigurno rukovanje i upravljanje predmetnim otpadom, kao i da bilo koja promena vlasništva otpada bude propraćena odgovarajućom dokumentacijom koja obavezno uključuje indeksni broj otpada. Otpad se razvrstava prema Katalogu otpada koji je usklađen s Evropskim katalogom otpada (European List of Waste/European Waste Catalog). U okviru Kataloga, otpad je sistematizovan, prvenstveno, prema delatnostima u okviru kojih je generisan, ali i prema tipu otpada, materijalima ili procesima. U Katalogu otpada je sistematizovano više od 800 vrsta otpada, podeljenih u 20 grupa, koje se označavaju dvocifrenim brojevima, te se dele na sledeći način:

1. Otpadi koji potiču od istraživanja, iskopavanja iz rudnika ili kamenoloma i fizičkog i hemijskog tretmana minerala
2. Otpadi iz poljoprvrede, holtikulture, avakulture, šumarstva, lova i ribolova, pripreme i prerade hrane
3. Otpadi od prerade drveta i proizvodnje papira, kartona, pulpe, panel i nameštaja
4. Otpadi iz kožne, krznarske i tekstilne industrije
5. Otpadi od rafinisanja nafte, prečišćavanja prirodnog gasa i pirolitičkog tretmana uglja
6. Otpadi od neorganske hemijske prerade
7. Otpadi od organske hemijske prerade
8. Otpadi od izrade, formulacije, pribavljanja i upotrebe premaza (boje, lakovi i staklene glazure), lepkovi, zaptivači i štamparska mastila
9. Otpadi iz fotografske industrije
10. Otpadi iz termičkih procesa
11. Otpadi od hemijskog tretmana površine i premazivanja metala i drugih materijala; hidrometalurgija obojenih metala
12. Otpadi od oblikovanja fizičke i mehaničke površinske obrade metala i plastike
13. Otpadi od ulja i ostataka tečnih goriva (osim jestivih ulja)
14. Otpadi od organskih supstanci koje se koriste kao rastvarači, sredstva za hlađenje i kao pogonski gasovi
15. Otpadi od ambalaže
16. Otpadi koji nisu drugačije specificirani u katalogu
17. Građevisnki otpad i otpad od rušenja (uključujući i zemlju sa kontaminiranih lokacija)

18. Otpadi od zdravstvene zaštite ljudi i životinja - iz sistema povezanog istraživnja
19. Otpadi iz objekata za obradu otpada, pogona za tretman otpadnih voda, dalje od lokacije proizvodnje i pripremu vode namenjenoj ljudskoj upotrebi i vode za industrijsku upotrebu
20. Opštinski otpadi (kućni otpad i slični komercijalni industrijski otpadi), uključujući odvojeno sakupljajuće frakcije

Iz nabrojanih kategorija otpada izdvajaju se sledeće podgrupe i to: plastika, metal, drvo, organski otpad, papir, elektronika, gume, staklo i otpadna ulja. Nabrojane vrste otpada, predstavljaju sekundarnu sirovinu za dobijanje novih proizvoda. Značajna uloga u recikliranju otpada pripada čvrstom otpadu. U čvrsti otpad spada komunalni, indistrijski i komercijalni, ambalažni i građevinski otpad. Industrijski i komercijalni otpad spadaju u najpoželjnije i najtraženije vrste otpada na tržištu. Bez ove vrste otpada ne mogu opstati operateri privatnog sektora. Predmeti i uređaji od metala koji su izgubili svoju upotrebnu vrednost, neretko završavaju na otpadu, te tako aktivno zagađuju životnu sredinu. Ova vrsta otpada predstavlja sekundarnu sirovinu za dobijanje metala, jer se sakupljanjem i vraćanjem u ponovnu preradu, dobijaju novi proizvodi, ujedno se štede primarni resursi, a samim tim i produžava vek primarnih rezervi sirovina. Na taj način se smanjuje zagađenje životne sredine. Primera radi, od ukupne količine proizvedenog bakra, procenjuje se da se izgubi 15%, dok se preostala količina ugrađuje u stvari i predmete koje služe ponovnoj upotrebi. Slično je i sa čelikom, o čemu govori podatak da se danas skoro 75% čelika dobija recikliranjem. Činjenica da je ukupna količina komunalnog otpada u svetu dostigla zabrinjavajuće visok nivo, ukazuje da je urgentno preduzeti akcije koje vode smanjenju istog.

Može se konstatovati da je količina otpada u direktnoj vezi sa obimom proizvodnje i sa razvijenošću zemlje. Razvijenije zemlje više proizvode otpad, zbog veće proizvodnje, ali sa druge strane prednjače u razvoju tehnologije za suzbijanje otpada. U ovim zemljama komunalni otpad se tretira u postrojenjim za sortiranje. Primera radi, u zemljama EU ukupno količina komunalnog otpada koji se sagoreva iznosi 33%. Nakon takvog tretmana, preostali deo otpada je količinski manji, te ga je lakše deponovati. Obzirom na sve iznete činjenice vezane za otpad, u daljem tekstu predstaviće se važnost uključivanja eksternih troškova, koji su u direktnoj vezi sa eksploatacijom mineralnih sirovina. To će dalje rasvetliti značaj reciklaže u smanjenju troškova za dobijanje metala i u njenoj ekonomskoj opravdanosti.

NEOPHODNOST UKLJUČIVANJA EKSTERNIH TROŠKOVA U EKSPLOATACIJI MINERALNIH SIROVINA

Eksternalije predstavljaju učinke, pozitivnog ili negativnog karaktera, koje proizilaze iz određene aktivnosti, a da pri tome nisu rezultat delovanja mehanizma cena. Termin „eksterni učinak“ prvi je upotrebio teoretičar ekonomije blagostanja A. S. Pigou (1912) koji je postavio osnove standardne teorije eksternalija. Polazeći od tržišnih nedostataka, Pigou je izneo postavku o neophodnosti državne intervencije koja bi trebala da obezbedi da tržišne cene odražavaju pun društveni trošak. Posmatrano sa teorijskog stanovišta, kako bi se izbeglo prenošenje eksternih troškova na celokupnu društvenu zajednicu, neophodna je njihova internalizacija, odnosno uključivanje troškova zagađenja u cenu proizvoda koje uzrokuju zagađenje (Ilić i drugi, 2013). U ekonomskoj teoriji i praksi postoje dve grupacije mera kojima se regulišu eksternalije: (Stanić, 2012)

1) komandno-kontrolne (standardi ili ograničenja) i
2) tržišne mere (porezi i prenosive dozvole).

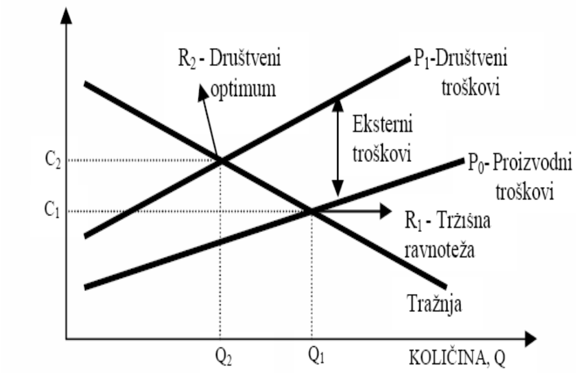
Potrebno je istaći da eksterni efekti mogu da postoje kako u proizvodnji, tako i u potrošnji, te da mogu biti pozitivni i negativani. *Pozitivni eksterni efekti* predstavljaju koristi za treća lica i nisu uključeni u cenu proizvoda. U slučaju eksternih efekata u potrošnji, jedan subjekat svojom potrošnjom donosi koristi nekom licu, s tim što se to dešava bez stvaranja dodatnih troškova za to drugo lice. Otuda, on nije spreman da ih prizna u ceni robe koju kupuje radi potrošnje.

S druge strane, kod pozitivnih eksternih efekata u proizvodnji, jedan proizvođač svojom aktivnošću pruža koristi nekom trećem licu, a ne onim licima kojima prodaje svoju robu, tako da za tu aktivnost ne naplaćuje nikakvu naknadu od trećih lica (Ilić - Popov, 2000). Primer pozitivnih eksternih efekata je obrazovanje. *Negativni eksterni efekti* označavaju troškove koje pravno ili fizičko lice uzrokuje, tj. nameće drugim članovima društva, a koji nisu uključeni u cenu proizvoda. S obzirom da su razmere negativnih eksternih efekata veće i njihove posledice dalekosežnije, ovoj vrsti eksternih efekata se posvećuje mnogo veća pažnja.

Prilikom održivog upravljanja mineralnim resursima, proizilazi da je cena metala jedan od glavnih ekonomskih instrumenata za dostizanje te održivosti. Ukoliko se u razmatranje uzme klasični ekonomski model ponude i tražnje, može se konstatovati da isti uključuje krivu ponude i tražnje, koje su definisane graničnim troškovima rada i kapitala. Međutim, proizvodnjom metala iz primarnih sirovina, nastaju troškovi koji su nastali posrednim ili neposrednim oštećenjem, odnosno zagađenjem, prirodne ili životne sredine, a koje proizvođač ne uključuje u svoje obrasce troškova. Ukoliko se oni izostave, to svakako neće biti stvarno stanje i objektivna slika savremenog ljudskog delovanja i troškova koji pri tom delovanju nastaju. S toga je u klasični model ponude i tražnje neophodno uključiti i eksternalije, odnosno eksterne troškove, koji predstavljaju monetarno ili finansijski izraženu vrednost zagađenja životne sredine. Ali, na koji način monetarno odrediti oštećenja životne sredine? Ovo pitanje se nameće iz razloga što se ne može tačno utvrditi koliko zaista iznose štete nastale od zagađenja sredine. Ukoliko se naruši reljef ili kvalitet vazduha, teško je proceniti koliko iznose gubici u odnosu na moguće koristi od ovih prirodnih uslova. Lakše je proceniti koliko iznosi gubitak od degradacije određene površine zemljišta, na osnovu izgubljene potencijalne dobiti od prinosa kultura koje se na njima gaje, ili bi se mogle gajiti. Troškovi nastali usled zdravstvenih problema stanovništva, mogu se takođe lakše monetarno izraziti i prikazati. Posmatrano kako sa ekološke, tako i sa finansijske strane, svakako da nikakva oštećenja životne sredine nisu poželjna. Ali su ta oštećenja realna i zaista postoje, sa tom razlikom što je neka nemoguće otkloniti, dok je pojedine moguće sanirati. Ukoliko se zagađenjima prirodne sredine ne dodeli nikava vrednost, te se kao takvi ne pojavljuju u ekonomskom modelu ponude i tražnje, onda bi praktično i njihova tržišna vrednost bila jednaka nuli. Bez obzira na to koliko je teško zaista odrediti vrednost pomenutih oštećenja, u cilju zaštite života, a samim tim i opstanka ljudskog društva, eksternailje se moraju uzeti u razmatranje savremene ekonomske analize. Funkcija troškova nastalih zagađenjem prirodnih uslova i sredine u ekonomskom modelu analize, proporcionlano raste sa porastom proizvodnje, te se za potrebe ovog rada može pretpostaviti da su ovi troškovi direktno proporcionalni proizvodnji metala (Magdalinović i drugi, 2011). U globalnim razmerama rudarstvo i metalurgija su najveći zagađivači životne sredine, sa kumulativnim i dalekosežnim posledicama po životnu sredinu i klimatske promene.

Najvidljivije i najdirektnije posledice zagađenja manifestuju se preko zagađenja vazduha štetnim gasovima (sumpor, ugljenik i azot), mineralnom prašinom i česticama teških metala (olovo, arsen, mangan, kadmijum, živa) čije su štetne posledice po zdravlje stanovništva alarmantne. S obzirom da savremena industrija, u koju spada i rudarska industrija, najviše zagađuje prirodnu sredinu, pomenuta analiza se može primeniti na bilo koju njenu granu.

Slika 1 prikazuje jednostavan način uvođenja eksternih troškova u analizu ponude i tražnje metala. Na grafiku se mogu videti troškovi proizvodnje metala, odnosno radne snage i kapitala. Tržišna ravnoteža **R_1,** koja je određene presekom grafika ponude i tražnje, odgovara količini metala **Q1** i ceni **C_1**. Ukoliko se u troškove proizvodnje uključe i procenjeni eksterni troškovi (oštećenje životne sredine), dobija se novi, viši grafik ponude koji predstavlja zbir proizvodnih i eksternih troškova, a koji se mogu nazvati društveni troškovi. Prilikom uvođenja eksternih troškova pomera se tačka ravnoteže ***R_1*** u tačku ***R_2***, koja predstavlja društveni optimum. Ukoliko je manja ponuda ***Q_2***, a veća cena ***C_2***, tim pre je lakše ostvariti društveni optimum. Ovakav pristup uvođenja troškova u analizu ponude i tražnje ima svoj opravdani smisao. Naime, troškovi zaista postoje i u novoj ravnoteži usporavaju iscrpljivanje primarnih rezervi metala (Magdalinović-Kalinović, 2010).



Sl. 1. *Model ponude i tražnje sa eksternim troškovima*

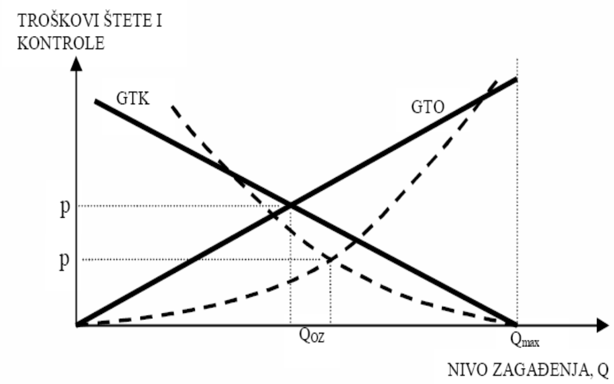
Nova ravnoteža ***R_2*** uslovljava rast cena ***C_2***, dok se prodata količina, sa **Q_1** smanjuje na ***Q_2***. Efekat ekonomske efikasnosti je dobar bez obzira što bi potrošači negodovali zbog porasta cene (one su samo rezultat realnih troškova proizvodnje). Ukoliko je prodaja manja, smanjuje se i proizvodnja, a takva proizvodnja će smanjiti i oštećenje životne sredine. Sa druge strane, uštedeće se na primarnim izvorima metala, jer će i njihovo iscrpljivanje rezultirati smanjenjem. Ovakav pristup, odnosno dobijeni novi grafik, je približan efikasnoj ravnoteži, odnosno društvenom optimumu proizvodnje metala (iz primarnih rezervi). Uvođenje eksternalija u klasičan model ponude i tražnje može se uraditi na različite načine, u zavisnosti kako od mineralne sirovine, tako i od načina na koji ista zagađuje prirodnu sredinu. Porez na zagađenje predstavlja jedan od načina uvođenja eksternih troškova, koji utiče ne samo na popunjavanje državne kase, već i na svest proizvođača o tome koliko se prirodno okruženje zaista zagađuje. Što je poreza na zagađenje veća, to je i ponuda sirovina na tržišti manja, a cena sirovine viša. Ova situacija odgovara ekolozima, jer ide u prilog smanjenog zagađenja životne sredine, obzirom da proizvođači na ovaj način, budu naterani da proizvode manje. Međutim, može se slobodno postaviti pitanje o tome koja je najviša cena metala do koje proizvođači mogu ići, odnosno koju potrošači mogu i prihvataju da plate. Ovo iz razloga što je i količina zagađenja povezana sa tehnologijom, koja se mora menjati i usavršavati. Ukoliko ostaje nepromenjena, poreza će imati samo ulogu u smanjenoj ponudi i višoj ceni.

Odgovor na ovo i slična pitanja moguće je pronaći u reciklaži. Ukoliko cena metala na tržištu ostvari kritičnu gornju granicu, potrošači će tražiti nove načine za zamenu istog, odnosno okrenuće se reciklaži. Metal se iz reciklaže dobija uz niže troškove, a takođe i uz manje zagađenje životne sredine. Sa stanovišta održivog razvoja, ovo je svakako najpovoljnija situacija, jer produžava vek trajanja primarnih rezervi za dobijanje metala, ujedno smanjujući loše efekte po okolinu.

Dakle, može se reći da je potrebno pronaći nivo optimalnog zagađenja i uskladiti visinu poreza sa tim nivoom. Međutim, nije li optimalno zagađenje ono koje i ne postoji? Paradoks je upotrebiti reč optimalno kada se govori o zagađenju, obzirom na realnu svest da je optimalno zagađenje, nulto zagađenje. Ali, ukoliko se uzme u obzir da ga svaka, pa i najmanja proizvodnja izaziva, sa ekonomske tačke gledišta, potrebno je da i proizvodnja bude nulta, odnosno da ne postoji. Društvo se u svakom slučaju mora opredeliti koju količinu zagađenja je spremno da prihvati. Ukoliko se uspostavi odredne nivo optimalnosti, neophodno je težiti smanjenju i tih „optimalnih“ štetnih efekata. Takvo smanjenje je jedino moguće ostvariti primenom novih tehnologija.

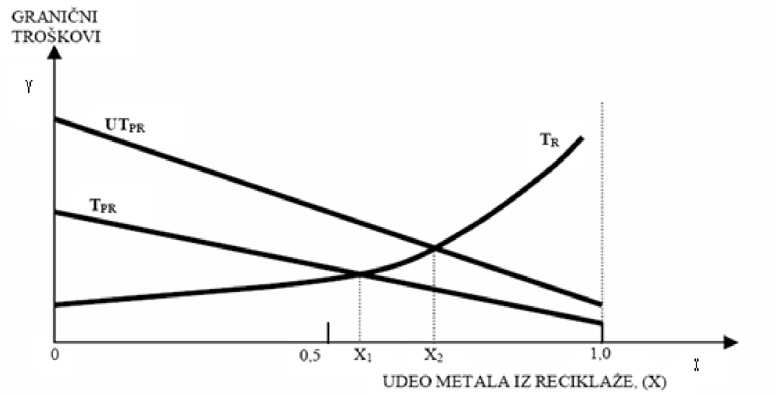
Može se konstatovati da dokle god postoji proizvodnja, postojaće i nivo zagađenja. Da bi se utvrdio optimalni nivo, ekonomisti su uveli u analizu poređenje graničnih troškova zagađenja **GTK**, sa graničnim troškovima oštećenja od zagađenja, koje će u ovom slučaju biti obeleženi sa **GTO**. Na slici 2 su prikazane krive ovih tro-škova, te se može zaključiti da je smanjenje zagađenja isplativo sve dok su i troškovi od kontrole zagađenja manji od koristi dobijenih od smanjene štete.

Tačka **Qmax,** kao maksimalni nivo zagađenja, predstavlja količinu zagađenja bez ikakve kontrole. Ukoliko se preduzimanjem mera zagađenje smanji, smanjiće se i granični troškovi oštećenja životne sredine. Međutim, što je svaka jedinica zagađenja manja, to je svaka jedinica troška kontrole veća, odnosno granični troškovi kontrole se povećavaju. U preseku grafika graničnih troškova zagađenja i troškova kontrole, nalazi se tačka optimalnog nivoa zagađenja**,** tj. $\mathbf{Q_{OZ}}$**.** Ova tačka određuje visinu poreza - *p* na zagađenje (sl. 2) (Magdalinović-Kalinović, 2010).



Sl. 2. *Granični troškovi štete i kontrole*

Iako je ova analiza u praksi vezana za određene poteškoće, u smislu monetarnog izražavanja određenih vrsta zagađenja, posebno kada je u pitanju kumulativno zagađenje ili estetsko oštećenje reljefa, ipak je to jedini model za pojašnjenje i shvatanje načina na koji politika kontrole zagađenja utiče na proizvođače, da promene način proizvodnje metala, te da podignu svest o zagađenju životne sredine. Recikalža predstavlja efikasan način za produženje veka trajanja primarnih rezervi metala. Na slici 3 dat je prikaz ekonomske operavdanosti reciklaže, predstavljenu garničnim troškovima proizvodnje metala iz primarnih izvora i iz reciklaže. Na *x* osi je dat udeo proizvodnje metala iz reciklaže, dok su na *y* osi dati granični troškovi. Što je veći udeo matala iz raciklaže, to više rastu i granični troškovi proizvodnje metala iz reciklaže, koji su označeni sa **TR**. Troškovi proizvodnje metala iz reciklaže rastu pravolinijski, a potom po eksponencijalnom grafiku. Za potrebe rada, može se pretpostaviti da granični troškovi proizvodnje metala iz primarnih rezervi, označeni sa **TPR** opadaju pravolinijski. Ukoliko se na **TPR**, odnosno na troškove proizvodnje metala iz primarnih rezervi dodaju troškovi oštećenja životne sredine, dobijaju se ukupni društveni troškovi proizvodnje metala iz primarnih rezervi, označeni sa **UTPR**. Tačka preseka graničnih troškova i ukupnih troškova proizvodnje metala, koji predstavljaju sumu troškova metala iz primarnih rezervi i troškova iz reciklaže, definiše optimalni udeo metala iz reciklaže. Ukupni troškovi su minimalni, te se i udeo metala iz reciklaže označava kao optimalni.



Sl. 3. *Granični troškovi proizvodnje metala iz primarnih rezervi i reciklaže*

Međutim, uključivanje eksternalija u ovu analizu, dovodi do povećanja optimalnog udela proizvodnje metala iz reciklaže i to sa $\mathbf{X_1}$ na $\mathbf{X_2}$. Potrebno je reći da iznad ove tačke optimalnog udela metala iz reciklaže **($\mathbf{X_2}$)**, troškovi metala iz reciklaže naglo rastu. Sudeći po grafiku, može se zaključiti da je stoprocentno recikliranje skupo i teško, te samim tim i neopravdano. U zavisnosti od razvijenosti zemlje, zavisi i količina metala kopji se dobija iz reciklaže. Međutim, nije jedini uslov razvijenost, već i procenjene rezerve, odnosno prirodno bogatstvo metaličnim sirovinama, kao i ekonomska isplativost dobijanja tih sirovina iz primarnih rezervi. Primer za visoko učešće dobijanja metala iz reciklaže predstavlljaju zemlje zapadne Evrope, obzirom da iste oskudevaju u primarnim sirovinama za dobijanje metala. Bogata bakrom, Južna Amerika, beleži duplo manje učešća bakra iz reciklaže, u odnosu na svetski prosek. U tabeli 1 i 2 prikazani su podaci o dobijenom bakru iz reciklaže po regionima, ali i po vrsti metala koji se najviše dobijaju iz reciklaže (Magdalinović i drugi, 2007).

Tabela 1. *Učešće recikliranog bakra u ukupnoj potrošnji bakra u svetu (izraženo %)*

Godina / **Region**	***2002***	***2003***	***2004***	***2005***	***2006***	***2007***	***2008***
Azija	30,9	30,0	31,7	33,1	37,7	34,2	34,0
Evropa	44,4	41,6	41,2	41,5	41,0	41,3	42,7
Sev. Amerika	32,4	31,5	30,5	31,1	33,2	34,1	33,0
Ostatak sveta	16,3	14,0	14,6	16,6	17,1	18,8	16,3
Ukupno svet	34,6	33,0	33,4	34,2	36,8	35,3	35,1

Izvor: International Copper Study Group, Copper Bulletion, 2010

Tabela 2. *Udeo metala iz reciklaže u svetu, 2006.god*

Metal	**Olovo**	**Cink**	**Bakar**	**Nikl**	**Zlato**	**Aluminijum**	**Srebro**	**Hrom**
% iz reciklaže	72	26	37	35	43	49	16	25

Izvor: http://home.clara.net/darvill/altenerg/wave.htm

Indeks održivosti

Održivi razvoj i njegovi postulati o usklađenosti ekologije, ekonomije i društva nalaze se u tesnoj vezi sa konceptom zelene ekonomije. Zelena ekonomija je svaka ekonomska aktivnost, koja podrazumeva dobit, ali koja usput vodi računa o prirodnom okruženju, te na taj način usklađuje ova dva.

Jaka održivost podrazmeva da ekonomski rast ne sme biti ostvaren po cenu iscrpljivanja neobnovljivih resursa. U glavne indikatore održivog razvoja, samim tim i ekonomije spadaju Intergeneracijska pravednost, kao i pravednost među jednakima. Intergeneracijska pravednost označav količinu korišćenih prirodnih resursa koji se ne mogu regenerisati, od strane ljudske zajednice, koja ne sme prekoračiti granicu iskorišćenja, jer to prekoračenje dovodi do ekološkog duga. Svaki ekološki dug biva ostavljen za plaćanje budućim generacijama, odnosno našoj deci. Dostignuća koncepta održivog razvoja se prate odgovarajućim indikatorima, zasnovanim na savremenim ekološkim zakonitostima, koji identifikuju uzročno posledične veze između ekonomske politike i politike zaštite i unapređenja životne sredine. Pouzdan indikator upozorava na problem pre nego što on postane suviše ozbiljan, te upućuje na mere koje je potrebno preduzeti kako bi se problem otklonio. Indikatori održivog razvoja ukazuju o slabosti uzročno posledičnih veza između privrede, životne sredine i društva. Oni se međusobno razlikuju, pored nekih zajedničkih osobina, karakterističnih za njihovu efikasnost. Održivi razvoj definiše pojam indeksa održivosti u eksploataciji mineralnih sirovina kao odnos između proizvodnje i potrošnje metala, a definisan je u odnosu na trošenje primarnih rezervi. Strategija održivog razvoja svodi se na kontinuirano, dugoročno smanjivanje potrošnje primarnih rezervi metala, uz istovremeno povećanje proizvodnje metala iz reciklaže. Samim tim dolazi se do odnosa proizvodnje metala iz reciklaže i njegove potrošnje. Indeks održivog razvoja, definisan na ovaj način se može kretati u intervalu od 0 do 1. Ukoliko je vrednost indeksa veća, odnosno bliža jedinici, to su i bolji uslovi za ostvarenje održivog razvoja. Veći indeks održivosti, odgovara pozitivnom doprinosu očuvanja prirodne sredine, jer se u datom slučaju, kada je u pitanju reciklaža količina komunalnog otpada smanjuje, kao i proizvodnja metala iz primarnih, neobnovljivih izvora. Indeks održivog razvoja može biti jednak nuli, ukoliko je i dobijanje metala iz reciklaže jednako nuli. A najveću vrednost, odnosno jedinicu, može imati ukoliko je proizvodnja metala iz reciklaže jednaka njegovoj potrošnji. Bez obzira što je indeks održivog razvoja definisan u odnosu na očuvanje primarnih rezervi, on ukazuje i na stepen negativnog uticaja proizvodnje metala na životnu sredinu. Što je ovaj indeks veći, to ukazuje na jaču održivost, odnosno na veću uštedu primarnih rezervi, a implicitno i na bolju zaštitu prirodne sredine.

ZAKLJUČAK

S obzirom na činjenično stanje, da se sa porastom broja stanovništva u Svetu, beleži i porast količine proizvedenog otpada, čovečanstvo je primorano da maksimalno posveti pažnju rešavanju problema pravilnog upravljanja otpadom. Nagli razvoj industrijske proizvodnje je doprineo i sve većoj potrošnji primarnih izvora energetskih sirovina. Ubrzano se troše i metali, a ukoliko se takva stopa nastavi, doći će se do potrošnje primarnih rezervi i to za relativno kratak vremenski period. Kako bi se potrošnja svela na neki optimalni nivo, a i u cilju smanjenja zagađenja životne sredine, koja je poprilično oštećena naglom industrijalizacijom, potrebno je u klasičan model ponude i tražnje metala, uvesti i kategoriju eksternih troškova. Ovi troškovi na određeni način iskazuju i vrednuju zagađenje životne sredine. Time se uspostavlja društveno optimalna tržišna ravnoteža, koja rezultira višom cenom i manjom ponudom metala iz primarnih rezervi. Manja proizvodnja metala iz primarnih rezervi je pozitivno sa stanovišta održivog razvoja, jer produžava vek trajanja primarnih rezervi i smanjuje zagađenje životne sredine. Viša cena metala, kao posledica uvođenja eksternih troškova, podstiče proizvođače da se okrenu većoj proizvodnji metala iz reciklaže, odakle se on dobija uz značajno niže troškove proizvodnje. Veća proizvodnja metala iz reciklaže dovodi do smanjenja proizvodnje metala iz primarnih rezervi, te tako produžava njihov vek trajanja. Reciklaža doprinosi i smanjenju otpada, što rezultira smanjenju zagađenja životne sredine. Samo smanjenje životne sredine, predstavlja pozitivan, odnosno zeleni trend, u koji se ubraja i koncept zelene ekonomije.

LITERATURA

[1] Ilić B., Stojanović D., Simeonović N.: Trgovina prenosivim dozvolama na berzanskom tržištu u funkciji poboljšanja kvaliteta životne sredine, Časopis Ekonomika Niš, broj 4, 2013, str. 172-185.

[2] Ilić-Popov, G.: Ekološki porezi, Pravni fakultet Univerziteta Beograd, 2000, str. 36.

[3] Katalog otpada Ministarstvo životne sredine i prostorno planiranje, Agencija za zaštitu životne sredine Srbije, Beograd, 2010

[4] Magdalinović-Kalinović M.: Magistarski rad, Tehnički fakultet Bor, 2010.

[5] Magdalinović - Kalinović M., Magdalinović N., Ekonomski model reciklaže metala. 5. Simpozijum Reciklažne tehnologije i održivi razvoj, Soko Banja, 2010, str. 106-117.

[6] Magdalinović N., Magdalinović-Kalinović M., Mihajlović D.: An Addition to the Definition of the Sustainable Development Index in the Field of Metal Raw Materials. 3rd Inter. Conf. on Sustainable Development Indicators in the Min. Ind., Milos island, Greece, 2007, str. 97-107.

[7] Magdalinović N., Magdalinović - Kalinović M., Popović G.: Činjenice i principi na kojima treba zasnivati upravljanje mineralnim resursima metala 3-13. Prvi simpozijum o upravljanju prirodnim resursima, sa međunarodnim učešćem, Fakultet za menadžment, Zaječar, 2011, str. 3-15.

[8] Stanić M., Javne mjere i instrumenti u politici zaštite životne sredine, 10. Međunarodni naučni skup Sinergija, Bijeljina, 2012, str. 413-420.

[9] http://home.clara.net/darvill/altenerg/wave.htm. Izveštaj američkog geološkog društva za 2007. god.

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RECLAMATION OF THE ASH AND SLAG LANDFILL GACKO - B&H[**]

Abstract

Technological process of coal combustion in thermal power plants produces the certain amounts of ash and slag that have to be transported and disposed at the selected location - landfill. Disposal of ash and slag from the power plant Gacko in Gacko, Bosnia and Herzegovina, was done in the cassette II, formed in the excavation area of the open pit Gračanica. With the need for a new space for disposal of ash and slag, the solution was found in forming the cassette III below the existing cassette II. After completion of exploitation and achieving the designed elevation of 940 meters above the sea level, the reclamation is carried out of all cassettes, which permanently eliminate any negative impact of ash from the landfill on the surrounding living space and air.

Key words: *reclamation, landfill, ash, slag.*

INTRODUCTION

Thermal power plant Gacko since 1995 has made a disposal of ash on the ash landfill - the first phase, cassette I, in the excavated area of the open pit mine Gračanica in a part of exploitation field A. After filling the cassette I, acontinuation of ash and slag disposal was carried out in a continuation of cassette II, in the excavation area of the open pit Gračanica, which was formed in a continuation of cassette I. After many-year disposal of ash and slag in cassette II, there was a reduction of landfill area and it was necessary to provide a new area for disposal of ash and slag, and thus to ensure a continuous operation of power plant Gacko. Andequate solution was found in formation of landfill in cassette III, in the excavation area of the open pit Gračanica. Cassette III is formed in a continuation of cassette II to the southern final slope of the open pit (Figure 1). Location of the landfill of ash and slag in cassette III was selected as the best techno-economic solution for disposal of ash and slag from the power plant Gacko with respect to the location of the settlement Gacko, developed infrastructure, availability of space, etc.

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[**] *This work is the results of the Project No. TR33021 "Research and Monitoring the Changes of Stress-strain State in the Rock Massif „in-situ" Around the Underground Rooms with Development a Model With a Special Review to the Tunnel of the Krivelj River and Jama Bor", funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia.*

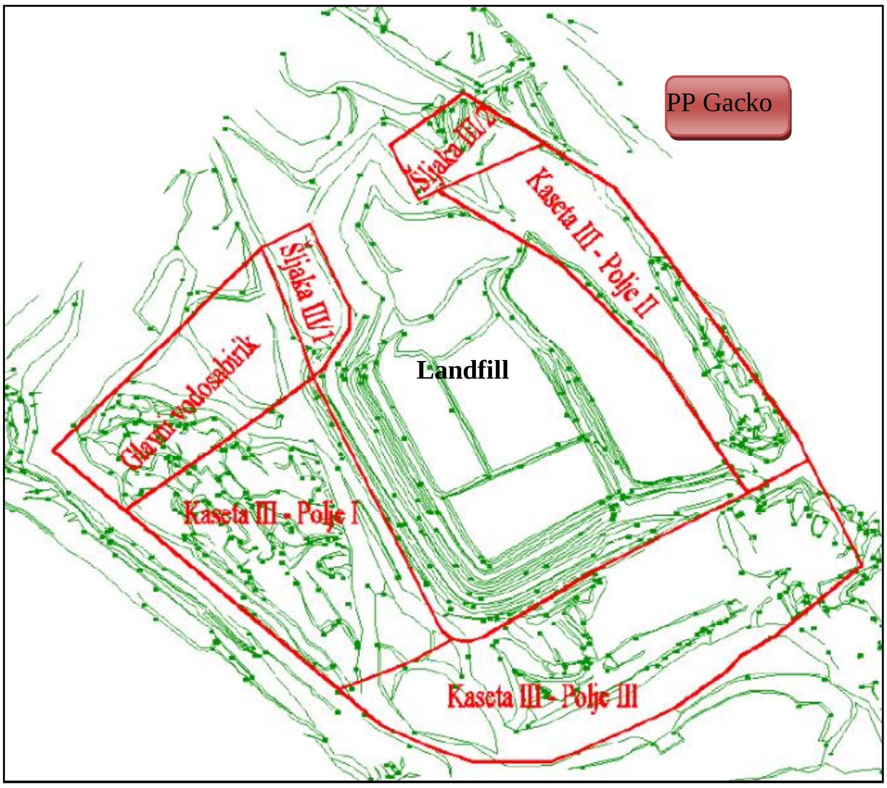

Figure 1 *Provided area for cassette III*

Process of coal mining at the open pit Gračanica has resulted into environmental degradation, i.e. there was a large surface soil degradation as well as disturbance of surface and groundwater regimes. By construction the power plant Gacko, the environmental quality was additionally degraded. The ash and slag landfills have the major influence on this.

Fly ash is the finest fraction which remains after coal combustion in thermal plants [1]. Fly ash is a heterogeneous mixture of particles of different physical, chemical, mineralogical and morphological properties, produced by coal combustion in power plants and whose characteristics are determined by the quality of burnt coal, combustion technology and combustion conditions [1]. Fine ash fractions may have a strong degrading effect on the living environment and environment, particularly during high winds, when blown in the environment, which may lead to the major ecological problems, especially damage the population health, having in mind that this raw material is categorized as a hazardous waste [2].

However, the air pollution is eliminated because the technogenic raw material is transported to the landfill in the form of hydro mixture, i.e. in wetted or submerged condition. Namely, the electro filter fly ash from PP Gacko belongs to the type of calcareous ash (high content of CaO), which means that it has the cementation properties and in contact with water builds a compact material of specific mechanical strength. In this way, the emission of fine ash particles into air is prevented.

Construction of landfill will conducted in two phases. The initial situation for formation of landfill is the formed landfill on cassettes I and II to the finished elevation K+940 m, and the prepared base of phase 1, cassette III. The initial landfill area of 141 750 m^2 was formed by the construction of massive dike of waterproof material on three sides and slope of the terrain to cassette I. The bottom of the newly designed landfill will be coated with a plastic foil to protect soil and groundwater from leachate. Underneath the plastic foil, the drainage for evacuation of underground water will be installed, which drains into the pumping station the seepage and drainage water. The initial situation in phase 2 is practically the final view of the landfill at the end of phase 1. The final view of the ash and slag landfill in phase 2 is shown in Figure 2.

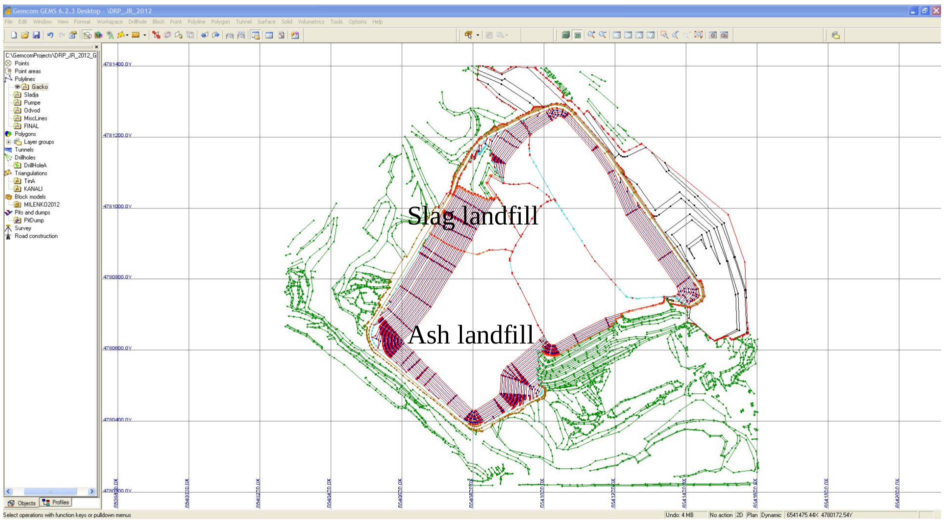

Figure 2 *Final view of the ash and slag landfill in phase 2, cassette 3, in the program Gemcom 6.2*

Re-cultivation and revitalization of degraded areas caused by coal exploitation at the open pit Gračanica and later disposal of ash and slag into the excavated area of open pit means the reclamation.

For revitalization of degraded areas on the ash and slag landfill, the optimum reclamation will be applied with phases: technical and biological reclamation.

According to the physical and chemical characteristics of the soil, geomorphology of landfill, the exposed area to the south, climate and natural vegetation in the region, the biological optimum stage of reclamation will be taken into consideration on the final planes of ash and slag landfill, where the afforestation with acacia will be carried out.

2 DEGRADED AREAS FOR RECLAMATION

Reclamation of degraded areas is planned on plateaus and slopes of the landfill. The surfaces for reclamation are shown in Tables 1 and 2

Table 1 *Surfaces in phase 1 for reclamation*

Location	Phase	Flat surfaces-level planes	Surface m^2	Reclamation method	Sloping surfaces – slopes of level panels	Surface m^2	Reclamation method
Landfill	1	plateau - 940	101 552	afforestation	E940/E937	4 558	filling
		937	5 375	filling	E937/E934	4 660	filling
		934	5 380	filling	E934/E931	4 600	filling
		931	5 390	filling	E931/E928	4 560	filling
		928	5 490	filling	E928/E925	3 898	filling
		925	3 535	filling	E925/E922	2 860	filling
		922	2 945	filling	E922/E919	2 580	filling
		919	2 500	filling	E919/E916	2 390	filling
		917	2 450	filling	E916/E913	2 247	filling
		913	2 240	filling	E913/E910	1 990	filling
		910	2 030	filling	E910/E907	1 800	filling
		907	1 880	filling	E907/E904	1 071	filling
		904	520	filling			
		Total	141 287			37 214	

Table 2 *Surfaces in phase 2 for reclamation*

Location	Phase	Flat surfaces-level planes	Surface m^2	Reclamation method	Sloping surfaces – slopes of level panels	Surface m^2	Reclamation method
Landfill	1	plateau - 940	176 518	afforestation	E940/E937	5 571	filling
		937	5 730	filling	E937/E934	5 112	filling
		934	6 530	filling	E934/E931	3 875	filling
		931	4 265	filling	E931/E928	2 628	filling
		928	2 875	filling	E928/E925	2 250	filling
		925	2 300	filling	E925/E922	4 473	filling
		Total	198 218			23 909	

3 PEDOLOGICAL PROPERTIES OF NATURAL SOIL

A soil layer in detecting the deposit (investment overburden) is removed and disposed at the borrow of humus where it will be used to fill the plateau of landfill.

To determine the benefits of natural soil for reclamation of degraded areas on the landfill, the agro-chemical analyses of taken samples D1 and D2 were carried out in the laboratory of the Mining and Meta-llurgy Institute Bor. The results of agrochemical analysis are for the sample D1: pH = 7.55, CaO = 3.85; P_2O_5 = 0.15; K_2O = 2.20, and the sample D2: pH = 7.69, CaO = 5.46; P_2O_5 = 0.16; K_2O = 1.33.

Data on analysis the samples D1 and D2 in this case were used to define the natural soil type and its properties. Natural soil from the borrow to the classification belongs to rendzinas, that is rendzinas on marl and marly limestone.

The soil is of neutral reaction, poorly supplied with phosphorous and NPK 10:20:30, in an amount of 400 kg/ha, should be included.

4 TECHNICAL RECLAMATION

Technical reclamation of the ash and slag landfill in the area of the open pit Gračanica is carried out under the European Regulation on disposal of waste at landfills (Council Directive 1999/31/EC of 26 April in 1999 on waste landfill - hereinafter the Directive).

Based on the recommendations of the Directive after disposal of ash and slag (elevation 940 m), on the entire surface of the landfill, a three final layers are placed, which serve as protection, as well as preparation for biological reclamation.

The first layer is formed by disposal of disposed material from the existing landfill. This material, based on geological data, belongs to marly limestone. It is estimated that the thickness of this material should be about 1 m. After formation the first layer, the formation of the second layer is made that presents a drainage layer. This layer consists of grit and sandy material. Layer height is 0.5 m. The final layer is a layer of humus, which would be a guarantee that the biological reclamation can be made on such base. It is estimated that the thickness of the final – third layer of humus should be 1 m. Humus is transported and disposed from the formed humus landfills in the vicinity of the landfill. The final view of the ash and slag landfill will be formed with slopes of about 1% to the drainage facilities in order to solve the drainage by gravity.

Technical reclamation includes the following activities:

- loading of materials for construction the service road and filling the slopes,
- loading of material for construction the layers - marl, drainage material, humus
- transport of materials,
- work of bulldozers on flattening and leveling of service road,
- work of bulldozers on flattening of landfill slope,
- work of bulldozers on flattening the layers of landfill plateau,
- placing of drainage pipes and canalettos,
- connecting the all segments of drainage system.

4.1 Works on Construction the Service Road

Works in this phase of technical reclamation would include construction the service road on the landfill plateau, and connection to the network of access roads to the landfill. The network of roads outside the landfill is constructed, and how it is in the constant use, it is maintained regularly, so that the road is in a good condition. With respect to the future works on landfill, the service roads will be constructed on the existing network.

Service road will be 5 meters wide. The construction consists of loading and transport of material from the landfill of marl and then filling the material - marl on the landfill plateau, and then flattening - leveling by bulldozer.

4.2 Description of Works for Reclamation the Landfill Slopes

Since the slopes of landfill are under a high incline, it is necessary to perform the reclamation of the same to stabilize the ground and prevent the eventual penetration of water. Technical reclamation of slopes includes filling the slopes to mitigate a decline where the angle of general slope of 18.3° (or 1:3 ratio) is formed.

Material for filling the slopes, i.e. placement a layer is taken from the formed marl landfills, located near the landfill. Loading and transport of this material is done on the landfill plateau. The material is unloaded in piles in various places as bulldozer would faster and more qualitative operate. Then the material is pushed along the slope of landfill. Height of mate rial, i.e. the final layer over the slopes should be around 1 m. Upon completed leveling of material is the phase in which the material is compacted. These works are carried out by roller. Since the general angle is less than 20°, the conditions for roller operation on the slopes are possible.

4.3 Works on Forming the Final Layer on the Landfill Plateau

Material for placement the first layer on the landfill plateau is taken from the formed marl landfills. Loading and transport of this material is done on the landfill plateau. By the work of planning machinery is formed a layer of marl in the height of 1 m (Figure 3). At the same time, the care is taken to put into position a single-ribbed drainage pipe ø160 mm. These pipes are placed at a distance of 80 m.

The function of these pipes is to collect the water and to drain the water by the set drainage system to the drain ditches, which are connected to the main drainage channels that drain this collected water into the river Gračanica or into the main water collectors.

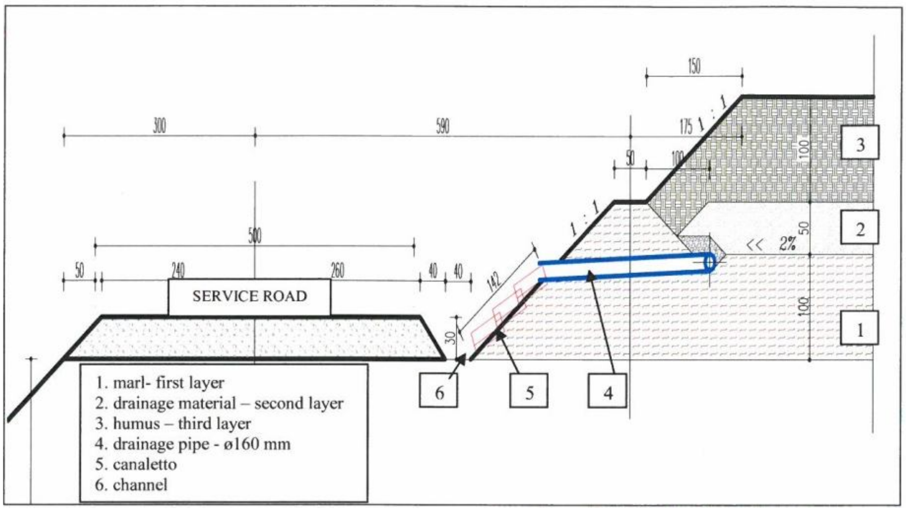

Figure 3 *Cross-section of the landfill with a view of all layers and service road*

After the material dumping by truck, planning of materials is done by bulldozer. During this, the care is taken that the planned base is 1%. Plateau is divided into sections of 80 m, Figure 4.

Each section has the view, shown in Figure 4, which presents the slopes of this layer. In this way, it enables the proper functioning of the drainage system. All collected water goes into formed "channel", and from there the water is collected with drainage pipe ø160 mm. This water is lowered by canalettos into the main channel that is constructed between the service road and this layer.

For drainage system functioning, it is necessary to form the first layer (marl) with a slight decline of 1%. In addition to the general decline, this layer is formed to have another decline towards "inside". As it is shown in Figure 4, the distance of 80 m to which the pipes will be placed, will be divided in half, wherein these halves will form a decline towards "inside" and thus all water will interflow to the pipes.

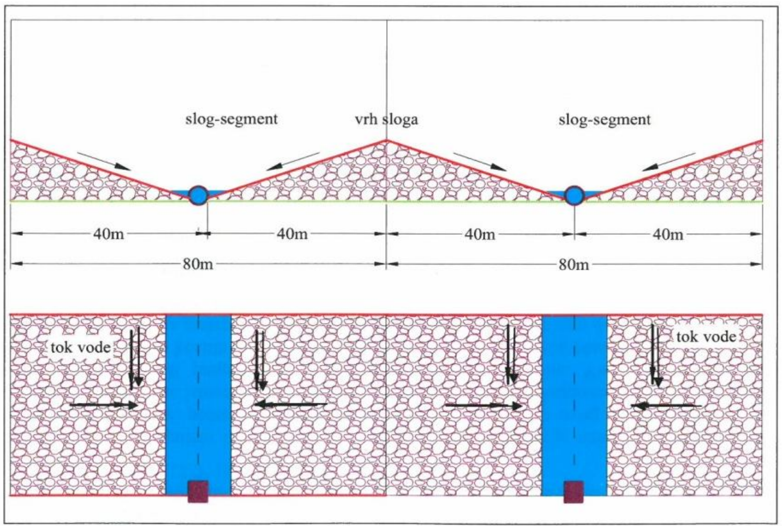

Figure 4 *View of the final layer segments*

After the completion of formation of the first layer, the formation of the second layer starts - the so-called drainage layer (Figure 3). The material that will be used for construction of this layer consists of gravel, size 5-25 mm. Transported material is disposed in piles along the newly-formed layer as bulldozer could easily and quickly manipulate with it. For continuous operation of mechanization along the slopes of the newly-formed layers of 1 m, a road will be temporarily constructed in the cut that after completion of the work will be turned back to the proper state. Planning the deposited material is also done by bulldozers. Layer thickness is about 0.5 m.

The final layer is formed of humus. In the vicinity of the landfill, temporary landfills of humus are formed topsoil, where the required amount of humus will be transported to the landfill plateau. Thickness of the layer is about 1 m. Works on planning and leveling of the final layer will be made by mechanization - bulldozer.

5 BIOLOGICAL PHASE OF OPTIMUM RECLAMATION

Biological phase of optimum reclamation involves the application of phyto-ameliorative measures on the substrate in order to establish and survival of vegetation for forming a stable ecosystem. For the success of biological cultivation, the preliminary works of technical reclamation are important as well as implementation the measures of care and protection of some cultures at all stages of their development. The selected culture - acacia fits into the existing landscape and will contribute to more beautiful appearance of micro location.

5.1 Working Technology in Afforestation of Flat Surfaces

On flat surfaces of the landfill, after technical reclamation, the pits seedlings are dug by articulated multifunctional combined machine (backhoe) of rectangular section, depth 40 cm (bucket width is 30 cm and length 40 cm) (Figure 5). Seedlings are planted by hand on a square pat tern as 2000 seedlings/ha. Each seedling after planting is added, at a certain distance around the see-dling, 0.2 kg NPK per plant.

Figure 5 shows a schematic view of a pit digging by ZMKM backhoe, from one position to 3 pits are dug in one row.

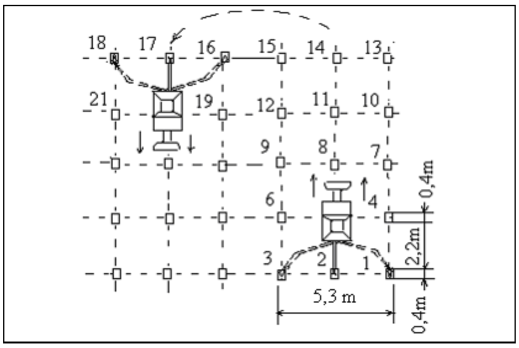

Figure 5 *Scheme of digging pits by backhoe for seedlings at the final plate*

CONCLUSION

Afforestation of degraded areas in the first place is aimed to preserve the environment, fertilizing the landscape, apiculture development and profit of acacia wood. The root system of acacia is deep and binds the substrate binds and stimulates the development of pedological processes (3). Acacia belongs to the bioameliorate **-** improves the soil properties and enables preparation for more economical species in the future period (3).

The effects of reclamation the ash and slag landfill are in:

- Forest plantations provide better soil bonding, stimulate the development of ground flora, activate the pedological processes in the substrate of root system, prevent insolation and drying of the soil, blowing strong winds and dust rising.
- Afforestation of degraded areas on the ash and slag landfill contributes to the environmental protection, improving the microclimate and aesthetic appearance of the landscape.

Total degraded area of the landfill is 400 628 m^2.

Total costs of reclamation for **40.06** ha are: T_t= **4 527 253.9** € (work dynamics of 2 years).

Total cost of reclamation per hectare is: **113 011.9 €/ha**

Total cost of reclamation per m^2 is: **11,30119 €/m^2**

REFERENCES

[1] I. Jovanović, M. Bugarin, S. Magda-linović: Review of Contemporary World Studies on Characteristics of Fly Ash as a Secondary Mineral Resource: Part 1. Mining and Metallurgy Engineering Bor 2/2013, pp. 147-156;

[2] Lj. Obradović, D. Urošević, G. Tomić: Physical Characterization of Ash and Slag from the Landfill in Medoševac, Mining Engineering 1/2010, pp. 57-68;

[3] Reclamation of Degraded Areas at the Open Pit of Marl Trešnja Holcim Popovac;

[4] Technical Design of Reclamation the Ash and Slag Landfill, June 2013.

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REKULTIVACIJA DEPONIJE PEPELA I ŠLJAKE GACKO - B i H**

Izvod

Tehnološki proces sagorevanja uglja u termoelektranama proizvodi određene količine pepela i šljake koje treba transportovati i odložiti na izabranoj lokaciji – deponiji. Deponovanje pepela i šljake iz TE Gacko u Gacku, B i H vršilo se u kaseti II formiranoj u otkopnom prostoru površinskog kopa Gračanica. Sa potrebom novog prostora za deponovanje pepela i šljake nađeno je rešenje u formiranju kasete III u nastavku postojeće kasete II. Nakon završetka eksploatacije i dostizanja projektovane kote od 940 mnv vrši se rekultivacija svih kaseta, čime se trajno eliminiše bilo kakav negativni uticaj pepela iz deponije na okolni životni prostor i vazduh.

Ključne reči: *rekultivacija, deponija, pepeo i šljaka*

UVOD

Termoelektrana Gacko od 1995. g. odlaganje pepela vrši na deponiji pepela - prva faza, kaseta I u otkopanom prostoru površinskog kopa Gračanica na delu ekploatacionog polja A. Nakon zapunjavanja kasete I, nastavak odlaganja pepela i šljake se vršilo u kaseti II, u otkopnom prostoru površinskog kopa Gračanica, koja je formirana u nastavku kasete 1. Nakon dugogodišnjeg odlaganja pepela i šljake u kaseti II, došlo je do smanjenja odlagališnog prostora pa je bilo neophodno obezbediti novi prostor za deponovanje pepela i šljake i time obezbediti kontinualni rad TE Gacko. Adekvatno rešenje je nađeno u formiranju deponije u kaseti III, u otkopnom prostoru površinskog kopa Gračanica. Kaseta III je formirana u nastavku kasete II do južne završne kosine kosine kopa (slika 1). Lokacija deponije i pepela u kaseti III je izabrano kao najpovoljnije tehno-ekonomsko rešenje za odlaganje pepela i šljake iz TE Gacko s obzirom na lokaciju naselja Gacko, razvijene infrastrukture, raspoloživosti prostora, itd.

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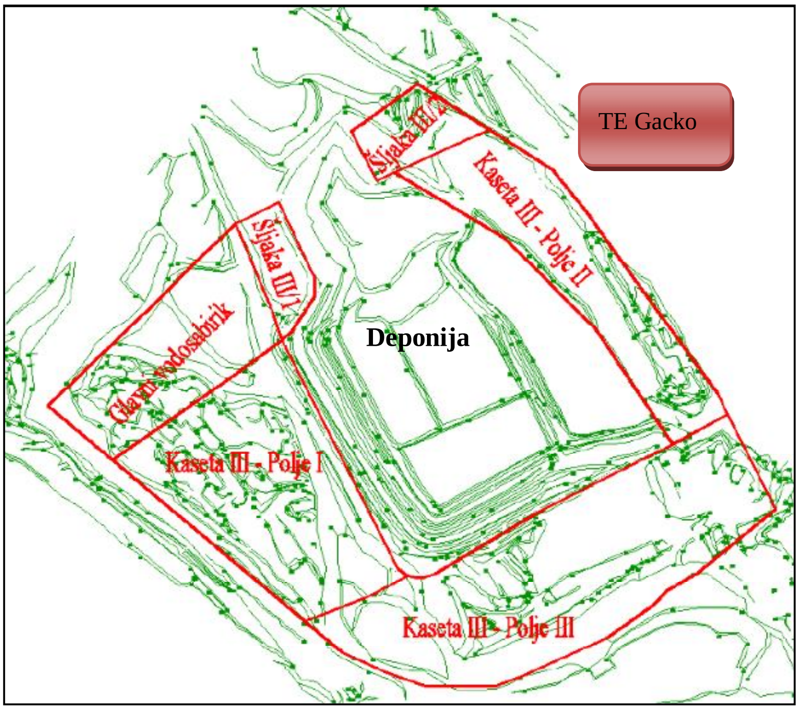
** *Rad je proizašao iz projekta broj TR 33021 „Istraživanje i praćenje promena naponsko deformacionog stanja u stenskom masivu „in-situ“ oko podzemnih prostorija sa izradom modela sa posebnim osvrtom na tunel Kriveljske reke i Jame Bor“, koji je finansiran sredstvima Ministarstva prosvete, nauke i tehnološkog razvoja Republike Srbije*



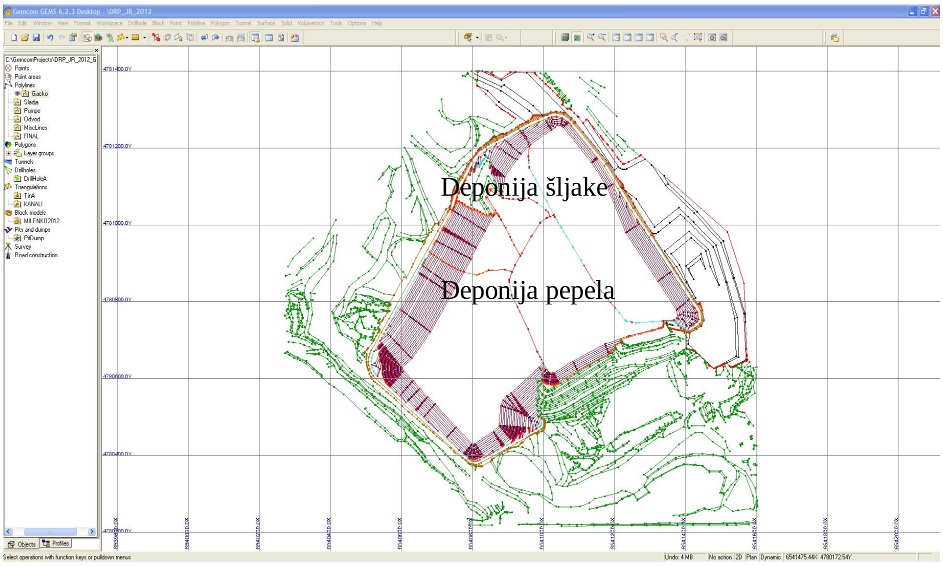
Sl. 1. *Prostor predviđen za kasetu III*

Procesom eksploatacije uglja na površinskom kopu Gračanica došlo je do narušavanja životne sredine tj. došlo je do degradiranja velikih povšina zemljišta kao i poremećaja režima površinskih i podzemnih voda. Izgradnjom termoelektrane TE Gacko kvalitet životne sredine se još više narušavao. Veliki uticaj na to su imale deponije pepela i šljake.

Leteći pepeo predstavlja najfiniju frakciju koja zaostaje nakon sagorevanja uglja u termalnim postrojenjima. [1]. Leteći pepeo je heterogena mešavina čestica različitih fizičkih, hemijskih, mineroloških i morfoloških osobina, koja nastaje sagorevanjem uglja u termoelektranama i čije su karakteristike određene kvalitetom izgorelog uglja, tehnologijom sagorevanja i uslovima sagorevanja. [1]. Fine frakcije pepela mogu imati jak degradirajući uticaj na životnu sredinu i okolinu, posebno u periodu jakih vetrova, kada se raznose po okolini, što može dovesti do velikih ekoloških problema, a pre svega narušavanja zdravlja stanovništva, imajući u vidu da je ova sirovina kategorisana kao opasan otpad. [2]

Međutim, aerozagađenje je eliminisano jer se tehnogena sirovina transportuje na deponiju u vidu hidromešavine tj. u okvašenom, odnosno potopljenom stanju. Naime, elektrofilterski pepeo iz TE Gacko pripada tipu karbonatnih pepela (visok sadržaj CaO), što znači da poseduje cementaciona svojstva i u kontaktu sa vodom gradi kompaktan materijal određene mehaničke čvrstoće. Na taj način sprečena je emisija finih čestica pepela u vazduh.

Izrada deponije će se odvijati u dve faze. Početna situacija za formiranje deponije je formirana deponija na kasetama I i II do završne kote K+940m, i pripremljena podloga faze 1 kasete III. Početna površina deponije od 141.750 m^2 fornirana je izgradnjom masivnog inicijalnog nasipa od vodonepropusnog materijala sa tri strane i kosinom terena ka kaseti I. Dno novoprojektovane deponije, biće presvučeno plastičnom folijom za zaštitu zemljišta i podzemnih voda, od procednih voda. lspod plastične folije biće postavljena drenaža za evakuaciju podzemnih voda, koje se odvode u pumpnu stanicu procedne i drenažne vode. Početna situacija u fazi 2 je praktično završni izgled deponije na kraju faze 1. Konačan izgled deponije pepela i šljake u fazi 2 je dat na slici 2.



Sl. 2. *Konačni izgled deponije pepela i šljake u fazi 2 kasete III u programu Gemcom 6.2*

Ponovno kultivisanje i revitalizaciju degradiranih površina nastalih ekploatacijom uglja na površinskom kopu Gračanica, a kasnije deponovanjem pepela i šljake u otkopani prostor površinskog kopa podrazumeva rekultivaciju.

Za revitalizaciju degradiranih površina na deponiji pepela i šljake primeniće se optimalna rekultivacija sa fazama: tehničke i biološke rekultivacije.

Prema fizičko hemijskim osobinama tla, geomorfologiji deponije, eksponiranost površina jugu, klimatskim uslovima i prirodnoj vegetaciji u okruženju u obzir dolazi biološka faza optimalne rekultivacije i to na završnim ravnima deponije pepela i šljake gde će se vršiti pošumljavanje bagremom.

2. DEGRADIRANE POVRŠINE ZA REKULTIVACIJU

Rekultivacija degradiranih površina planirana je na platoima i kosinama deponije. Površine za rekultivaciju prikazane su u tabeli 1 i 2.

Tabela 1. *Površine u Fazi 1 za rekultivaciju*

Lokacija	Faza	Ravne površine-etažne ravni	Površina m^2	Metoda rekultivacije	Kose površine -kosine etažnih ravni	Površina m^2	Metoda rekultivacije
Deponija	1	plato - 940	101 552	pošumljavanje	E940/E937	4 558	zasipavanje
		937	5 375	zasipavanje	E937/E934	4 660	zasipavanje
		934	5 380	zasipavanje	E934/E931	4 600	zasipavanje
		931	5 390	zasipavanje	E931/E928	4 560	zasipavanje
		928	5 490	zasipavanje	E928/E925	3 898	zasipavanje
		925	3 535	zasipavanje	E925/E922	2 860	zasipavanje
		922	2 945	zasipavanje	E922/E919	2 580	zasipavanje
		919	2 500	zasipavanje	E919/E916	2 390	zasipavanje
		917	2 450	zasipavanje	E916/E913	2 247	zasipavanje
		913	2 240	zasipavanje	E913/E910	1 990	zasipavanje
		910	2 030	zasipavanje	E910/E907	1 800	zasipavanje
		907	1 880	zasipavanje	E907/E904	1 071	zasipavanje
		904	520	zasipavanje			
		Ukupno	141 287			37 214	

Tabela 2. *Površine u Fazi 2 za rekultivaciju*

Lokacija	Faza	Ravne površine-etažne ravni	Površina m^2	Metoda rekultivacije	Kose povrsine –kosine etažnih ravni	Površina m^2	Metoda rekultivacije
Deponija	1	plato - 940	176 518	pošumljavanje	E940/E937	5 571	zasipavanje
		937	5 730	zasipavanje	E937/E934	5 112	zasipavanje
		934	6 530	zasipavanje	E934/E931	3 875	zasipavanje
		931	4 265	zasipavanje	E931/E928	2 628	zasipavanje
		928	2 875	zasipavanje	E928/E925	2 250	zasipavanje
		925	2 300	zasipavanje	E925/E922	4 473	zasipavanje
		Ukupno	198 218			23 909	

3. PEDOLOŠKE OSOBINE PRIRODNOG ZEMLJIŠTA

Sloj tla pilikom otkrivanja ležišta (investiciona raskrivka) je skinut i odlagan na pozajmištu humusa odakle će se koristiti za nasipavanje platoa deponije.

Za određivanje pogodnosti prirodnog zemljišta za rekultivaciju degradiranih površina na deponiji izvršene su agrohemijske analize uzetih uzoraka D1 i D2 u laboratoriji Instituta za rudarstvo i metalurgiju Bor. Rezultati agrohemijske analize su za uzorak D1: pH= 7,55, CaO =3,85; P_2O_5=0,15; K_2O=2,20, a za uzorak D2: pH= 7,69, CaO =5,46; P_2O_5=0,16; K_2O=1,33.

Podaci analize uzoraka D1 i D2 u ovom slučaju poslužili su za definisanje tipa prirodnog zemljišta i njegovih svojstava. Prirodno zemljište sa pozajmišta prema klasifikaciji pripada rendzinama i to rendzinama na laporu i laporovitom krečnjaku.

Zemljište je neutralne reakcije, slabo obezbeđeno fosforom i treba uneti NPK 10:20:30. u količini 400 kg/ha.

4. TEHNIČKA REKULTIVACIJA

Tehnička rekultivacija deponije pepela i šljake na prostoru površinskog kopa Gračanica vrši se osnovu Evropske Uredbe o odlaganju otpada na deponije (DIREKTIVA VIJEĆA 1999/31/EC od 26. travnja 1999. o odlagalištu otpada - u daljem tekstu Direktiva).

Na osnovu preporuke Direktive posle završetka odlaganja pepela i šljake (kota 940 m), na celokupnoj površini deponije postavljaju se tri završna sloja, koja imaju ulogu zaštite, kao i pripremu za biološku rekultivaciju.

Prvi sloj se formira odlaganjem odloženog materijala sa postojećeg odlagališta. Ovaj materijal na osnovu geoloških podataka pripada laporovitim krečnjacima. Procenjeno je da debljina ovog materijala treba da iznosi oko 1 m. Nakon formiranja prvog sloja vrši se formiranje drugog sloja koji predstavlja drenažni sloj. Ovaj sloj se sastoji od rizle i peskovitog materijala. Visina sloja iznosi 0,5 m. Završni sloj predstavlja sloj humusa, što bi bila garancija da se na ovakvoj podlozi može vršiti biološka rekultivacija. Procenjeno je da debljina završnog-trećeg sloja od humusa treba da iznosi 1 m. Humus se transportuje i odlaže sa formiranih humusnih odlagališta koji su u blizini deponije. Završni izgled deponije pepela i šljake će biti formiran sa nagibima oko 1% prema objektima odvodnjavanja u cilju rešenja odvodnjavanja putem gravitacije.

Tehnička rekultivacija obuhvata sledeće radove:

- utovara materijala za izradu servisnog puta i zasipavanje kosina,
- utovara materijala za izradu slojeva – laporac, drenažni materijal, humus,
- transporta materijala,
- rad buldozera na ravnjanju i nivelaciji servisnog puta,
- rad buldozera na ravnjanju kosine deponije,
- rad buldozera na ravnjanju slojeva na platou deponije,
- postavljanje drenažnih cevi i kanaleta,
- povezivanje svih segmenata drenažnog sistema.

4.1. Radovi na izgradnji servisnog puta

Radovi u ovoj fazi tehničke rekultivacije bi obuhvatali izradu servisnog puta na platou deponije, i uspostavljanje veze sa mrežom pristupnih puteva ka deponiji. Mreža puteva van deponije je izrađena, i kako je u stalnoj upotrebi, održava se redovno, tako da je put u dobrom stanju. S obzirom na buduće radove na deponiji izradiće se servisni putevi na istoj, koji će se nadovezati na postojeću mrežu.

Servisni put će viti širok 5 m. Sama izrada se sastoji od utovara i transporta materijala sa odlagališta laporca, a zatim nasipavanja materijala - laporca na plato deponije, a zatim ravnjanja - nivelacije buldozerom.

4.2. Opis radova za rekultivaciju kosina deponije

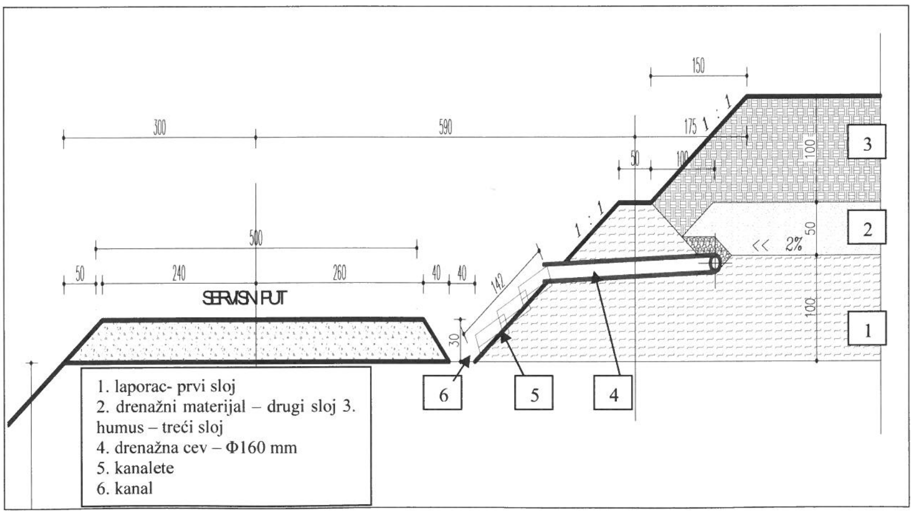
S obzirom da su kosine deponije pod velikim nagibom, nepohodno je izvršiti rekultivaciju istih kako bi se stabilizovao teren i sprečili eventualni prodori voda. Tehnička rekultivacija kosina obuhvata zasipavanje kosina kako bi se ublažio pad i pri čemu se formira ugao generalne kosine od 18,3° (ili odnos 1:3).

Sa formiranih odlagališta laporca koji se nalaze u blizini deponije uzima se materijal za nasipavanje kosina tj. postavljanje sloja. Vrši se utovar i transport ovog materijala na plato deponije. Materijal se istovaruje na gomile na više mesta kako bi buldozer brže i kvalitetnije radio. Zatim se vrši preguravanje materijala po kosini deponije. Visina materijala, tj. završnog sloja preko kosina treba da iznosi oko 1 m. Nakon završenog planiranja prelazi se na fazu u kojoj se sabija materijal. Ovi radovi se vrše valjkom. S obzirom da je generalni ugao manji od 20°, uslovi za rad valjka na kosinama su mogući.

4.3. Radovi na formiranju završnog sloja na platou deponije

Sa formiranih odlagališta laporca koji se nalaze u blizini deponije uzima se materijal za postavljanje prvog sloja na platou deponije. Vrši se utovar i transport ovog materijala na plato deponije. Radom mehanizacije na planiranju formira se sloj laporca u visini od 1 m (slika 3). Pri tome se vodi računa da se na predviđenim mestima postavljaju rebraste jednoslojne drenažne cevi ϕ160 mm. Ove cevi se postavljaju na rastojanju od 80 m.

Funkcija ovih cevi jeste da prikupljaju vodu i postavljenim sistemom za drenažu odvode vodu do odvodnih kanala, koji su povezani sa glavnim odvodnim kanalima, koji ove sakupljene vode odvode u reku Gračanicu ili u glavne vodosabirnike.

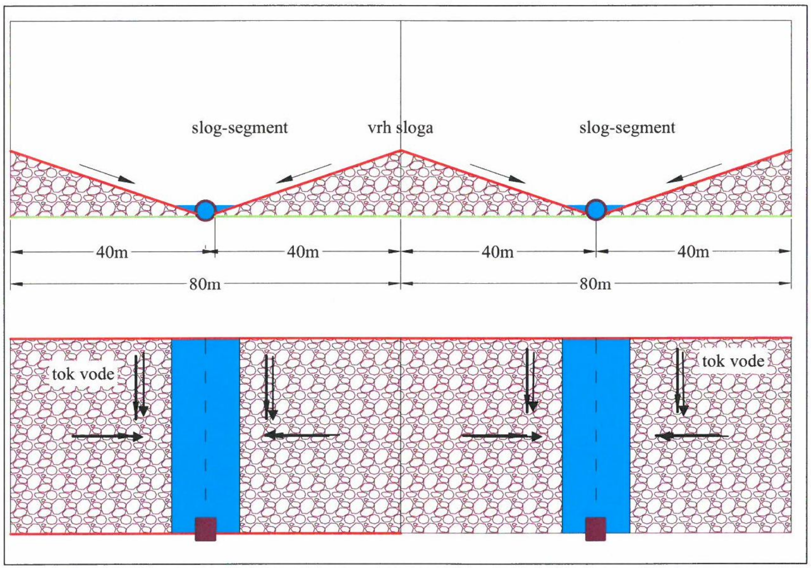


Sl. 3. *Poprečni presek deponije sa prikazom svih slojeva i servisnog puta*

Nakon istresanja materijala kamionom, prelazi se sa planiranjem materijala buldozerom. Pri tome se vodi računa da planirana podloga ima pad 1 %. Plato je podeljen na deonice od 80 m, slika 4.

Svaka deonica ima izgled prikazan na slici 4, na kojoj su prikazani padovi ovog sloja. Na ovaj način se omogućuje pravilno funkcionisanje drenažnog sistema. Sva prikupljena voda odlazi u formirani ,,kanal'' a odatle se voda skuplja sa drenažnom cevi ϕ160 mm. Ova voda se kanaletama spušta u glavni kanal koji je izrađen između servisnog puta i ovog sloja.

Da bi sistem drenaže funkcionisao neophodno je da se prvi sloj (laporac) formira sa blagim padom od 1 %. Pored generalnog pada, ovaj sloj se formira da ima još jedan pad ka ,,unutra''. Kako je prikazano na slici 4, rastojanje od 80 m na kojima će biti postavljene cevi, će se podeliti na pola, pri tome će ove polovine formirati pad ka ,,unutra'' i na taj način će se sve vode slivati ka cevima.



Sl. 4. *Prikaz segmenta završnog sloja*

Nakon završetka formiranja prvog sloja počinje se sa radom na formiranju drugog sloja – tzv. drenažnog sloja (slika 3). Materijal koji će se primeniti za izradu ovog sloja sastoji se od šljunka veličine 5-25 mm. Transportovani materijal se odlaže na gomile po novo formiranom sloju kako bi buldozer mogao da lakše i brže manipuliše sa njim. Da bi mehanizacija funkcionisala kontinualno po kosinama novoformiranog sloja od 1 m, će se privremeno napraviti put u useku koji će se nakon završetka radova vratiti u odgovarajuće stanje. Planiranje deponovanog materijala se takođe vrši buldozerima. Debljina sloja iznosi oko 0,5 m.

Završni sloj se formira od humusa. U blizini deponije su formirana privremena odlagališta humusa, odakle će se potrebna količina humusa transportovati do platoa deponije. Debljina sloja iznosi oko 1 m. Radovi na planiranje i nivelisanju završnog sloja će se vršiti mehanizacijom – buldozerom.

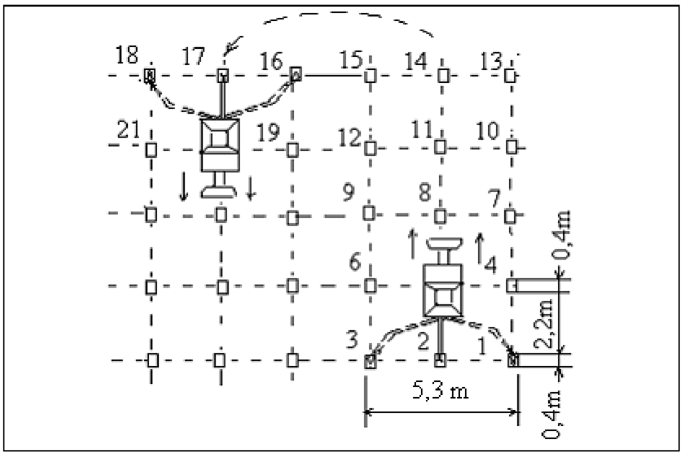
5. BIOLOŠKA FAZA OPTIMALNE REKULTIVACIJE

Biološka faze optimalne rekultivacije podrazumeva primenu fitomeliorativnih mera na supstratu u cilju uspostavljanja i opstanka vegetacije radi formiranja stabilnog ekosistema. Za uspeh biološke rekultivacije važni su prethodni radovi tehničke rekultivacije kao i sprovođenje mera nege i zaštite podignutih kultura u svim fazama njihovog razvoja. Izabrane kulture – bagrem se uklapaju u postojeći pejzaž i doprinosiće lepšem izgledu mikrolokacije.

5.1. Tehnologija rada pri pošumljavanju ravnih površina

Na ravnim površinama deponije posle tehničke rekultivacije kopaju se jame sadnica zglobnom multifunkcionalnom kombinovanom mašinom (rovokopačem) pravougaonog preseka dubine 40 cm (širina kašike iznosi 30 cm, a dužina 40 cm) (slika 5). Sadnice se sade ručno po kvadratnoj šemi i to 2000 sadnica/ha. Svakoj sadnici posle sadnje se dodaje na određenom rastojanju oko sadnice 0,2 kg NPK po sadnici.

Na slici 5 dat je šematski prikaz kopanje jama ZMKM - rovokopačem, iz jednog položaja mašine kopaju se 3 jame u jednom redu.



Sl. 5. *Šema rada rovokopača na kopanju jama za sadnice na završnoj ravni*

ZAKLJUČAK

Pošumljavanje degradiranih površina na prvom mestu ima za cilj očuvanje životne okoline, oplemenjivanje peijzaža, razvoj pčelarstva i dobit od bagremove šume. Korenov sistem bagrema se duboko zakorenjuje i vezuje supstrat i podstiče razvijanje pedoloških procesa.(3) Bagrem pripada biomeliorativnoj vrsti - popravlja svojstvo zemljišta i omogućava pripremu sredine za ekonomičniju vrstu u budućem periodu.(3)

Efekti rekultivacije deponije pepela i šljake ogledaju se u tome da:

- Šumski zasadi omogućavaju bolje vezivanje zemljišta, stimulišu razvoj prizemne flore, aktiviraju pedološke procese u supstratu korenovim sistemom, sprečavaju insolaciju i sušenje tla, duvanje jakih vetrova i podizanje prašine.
- Pošumljavanjem degradiranih površina na deponiji pepela i šljake doprinosi se zaštiti životne sredine, poboljšavanju mikroklime i estetskom izgledu okoline.

Ukupne degradirane površine na odlagalištima iznosi 400.628 m^2.

Ukupni troškovi rekultivacije za **40,06** ha iznose: T_u= **4.527.253,9** € (dinamika rada 2 godine).

Ukupna cena rekultivacije po jednom hektaru iznosi: **113.011,9 €/ha**

Ukupna cena eurekultivacije po jednom m^2 iznosi: **11,30119 €/m²**

LITERATURA

[1] I. Jovanović, M. Bugarin, S. Magdalinović: Pregled savremenih svetskih istraživanja o karakteristikama letećeg pepela kao sekundarne mineralne sirovine; Deo 1, Mining and Metallurgy Engineering Bor 2/2013, str. 157-166.

[2] Lj. Obradović, D. Urošević, G. Tomić: Fizička karakterizacija pepela i šljake sa deponije u Medoševcu, Rudarski radovi 1/2010, str. 57-68.

[3] Rekultivacija degradiranih površina na površinskom kopu laporca Trešnja Holcim Popovac

[4] Tehnički projekat rekultivacije deponije pepela i šljake, Jun 2013.

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Milan Petrov, Ljubiša Andrić*, Živko Sekulić*, Vladimir Jovanović**

MODELING THE MILL OPERATION ACCORDING TO DENSITY OF MILL BATCH AND SPECIFIC CAPACITY**

Abstract

This paper presents a new method of modeling the technological parameters of mill for the new conditions of mechanochemical treatment of mineral resources based on the Buckingham hypothesis. The specific volume of designed mill is changed if there is a change in the charge density of the mill, and dependence of the change is determined using a criterion equation. After examining the most well-known dimensional criteria, it was observed that Damkohler's criterion would quantitatively model the specific volume and density of the mill batch.
Keywords: *specific volume, batch density, Damkohler's criterion*

INTRODUCTION

It is known that by changing the type of the milling bodies is different efficiency of grinding of mineral raw material and thus different grinding fineness. In this paper, a hypothesis on the density of the charge of the mill as an influential factor in the specific capacity of grinding certain mineral deposits. The aim of this modeling is the ability to predict the capacity of the mill in terms of changes in the charge density of the mill. Density of the batch mill is the sum of densities of balls in bulk density, material density and the density of water, which is located in the gaps between the spheres. The density of the charge depends on the type of milling body, and grinding efficiency is increased with the use of the higher density spheres. This paper studies the effect of changes in the specific capacity [1] of the industrial mills in operation of the mill charge density and the possibility of adaptation of the mill plant to increase the capacity of the mill. Variations in the specific capacity of the mill was carried out to determine the Damkohler criterion [2]. The good factor regarding the specific mill that was built in the silica sand separation plant in Lukic polje near Milici, on which are carried out tests, is that the motor of the mill can support higher density batch milling body, so that the realized tests can be carried out in practice.

MATERIALS AND METHODS

Plant for grinding the quartz raw materials in Milici operates with the following operating characteristics [3]: the mill ca

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pacity is q = 10 t/h with the grain size is 90% - 600 μm Power of mill motor is N=280 kW, and mill volume is V = 13 m^3. Mass of silex milling bodies in the mill is 9000 kg. The mill rpm is 17.8 mills/min. The mill is discharged through a branch, and the pulp density in the outlet is 1.125 kg/l which means that it has 18% solid in the pulp, (C: T is then 1:4.94). Material mass in the mill is 2.34 t. Grinding time is 14 minutes. Value of the Bond work index for quartz sand is 15.0 kWh/t. Variations in the specific capacity of the mill was carried out to determine the Damkohler criterion.

Density of mill batch

In order to carry out the grinding process in a mill the amount of material that is mechano-chemically treated have to be present to such an extent that the filling of empty space between balls is larger from 5 to 10% by volume relative to the volume of empty space in the mill, when the balls are present without material. Density of mill batch is the sum of ball densities in bulk state, material density and water density, which is located in the gaps between the balls, Equation 1. Density of filled gaps between the balls is actually the second summand in Equation 1 and it is expressed through the pulp density ρ_p. Density of charge in the mill [4] is ρ_p:

$$\rho_s = \rho_{vk} + 1{,}15 \cdot (1 - \frac{\rho_{vk}}{\rho_{sk}}) \cdot \rho_p, \frac{kg}{m^3} \qquad (1)$$

Where:

- ρ_{vk} - *Density of balls in bulk state in kg/m³*
- ρ_{sk} - *Density of material from which the ball is made, in kg/m³*
- ρ_p - *Pulp density in kg/m³*

Density of material from which the ball is made;

Fe cast - ρ_{sk} = 7800 kg/m^3

Silicate - ρ_{sk} = 2600 kg/m^3

Density of balls in bulk state;

Fe cast - ρ_{vk} = 4100 to 4200 kg/m^3

Silicate - ρ_{vk} = 1800 to 1900 kg/m^3

Calculating the Density Values of Mill Batch in the Site of Quartz Sand Separation "Lukic polje" near Milici

Density of mill batch in the industrial process of mill operation in the site of separation Milici, was calculated according to Equation 1

$$\rho_s = \rho_{vk} + 1.15 \cdot (1 - \frac{\rho_{vk}}{\rho_{sk}}) \cdot \rho_p =$$
$$= 1800 + 1.15 \cdot (1 - \frac{1800}{2600}) \cdot 1125 =$$
$$= 2198 \frac{kg}{m^3}$$

The pulp density ρ_p is measured by mining pycnometer and scale for measuring of density. The pulp density ρ_p cannot be high when the charge is of the same material, or when balls and raw materials to be crushed are the same material. Experimentally, it was found that the required optimum thickness of the pulp is ρ_p = 1125 kg/m^3 or 18% Č, in order to ensure the movement of material through the mill. This fact was obtained visually recognizing higher viscosity of batches if the pulp density increases, which causes release of balls from mill when the effects of mechano-chemical treatment cease. Density of mill batch can be increased if the type of grinding bodies is changed and the steel balls with higher density are adopted instead of silex balls, and then the pulp density can be increased what is a prerequisite for increasing the specific capacity [4,5].

Specific Capacity of Tested Mill

In order to find the specific capacity of mill for different product sizes, a change was experimentally carried out for hour capacity [6,7] of mill at optimal pulp density. The experiment began with small hour capacity, which amounted to 4 *t/h* and pulp density ρ_p =1125 g/dm^3, when it was necessary to add 18.2 m^3/h of water. Then, about 98.5% of class -200 µm was obtained in the final product, Figure 1, curve 1.

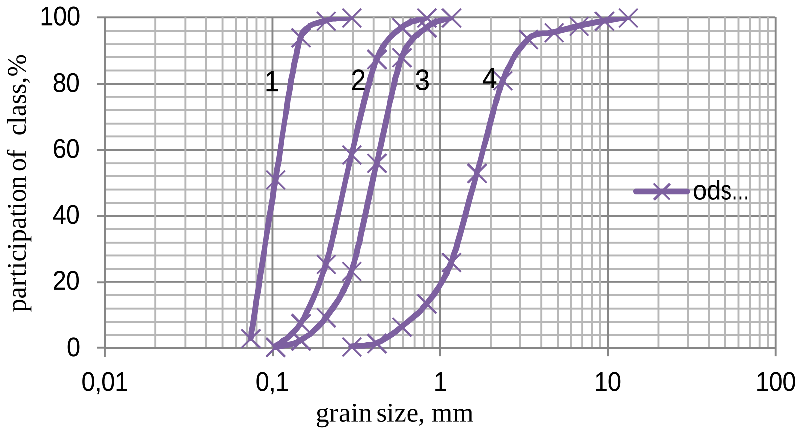

Figure 1 *Grain size distribution of grinding products Q = 4, 10, 15 t / h and grain size distribution of the starting sample*

After that, the hour capacity of mill was increased to 10 t/h, and the pulp density remained the same ρ_p =1125 g/dm^3 when 45.6 m^3/h water had to be added, and when about 98% of class -600 µm was obtained in the final product, Figure 1, curve 2. In the third attempt, the hour capacity of mill was maintained at 15 *t/h* with the same pulp density ρ_p =1125 m^3/h when 68.4 m^3/h water had to be added, so about 97% of class -830 μm was obtained in the final product, Figure 1, curve 3. In the starting sample according to the developed grain size distribution, the contents of given size classes were: 0% -200 class μm 6% of class 600 μm and 12.3% -830 class μm, Figure 1, curve 4.

Specific capacity was able to be calculated using the formula 2 on the basis of data from Table 1. Specific capacity of the mill according to Magdalinović [1] is

$$q_{-d} = \frac{M}{V \cdot t} \cdot (\beta_{-d} - \alpha_{-d}) \left[\frac{kg}{m^3 \cdot s} \right] \quad (2)$$

Where:

q_{-d} - Specific capacity of the mill by the newly created accrual class

Grain size $-d$, in $kg/(m^3 s)$ (*d* is a square hole of sieve)

M - Mass of material in the mill, kg

V - Volume of the mill m^3

t - Grinding time, s

α_{-d} and β_{-d} Content of accrual size class $-d$ in the inlet and grinding product in parts of the unit.

Table 1 *Kinetic experiments of grinding in the industrial mill conducted to determine the specific capacity of mill by the newly accrual size class -d*

Capacity $Q\left[\frac{t}{h}\right]$	**Grinding time, t** $t=\frac{M}{Q}\cdot 3600[s]$	**Mass of material in the mill,** [*M/kg*]	**Volume in mill** [V/m^3]	**Content of accrual size class in grinding products and inlet**		$q_{-d} = \frac{M}{V\cdot t}\cdot(\beta_{-d}-\alpha_{-d})$ $\left[\frac{kg}{m^3\cdot s}\right]$
				β_{-d}	α_{-d}	
4	2106	2340	13	0.98	0	$q_{-200}=0.084$
10	842.4	2340	13	0.97	0.06	$q_{-600}=0.194$
15	561.6	2340	13	0.97	0.12	$q_{-830}=0.272$

Mass of Material in Mill M

Mass of material for grinding is calculated by the formula 3 [1]

$$M=0.12\cdot V\cdot\Delta = 0.12\cdot 13\cdot 1.5\cdot 10^3 = 2{,}340\ kg \quad (3)$$

Where:

M - mass of material in mill, kg;

V - volume of mill m^3;

Δ - density of material in bulk density or material bulk density, kg/m^3;

0.12 - volume filling of empty space between the balls of the mill units.

Percentage of sample in a mill in the industrial grinding conditions in discharging through the sleeve is such that the bulk density occupies a space of 12% of the mill volume [6]. Such conditions are obtained when the level of mill filling with charge is 40%, and the empty space between the balls is of 30%, ($0.4\cdot 0.3=0.12$).

Volume of of mill V:

$$V=\frac{D^2\cdot\pi}{4}\cdot L = \frac{2.2^2\cdot 3.14}{4}\cdot 3.4 = 13\left[m^3\right] \quad (4)$$

Measured bulk density of material Δ:

$$\Delta = 1.5\cdot 10^3\ kg/m^3 \quad (5)$$

EQUATION OF MODELING SPECIFIC CAPACITY OF THE MILL

According to the Buckingham π theorem, each equations contains υ of the associated physical quantities (υ, where υ = nd, ρ, D,, r .., etc.), between which unites m_1 values have independent dimensions of the size (M, L, t), which can be transformed into an equation that has m_1, and the dimensionless criteria and simplex, composed of those values [2,4]. This theorem is of great importance in the experimental and theoretical work. Dimensionless numbers encountered practically in solving any problems in chemical engineering. The formation of dimensionless numbers for a particular problem is the most easily achieved using the dimensional matrixes. Dimensional matrix consists of a square and remaining matrix. Rows of the matrix form the basis of size, and it will form a rank r matrix. The columns of the matrix represent the physical size or process parameters. Size of squares elementary matrices appear in all dimensionless numbers, while each element of the remaining matrix appears only in one dimensionless number.

Due to this reason, the remaining matrix should be comprised of the most important variables. Rearrange matrix (linear transformation) is done by the core matrix becoming a common matrix. After creation of a common matrix, dimensionless numbers arise in the following way. Each element of the remaining matrix, which is the numerator divided by the square of the matrix parameters that are graded below the number of the remaining elements of matrix. In the modeling process, where applicable chemistry reactions with transfer of impulse force and heat the criterion Damkohler (D_a) [2,3] as dimensionless units. Damkohler represents an equation modeling and specific capacity of the mill:

$$D_a = \frac{q_{-d}}{n \cdot \rho_s} \quad (6)$$

Where:

- q_{-d} - specific capacity of mill according to the newly $-d$ accrual size class, $M/(L^3 t^1)$
- n - number of revolutions per unit time of t mill, $1/t$
- ρ_s - batch density, M/L^3

Table 2 *Dimensional matrix of the Damkohler criterion*

	ρ_{up}	***d.***	***n***	q_{-d}
Mass M	1	0	0	1
length L	3.	1	0	3.
Time t	0	0	-1	-1
	Basic matrix			Remaining matrix

It only takes one dimensional linear transformation matrix I to -3 in the L line and ρ_{up} a column to zero, in order to be come converted dimensional matrix. Later should change character into t, so -1 to take the 1.

Table 3 *Renovated dimensional matrix*

	ρ_{up}	***d***	***n***	q_{-d}
M	1	0	0	1
3M + L	0	1	0	0
-t	0	0	1	1
	Basic matrix			Remaining matrix

The remaining matrix comprises one parameter, so

$$\frac{q_{-d}}{\rho^1 \cdot d^0 \cdot n^1} = \frac{q_{-d}}{\rho \cdot n} \equiv D_a$$

The Damkohler Criterion Values for Experimental Conditions

The Damkohler criterion value is calculated according to equation 6, and is given in Table 4 (column 5) for the following fineness of mechano-chemical treatment of 200 μm, 600 μm and 830 μm.

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Table 4 *Values of the criteria* D_a *for various specific capacities* q_{-d}

Measured capacity, $Q\left[\frac{t}{h}\right]$	**Specific grinding capacity,** $q_{-d}\left[\frac{kg}{m^3 \cdot s}\right]$	**Charge density in mill,** $\rho_s\left[\frac{kg}{m^3}\right]$	**r.p.m. of mill.** $n\left[s^{-1}\right]$,	**Value of Damkohler's criterion** $D_a = \frac{q_{-d}}{n \cdot \rho_{up}}$
4	0.084	2198	0.3	$D_a = \frac{q_{-200}}{n \cdot \rho_{up}} \cong 0{,}000127$
10	0.194	2198	0.3	$D_a = \frac{q_{-600}}{n \cdot \rho_{up}} \cong 0{,}000295$
15	0.272	2198	0.3	$D_a = \frac{q_{-830}}{n \cdot \rho_{up}} \cong 0{,}000413$

Density of mill charge can be significantly increased only if the higher density balls are used, and then to increase the specific grinding capacity that criterion D_a remains the same with those values given in Table 4 (column 5), and 6 according to the equation.

New Density of Mill Batch in a Case of Changing the Type Grinding Bodies

$$\rho_{up} = \rho_{vk} + 1.15 \cdot (1 - \frac{\rho_{vk}}{\rho_{sk}}) \cdot \rho_{vm} = $$
$$= 4200 + 1.15 \cdot (1 - \frac{4200}{7800}) \cdot 1719 =$$
$$= 5112 \frac{kg}{m^3}$$

A new batch of density can be increased by changing the type of grinding bodies so that the instead silekx balls $\rho_{vk} = 1800$ kg/m^3 the steel balls $\rho_{vk} = 4200$ kg/m^3 will be used. Pulp density can also be increased without the risk due to the increased viscosity of the pulp that reaches discharge batch of balls through the sleeve, and it is adopted to be about 68%, which is typical for this type of raw material and the type of mill, and then $\rho_p = 1719$ kg/m^3.

New Specific Capacity of Mill a Case of Changing the Type Grinding Bodies

A new specific capacity of mill for a new value of charge density can be obtained by calculation such as the value of criterion D_a for specific accounting of size class remain the unchanged. The requirement that the criterion D_a remained the unchanged for the new operating conditions of mill and the increased value of charge density in mill is that it must increase the specific capacity of mill for a given size class. After the new calculation of specific capacity, the grinding time can be easily calculated as well as the hour capacity of the mill as it is shown in Table 5.

Tabela 5 *New specific capacity of mill in using larger charge density in mill*

Calculated capacity, $Q\left[\frac{t}{h}\right]$	Specific grinding capacity, q_{-d} $\left[\frac{kg}{m^3 \cdot s}\right]$.	Charge density in mill, $\rho_s\left[\frac{kg}{m^3}\right]$	r.p.m. of mill $n\left[s^{-1}\right]$	Value of Damkohler's criterion $D_a = \frac{q_{-d}}{n \cdot \rho_{up}}$
10	0.209	5112	0.3	$D_a = \frac{q_{-200}}{n \cdot \rho_{up}} \cong 0.000127$
23	0.447	5112	0.3	$D_a = \frac{q_{-600}}{n \cdot \rho_{up}} \cong 0.000295$
35	0.635	5112	0.3	$D_a = \frac{q_{-830}}{n \cdot \rho_{up}} \cong 0.000413$

It is seen that it can be expected in the future at least two times higher capacity of grinding with a change of ball type, i.e. 10 t/h for the fineness of 85% 200 μm.

CONCLUSION

Specific grinding capacity according to the Damkohler criterion and equation 6 depends on the mill charge density, r.p.m. of mill and specific grinding capacity. In realization the idea to change the specific mill capacity, the charge density have to be changed, so from the criterion Damkohler equation it is easily to calculate the new higher specific mill capacity. With a change the type of grinding bodies (from silex balls to steel balls), it is possible to change the specific mill capacity or increase the fineness of 200 μm and that the capacity remains the same 10 t/h.

REFERENCES

[1] N. Magdalinović, Comminution and Classification of Mineral Raw Materials, Technical Faculty in Bor, Bor 1985, p. 70;

[2] E. Beer, Manual for Sizing the Devices of Chemical Processing Industry SKTH / Chemistry in the Industry, Zagreb 1985, p. 491;

[3] M. Petrov et al., Technical-technological Solution, "Development of Software Systems for Grinding the Quartz Sand from the Deposit Skočić for the Needs of Chemical I of the Birač - Zvornik Silica Plant Obtained Using the Criterion of Equation Modeling", ITNMS Belgrade, 2012;

[4] S. Rozgaj, Processing Apparatus and Devices, IGKRO "Svjetlost", Sarajevo, 1980, p. 63;

[5] Lj. Andrić, M. Petrov, Z. Aćimović-Pavlović, M. Trumić, A kinetic Study of Mechanical Activation of Mica in a Vibratory Mill, Metalurgia Internacional, No. 7. (2012), p. 33-38;

[6] M. Grbović, N. Magdalinović, Processing Equipment for Crushing and Grinding of Mineral Raw Materials, "Copper", Bor, 1980, p. 88;

[7] S. Puštrić, Selection and Calculation of Machinery and Equipment for Crushing, Screening and Grinding of Mineral Raw Materials, Mining and Geology, Belgrade 1974, p. 48.

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MODELOVANJE RADA MLINA PREMA GUSTINI ŠARŽE MLINA I SPECIFIČNOM KAPACITETU**

Izvod

U radu je prikazana nova metoda modelovanja tehnoloških parametara rada mlina za nove uslove mehano-hemijskog tretmana mineralne sirovine na bazi hipoteze Buckinghama. Specifični kapacitet projektovanog mlina menja se ukoliko dolazi do promene gustine šarže mlina, a zavisnost te promene određuje se upotrebom kriterijumskih jednačina. Uvidom u većinu poznatih dimenzionih kriterijuma uočeno je da bi Damkohler-ov kriterijum mogao kvantitativno da modeluje specifični kapacitet i gustinu šarže mlina.

Ključne reči: *specifični kapacitet, gustina šarže, Damkohler-ov kriterijum*

UVOD

Poznato je da se promenom vrste meljućih tela ostvaruju različite efikasnosti mlevenja mineralne sirovine i time različita finoća mlevenja. U radu je postavljena hipoteza o gustini šarže mlina kao uticajnom faktoru na specifični kapacitet mlevenja odredjene mineralne sirovine. Cilj ovakvog modelovanja je mogućnost predviđanja kapaciteta mlina u uslovima promene gustine šarže mlina. Gustina šarže mlina jeste zbir gustine kugli u nasutom stanju, gustine materijala i gustine vode koja se nalazi u praznini između kugli. Gustina šarže najviše zavisi od vrste meljućih tela, a efikasnost mlevenja se povećava sa upotrebom kugli veće gustine. U ovom radu je ispitivan uticaj promene specifičnog kapaciteta [1] industrijskog mlina u funkciji gustine šarže mlina i mogućnosti adaptacije mlinskog postrojenja da bi se povećao kapacitet mlina. Variranje specifičnog kapaciteta mlina vršeno je da bi se utvrdio kriterijum Damkohlera [2]. Dobra okolnost u vezi sa konkretnim mlinom koji je ugrađen u pogonu separacije kvarcnog peska u Lukića polju kod Milića, i na kojem su izvršena ispitivanja, je ta što motor mlina može da podrži veću gustinu šarže meljućih tela, tako da se realizovana ispitivanja mogu sprovesti u praksi.

MATERIJAL I METODE

Postrojenje za mlevenje kvarcne sirovine u Milićima radi sa sledećim radnim karakteristikama [3]: kapacitet mlina je q = 10 t/h

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pri krupnoći od 90% - 600 μm. Snaga motora mlina je N=280 kW, a zapremina mlina je V = 13 m^3. Masa sileks meljućih tela u mlinu je 9.000 kg. Broj obrtaja mlina je 17,8 o/min. Mlin se prazni kroz rukavac, a gustina pulpe na izlazu je 1,125 kg/l što znači da ima 18% čvrstoga u pulpi, (Č:T je tada 1:4,94). Masa materijala u mlinu je 2,34 t. Vreme mlevenja je 14 minuta. Vrednost Bondovog radnog indeksa za kvarcni pesak je 15,0 kWh/t. Variranje specifičnog kapa-citeta mlina vršeno je da bi se utvrdio kriterijum Damkohlera.

Gustina šarže mlina

Da bi se vršio proces mlevenja u mlinu količina materijala koji se mehano hemijski tretira mora biti zastupljena u takvoj meri da je zapunjenost praznog prostora između kugli veća za 5 do 10% zapreminski u odnosu na zapreminu praznog prostora u mlinu kada su prisutne samo kugle bez materijala. Gustina n šarže mlina jeste zbir gustine kugli u nasutom stanju, gustine materijala i gustine vode koja se nalazi u praznini između kugli, jednačina 1. Gustina popunjene praznine između kugli je zapravo drugi sabirak u jednačini 1 i izražena je preko gustine pulpe ρ_p. G gustina šarže u mlinu [4] je ρ_s:

$$\rho_s = \rho_{vk} + 1{,}15 \cdot (1 - \frac{\rho_{vk}}{\rho_{sk}}) \cdot \rho_p, \frac{kg}{m^3} \qquad (1)$$

gde je:

ρ_{vk} - *gustina kugli u nasutom stanju, u kg/m^3*

ρ_{sk} - *gustina materijala od kog je sačinjena kugla, u kg/m^3*

ρ_p - *gustina pulpe, u kg/m^3*

Gustina materijala od kog je sačinjena kugla;

Fe livene - ρ_{sk} = 7800 *kg/m^3*

Silikatne - ρ_{sk} = 2600 *kg/m^3*

Gustina kugli u nasutom stanju;

Fe livene - ρ_{vk} = 4100 do 4200 *kg/m^3*

Silikatne - ρ_{vk} = 1800 do 1900 *kg/m^3*

Izračunavanje vrednosti gustine šarže mlina u pogonu separacije kvarcnog peska „Lukića polje“ kod Milića

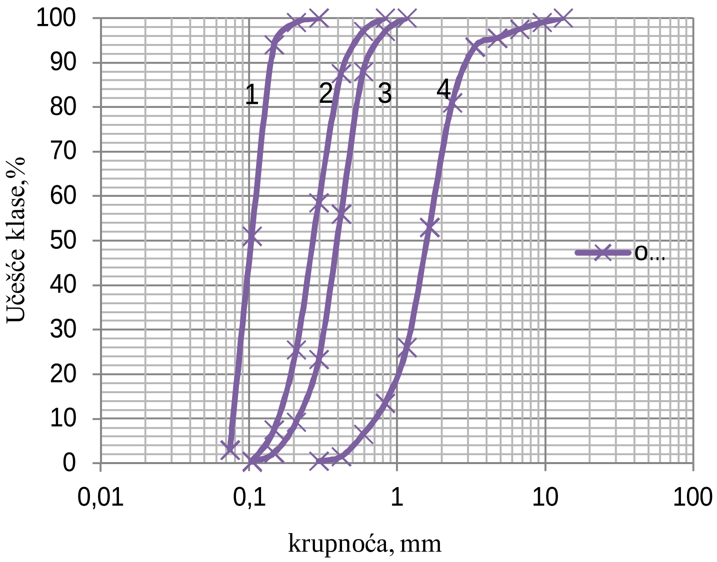
Gustinu šarže mlina u industrijskom procesu rada mlina u pogonu separacije Milići izračunali smo prema jednačini 1.

$$\rho_s = \rho_{vk} + 1{,}15 \cdot (1 - \frac{\rho_{vk}}{\rho_{sk}}) \cdot \rho_p =$$
$$= 1800 + 1{,}15 \cdot (1 - \frac{1800}{2600}) \cdot 1125 =$$
$$= 2198 \frac{kg}{m^3}$$

Gustina pulpe ρ_p meri se rudarskim piknometrom i vagom za merenje gustine. Gustina pulpe ρ_p ne može biti velika kada je šarža od istog materijala, odnosno kada su kugle i sirovina koja se usitnjava od istog materijala. Eksperimentalno smo utvrdili da je potrebna optimalna gustina pulpe ρ_p = 1125 *kg/m^3* ili 18% Č, da bi se obezbedilo kretanje materijala kroz mlin. Do ovakvog saznanja smo došli vizuelno uočavajući veću viskoznost šarže ukoliko se povećava gustina pulpe, a koja prouzrokuje izlazak kugli iz mlina kada prestaju efekti mehano-hemijskog tretmana. Gustina šarže mlina može da se poveća ukoliko se promeni vrsta meljućih tela i umesto sileks kugli usvoje čelične kugle sa većom gustinom, a tada može da se poveća i gustina pulpe što je preduslov za povećanje specifičnog kapaciteta [4,5].

Specifični kapacitet testiranog mlina

U cilju iznalaženja specifičnog kapaciteta mlina za različite finoće proizvoda eksperimentalno je vršena promena časovnog kapaciteta [6,7] mlina pri optimalnoj gustine pulpe. Eksperiment je otpočeo sa manjim časovnim kapacitetom koji je iznosio 4 t/h i gustinom pulpe ρ_p=1125 *gd/m*^{3}, kada je trebalo dodavati 18,2 m^3/h^1 vode. Tada smo dobili oko 98,5% klase -200 µm u finalnom proizvodu, slika 1, kriva 1.



Sl. 1. *Granulometrijski sastavi proizvoda mlevenja Q = 4, 10 i 15 t/h, kao i polaznog uzorka*

Nakon toga povećan je časovni kapacitet mlina na 10 *t/h*, a gustina pulpe ostala je ista ρ_p=1125 *gd/m*^{3} kada je trebalo dodavati 45,6 m^3/h vode, i kada smo dobili oko 98% klase -600 µm u finalnom proizvodu, slika 1, kriva 2. U trećem pokušaju smo časovni kapacitet mlina održavali na 15 *t/h* sa istom gustinom pulpe ρ_p=1125 *gd/m*^{3} kada je trebalo dodavati 68,4 m^3/h vode, pa smo dobili oko 97% klase -830 μm u finalnom proizvodu, slika 1, kriva 3. U polaznom uzorku prema urađenom granulometrijskom sastavu sadržaji pomenutih klasa krupnoće iznosili su; 0% klase -200 μm, 6% klase-600 µm, i 12,3% klase -830 µm, slika 1 kriva 4. Specifični kapacitet smo tada mogli izračunati prema formuli 2 na osnovu podataka iz tabele 1. Specifični kapacitet mlina prema Magdalinoviću [1] je:

$$q_{-d} = \frac{M}{V \cdot t} \cdot \left(\beta_{-d} - \alpha_{-d}\right) \left[\frac{kg}{m^3 \cdot s}\right] \quad (2)$$

gde je:

q_{-d} - specifični kapacitet mlina po novo stvorenoj obračunskoj klasi krupnoće *-d*, u kg/m^3/s (*d* predstavlja kvadratni otvor sita),

M - masa materijala u mlinu, *kg*

V - zapremina mlina, m^3

t - vreme mlevenja, *s*

α_{-d} i β_{-d} - sadržaj obračunske klase krupnoće *-d* u ulazu i proizvodu mlevenja u delovima jedinice

Tabela 1. *Opiti kinetike mlevenja u industrijskom mlinu sprovedeni da bi se odredio specifični kapacitet mlina po novostvorenoj obračunskoj klasi krupnoće -d*

Kapacitet $Q\left[\frac{t}{h}\right]$	**Vreme mlevenja, *t*** $t=\frac{M}{Q}\cdot 3600[s]$	**Masa materijala u mlinu** $[M/kg]$	**Zapremina mlina,** $[V/m^3]$	**Sadržaj obračunske klase krupnoće u proizvodu mlevenja i u ulazu**		$q_{-d}=\frac{M}{V\cdot t}\cdot(\beta_{-d}-\alpha_{-d})$ $\left[\frac{kg}{m^3\cdot s}\right]$
				β_{-d}	α_{-d}	
4	2106	2340	13	0,98	0	$q_{-200}=0{,}084$
10	842,4	2340	13	0,97	0,06	$q_{-600}=0{,}194$
15	561,6	2340	13	0,97	0,12	$q_{-830}=0{,}272$

Masa materijala u mlinu M

Masa materijala za mlevenje računa se prema formuli 3 [1]

$$M=0{,}12\cdot V\cdot\Delta=$$
$$=0{,}12\cdot 13\cdot 1{,}5\cdot 10^3=2340\ kg \qquad (3)$$

gde je:

M - masa materijala u mlinu, kg;

V - zapremina mlina, m^3;

Δ - gustina materijala u nasutom stanju ili nasipna masa materijala, *kg/m*^{3}

0,12 - zapreminska zapunjenost praznog prostora između kugli u mlinu u delovima jedinice.

Procentualna zastupljenost uzorka u mlinu u industrijskim uslovimamlevenja kada je pražnjenje kroz rukavac je takva da u nasutom stanju zauzima prostor od 12% zapremine mlina [6]. Ovi uslovi se dobijaju kada je stepen zapunjenosti mlina šaržom do 40 % i za prazan prostor između kugli od 30 %, ($0{,}4\cdot 0{,}3=0{,}12$).

Zapremina mlina V:

$$V=\frac{D^2\cdot\pi}{4}\cdot L=\frac{2{,}2^2\cdot 3{,}14}{4}\cdot 3{,}4=13{,}m^3 \qquad (4)$$

Izmerena nasipna masa materijala Δ:

$$\Delta=1{,}5\cdot 10^3\ kg/m^3 \qquad (5)$$

JEDNAČINA MODELOVANJA SPECIFIČNOG KAPACITETA MLINA

Prema Buckinghamovom π teoremi svaka jednačina koja sadrži n_i povezanih fizičkih veličina (υ, gde je υ = n d, ρ, D, r .., itd.), između kojih m_i veličine imaju nezavisne dimenzije (M, L, t), može biti prevedena u jednačinu koja ima n_i do m_i bez dimenzionih kriterijuma i simpleksa, sastavljenih iz tih veličina [2,4]. Ova teorema ima veliki značaj u eksperimentalnom i teorijskom radu. Bezdimenzioni brojevi susreću se praktično kod rešavanja svakog problema iz hemijskog inženjerstva. Formiranje bezdimenzionih brojeva za određeni problem najlakše se postiže upotrebom dimenzionih matrica. Dimenziona matrica sastoji se od kvadratne i preostale matrice. Redovi matrica formiraju bazu dimenzija, a ona će formirati rang r matrice. Kolone matrice predstavljaju fizičke veličine ili parametre procesa. Veličina kvadrata osnovne matrice pojavljuju se u svim bezdimenzionim brojevima, dok će se svaki elemenat preostale matrice pojaviti samo u jednom bezdimenzionom broju. Iz ovog razloga preostala matrica bi trebalo da bude sastavljena od najvažnijih promenljivih veličina. Preuređivanje matrice (linearna transformacija) vrši se tako što jezgro matrice prelazi u zajedničku matricu. Nakon stvaranja zajedničke matrice bezdimenzioni brojevi nastaju na sledeći način. Svaki elemenat preostale matrice koji stoji u brojiocu deli se sa parametrima kvadratne matrice koji su stepenovani brojem ispod elementa preostale matrice. U području modelovanja procesa gde se primenjuju hemijske reakcije uz prenos impulsa sile i toplote koristi se kriterijum Damkohler (D_a) [2,3] kao bezdimenziona veličina. Damkohler predstavlja jednačinu modelovanja i specifičnog kapaciteta mlina:

$$D_a = \frac{q_{-d}}{n \cdot \rho_s} \tag{6}$$

gde je:

q_{-d} - specifični kapaciteta mlina prema novostvorenoj $-d$ obračunskoj klasi krupnoće, $M/(L^3 \cdot t)$

n - broj obrtaja mlina u jedinici vremena, $1/t$

ρ_s - gustina šarže, M / L^3

Tabela 2. *Dimenziona matrica Damkohler ovog kriterijuma*

	ρ_{up}	***d***	***n***	q_{-d}
Masa M	1	0	0	1
dužina L	-3	1	0	-3
Vreme t	0	0	-1	-1
	Osnovna matrica			Preostala matrica

Potrebna je samo jedna linearna transformacija dimenzione matrice I to -3 u L redu i ρ_{up} koloni na nulu, kako bi postala preuređena dimenziona matrica. Kasnije treba promeniti znak u t redu, tako da -1 pređe u 1.

Tabela 3. *Preuređena dimenziona matrica*

	ρ_{up}	***d***	***n***	q_{-d}
M	1	0	0	1
3M+L	0	1	0	0
-t	0	0	1	1
	Osnovna matrica			Preostala matrica

Preostala matrica sadrži jedan parameter pa je,

$$\frac{q_{-d}}{\rho^1 \cdot d^0 \cdot n^1} = \frac{q_{-d}}{\rho \cdot n} \equiv D_a$$

Vrednosti kriterijuma Damkohler za eksperimentalne uslove

Vrednosti kriterijuma Damkohler izračunavaju se prema jednačini 6, a date su u tabeli 4 (kolona 5) za sledeće finoće mehanohemijskog tretmana 200 µm, 600 µm i 830 µm.

Tabela 4. *Vrednosti kriterijuma D_a za različite specifične kapacitete q_{-d}*

Izmereni kapacitet $Q\left[\frac{t}{h}\right]$	**Specifični kapacitet mlevenja** $q_{-d}\left[\frac{kg}{m^3 \cdot s}\right]$	**Gustina šarže u mlinu** $\rho_s\left[\frac{kg}{m^3}\right]$	**Broj obrtaja mlina** $n\left[s^{-1}\right]$	**Vrednost Damkohler-ovog kriterijuma** $D_a = \frac{q_{-d}}{n \cdot \rho_{up}}$
4	0,084	2198	0,3	$D_a = \frac{q_{-200}}{n \cdot \rho_{up}} \cong 0{,}000127$
10	0,194	2198	0,3	$D_a = \frac{q_{-600}}{n \cdot \rho_{up}} \cong 0{,}000295$
15	0,272	2198	0,3	$D_a = \frac{q_{-830}}{n \cdot \rho_{up}} \cong 0{,}000413$

Gustina šarže u mlinu može značajno da se povećava jedino ako upotrebimo kugle veće gustine, a tada treba povećati i specifični kapacitet mlevenja, da bi kriterijum D_a ostao jednak sa onim vrednostima koje su date u tabeli 4, (kolona 5) i prema jednačini 6.

Nova gustina šarže mlina u slučaju promene vrste meljućih tela

$$\rho_{up} = \rho_{vk} + 1{,}15 \cdot (1 - \frac{\rho_{vk}}{\rho_{sk}}) \cdot \rho_{vm} =$$
$$= 4200 + 1{,}15 \cdot (1 - \frac{4200}{7800}) \cdot 1719 =$$
$$= 5112\ \frac{kg}{m^3}$$

Nova gustina šarže može se povećati tako što će se promeniti vrsta meljućih tela, pa će se umesto sileks kugli ρ_{vk} =1.800 *kg/m*^{3} koristiti čelične kugle ρ_{vk} = 4.200 *kg/m*^{3}. Gustina pulpe takođe može biti povećana bez opasnosti da zbog povećanog viskoziteta pulpe dođe do pražnjenja šarže kugli kroz rukavac, i mi smo usvojili da ona bude oko 68% što je uobičajeno za ovu vrstu sirovine i tip mlina, a tada je ρ_p =1.719 *kg/m*^{3}

Novi specifični kapacitet mlina u slučaju promene vrste meljućih tela

Novi specifični kapacitet mlina za novu vrednost gustine šarže može se dobiti računskim putem tako što će vrednost kriterijuma D_a za određenu obračunsku klasu krupnoće ostati nepromenjena. Uslov da bi kriterijum D_a ostao nepromenjen za nove uslove rada mlina odnosno za povećanu vrednost gustine šarže u mlinu jeste taj da se mora povećati specifični kapacitet mlina za datu obračunsku klasu krupnoće. Nakon izračunavanja novog specifičnog kapaciteta lako se može izračunati vreme mlevenja i časovni kapacitet mlina što je i prikazano u tabeli 5.

Tabela 5. *Novi specifični kapaciteta mlina pri upotrebiveće gustini šarže u mlinu*

Izračunati kapacitet $Q\left[\frac{t}{h}\right]$	**Specifični kapacitet mlevenja** $q_{-d}\left[\frac{kg}{m^3 \cdot s}\right]$.	**Gustina šarže u mlinu** $\rho_s\left[\frac{kg}{m^3}\right]$	**Broj obrtaja mlina** $n\left[s^{-1}\right]$	**Vrednost Damkohler-ovog kriterijuma** $D_a = \frac{q_{-d}}{n \cdot \rho_{up}}$
10	0,209	5112	0,3	$D_a = \frac{q_{-200}}{n \cdot \rho_{up}} \cong 0{,}000127$
23	0,447	5112	0,3	$D_a = \frac{q_{-600}}{n \cdot \rho_{up}} \cong 0{,}000295$
35	0,635	5112	0,3	$D_a = \frac{q_{-830}}{n \cdot \rho_{up}} \cong 0{,}000413$

Vidimo da se u perspektivi može očekivati najmanje dva puta veći kapacitet mlevenja sa promenom vrste kugli odnosno 10 *t/h* za finoću 85% -200 μm.

ZAKLJUČAK

Specifični kapacitet mlevenja prema kriterijumu Damkohler i jednačini 6 zavisi od gustine šarže mlina broja obrtaja mlina i specifićnog kapaciteta mlevenja. Kod realizacije ideje da se menja specifični kapacitet mlina morala bi se promeniti gustina šarže pa je iz kriterijumske Damkohler jednačine lako izračunati novi veći specifični kapacitet mlina. Uz promenu vrste meljućih tela (sa sileks kugli na čelične kugle) moguće je izvršiti promenu specifičnog kapaciteta mlina ili povećati finoću mlevenja na 200 μm a da kapacitet ostane isti 10 *t/h*. Ukoliko bi finoća ostala ista kapacitet bi se povećao 2,3 puta.

LITERATURA

[1] N. Magdalinović, Usitnjavanje i klasiranje mineralnih sirovina, Tehnički fakultet u Boru, 1985, Bor, str. 70.

[2] E. Beer, Priručnik za dimenzioniranje uređaja kemijske procesne industrije SKTH/kemija u industriji, Zagreb 1985, str. 491.

[3] M. Petrov i ostali autori, Tehničko tehnološkog rešenje: "Razvoj programskog sistema mlevenja kvarcnog peska ležišta Skočić za potrebe hemijske industrije fabrike glinice Birač - Zvornik dobijen korišćenjem kriterijumskih jednačina modeliranja". ITNMS Beograd, 2012.

[4] S. Rozgaj, Procesni aparati i uređaji, IGKRO "Svjetlost", Sarajevo, 1980, str. 63.

[5] Lj. Andric, M. Petrov, Z. Aćimović Pavlovic, M. Trumić, A kinetic Study of Mechanical Activation of Mica in a Vibratoriy Mill, Metalurgia Internacional, No. 7. (2012), str. 33-38.

[6] M. Grbović, N. Magdalinović, Procesna oprema drobljenja i mlevenja mineralnih sirovina, “Bakar”, Bor, 1980, str. 88.

[7] S. Puštrić, Izbor i proračun mašina i uređaja za drobljenje prosejavanje i mlevenje mineralnih sirovina, RGF, Beograd, 1974, str 48.

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THE FLAWS OF ALUMINIUM-MAGNESIUM ALLOY ELEMENTS – INFLUENCE OF INCLUSIONS[*****]

Abstract

The investigation results of gas removal from smelted metal and the effect on performances of aluminium-magnesium alloy cast elements are presented in this paper. The investigated alloy is based on recycled material. The obtained results define the specific procedure which is used for removal and reduction the presence of inclusions of various types in the cast elements, which is the basic step in achieving the designed quality of cast material and quality final products. Kinetics and mechanisms of degasification process were investigated, parameters of degasification procedures were defined, and the new agents for degasification of alloy cast were implemented. The results of this investigation are significant from the aspect of sustainable development the production of cast elements of aluminium alloys.

Keywords*: aluminium-magnesium alloys, inclusions, cast quality, secondary raw materials*

1 INTRODUCTION

The goal of modern casting procedure is to meet the proposed requirements for composition, structure, properties, and quality of cast material. The final product should not have any flaws which could limit its usage [1]. The structure of cast material is shaped by cooling conditions, and in addition it affects the final properties of cast elements. On the other hand, the quality of cast is significantly affected by the parameters of casting technology. Detection and evaluation of flaws in casts has to be performed systematically during developmental phase of the process, using preventive measures to avoid them [2]. Aluminuim- magnesium alloys are a significant group of alloys, primarily because their high mechanical strength was achieved without thermal processing, then their high corrosion resistance, good wetability, etc. [3, 4]. The investigation the effect of non-metal inclusions and gases on the quality of elements made of aluminium AlMg3 alloy, obtained by semi-continuous casting, was conducted. Since the recycled raw materials were used in production of the Al-Mg alloy, the certain flaws of gas type or inclusions occurred in the casts. Flaws were positioned internally as a substructure of the

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surface, or within entire cast element. All flaws were relatively small, individually scattered or grouped. The main problem, caused by gas content, being trapped within metal, is porosity which might reduce the capability of plastic processing of hot aluminum.

The main objective of smelting technology is to provide a cast of adequate metal or alloy with the lowest possible content of gases and non-metal ingredients. In aluminum and its alloys, it is hydrogen that increases the quantity of rejects. Hydrogen content in the cast aluminum is usually in the range of 0.5-1.1 cm^3/100 g metal, whilst the content is lower in the alloys. Solubility of hydrogen is affected by presence of the following alloying components: Si, Cu, Zn, Pb, Ag, Bi, Cd that decrease the solubility of hydrogen, whilst Mg increases it [5]. The most common non-metal ingredient in aluminum and its alloys is aluminium-oxide which affects the presence of hydrogen in the cast. Aluminum-oxide actively absorbs hydrogen decreasing the concentration of solute hydrogen. However, the additional dissolution of H occurs due to the absorption of steam from atmosphere on oxide film on liquid metal. Then decomposition with Al occurs increasing in this way concentration of hydrogen until saturation of the cast. By superheating of the cast and afterwards cooling it down, the hydrogen saturation occurs because oxides are becoming passive related to hydrogen [6]. Removal of non-metal components is efficiently performed by filtration of the cast [7, 8]. Alloying elements have different effect on hydrogen content in the cast: 1% of Ca, Ba or Be might decrease the hydrogen concentration; 0.1% of Fe or Si adversely effects degasification; Na increases hydrogen content from 0.05 to 0.45 cm^3/100g; Cu, Sn, Si lower solubility of hydrogen in liquid Al; H content increases with increase of Mg in the alloy [9-11]. Better effect of degasification is always achieved without utilization of salt and with air curing and treatment of melt with intergases [12, 13].

2 MATERIALS AND METHODS

AlMg3 alloy was investigated due to the appearance of small cracks and bubbles during cold processing, which were probably caused by gases and non-metal inclusions residual from the casting process. All series of semi-continuous casting of elements made of $AlMg_3$ alloy were performed in the laboratory environment. Smelting of the metal for all series was performed in the melting furnace "FXM-45", Shanghai Fortune Electric, with automatic temperature regulation. Degasification was performed with inert gas, nitrogen and argon being degasification agents. Casting temperature was 700 °C and casting rate: 40±2 mm/min. The effect of gas quantity and non-metal inclusions on porosity, structure and mechanical properties were monitored. Table 1 shows the parameters of semi-continuous casting process per series. Three elements with different dimensions were casted for each series.

Table 1 *Parameters of semi-continuous casting process*

Variable process parameters		
Sample	**Block dimension, m**	**Degasification time, min**
T_1	0.3x0.5x0.5	10
T_2	0.3x0.5x0.5	15
T_3	0.3x0.5x0.5	30
T_4	0.4x0.5x0.5	10
T_5	0.4x0.5x0.5	15
T_6	0.4x0.5x0.5	30

Pre-alloy (Al (4%Ti; 2%B)), as a modification agent, was added into the casting furnace 10 min before casting, after which the cast was mixed. Nitriding was performed in smelting furnace before casting and it lasted 15 min. Argon was used for degasification in conditional furnace and, before pouring, ALPUR was applied. ALPUR is an apparatus which can prolong degasification. Temperature is maintained by automatic heating. Argon was induced into liquid metal under 2 bar pressure. Air curing with argon was performed using a special long tube immersed to the bottom of furnace. The aim of argon induction was to remove non-metal inclusions and harmful gases. Degasification effect of argon is based on absorption and diffusion. The initial speed of diffusion was fast, with decreasing tendency over time, proportionally to partial pressure of hydrogen within argon bubble. Once partial pressures are equalized, the diffusion stops. Non-metal inclusions are stick to bubbles and surface from the cast. In this way, the cast is cleaned from slag. This degasification did not remove total quantity of gas, but its presence was reduced up to 50 % compared to the quantity of gas that metal contains whilst entering into ALPUR.

Chemical composition of the alloy was tested on samples extracted from the cast just before casting. Investigation of mechanical properties of the casts was performed on test-tubes with diameter of ϕ10 mm. Special samples were taken from cut parallelepiped slabs and machined for solidity testing. Tensile strength and relative elongation were tested on electronic testing machine with power of 400 kN, brand Karl Frank GMBH, type 81105. Solidity was measured using the Brunel's method HB (2.5/62.5/30), 2.5 mm ball and 625 kN load in time of 30 s. Research was performed on apparatus Karl Frank GMBH, type 38532. Testing was performed on casted samples. Quantity of present hydrogen in the casts was measured whilst metal was still in a liquid state, i.e. channel just before pouring using device Alskan, ABB Inc from Canada. Measuring period was 10 min. Table 2 shows the cast motion rate and cooling water flow during crystallization of the cast.

Table 2 *Cast motion rate and water flow during crystallization*

Alloy	Dimensions, m	Rate 1, cm/min	Flow 1, m^3/h	Rate 2, cm/min	Flow 2, m^3/h	Water temperature °C
$AlMg_3$	0.3x1	5.0	80	7.0	120	20
	0.4x1.5	5.0	90	7.0	130	20

3 RESULTS AND DISCUSSION

The values of mechanical properties of all casted samples (T_1-T_6) are given in Table 3, and Figure 1.

Table 3 *Mean values of mechanical properties of casts obtained by semi-continuous casting*

Samples	Degasification time, min	E module, MPa	Rm, MPa	HB, 2.5/62.5/30	A50, %
T_1, T_3	10	69.16	235.26	51.45	24.25
T_2, T_4	15	68.95	240.68	54.30	26.91
T_3, T_6	30	67.23	247.50	55.25	29.05

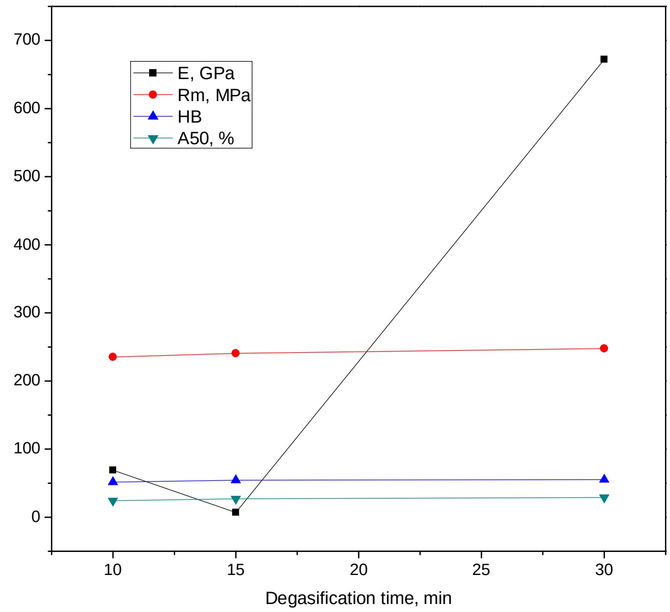

Figure 1 *Changes of E, Rm, HB and A50 in a function of degasification time*

It can be seen that lower values of mechanical properties are obtained due to the insufficient degasification time. Namely, samples obtained by casting with insufficient degasification contain more gas, i.e. have the increased porosity. The change of gas concentration with increase of degasification time is given in Figure 2.

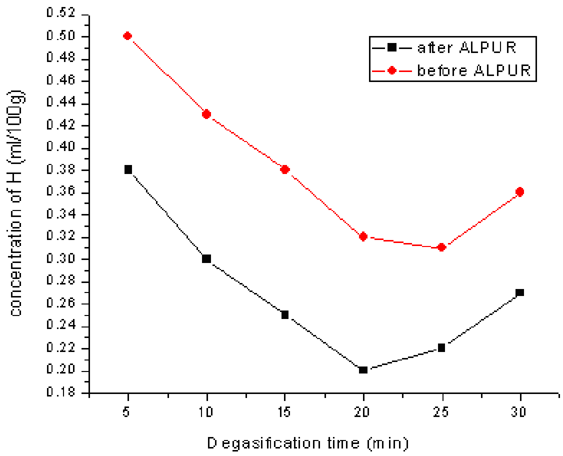

Figure 2 *Changes of gas concentration with increase of degasification time*

The results of investigation the hydrogen concentration in liquid metal, before pouring into mould, show noticeable differences depending on degasification time. If degasification time is short, the gas is removed only partially from metal. Disregarding of the fact that ALPUR performs afterward removal of present gas, it will lapse in higher concentrations in metal, what is confirmed by measured concentrations.

The large quantity of gas presence largely affects the quantity of casts and it is easily visible during analysis of microstructure. Porosity of sample with the shortest time of degasification is given in Figure 3.

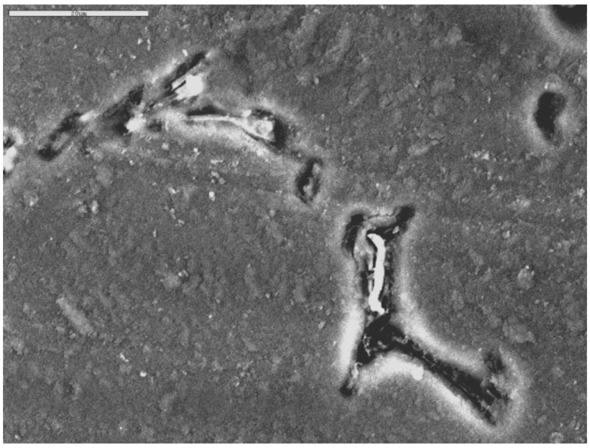

Figure 3 *Porosity of sample with the shortest degasification time*

The best results of measured gas concentration occurred during degasification which lasted for 15 min with the constant standing periods. Prolonging of degasification in the conditional furnace influences a slight increase of gas concentration. This can be explained by increase of total gas pressure in the furnace atmosphere and that gas, previously removed from metal, again returns to metal in the standing period. Microstructure of samples with different degasification times is given in Figure 4 – 6.

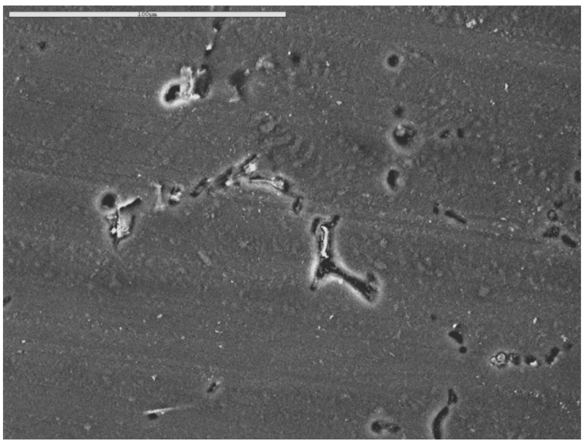

Figure 4 *Microstructure of sample with maximum degasification time*

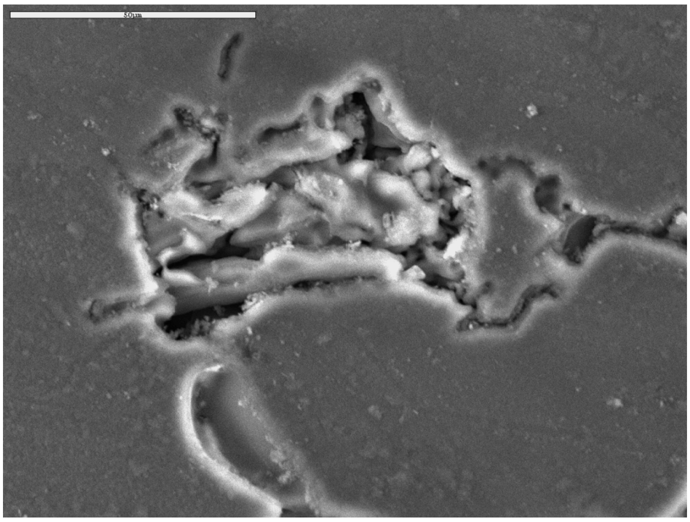

Figure 5 *Microstructure of sample with minimum degasification time*

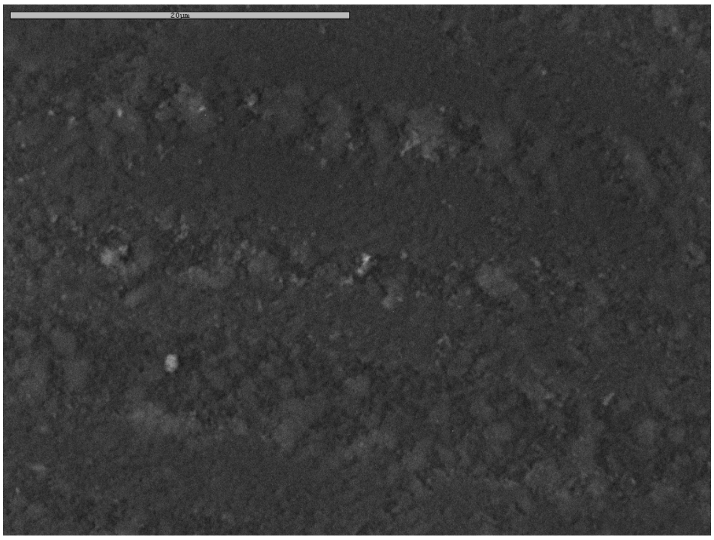

Figure 6 *Microstructure of sample with optimal degasification time*

During crystallization process of the casts, motion of gas from cast surface toward the center is performed pushing the growing crystals until gas forms bubbles whose motion rate through metal becomes slower than crystallization rate and they are trapped in metal. This explains the increased porosity during transitional period. Gas residue reaches the center of cast that last solidifies. Some gas, however, remained in the cast which can be confirmed by analysis of microstructure. It is proved that quantities of present gas found in microstructure depend on degasification time.

Analysis of the results indicates the certain causes of flaws in $AlMg_3$ alloy cast elements: foremost they are related to occurrence of segregation layer; porosity in transitional phase; and porosity in the center of cast, i.e. element. Presence of gas in the casts can be regulated taking actions and permanent control, with fundamental process in a form of degasification where degasification element has a special role, as proven by the research conducted on microstructure. Results of microstructural analysis showed that the quality of cast elements is affected by numerous parameters of the process and phenomena occurring during smelting and casting process. It is showed that batching and melting of batch components should be performed in one sequence with increase of affinity for oxygen, melting temperature, volatility and reduction of quantity of components. Batch components with high values of affinity for oxygen, melting temperature and volatility can be batched and melted together.

4 CONCLUSIONS

The main conclusions deducted from the performed investigation are as follows:

- Basic reason for selecting aluminium-magnesium alloy was the occurrence of cracks and bubbles which appeared during cold processing. It was assumed that this is caused by gases and non-metal inclusions left behind after casting process. Since gas is very harmful, it is necessary to know its concentration in the alloy, thus special attention was paid to the measuring concentration of hydrogen in the cast.
- Nitrogen and argon were chosen as degasification agents. Nitriding was performed in a smelting furnace before casting, in duration of 15 min. Inert gas argon was used in a conditional furnace and ALPUR (before pouring). The best results are achieved with degasification of the cast with argon in duration of 15 minutes. During prolonged degasification in the conditional furnace, the gas concentration in the cast slightly increases, what can be explained by increase of total gas pressure in the atmosphere, so gas previously removed from metal is returned to metal in the standing period.
- Microstructural analysis showed that the quantity of present gas depends on degasification time. Insufficient degasification time results in obtaining lower values of mechanical properties of cast blocks. These values are somewhat lower than values proscribed in standards. With longer degasification time, mechanical properties are at lower limits proscribed in standards for this type of alloy. Namely, the samples obtained from casting with insufficient degasification, as well as samples with prolong degasification contain larger quantity of gas, i.e. they have higher porosity which reflected on occurrence of flaws - tiny cracks, bubbles during cold processing of these blocks.

REFERENCES

[1] R. González, D. Martínez, J. González, J. Talamantes, S. Valtierra, R. Colás, Experimental Investigation for Fatigue Strength of a Cast Aluminium Alloy, International Journal of Fatigue, 33 (2011), pp. 273–278;

[2] M. A. Irfan, D. Schwam, A. Karve, R. Ryder, Porosity Reduction and Mechanical Properties Improvement in Die Cast Engine Blocks, Materials Science and Engineering A, 535 (2012), pp.108– 114;

[3] N. Vanderesse, É. Maire, A. Chabod, J. Y. Buffière, Microtomographic Study and Finite Element Analysis of the Porosity Harmfulness in a Cast Aluminium Alloy, International Journal of Fatigue, 33 (2011), pp. 1514–1525;

[4] H. Mindivan, A study on Wear and Corrosion Behavior of Thermally Sprayed Alumina-titania Composite Coatings on Aluminium Alloys, Kovove Mater. 48 (2010), pp. 203–210;

[5] H. Kaya, U. Boyuk, E. Cadırlı, N. Maraslı, Unidirectional Solidification of Aluminium-Nickel Eutectic Alloy, Kovove Mater., 48 (2010), pp. 291–300;

[6] L. Ceschini, Alessandro Morri, Andrea Morri, A. Gamberini, S. Messieri, Correlation between Ultimate Tensile Strength and Solidification Microstructure for the Sand Cast A357 Aluminium Alloy, Materials and Design, 30 (2009), pp. 4525–4531;

[7] A. M. A. Mohamed, A. M. Samuel, F. H. Samuel, H. W. Doty, Influence of Additives on the Microstructure and Tensile Properties of near Eutectic Al–10.8% Si Cast Alloy, Materials and Design, 30 (2009), pp. 3943–3957;

[8] J. Cadek, K. Kucharova, K. Milicka, S. J. Zhu, Creep of Discontinuous Aluminium Alloy Matrix Composites Produced by Powder Metallurgy Route, Kovove Mater., 37 (1999), pp. 213 – 245;

[9] R. Sadeler, S. Atasoy, H. Altun, Fretting Fatigue behaviour of a 2014-T6 Aluminium Alloy Coated with an Electroless Nickel under Rotating Bending Loading, Kovove Mater., 47 (2009), pp. 95–100;

[10] J. Espinoza-Cuadra, G. Garcıa-Garcıa, H. Mancha-Molinar, Influence of Defects on Strength of Industrial Aluminum Alloy Al–Si 319, Materials and Design, 28 (2007), pp.1038–1044;

[11] Y. Sahin, Preparation and Some Properties of SiC Particle Reinforced Aluminium Alloy Composites, Materials and Design, 24 (2003), pp. 671–679;

[12] X. Sauvage, M. Yu. Murashkin, R. Z. Valiev, Atomic Scale Investigation of Dynamic Precipitation and Grain Boundary Segregation in a 6061 Aluminium Alloy Nanostructured by ECAP, Kovove Mater., 49 (2011), pp. 11–15;

[13] T. Pelachova, J. Lapin, Analysis of Intermetallic Phases in Wrought Aluminium Alloy Prepared by Recycling of Composite Scrap, Kovove Mater., 37 (1999), pp. 399 – 411.

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GREŠKE NA ELEMENTIMA OD ALUMINIJUM-MAGNEZIJUM LEGURE - UTICAJ UKLJUČAKA[*****]

Izvod

Rezultati ispitivanja uticaja uklanjanja gasa iz tečnog metala na kvalitet livenih elemenata od aluminijum-magnezijum legure, a na bazi recikliranih materijala su dati ovom radu. Dobijeni rezultati praktično definišu proceduru livenja kojom se može umanjiti prisustvo uključaka i gasova u livenim elementima, što je osnovni preduslov za postizanje projektovanog kvaliteta livenog materijala i krajnjih proizvoda. Ispitivani su kinetika i mehanizmi procesa degasifikacije, zatim su definisani parametri procesa degasifikacije, i na posletku primenjeni novi agensi za degasifikaciju legura. Rezultati ovog ispitivanja su značajni sa ekološkog aspekta i sa aspekta održivog razvoja proizvodnje livenih elemenata od aluminijumskih legura.

Ključne reči*: aluminijum-magnezijum legure, ukljički, kvalitet odlivaka, otpadne sirovine*

1. UVOD

Cilj u savremenom livarstvu je ispunjenje zahteva u pogledu sastava, strukture, svojstava, i kvaliteta odlivka. Odlivak ne sme imati nikakve greške koje bi mogle da ograniče njegovu upotrebu [1]. Struktura koja se formira pod različitim uslovima hlađenja, u nekoj određenoj metodi livenje, utiče na razilčita krajnja, upotrebna svojstva dobijenih odlivaka. Isto tako, na kvalitet odlivaka utiču i parametri tehnologije livenja. Otkrivanje i evaluacija grešaka pri livenju mora da se obavlja sistematično u razvojnoj etapi procesa kako bi se izbegle greške [2]. Aluminijum-magnezijum legure su značajna grupa legura, najpre zbog visoke mehaničke čvrstoće postignute bez termičke obrade, a zatim i zbog visoke otpornosti na koroziju, dobre prionljivosti, itd [3, 4]. Ispitivan je uticaj nemetalnih uključaka i gasova na kvalitet aluminijumskih elemenata dobijenih na bazi AlMg3 legure metodom polukontinualnog livenja. Pošto su u proizvodnji Al-Mg legura korišćene reciklažne sirovine, određene greške kao što su zarobljeni gasovi ili uključci, su se pojavljivale u odlivcima tokom ispitivanja. Greške su pozicionirane

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interno - kao substruktura površine ili greške rasprostranjene po celom elementu. U pogledu veličine greške su bile male, ili pojedinačno rasute, ili u grupama. Osnovni problem koji prouzrokuje prisustvo gasa u metalu je nastanak različitih oblika poroznosti koji umanjuju sposobnost plastičnog presovanja vrućeg aluminijuma.

Jedan od glavnih ciljeva tehnologije topljenja je: dobiti rastop metala ili legure sa najnižim mogućim sadržajem gasa i nemetalnih konstituenata. U aluminijumu i njegovim legurama, vodonik direktno utiče na formiranje škartova. Sadržaj vodonika u livenom aluminijumu je obično u granicama 0,5-1,1cm^3/100 g metala, dok je u legurama sadržaj nešto niži. Rastvorljivost vodonika je određena prisustvom sledećih legirajućih kompomentui: Si, Cu, Zn, Pb, Ag, Bi, Cd uslovljava smanjenje rastvorljivosti vodonika; dok je Mg povećava [5]. Najčešći nemetalni sastojak u aluminijumu i njegovim legurama je aluminijum-oksid, koji utiče na prisustvo vodonika u rastopu legure. Aluminijum-oksid aktivno apsorbuje vodonik u toku livenja, što dalje umanjuje koncentraciju rastvorenog vodonika. Međutim, dolazi do dodatnog rastvaranja H usled apsorpcije pare iz atmosfere na filmu oksida koji se formirao na na rastopu metala. Zatim dolazio do njegovog razgrađivanje sa Al, povećavajući na taj način koncentraciju vodonika do saturacije. Pregrevanjem rastopa i potom hlađenjem dolazi do saturacije, jer oksidi postaju pasivni prema vodoniku [6]. Uklanjanje nemetalnih sastojaka se efikasno obavlja filtracijom odlivka [7, 8]. Legirajući elementi imaju različiti uticaj na sadržaj vodonika u odlivku: 1% Ca, Ba ili Be utiče na umanjenje sadržaja vodonika; 0,1 % Fe ili Si ima suprotan efekat na degasifikaciju; Na utiče na povećavnje sadržaja vodonika u količini 0,05 do 0,45 cm^3/100 g; Cu, Sn, Si smanjuju rastvorljivost vodonika u tečnom Al. Sadržaj vodonika se povećava sa povećanjem sadržaja Mg u leguri [9-11]. Bolji efekat degasifikacije se postiže bez primene soli i tretiranjem rastopa internim gasovima [12,13].

2. MATERIJALI I METODE

AlMg3 legura je ispitivana zbog pojave sitnih pukotina ili mehurića u toku hladne obrade legure, koji su najverovatnije prouzrokovani zaostatkom gasova i nemetalnih uključaka u toku livenja. Sve serije polukontinualo livenih elemenata od legure AlMg3 spravljene su u laboratorijskim uslovima. Topljenje metala za sve serije obavljeno je u peći za “FXM-45”, Shanghai Fortune Electric, sa automatskom regulacijom temperature. Degasifikacija je obavljena pomoću inertnog gasa, azot i argon su korišćeni kao degasifikacioni agensi. Temperatura livenja je bila 700 °C a brzina livenja 40±2 mm/min. Praćen je uticaj količine gasa i nemetalnih uključaka na pojavu poroznosti, strukturu i mehanička svojstva. U Tabeli 1. su dati procesni parametri polu-kontinuiranog livenja po serijama. Za svaku seriju livena su po tri elementa različitih dimenzija.

Tabela 1. *Parametri procesa polu-kontinualnog livenja*

Promenjivi parametri procesa		
Uzorci	**Dimenzije, m**	**Vreme degasifikacije, min**
T_1	0.3x0.5x0.5	10
T_2	0.3x0.5x0.5	15
T_3	0.3x0.5x0.5	30
T_4	0.4x0.5x0.5	10
T_5	0.4x0.5x0.5	15
T_6	0.4x0.5x0.5	30

Predlegura (Al (4%Ti; 2%B)) kao modifikujući agens je dodata u peći za livenje 10 min pre početka livenja, nakon toga je rastop mešan. Azotiranje je izvršeno u peći za topljenje neposredno pred izlivanje i trajalo je 15 min. Argon je upotrebljen za degasifikaciju u kondicionoj peći i neposredno pred ulivanje upotrebljen je ALPUR. ALPUR je aparat koji može da produži degasifikaciju. Temperatura je održavana uz pomoć automatskog zagrevanja. Argon je u tečni metal ubacivan pod pritiskom od 2 bara. Produvavanje sa argonom je obavljeno pomoću specijalne duge cevi, uranjanjem do dna u peć. Cilj uvođenja argona bio je odstranjivanje nemetalnih uključaka i štetnih gasova. Degasifukujuće dejstvo argona zasniva se na adsorpciji i difuziji. Početna brzina difuzije je velika, sa tendencijom padanja sa vremenom proporcionalno parcijalnom pritisku vodonika unutar mehurića argona. Kada se parcijalni pritisci izjednače difuzija prestaje. Nemetalni uključci se lepe za mehuriće i izlaze na površinu rastopa čisteći rastop od šljake. Degasifikacijom nije uklonjena ukupna količina gasa, ali je njegovo njegovo prisustvo umanjeno do 50% u odnosu na količinu gasa koju metal nosi u sebi pri ulasku u ALPUR.

Hemijski sastav legura je ispitan na uzorcima izvađenim iz liva pred samo livenje. Mehaničkih svojstava odlivaka su ispitana na epruvetama kružnog preseka ø 10 mm. Epruvete su izrezane iz sredine ploče i mašinski obrađene. Zatezna čvrstoća i relativno izduženje su ispitivani na elektronskoj kidalici snage 400 kN, marke Karl Frank GMBH, tipa 81105. Tvrdoća je izmerena Brinelovom metodom HB (2.5/62.5/30), kuglicom od 2,5 mm i opterećenjem 625 kN u trajanju od 30 s. Ispitivanje je obavljeno na aparatu Karl Frank GMBH - 38532. Ova ispitivanja su urađena na uzorcima u livenom stanju. Količina prisutnog vodonika u odlivcima merena je dok je metal u tečnom stanju, tj. u kanalu pred samo ulivanje uređajem Alskan ABB Inc Kanada. Vreme merenja je 10 min. U Tabeli 2. prikazana je brzina kretanja odlivaka i brzina protoka vode za hlađenje u toku kristalizacije odlivaka.

Tabela 2. Brzina kretanja odlivaka i protoka vode u toku kristalizacije

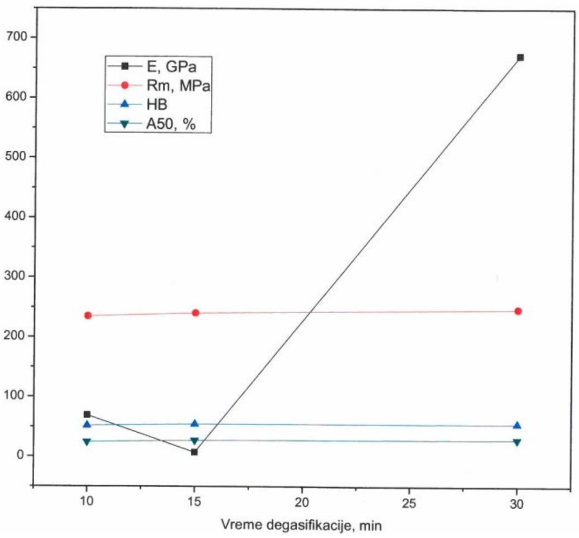
Legura	Dimenzije, m	Brzina 1, cm/min	Protok 1, m^3/h	Brzina 2, cm/min	Protok 2, m^3/h	Temperatura vode, °C
AlMg3	0,3x1	5,0	80	7,0	120	20
	0,4x1.5	5,0	90	7,0	130	20

3. REZULTATI I DISKUSIJA

U Tabeli 3. i na Slici 1. je dat prikaz srednjih vrednosti mehaničkih svojstava uzoraka (T_1-T_6).

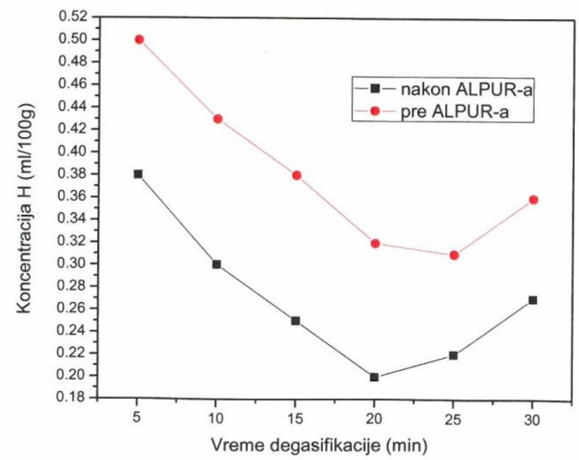
Tabela 3. *Srednje vrednosti mehaničkih svojstava odlivaka*

Uzorci	Vreme degasifikacije, min	E modul, MPa	Rm, MPa	HB	A50, %
T_1, T_3	10	69,16	235,26	51,45	24,25
T_2, T_4	15	68,95	240,68	54,30	26,91
T_3, T_6	30	67,23	247,50	55,25	29,05



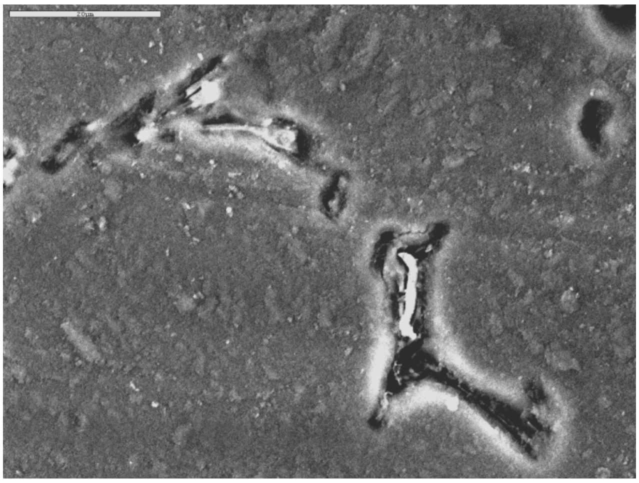
Sl. 1. *Promene parametara E, Rm, HB i A50 u funkciji vremena degasifikacije*

Može se uočiti da se niže vrednosti mehaničkih svojstava dobijaju usled kratkog vremena degasifikacije. Naime, uzorci dobijeni livenjem sa nedovoljnom degasifikacijom sadrže veću količinu gasa i imaju povećanu poroznost. Na slici 2 prikazana je promena koncencentacije gasa sa povećanjem vremena degasifikacije.



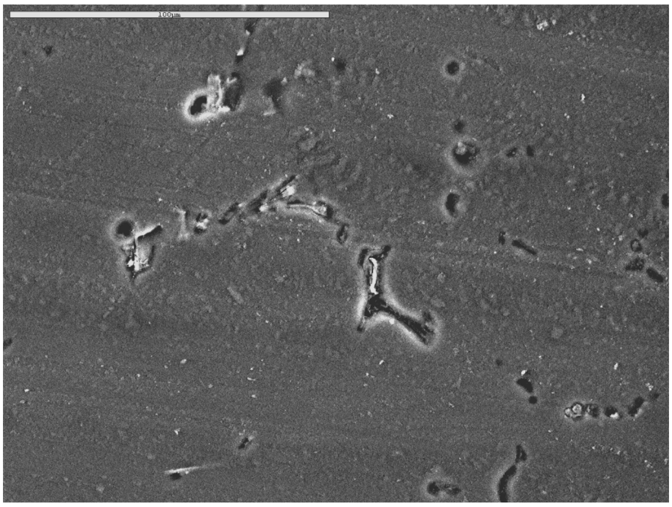
Sl. 2. *Promena koncencentacije gasa sa porastom vremena degasifikacije*

Rezultati ispitivanja koncentracije vodonika u tečnom metalu pred ulivanje u kalup, pokazuju značajne razlike zavisno od vremena degasifikacije. Ako je vreme degazacije kratko gas će u maloj meri biti uklonjen iz metala. Bez obzira što se ALPUR-om izvrši naknadno odstranjivanje prisutnog gasa on će zaostajati u većim koncentracijama u metalu, što se potvrđuje izmerenim koncentracijama. Ovako prisutan gas u velikoj meri utiče na kvalitet odlivaka i može se uočiti mikrostrukturnom analizoma. Na Slici 3. prikazan je izgled poroznosti u uzorku sa najkraćim vremenom degasifikacije.

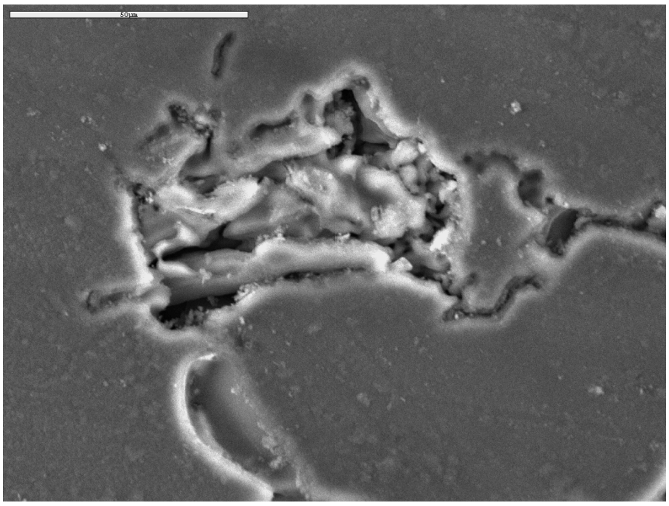


Sl. 3. *Poroznost uzorka sa najkraćim vremenom degasifikacije*

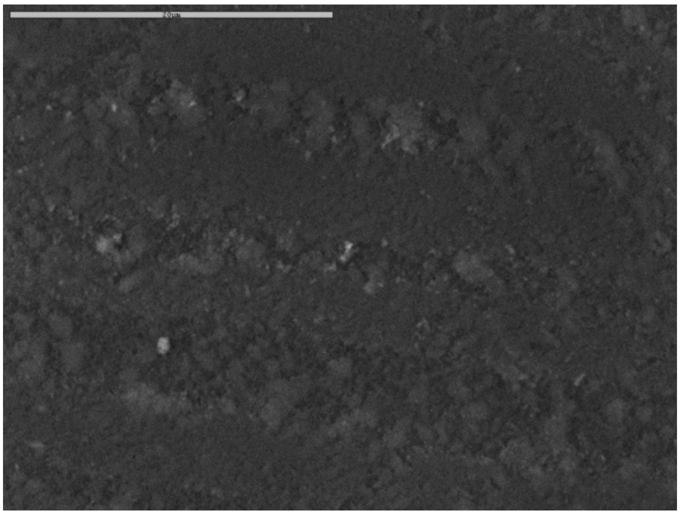
Najbolji rezultati pri merenju koncentracije gasa dobijeni su pri degasifikaciji od 15 min za konstantno vreme odstojavanja. Produženom degasifikacije u kondicionoj peći koncentracija gasa se u manjoj meri povećava. Ovo se može objasniti povećanjem ukupnog pritiska gasa u atmosferi peći, pa se gas predhodno odstranjen iz metala ponovo vraća u metal u periodu odstojavanja. Na sl. 4-6. prikazana je mikrostruktura uzoraka sa različitim vremenima degasifikacije.



Sl. 4. *Mikrostruktura uzorka sa maksimalnim degasifikacionim vremenom*



Sl. 5. *Mikrostruktura uzorka sa minimalnim degasifikacionim vremenom*



Sl. 6. *Mikrostruktura uzorka sa optimalnim degasifikacionim vremenom*

U toku kristalizacije odlivaka kretanje gasa sa površine odlivka ka centru vrši se guranjem od strane rastućih kristala sve do momenta dok gas ne obrazuje mehuriće čija brzina kretanja kroz tečan metal postaje manja od brzine kristalizacije i on biva zarobljen u metalu. Ovo objašnjava pojavu veće poroznosti u prelaznom periodu. Ostatak gasa dospeva do centra odlivka koji zadnji očvršćava odakle sva količina gasa ne stiže da ispliva na površinu već ostaje u odlivku što je potvrđeno mikrostrukturnom analizom. Dokazano je da količina prisutnog gasa koja je konstatovana mikrostrukturnim ispitivanjima zavisi od vremena degasifikacije.

Analiza rezultata ukazuje na izvesne uzroke nastanka grešaka kod livenih elemenata AlMg3 legure: pojava segregacionog sloja; poroznosti; poroznosti u prelaznoj fazi; kao i poroznosti u centru odlivka, tj. elemenata. Prisutstvo gasa u odlivcima se može regulisati određenim merama i stalnom kontrolom procesa, a osnov su postupak degasifikacije pri čemu vrsta degasifikacionog agensa ima posebnu ulogu, što su ispitivanja mikrostrukture i pokazala. Rezultati mikrostrukturnih ispitivanja su pokazali da na kvalitet livenih blokova utiču mnogi parametri procesa i fenomeni koji se odvijaju tokom faze topljenja i livenja. Pokazalo se da šaržiranje i topljenje komponenata šarže treba voditi u jednom redosledu s povećanjem: afiniteta prema kiseoniku, temperaturi topljenja, isparljivosti i smanjenju količine komponenata. Komponente šarže koje imaju velike vrednosti afiniteta prema kiseoniku, temperature topljenja i isparljivosti mogu da se šaržiraju i tope zajedno.

4. ZAKLJUČCI

Glavni zaključci izvedeni na osnovu sprovedenog istraživanja su:

- Osnovni razlog za izbor aluminijum-magnezijum legure je bila pojava sitnih pukotina ili mehurića u toku hladne prerade. Pretpostavka je se da su uzrok gasovi i nemetalni uključci zaostali u toku procesa livenja. Pošto je gas vrlo štetan potrebno je uvek znati njegovu koncentraciju u leguri, pa je posebna pažnja posvećena merenju koncentracije prisutnog vodonika u odlivcima.
- Azot i argon su korišćeni kao agensi za degasifikaciju. Azotiranje je vršeno u peći za topljenje pred izlivanje u trajanju od 15 min. Inertni gas argon se koristio za degasifikaciju u kondicionoj peći i ALPUR-u (pred ulivanje). Najbolji rezultati postignuti su pri degazaciji rastopa sa argonom u trajanju od 15 minuta. Sa produženom degasifikacije u kondicionoj peći koncentracija gasa u rastopu u manjoj meri se povećava. Ovo se može objasniti povećanjem ukupnog pritiska gasa u atmosferi peći, te se gas predhodno odstranjen iz metala ponovo vraća u metal u periodu odstojavanja.
- Mikrostrukturne analize su pokazale da količina prisutnog gasa zavisi od vremena degasifikacije. Nedovoljno vreme degasifikacije ima za posledicu dobijanje nižih vrednosti mehaničkih svojstava izlivenih blokova. Ove vrednosti su nešto niže od vrednosti propisanih standardima. Sa dužim vremenom degazacije mehanička svojstva su na donjim granicama vrednosti propisanih standardom za ovaj tip legure. Naime, uzorci dobijeni livenjem sa nedovoljnom degazacijom, kao i uzorci sa produženim degazacijom u sebi sadrže veću količinu gasa, tj. imaju povećanu poroznost, što se odrazilo na pojavu grešaka - sitne pukotine ili mehuriće u procesu hladne obrade ovih blokova.

LITERATURA

[1] R. González, D. Martínez, J. González, J. Talamantes, S. Valtierra, R. Colás, Experimental Investigation for Fatigue Strength of a Cast Aluminium Alloy, International Journal of Fatigue, 33 (2011), pp. 273–278.

[2] M. A. Irfan, D. Schwam, A. Karve, R. Ryder, Porosity Reduction and Mechanical Properties Improvement in Die Cast Engine Blocks, Materials Science and Engineering A, 535 (2012), pp. 108– 114.

[3] N. Vanderesse, É. Maire, A. Chabod, J. Y. Buffière, Microtomographic Study and Finite Element Analysis of the Porosity Harmfulness in a Cast Aluminium Alloy, International Journal of Fatigue, 33 (2011), pp. 1514–1525.

[4] H. Mindivan, A Study on Wear and Corrosion Behaviour of Thermally Sprayed Alumina-titania Composite Coatings on Aluminium Alloys, Kovove Mater. 48 (2010), pp. 203–210.

[5] H. Kaya, U. Boyuk, E. Cadırlı, N. Maraslı, Unidirectional Solidification of Aluminium-nickel Eutectic Alloy, Kovove Mater. 48 (2010), pp. 291–300.

[6] L. Ceschini, Alessandro Morri, Andrea Morri, A. Gamberini, S. Messieri, Correlation Between Ultimate Tensile Strength and Solidification Microstructure for the Sand Cast A357 Aluminium Alloy, Materials and Design 30 (2009), pp. 4525–4531.

[7] A. M. A. Mohamed, A. M. Samuel, F. H. Samuel, H. W. Doty, Influence of Additives on the Microstructure and Tensile Properties of Near-eutectic Al–10.8% Si Cast Alloy, Materials and Design, 30 (2009), pp. 3943–3957.

[8] J. Cadek, K. Kucharova, K. Milicka, S. J. Zhu, Creep of Discontinuous Aluminium Alloy Matrix Composites Produced by Powder Metallurgy Route, Kovove Mater., 37 (1999), pp. 213 - 245.

[9] R. Sadeler, S. Atasoy, H. Altun, Fretting Fatigue Behaviour of a 2014-T6 Aluminium Alloy Coated With an Electroless Nickel Under Rotating Bending Loading, Kovove Mater., 47 (2009), pp. 95–100.

[10] J. Espinoza-Cuadra, G. Garcıa-Garcıa, H. Mancha-Molinar, Influence of Defects on Strength of Industrial Aluminum Alloy Al–Si 319, Materials and Design, 28 (2007), pp. 1038–1044.

[11] Y. Sahin, Preparation and Some Properties of SiC Particle Reinforced Aluminium Alloy Composites, Materials and Design, 24 (2003), pp. 671–679.

[12] X. Sauvage, M. Yu. Murashkin, R. Z. Valiev, Atomic Scale Investigation of Dynamic Precipitation and Grain Boundary Segregation in a 6061 Aluminium Alloy Nanostructured by ECAP, Kovove Mater., 49 (2011), pp. 11–15.

[13] T. Pelachova, J. Lapin, Analysis of Intermetallic Phases in Wrought Aluminium Alloy Prepared by Recycling of Composite Scrap, Kovove Mater., 37 (1999), pp. 399 – 411.

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KNOWLEDGE AND INNOVATIONS - KEY FACTORS OF DEVELOPMENT AND EMPLOYMENT IN THE MINING COMPANIES

Abstract

The epoch of modern economic development particularly emphasized in the nineties of the twentieth century has a special feature in developed world through development of science and technology whose creator is the man. The intensive model of economic growth, based on the comparative advantages of natural resources and unskilled labor force, is more and more abandoned. Today, this place is taken by a new form of economic creativity that increasingly inaugurates non-material resources: knowledge, innovation, information, quality, standards, time, design, speed, know-how and other. The quality of success of developed economies in the world today is convincingly reflected to the rest of the world, with a desire for rapid and better integration of that part. The level of business success depends primarily on the quality of human resources-central resources available to companies and especially today's mining companies in view of the specificity and nature of the work being carried out. New knowledge about the job and the people are resources of a completely new business philosophy, driver of the new changes and risk bearer, creator of innovation and resource allocation, creator of the new quality and values, creator of jobs and new working places in the mining companies, which is the basic need of our time. That time is the time of our Serbian economy and society that is going through the transition process in the pursuit of European integration.

Keywords: *human resources, knowledge, education, creativity, innovation, growth and employment*

1 INTRODUCTION

The economy of our time and economic development are growing fast in very complex and turbulent environment. In analyzing the competitive factors, more prevalent notion is that a man with his values and his position is not only the structure but the basis from which all began and from whom everything depends. Changing the role and functioning of today's mining companies is conditioned by the radical change in the role and importance of their employees. It is necessary to create the new, modern and qualitative human resources, which can provide an efficient realization the objectives of business and development policies of mining companies in the conditions of great economic uncertainty, rapid technological change, dynamic transformation and property relations changes. On the social scene is the civilization whose foundation is in the education and development system, which requires that every person works in a scientific manner in order to participate actively in the social and economic reality, creating the social and personal wealth. The competitive position of any business system, in the global business environment, depends on its flexibility, inventiveness and focus on the

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quality of its employees. Knowledge, as the result of development of employees, has become a strategic resource and source of competitive advantage of mining companies and their differentiation in today's economy. The whole process of globalization in all its complexity, which has caused all stronger interdependence of various economy branches and companies on the worldwide basis, leads to actualization the new issues related to human resources and their knowledge as the only creative factor creating new values and profits. Due to the dynamic changes that take place, it can be concluded that all is changeable, but only learning is permanent. This is the most important resource which can have one company, operating system, or individual. The new market positioning requires the growth and development of mining enterprises. Bearer of the growth is competitiveness of companies in this field, and source of growth in them are high- quality human resources, i.e. their knowledge creating the new values.

In development of today's society, the following participate: knowledge, people who know how to apply that knowledge, focus of business systems and whole society to permanent learning and development. Modern developments will be embodied in mining companies with the speed and efficiency that is allowed by development of human resources and speed of adoption the new creative knowledge, skills, habits required by business environment. Development and human labor are categories that complement and condition each other, separated mean nothing. Care and development of human resources can be achieved everywhere where there are employees who need a new and high-quality knowledge by permanent organization of educational process in the business system. The concern about the quality of human resources and their development is reflected through the acquisition of the new innovative knowledge, where the focus of national economy is transferred to the level of business system, which is a feature of the global business economy and global economic development. Business systems, including mining companies, increasingly become the "learning organizations" , which are organized, systematic learning and development at every organizational level, in every workplace and everywhere where they become the slightest need .

2 KNOWLEDGE - RESORCE OF THE NEW CENTURY

Knowledgebased economy is a modern economy; it is where the value of produced and realized goods and services is created on the basis of applied knowledge which is to say that the exploitation of knowledge play a dominant role in creation of material goods and social wealth. That is why it is said that the world today came into a new era - the era of knowledge. The basic infrastructure elements of prosperity in a knowledge economy are: knowledge as a source of economic development, innovation - as the most valueble source of creating new values and making changes. The era of knowledge lays the foundation of a new economic order and opportunity to create the future that is increasingly reliant on the value of human resources. The new economic era is defined by many scientists, one of them is Peter Drucker, who points out that in the knowledge economy natural resources and labor are no longer the main economic resources, but also the intellectual capital, which is defined as "knowledge that flows through the technology and is in the people." It follows that knowledge is a priority factor of competitiveness. In the global economy, competitiveness in the know-ledge economy becomes tied to the individual businesses, companies and other organizational systems, rather than to the national economy. Globalization as the universal process permeates all aspects of society, it crosses boundaries and establishes the new connections and relationships, creating conditions for faster and more efficient exchange of people, capi tal, goods, services, money, information and knowledge. Globalization of knowledge can be understood as the growth, development and exchange of knowledge between different business entities on the global basis.

In the knowledge economy, know-ledge takes on some specifics, and becomes the focus of interest of economic science and practice. It now becomes an organizational knowledge (at the level of business system) and increasingly becomes an essence and bearer of business development and growth, as well as the structure for creation the new knowledge. Doing business in the knowledge economy is characterized by large and sudden changes at all levels and in their sectors and industries; companies becomes larger (the new products, services, increase market); business has an international character; there are the new forms of cooperation between the business system; the fight in the competition becomes sophisticated and takes on new forms; the market becomes more selectively; there are the new requirements of competitiveness.

Knowledge economy as a whole is transformed industrial economy where employees in the industrial economy and all its undertakings are treated as a cost generator. In the knowledge economy, they are considered to be a generator of income and wealth and make valuable economic capital, as it is the case with the mining production today. The power of management, in the industrial economy, depends on the level of organizational hierarchy; in the knowledge economy management power depends on the level of knowledge.

The basic form of profit in the industrial economy was "tangible" – money; in the new economy profit becomes the "intangible", "invisible" – learning, new ideas, new quality, new customers and clients because they are the bearers of economic development. Bottlenecks were money and skills; in the modern economy they are time and knowledge. Era of knowledge brings a whole new perspective on the world economy and inaugurates a brand new manage ment. Man with his knowledge, skills, habits, creativit, motivation and energy is the most important factor of the whole human creativity and the holder of the overall economic development of our time.

2.1 SPIRITUAL CAPITAL

Owing to development of human knowledge, the modern world is found in the scientific and technological revolution, which is characterized by an adequate concept of production, exchange and consumption. This shows that the contemporary economic conditions interact with the new forms of organization and management at all levels of business system, branch, national and global economy, where the quality of human resources have a crucial role. The time we live in is, therefore, the time of knowledge, creativity and information. These are the resources of modern economies, which are expected to be able to expand the boundaries of knowledge, but also the productivity and business results.

Without the new creativity and knowledge, restructuring of large systems, resolving redundancies, operation of large mining system, survival of small and medium-sized enterprises, the creation of new jobs is not possible. Creativity and ideas are the most valuable gifts that an individual can possess - the largest social wealth. Therefore, the current economic development focuses on the human side of organizations where human capital is the central to strategic operations. In the current conditions, development the global economy has created an appropriate system of international division of labor. Because the world economic experts rightly claim that functioning of the global economy is a complex system that every day becomes more and more advanced. No national economy and industry can ensure their survival and development today without adequate international affirmation and involvement in the world economy. All events on the world stage and in the global economy as well as all events in the national economy and all businesses depend primarily on the knowledge and skills of the human factor. In the world today, most investments are in the labor force as one of basic factors of production, since the economic conditions in the world eco-nomy more and more require increasing knowledge, innovation and motivation to work. The role of human resources has crucial role in today's mining systems that work in quite difficult conditions. In these systems, it should be done more on implementation of the best possible technologies that will facilitate the work of employees and create as safe as possible working conditions. Every part of development the mining system directly depends on development of its employees because it is the only way of use the modern mining technology and modern technical achievements in reaching the business goals and personal interests of any individual. In the world despite all revolutions that have occurred to date (the industrial revolution, scientific-technological revolution, and energy revolution), the “intelligence revolution and profession” is very important. It involves rapid transfer and app-lication of intensive knowledge in deve-lopment of economy and technology. Because nowadays no one and does not question the crucial role of human resources in the entire development. Quality human resources require investment in their development as the "industry knowledge". This is achieved by allocation the funding for human resource development - education and scientific research. Such financial contributions to the world are uneven and different depending on the development of individual countries, and therefore highly skilled and developed human resources are concentrated in the certain parts of the world.

3 CREATIVITY AND INNOVATION

Creativity, innovation and knowledge have become the infrastructure for economic creation and further economic progress. The gained experience has proven that overall social and economic development of a country has to bear the entire economically active society (OECD members at their Conference in 1990 proclaimed the "Program of Active Society" as the goal of any national policy). Under this program, all members of the society according to their abilities and mental and physical characteristics should contribute to economic and social development. In order to achieve the set goal, a creative climate in society should be created. Today, it is equated with political freedom, their democracy and equality before the law and other. To create a creative climate, it needs to have primarily fair and humane relationship between: the state - individual, organization - individual, group - individual and individual - individual. The most important relationship, that makes individual act creative and motivated for creativity, is the ratio of state - individual, where the individual feels belonging and freedom. The undisputed fact in the world today is the fastest growing company and those industries that use well the creative individuals who have always been the engine of mankind growth. Therefore, the issue has been raised today, both at the national level or at the level of business system, how to identify, develop and use creativity of individuals or groups who have the greatest creative abilities.

Creativity is a set of capabilities that enable an individual in certain circumstances to create the new products, expand the new ideas in order to progress the wider community. The basic philosophy of human resource management in this case is to treat an individual as a mature person, bearer of ideas and creativity, productivity and quality. Creative individuals are characterized by: intellectual curiosity, sensitivity to problems at the time, mental openness, restless mind, activity, often dissatisfaction, the ability to see connections between various facts, the tendency to solve problems, rather than to study the phenomena, high intelligence and hunger for creativity. Creativity is caused by the creative climate that should be developed in operating systems, which is reflected in a democratic atmosphere, different types of awards, commendations, and other benefits. Here, in fact, business and healthy creative environment worthy of the man and the treatment of employees as associates is required. In order to develop creativity as an resource of innovation in mining systems, it is necessary to create the motivation for its development and creativity because this area of work is one of the most difficult areas of human creativity, that is, the riskiest area. If employees in these systems are considered to be carriers of development and therefore are adequately rewarded and, if it is invested in their development and creativity, the mining systems will develop and the all results will be more productive.

Creativity cannot be expressed by command, under pressure, conditions and under adverse circumstances. In contrast, the humane conditions consistent with human nature should be created in mining systems for activation and expression skills, knowledge, intellect, talent and their transferring to the material and social goods, which is the goal of the individual and mining system. Here is the important question of how the objectives of the business system will be aligned with the goals and needs of the individual and its employees. Individual will be creative at work until he/she has a corresponding benefit in return, compensation, reward or recognition in response to their contribution and will remain on it until he/she is able to prove himself professionally and as such achieves individual and organizational interests. Type of creativity that will be present in an individual (innovative, productive, inventive or emergent top - revolutionary creativity), is caused by a number of specific characteristics, abilities and personality traits as well as by characteristics of these business systems and the nature of work in them.

4 INNOVATION - THE WAY TO THE NEW JOBS

Each operating system has a built in system of human resource management. Regardless of whether the system is developed and a comprehensive or not, whether it is functional or not, it is an inseparable segment of the business system , because it works through purposeful actions of people. This appropriateness, that is, human labor has to be shaped and enabled, started and appropriate people should be involved. How the management of human resources will be organized at the level of systemic presence of the management of this key resource, depend on a number of factors. The essence of human resource management in mining systems refers to the "management of employment and development of people" and "management of people engagement" when they have been formally employed.

Production development of mining systems is determined by condition of the human factors of production. The level of employment in the mining enterprises is seen as a significant factor in the economic growth of these systems. In addition to the level of employment for themselves, an important factor that affects the efficiency and effectiveness of the mining system is productive employment, which goes beyond the unproductive employment, and extensive management problem.

Unproductive employment grows, and productive employment decreases if the business system employs an increasing number of people above the level required by the current volume of its production. This often happens due to introduction the new technology and new technological procedure in which highly productive machines, robots and other automated systems replace a large number of previously employed people, but this is how it comes to redundant that remains formally employed in the business system. Similar character is with redundancies resulting from more rational organization of work, changes in productive organization of business systems, as well as reduction the physical volume of production. Unproductive employment in our environment often has been developed and grown for mass employment motivated not by productive but social and political reasons (characteristic of the eighties of the last century). Extensive employment may occur when the business system is not in a position to adequately recruit candidates from internal sources for vacant or new positions and is then sent to an external source. This form of extensive employment is conditioned not only by subjective causes, but often by insufficient possibilities for engagement the adequate workers on one hand, and on the other avoiding or reducing the possibility for downsizing or retraining the existing employees. Here the problem is that the structure of knowledge of employees in business systems, as well as of those that are available on the job market, more and more is behind the required knowledge structure. In these situations, business systems are in a state of unproductive employment and labor market is in situation of structural unemployment. Although, it is characteristic for our state of the eighties that problem is present in a somewhat milder varieties today, what is a big problem. This is usually a problem on the global scale, which is unequally expressed in different parts of the world. The key to solve this important problem can be found in dynamic restructuring of knowledge through various forms of professional development and training in both business systems and labor markets, and what is their obligation and duty. The problem of the world economy, and our in it, is that in the postwar years hundreds of different occupations disappeared, giving way to hundreds of new jobs that did not find their proper application, all to the detriment of many basic jobs such as miners , metal worker, builders and other basic jobs. This indicates that there is a growing disharmony between the production and education system. Education reforms even in many developed countries did not give the expected results and inflexibility of educa tion acted as a factor slowing down technical and technological development, as it is the case with us. At present time, the situation is much better, but not sufficient. High speed and degree of development of modern science and new technologies as well as increasing use of micro - processors and biotechnology, robotics and other numerous business and economic activities, increasing emphasis is placed on the rigid educational system in order to adequately restructure and form a quality profile.

These situations increasingly point out to the new shapes and forms of non-formal education and development, as well as self-education which in recent years has received a form of permanent process. Systematic education and additional training for new occupations remain developing the ultimate task in our country.

5 TRANSITION AND EMPLOYMENT

The transition process in which there is Serbia, the transformation of social ownership in different forms of ownership, participation in global trade flows, foreign investment in the domestic economy and everything else requires a radical change in the attitude toward human resources, in the way of their education, development, use and management. Ways to raise productive employment are different in different countries and different industries. The general trend in developing countries, where our country is, is attractive to the foreign capital, completion of transition process of ownership, transformation of large business systems in more small and medium-sized with integral process of educational restructuring of knowledge, abilities and skills of both those who are employed and those being educated for employment.

Rapid economic development requires the new and modern knowledge which must be in accordance with the innovations in the region because it is the only requirement, not only for reducing the gap between developed and underdeveloped, but also for survival in today's global marketplace. That is why today's global economy is called the "knowledge economy", because the resource contained in knowledge becomes the basis of production and source of wealth. The biggest flaw in Serbian development is related to the human resources, and to inadequate education and inadequate training of employees, both at micro and macro level, inadequate care of this factor, as well as inadequate human resources management .Such state of key resource is the base for insufficient competitiveness of the local economy, as well as one of its deep, structural caused problems. To get out of those situations in which is the entire Serbian economy, including the mining production, it is necessary to turn the scientific and educational system toward the production and diffusion of intensive required knowledge and toward flexible use and benefit of knowledge and continuous improvement. Business systems as the main economic actors need to develop and act on the principles of the new business philosophy that is conditioned by radical changes in the role and importance of human factor in them. Today, more and more, the entirely new organizational forms constitute, which in the global economy on the basis of principles of entrepreneurship, provide intensification of all business resources, especially human resources, as well as the efficient management and use of the same for larger business results and increased market competitiveness.

CONCLUSION

The changes are characteristic of the twenty-first century. They are deep and fast covering all areas of work and life. Changes in the environment have a crucial impact on shaping the future goals of economic entities, giving them a new feature and a new approach, which is a strategic approach. The strategic approach is the new, modern and necessary access to the mining systems management, which implies a continuous process of adaptation to variable operating system environment. This leads to the emergence of strategic management, and so human resources have become the main strategist and the holder of such management. By focusing on human resources and their development, the business systems become means of change and creators of their own destiny. Knowledge as the result of development of employees has become the strategic resource and source of competitive advantage and differentiation in today's economy. Investment in knowledge become the most lucrative investments in social capital, and the only way out of the economic recession in which the Serbian economy and society is. Only the new and high quality knowledge and creative people can create the new jobs, and thus the new processes and new values making the source of wealth and social well-being. The current level of competitiveness of Serbian economy and mining company does not provide the international positioning. For Serbian overall situation, in which the entire society is found, there is no easy or quick way to remove barriers of large determinant of uncompetitive. In all obstacles, it needs to work intensively, studiously, professionally, with the help of foreign accumulation for which an appropriate business environment should be created. The new environment and new social laws are infrastructure for new economic activity, which requires development of education system and quality of human resources through large investments in development of innovation and new businesses with respect and integration into the global standards of good management.

REFERENCES

[1] Grozdanić R.: Entrepreneurship, Faculty of Technical Science, Čačak, 2005;

[2] Senge P.: The Fifth Discipline, Mosaic Books, Zagreb, 2001;

[3] Drucker P.: Managing in the New Society, Adizes, Novi Sad, 2005;

[4] Drucker P.: Innovation and Entrepreneurship, Globus, Zagreb, 1992;

[5] Torrington D.: Human Resource Management, Data Status, Belgrade, 2002;

[6] Janićijević N.: Organizational Behavior, Data Status, Belgrade, 2009;

[7] Ćamilović S., Vidojević V.: Fundamentals of Human Resource Management, Tekon, Belgrade, 2007;

[8] Bahtijarević - Siber, F.: Human Potential Management, Zagreb, 1999;

[9] Radovanović V.: Human Resource Management, MST Gajic, Belgrade, 2009;

[10] Radovanović V.: Organizational Behavior, MST Gajic, Belgrade, 2011;

[11] Stephen P. R.: Organizational Behavior, the second edition, Prentice Hall, USA 2003;

[12] Vujic D.: Human Resource Management and Quality, Center for Applied Psychology, Belgrade 2003.

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ZNANJE I INOVACIJE KLJUČNI FAKTORI RAZVOJA I ZAPOŠLJAVANJA U RUDARSKIM PREDUZEĆIMA

Izvod

Epoha modernog ekonomskog razvoja, posebno potencirana devedesetih godina dvadesetog veka, u razvijenom delu sveta ima posebno obeležje u razvoju nauke i tehnologije čiji je kreator i tvorac čovek. Sve više se napušta intenzivni model ekonomskog rasta zasnovan na komparativnoj prednosti prirodnih resursa i nisko kvalifikovane radne snage. Danas to mesto zauzima jedan novi oblik ekonomskog stvaralaštva koji sve više inauguriše nematerijalne resurse: znanje, inovacije, informacije, kvalitet, standarde, vreme, dizajn, brzinu, know-how i drugo. Kvalitet uspeha razvijenih ekonomija sveta danas se sve ubedljivije reflektuje na ostatak sveta, sa željom na što brže i kvalitetnije integrisanje tog dela. Stepen poslovnog uspeha prvenstveno zavisi od kvaliteta ljudskih resursa-centralnog resursa sa kojima raspolažu privredna društva a naročito današnja rudarska preduzeća sobzirom na specifičnost i prirodu poslova koji se u njima obavljaju. Nova znanja o poslu i ljudima su agens potpuno nove poslovne filozofije, pokretač novih promena i nosilac rizika, tvorac inovacija i alokacije resursa, tvorac novih kvaliteta i vrednosti, stvaralac poslova i novih radnih mesta u rudarskim preduzećima, što je nasušna potreba današnjeg vremena. To vreme je vreme naše srpske privrede i društva u celini koje prolazi kroz tranzicioni proces u težnji ka evropskim integracijama.

Ključne reči: *ljudski resursi, znanje, obrazovanje, kreativnost, inovacije, razvoj, zapošljavanje.*

UVOD

Ekonomija današnjeg doba i privredni razvoj nalaze se u brzom usponu i veoma složenom i turbulentnom okruženju. U analizi njihovih konkurentnih faktora, sve više preovladava shvatanje da čovek sa svojim vrednostima i njegov položaj nije samo struktura već osnov od koga sve počinje i od koga sve zavisi. Promena uloge i načina funkcionisanja današnjih rudarskih preduzeća uslovljena je radikalnom promenom uloge i značaja zaposlenih u njima. Potrebno je stvoriti nove, savremene i kvalitetnije ljudske resurse, koji mogu da obezbede efikasno ostvarivanje ciljeva poslovne i razvojne politike rudarskih preduzeća i to u uslovima velike privredne neizvesnosti, brzih tehnoloških promena, dinamične transformacije i promene svojinskih odnosa. Na društvenu scenu stupa civilizacija čiji se osnov nalazi u obrazovnom i razvojnom sistemu, koji zahteva da svaki čovek na naučni način radi, kako bi aktivno učestvovao u društvenoj i privrednoj stvarnosti, stvarajući drušveno i lično bogatstvo. Konkurentna pozicija svakog poslovnog sistema, u globalnom poslovnom okruženju, zavisi od njegove fleksibilnosti, invetivnosti i fokusa na kvalitet svojih zaposlenih. Znanje kao rezultat razvoja zaposlenih, postalo je strateški resurs i

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izvorište konkurentne prednosti rudarskih preduzeća i njihove diferencijacije u savremenoj ekonomiji. Čitav proces globalizacije u celoj svojoj kompleksnosti, koji je uslovio sve čvršću međuzavisnost različitih ekonomija, grana i privrednih subjekata na svetskom nivou, dovodi do aktuelizacije novih pitanja u vezi sa ljudskim resursima i njihovim znanjima kao jedinim kreativnim faktorom stvaranja nove vrednosti i profita. S obzirom na dinamičnost i promene koje se dešavaju, može se zaključiti da je sve promenljivo samo je sticanje znanja stalno. To je najvažniji resurs kojim može da raspolaže jedno društvo, poslovni sistem ili pojedinac. Novo pozicioniranje na tržištu zahteva rast i razvoj rudarskih preduzeća. Nosilac rasta je konkurentnost preduzeća u ovoj delatnosti, a izvor rasta u njima su kvalitetni ljudski resursi tj. njihova znanja koja stvaraju nove vrednosti

U razvoju današnjeg društva učestvuju: znanje, ljudi koji znaju kako to znanje da primene, usmerenost poslovnih sistema i čitavog društva na permanentno učenje i razvoj. Savremena dostignuća biće opredmećena u rudarskim preduzećima onom brzinom i efikasnošću koju dopušta razvijenost ljudskih resursa i brzina usvajanja novih kreativnih znanja, veština, navika, sposobnosti koje zahteva poslovno okruženje. Razvoj i ljudski rad su kategorije koje se dopunjuju i uslovljavaju, a odvojeno ne znače ništa. Razvoj i briga za ljudske resurse može se postići svuda tamo gde se nalaze zaposleni kojima su potrebna nova i kvalitetna znanja, i to stalnim organizovanjem obrazovnog procesa u poslovnom sistemu. Ovde se briga o kvalitetu ljudskih resursa i njihovom razvoju ogleda preko sticanja novih inovativnih znanja, gde se fokus sa nacionalnih ekonomija prenosi na nivo poslovnog sistema, što je odlika globalne poslovne ekomije i globalnog ekonomskog razvoja. Poslovni sistemi, a među njima i rudarska preduzeća, sve više postaju ”organizacije koje uče”, što podrazumeva organizovano, sistematsko učenje i razvoj na svakom organizacionom nivou, na svakom radnom mestu i svuda tamo gde se za njim ukaže i najmanja potreba.

2. ZNANJE- RESURS NOVOG VEKA

Ekonomija zasnovana na znanju je savremena ekonomija, u njoj je vrednost ukupno proizvedenih i realizovanih roba i usluga stvorena na bazi primenjenog znanja, što će reći da eksploatacija znanja igra dominantnu ulogu u stvaranju materijalnih dobara i društvenog bogatstva. Zato se i kaže da je današnji svet ušao u jedno novo doba – doba znanja. Osnovni ifrastrukturni elementi za prosperitet u ekonomiji znanja su: znanje kao izvor ekonomskog razvoja, inovacije- kao najvredniji izvor stvaranja nove vrednosti i stvaranje promena. Doba znanja postavlja temelje novog ekonomskog poretka i šansu kreiranja nove budućnosti, koja se sve više oslanja na vrednost ljudskog potencijala. Novo ekonomsko doba definišu mnogi naučnici, jedan od njih je Piter Drucker koji ističe da u ekonomiji znanja prirodni resursi i rad nisu više osnovni ekonomski resursi, već je to intelektualni kapital koji definiše kao „znanje koje teče kroz tehnologiju i nalazi se u ljudima“. Iz navedenog proizilazi da je znanje prioritetni faktor konkurentnosti. U globalnom poslovanju u ekonomiji znanja konkurentnost postaje vezana za pojedinačne privredne subjekte, preduzeća i druge organizacione sisteme, a sve manje za nacionalne ekonomije. Globalizacija kao univerzalni proces prožima sve aspekte društva, ona ruši granice i uspostavlja nove veze i odnose stvarajući uslove za bržu i efikasniju razmenu ljudi, kapitala, roba, usluga, novca, informacija i znanja. Globalizaciju znanja možemo razumeti kao rast, razvoj i razmenu znanja između različitih ekonomskih subjekata na globalnoj osnovi.

U ekonomiji znanja, znanje poprima neke specifičnosti i postaje fokus interesovanja ekonomske nauke i prakse. Ono danas postaje organizacijsko znanje (na nivou poslovnog sistema) i sve više postaje suština i nosilac poslovnog razvoja i rasta, kao i struktura za stvaranje novih znanja. Poslovanje u ekonomiji znanja karakteriše se velikim i naglim promenama na svim nivoima i u svom sektorima i granama, privredni subjekti postaju veći (novi proizvodi, usluge, povećanje tržišta), poslovanje ima internacionalni karakter, niču novi oblici saradnje između poslovnih sistema, borba u konkurenciji postaje sofisticirana i poprima nove oblike, tržište postaje sve probirljivije, nastaju novi zahtevi konkurentnosti.

Ekonomija znanja u celini predstavlja transformisanu industrijsku ekonomiju gde se zaposleni u industrijskoj ekonomiji i svim njenim privrednim subjektima tretirani generatorom troška. U ekonomiji znanja oni se smatraju generatorom prihoda i bogatstva i čine najvredniji ekonomski kapital, što je slučaj i sa rudarskom proizvodnjom danas. Moć menadžmenta, u industrijskoj ekonomiji, zavisi od nivoa u organizacionoj hijerarhiji, u ekonomiji znanja moć menadžmenta zavisi od nivoa znanja.

Osnovni oblik dobiti u industrijskoj ekonomiji bio je „ opipljiv" – novac, u novoj ekonomiji dobit postaje „neopipljiv", „nevidljiv"- učenje, nove ideje, novi kvaliteti, novi kupci i klijenti, jer su to nosioci privrednog razvoja. Uska grla bila su novac i veštine u modernoj ekonomiji to postaju vreme i znanje. Era znanja donosi potpuno nove poglede na svet ekonomije i inauguriše potpuno novi menadžment. Čovek sa svojim znanjima, sposobnostima, navikama, veštinama, kreativnošću, motivacijom i energijom najbitniji je faktor celokupnog ljudskog stvaralaštva i nosilac celokupnog privrednog razvoja današnjeg doba.

2.1. DUHOVNI KAPITAL

Zahvaljujići razvoju ljudskih znanja, savremeni svet se našao u naučno-tehnološkoj revoluciji koju karakteriše adekvatan koncept proizvodnje, razmene i potrošnje. To pokazuje da su savremeni uslovi privređivanja u interakciji sa novim oblicima organizovanja i menadžmenta na svim nivoima od poslovnog sistema, granske, nacionalne do svetske privrede, gde presudnu ulogu imaju kvalitetni ljudski resursi. Vreme u kome živimo je, dakle, vreme znanja, kreativnosti i informacija. To su resursi savremene ekonomije od kojih se očekuje da mogu proširiti granice saznanja, ali i produktivnosti i poslovnih rezultata.

Bez novih kreativnosti i znanja nije moguće restruktuiranje velikih sistema, rešavanje viškova zaposlenih, funkcionisanje velikih rudarskih sistema, opstanka malih i srednjih preduzeća, otvaranje novih radnih mesta. Kreativnost i ideje su najvredniji darovi koje pojedinac može posedovati, najveće društveno bogatstvo. Stoga se današnji ekonomski razvoj fokusira na ljudsku stranu organizacije gde ljudski kapital zauzima centralno mesto u strateškom poslovanju. U današnjim uslovima razvoja globalizacije svetske privrede stvoren je i odgovarajući sistem međunarodne podele rada. Zato svetski ekonomski eksperti s punim pravom tvrde da funkcionisanje svetske privrede predstavlja najsloženiji sistem koji se svakog dana sve više razvija i usavršava. Nijedna nacionalna ekonomija i privredna grana, danas ne može obezbediti svoj opstanak i razvoj bez adekvatne međunarodne afirmacije i uključivanja u svetske privredne tokove. Sva dešavanja na svetskoj sceni i u globalnoj ekonomiji kao i sva dešavanja u nacionalnim ekonomijama i svim privrednim subjektima zavise prvenstveno od znanja i sposobnosti ljudskog faktora. Danas se u svetu od osnovnih faktora proizvodnje najviše ulaže u radnu snagu, pošto uslovi privređivanja u svetskoj ekonomiji sve više zahtevaju sve veća znanja, inovacije i motive za rad. Uloga ljudskog resursa ima presudnu ulogu u današnjim rudarskim sistemima koji rade u dosta teškim uslovima. U ovim sistemima treba sve više raditi na primeni što kvalitetnije tehnologije kojom će se olakšati rad zaposlenih i stvoriti što bezbedniji uslovi za rad. Svaki deo razvoja rudarskih sistema u direktnoj je zavisnosti od razvijenosti njegovih zaposlenih, jer je to jedini put i način korišćenja savremene rudarske tehnologije i savremenih tehničkih dostignuća u ostvarenju poslovnih ciljeva i ličnih interesa svakog pojedinca. U svetu pored svih revolucija koje su se do danas dešavale (industrijska revolucija, naučno-tehnološka revolucija, energetska revolucija), veoma je bitna "revolucija inteligencije i profesije. "Ona podrazumeva ubrzan transfer i primenu intenzivnih znanja u razvoju ekonomije i tehnologije. Zato danas niko više i ne dovodi u pitanje ključnu ulogu ljudskih resursa u celokupnom razvoju. Kvalitetni ljudski resursi zahtevaju investiciona ulaganja u njihov razvoj kao "industriju znanja". To se postiže izdvajanjem finansijskih sredstava za razvoj ljudskih resursa - za obrazovanje i za naučno istraživački rad. Ovakva finansijska izdvajanja u svetu su neujednačena i različita što zavisi od razvijenosti pojedinih zemalja, pa su zato visoka znanja i razvijeni ljudski resursi koncentrisani u određenim delovima sveta.

3. KREATIVNOST I INOVATIVNOST

Kretivnost, inovativnost i znanje postali su infrastruktura za ekonomsko stvaralaštvo i dalji ekonomski napredak. Dosadašnje iskustvo dokazalo je da ukupni društveni i ekonomski razvoj jedne zemlje mora da nosi celo radno aktivno društvo, (članice OECD-a su na svojoj konferenciji 1990. godine proklamovale "program aktivnog društva" kao cilj svake nacionalne politike). Po tom programu svi članovi društva prema svojim sposobnostima i psihofizičkim osobinama treba da doprinesu ekonomskom i društvenom razvoju. Da bi se postavljeni cilj postigao treba stvoriti stvaralačku klimu u društvu. Danas se to izjednačava sa političkim slobodama, demokratičnošću i jednakošću ljudi pred zakonom i dr. Za stvaranje stvaralačke klime potreban je prvenstveno korektan i human odnos na relaciji: država - pojedinac, organizacija-pojedinac, grupa - pojedinac kao i pojedinac - pojedinac. Najbitniji odnos, kako bi pojedinac stvaralački delovao i bio motivisan za kreativnost, je odnos država-pojedinac, gde pojedinac oseća pripadnost i slobodu. Neosporna činjenica danas u svetu je da se najbrže razvijaju ona društva i one privredne grane koje najbolje koriste kretivne pojedince, koji su oduvek bili pokretači razvoja čovečanstva. Zato je danas usledilo pitanje, kako na nacionalnom nivou ili na nivou poslovnog sistema prepoznati, razvijati i koristiti kreativnost pojedinaca ili grupa koji imaju najveće stvaralačke sposobnosti.

Kreativnost je skup onih sposobnosti koje pojedincu omogućavaju da u određenim okolnostima stvara nove proizvode, širi nove ideje u cilju progresa šire društvene zajednice. Osnovna filozofija menadžmenta ljudskih resursa u ovom slučaju je tretiranje pojedinca kao sveukupne, zrele ličnosti, nosioca ideja i kreativnosti, produktivnosti i kvaliteta. Kreativnog pojedinca karakteriše: intelektualna radoznalost, osetljivost za probleme u datom trenutku, mentalna otvorenost, nemiran um, aktivan, često nezadovoljan, sposobnost sagledavanja veze između najrazličitijih činjenica, sklonost ka rešavanju problema, umesto ka proučavanju pojava, visoka inteligencija i glad za stvaralaštvom. Kreativnost je uslovljena stvaralačkom klimom koja treba da bude razvijena u poslovnim sistemima, koja se ogleda kroz demokratsku atmosferu, kroz različite vidove nagrada, pohvala, beneficija i dr. Ovde je, u stvari, potrebna poslovna i zdrava stvaralačka sredina dostojna čoveka i tretman zaposlenih kao saradnika. Da bi se razvijala kreativnost kao agens inovacija u rudarskim sistemima, nužno je stvoriti motiv više za njen razvoj i stvaralaštvo iz razloga što ova oblast rada spada u najteže oblasti ljudskog stvaralašta tj u najrizišnije oblasti. Ukoliko se u ovakvim sistemima zaposleni smatraju nosiocem razvoja i shodno tome se nagrađuju i u njihov razvoj i kreativnost se adekvatno ulažu finansijska sredstva rezultati neće izostati, već će se, naprotiv, rudarski sistemi razvijati a njihovi rezultati biti sve produktivniji.

Kreativnost se ne može izraziti naredbom, pod pritiskom, uslovljavanjem i u nepovoljnim okolnostima. Nasuprot tome, u rudarskim sistemima treba stvarati humane uslove usklađene sa prirodom čoveka radi aktiviranja i ispoljavanja sposobnosti, znanja, intelekta, talenta i njihovo pretakanje u materijalna i društvena dobra što je cilj kako pojedinca tako i rudarskih sistema. Ovde je bitno pitanje koliko će ciljevi poslovnog sistema biti usklađeni sa ciljevima i potrebama pojedinaca i zaposlenih u njoj. Zaposleni pojedinac biće kreativan u svom poslu sve dok za uzvrat ima odgovarajuću korist, nadoknadu, nagradu ili priznanje kao odgovor za svoj doprinos i ostaće na njemu dok mu je omogućeno profesionalno dokazivanje, potvrda sopstvene vrednosti i dok tako postiže individualne i organizacione interese. Tip kreativnosti koja će biti zastupljena kod pojedinca (inovativna, produktivna, inventivna ili emergentna - vrhunska revolucionarna kreativnost), uslovljen je brojnim specifičnim osobinama, sposobnostima i svojstvima ličnosti, kao i karakteristikama samih poslovnih sistema i prirode posla u njima.

4. INOVACIJE PUT DO NOVIH RADNIH MESTA

Svaki poslovni sistem ima izgrađen sistem upravljanja ljudskim resursima. Bez obzira da li je taj sistem razvijen i sveobuhvatan ili nije, da li je funkcionalan ili nije, on je neodvojiv segment poslovnog sistema, jer on funkcioniše zahvaljujući svrsishodnom delovanju ljudi. Ta svrsishodnost tj. ljudski rad mora biti oblikovan i omogućen, pokrenut i za njega moraju biti angažovani odgovarajući ljudi. To kako će menadžment ljudskih resursa biti organizovan na nivou svesadržajnom sistemskom prisustvu upravljanja ovim ključnim resursom, zavisi od brojnih faktora. Suština upravljanja ljudskim resursima u rudarskim sistemima se odnosi na: „upravljanje zapošljavanjem i razvojem ljudi“ i „upravljanje angažovanjem ljudi“ kada su oni formalno već zaposleni.

Proizvodni razvoj rudarskih sistema je uslovljen stanjem ljudskog faktora proizvodnje. Sam nivo zaposlenosti u rudarskim preduzećima se pokazuje kao značajan činilac ekonomskog rasta ovih sistema. Pored nivoa zaposlenosti samog za sebe značajan činilac koji utiče na efikasnost i efektivnost rudarskih sistema je produktivna zaposlenost, kojom se prevazilazi neproduktivna zaposlenost, odnosno problem ekstenzivnog upravljanja.

Neproduktivna zaposlenost raste, a produktivna zaposlenost opada ako poslovni sistem zapošljava sve veći broj ljudi, iznad nivoa koji zahteva aktuelni obim njene proizvodnje. To se često događa zbog uvođenja novih teenologija i novih tehnoloških procedura u kojima visoko produktivne mašine, roboti i drugi automatizovani sistemi, zamenjuju veliki broj ranije zaposlenih ljudi, ali tako nastaje tehnološki višak koji ostaje formalno zaposlen u poslovnom sistemu. Sličnog karaktera je i višak zaposlenih koji nastaje racionalnijim organizovanjem rada, promenama proizvodno poslovne organizacije poslovnog sistema, kao i smanjivanjem fizičkog obima proizvodnje. Neproduktivna zaposlenost u našim uslovima često je nastajala i rasla zbog masovnog zapošljavanja motivisanog ne proizvodnim već socijalnim i političkim razlozima, (karakteristična je za osamdesete godine prošlog veka). Ekstenzivno zapošljavanje može nastati i kada poslovni sistem nije u situaciji da iz unutrašnjih izvora adekvatno regrutuje kandidate za upražnjena ili nova radna mesta pa je onda upućen na eksterne izvore. Ovakav oblik ekstenzivog zapošljavanja uslovljeno je ne samo subjektivnim uzrocima, već često i nedovoljnim mogućnostima angažovanja adekvatnih radnika sa jedne strane, a sa druge strane izbegavanjem ili smanjenim mogućnostima otpuštanja ili prekvalifikacije već postojećih zaposlenih. Ovde je problem u tome da struktura znanja zaposlenih u poslovnim sistemima, kao i onih koji su dostupni na tržištu rada, sve više zaostaje za potrebnom strukturom znanja. U ovakvim situacijama poslovni sistemi se nalaze u stanju neproduktivne zaposlenosti, a tržište rada u situaciji strukturne nezaposlenosti. Taj problem koliko god da je odlika našeg stanja osamdesetih godina prošlog veka on je prisutan u nešto blažoj varijanti i danas, što je veliki problem. Ovo je inače problem u svetskim razmerama, koji je neravromerno izražen u različitim delovima sveta. Ključ razrešavanja ovog bitnog problema može se naći u dinamičnom restruktuiranju znanja kroz brojne oblike profesionalnog razvoja i treninge kako u poslovnim sistemima, tako i na tržištima rada, što i jeste njihova obaveza i zadatak. Problem svetske ekonomije, a naše u njoj, je u tome što su u posleratnim godinama nestale stotine različitih zanimanja, ustupajući mesto stotinama novih zanimanja koja nisu našla svoju adekvatnu primenu, a sve na štetu brojnih bazičnih zanimanja kao što su: rudari, metalci, građevinari i druga bazična zanimanja. Ovo ukazuje da je sve veći nesklad između proizvodnog i obrazovnog sistema. Reforme obrazovanja čak u mnogo razvijenim zemljama nisu dale očekivane rezultate, pa je nefleksibilnost obrazovanja delovala kao faktor usporavanja tehničko tehnološkog razvoja, što je slučaj i kod nas. U današnje vreme situacija je znatno bolja, ali ne i zadovoljavajuća. Velika brzina i stepen današnjeg razvoja nauke i novih tehnologija, kao i sve veća primena mikro procesora i biotehnologije, robotike i drugo u brojnim privrednim i neprivrednim delatnostima sve veći akcenat se stavlja na nefleksibilne obrazovne sisteme kako bi se adekvatno restruktuirali i obrazovali kvalitetne profile.

Ovakve situacije sve više upućuju na nove oblike i forme neformalnog obrazovanja i razvoja, kao i na samobrazovanje koje je poslednjih godina dobilo oblik permanenog procesa. Sistemsko obrazovanje i dopunsko osposobljavanje za nova zanimanja ostaje i dalje razvojni zadatak ultimativnog karaktera i u našoj zemlji.

5. TRANZICIJA I ZAPOŠLJAVANJE

Proces tranzicije u kome se nalazi Srbija, transformacija društvene svojine u drugačije svojinske oblike, uključivanje u svetske trgovinske tokove, strana ulaganja u domaću privredu i sve drugo zahteva korenitu promenu i stav prema ljudskim resursima, u načinu njihovog obrazovanja, razvoja, korišćenja i upravljanja. Putevi za podizanje produktivne zaposlenosti su različiti u različitim zemljama kao i različitim industrijama. Opšti trend zemalja u razvoju, gde se nalazi i naša zemlja, je privlačenje stranog kapitala, završetak tranzicionog procesa svojine, transformacija velikih poslovnih sistema u više malih i srednjih uz neodvojivi proces obrazovnog restruktuiranje znanja, sposobnosti i veština kako već zaposlenih tako i onih koji se obrazuju za zaposlenje.

Ubrzan privredni razvoj zahteva nova i savremena znanja koja moraju biti u skladu sa inovacijama iz okruženja jer je to jedini uslov, ne samo smanjenja gepa između razvijenih i nerazvijenih, već i opstanka na današnjem višesfernom globalnom tržištu. Zato se današnja globalna ekonomija naziva, “ekonomijom znanja”, jer resurs sadržan u znanju postaje temelj proizvodnje i izvor bogatstva. Najveće mane u srpskom razvoju tiču se ljudskih resursa, a odnose se na neadekvatan sistem obrazovanja i nedovoljan razvoj zaposlenih kako na mikro tako i na makro planu, neadekvatnu brigu o ovom faktoru, kao i neadekvatno upravljanje ljudskim resursima. Tako stanje ključnog resursa osnov je nedovoljne konkurentnosti ovdašnje privrede, kao i jedan je od njenih dubokih, strukturno uslovljenih problema. Da bi se izašlo iz navedene situacije u kojoj se nalazi čitava srpska privreda uključujući i rudarsku proizvodnju, neophodno je čitav obrazovni i naučni sistem okrenuti prema proizvodnji i difuziji intenzivnih potrebnih nanja kao i fleksibilnom raspolaganju i korišćenju tih znanja i njihovom stalnom usavršavanju. Poslovni sistemi kao osnovni subjekti privređivanja treba da se razvijaju i da deluju na principima nove poslovne filozofije koja je uslovljena radikalnim promenama uloge i značaja ljudskog faktora u njima. Danas se sve više konstituišu sasvim novi organizacioni oblici, koji u uslovima globalne privrede, na principima preduzetništva, obezbeđuju intenziviranje svih poslovnih resursa, a naročito ljudskih resursa, kao i efikasnije upravljanje i korišćenje istih radi većih poslovnih rezultata i veće konkurentnosti na tržištu.

ZAKLJUČAK

Promene su obeležje dvadeset prvog veka. One su duboke i brze, zahvataju sve oblasti delovanja i življenja. Promene u okruženju presudno utiču na oblikovanje budućih ciljeva privrednih subjekta, dajući im jedno novo obeležje i nov pristup, a to je strategijski pristup. Strategijski pristup predstavlja novi, modederan i nužan pristup upravljanja rudarskim sistemima, pod kojim se podrazumeva kontinualan proces prilagođavanja poslovnih sistema promen-ljivoj okolini. To dovodi do pojave strategijskog menadžmenta, a sa njime ljudski resursi postaju osnovni strateg i nosilac takvog upravljanja. Fokusiranje na ljudske resurse i na njihov razvoj poslovni sistemi postaju nosioci promena i stvaraoci sopstvene sudbine. Znanje kao rezultat razvoja zaposlenih, postalo je strateški resurs i izvorište konkurentne prednosti i diferencijacije u savremenoj ekonomiji. Investicije u znanje postaju najunosnija ulaganja u društveni kapital i jedini put za izlazak iz ekonomske recesije u kojoj se nalazi srpska privreda i društvo. Samo nova i kvalitetna znanja i kreativnost ljudi mogu stvoriti novi posao, nova radna mesta, a time i nove procese i nove vrednosti čineći tako izvor bogastva i društvenog blagostanja. Trenutni nivo konkurentnosti srpske privrede i rudarskih preduzeća u njoj ne obezbeđuje osmišljeno međunarodno pozicioniranje. Za srpsku sveopštu situaciju, u kome se našlo celokupno društvo, nema lakog, niti brzog načina da ukloni barijere krupne determinante nekonkurentnosti. Na svim preprekama treba raditi intenzivno, studiozno, stručno, kvalitetno i domaćinski, uz pomoć inostrane akumulacije, za koju je nophodno stvoriti adekvatan privredni ambijent. Nov ambijent i novi društveni zakoni su infrastruktura za novo privredno delovanje, koje zahteva razvoj obrazovnog sistema i kvalitetnih ljudskih resursa preko velikih investicionih ulaganja u razvoj inovativnosti i novih privrednih subjekata s poštovanjem i uklapanjem u svetske standarde dobrog menadžmenta.

LITERATURA

[1] Grozdanić R.: Preduzetništvo, Fakultet Tehničkih nauka, Čačak, 2005.

[2] Senge P.: Peta Disciplina, Mozaik knjiga, Zagreb, 2001.

[3] Draker P.: Upravljanje u novom društvu, Adižes, Novi Sad, 2005.

[4] Draker P.: Inovacije i Preduzetništvo, Globus, Zagreb, 1992.

[5] Torrington D.: Menadžment ljudskih resursa, Data Status, Beograd, 2002.

[6] Janićijević N.: Organizaciono ponašanje, Data Status, Beograd, 2009.

[7] Ćamilović S., Vidojević V.: Osnove menadžmenta ljudskih resursa, Tekon, Beograd, 2007.

[8] Bahtijarević-Šiber F.: Menadžment ljudskih potencijala, Zagreb, 1999.
[9] Radovanović V.: Menadžment ljudskih resursa, MST Gajić, Beograd, 2009.
[10] Radovanović V.: Organizaciono ponašanje, MST Gajić, Beograd, 2011.
[11] Stephen P. R.: Organizational Behavior, the second edition, prentice Hall, USA, 2003.
[12] Vujić D.: Menadžment ljudskih resursa i Kvalitet, Centar za primenjenu psihologiju, Beograd, 2003.

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[3] www: http://www.vanguard.edu/psychology/apa.pdf (for web document)

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