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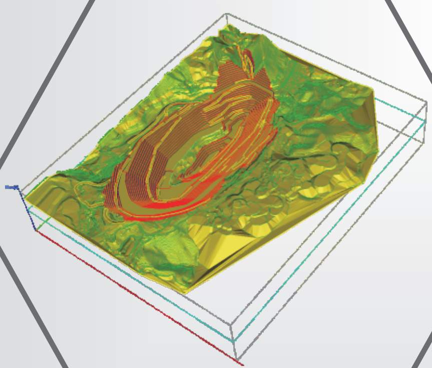

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Editor-in-chief

Academic Ph.D. Milenko Ljubojev, Principal Reasearch Fellow, Associate member of ESC
Mining and Metallurgy Institute Bor
E-mail: milenko.ljubojev@irmbor.co.rs
Phone: +38130/454-109, 435-164

Editor

Vesna Marjanović, B.Eng.

English Translation

Nevenka Vukašinović

Technical Editor

Suzana Cvetković

Preprinting

Vesna Simić

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19210 Bor, Zeleni bulevar 35
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Phone: +38130/454-110

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Glavni i odgovorni urednik

Akademik dr Milenko Ljubojev, naučni savetnik
Institut za rudarstvo i metalurgiju Bor
E-mail: milenko.ljubojev@irmbor.co.rs
Tel. 030/454-109, 435-164

Urednik

Vesna Marjanović, dipl.inž.

Prevodilac

Nevenka Vukašinović, prof.

Tehnički urednik

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Ratomir Popović, Milenko Ljubojev*, Lidija Đurđevac Ignjatović**

DEFORMABILITY PARAMETERS FOR FORMING THE STRESS - STRAIN STATE MODELS OF ROCK MASSIF**

Abstract

This paper describes the principle of development the structural models of rocks, based on which the geomechanical model rock massif is developed, to which the applied numerical methods of stress analysis can be applied in solving the practical problems in the field of underground and surface mining of mineral raw materials.

Keywords: *deformability, stress-strain state, rock mass*

INTRODUCTION

Stress-strain state of rock massif has great importance in designing and construction of structures and their stability. In construction the underground facilities, regardless of the cross-section of room, the rock massif is the main supporting element. Deformations of rock massif, around the underground facility, cause stresses in support structure or coverings, i.e. the both elements mutually affect each other. Due to a huge variety of the rock massif structure and its properties, it is very difficult to develop a model that can describe the stress-strain state of the rock massif. Such model should be as simple as it could be as it can be widely applied and the obtained results acceptable. The first step in the study of rock mechanics is to develop a structural model that reflects all characteristics of rock structures and their physical-mechanical and deformation properties.

Walter Wittke developed in a detail this issue. Practically, he classified all rock types into granular structure, i.e. the rocks composed of individual elements of grain. Density was determined by packed grains or grains made of their aggregates with the specific disruption of the cracks. Rock is idealized as a quasi-plane and quasi-homogeneous element of rock massif. Depending on the shape and orientation of grains or aggregates in the rock, three main cases will be considered:

1 Rock with non-oriented granular structure, Figure 1a.
2 Rock with layered structure, Figure 1b.
3 Rock with schistose structure, Figure 1c.

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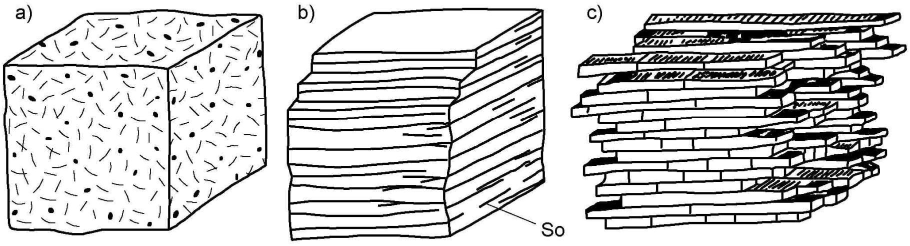

Figure1 *Structural rock model*

a – non-oriented isotropic grnular structure

b - layered anisotropic structure

c - structure of anisotropic schistose

Based on the structural rock model, it is possible to make such geomechanical model of rock massif for the use of numerical methods of stress analysis in solving practical problems in the field of underground and open pit mining. These numerical methods are based on the assumption of elastic-viscous plastic deformation. Such model allows taking into account the mechanical-deformation anisotropy, caused by granular structure and surface texture cracks.

Suppose that in a part of the load that does not exceed the limit resistance to uniaxial pressure, the elastic deformations are exclusively developed independently on time and proportional to load, Figure 2. When the load reaches the limit value σ_{gr}, it causes the irreversible non-elastic deformations. The experiments proved that the irreversible deformations, and connected to this the redistribution of stress are highly depend on time. These deformations in geomechanical model are based on the viscous-plastic properties.

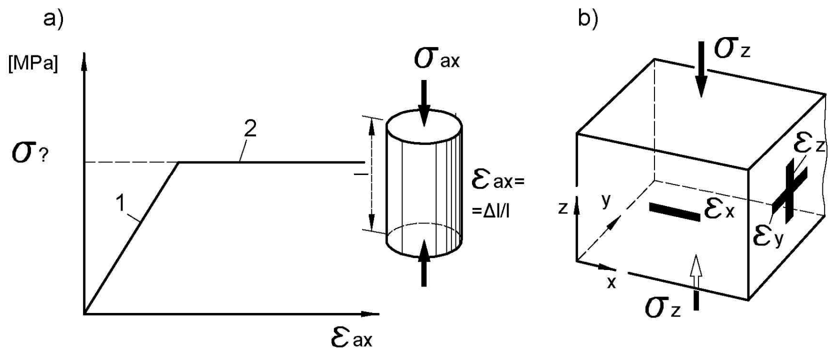

Figure 2 *Deformability of isotropic rocks*

a - dependence of elastic and ideal viscous- plastic deformations εax of stress σax

b - determination the elastic modulus and Poisson ratio ν for rocks

1 - elastic deformation

2 – viscous-plastic deformation

1 STRESS-DEFORMATION STATE OF ROCKS

1.1 Elastic deformation

Description of elastic deformations of rocks is derived from a model of their structure. In the rock with non-oriented granular structure in uniaxial or triaxial load which is less than limit strength, the elastic deformations appear independently of load direction. Deformable constants, modulus of elasticity E and the Poisson ratio *v* are expressed as follows:

$$E = \frac{\sigma_z}{\varepsilon_z}[MPa]; \;\; \nu = \frac{\varepsilon_x}{\varepsilon_z} = \frac{\varepsilon_y}{\varepsilon_z}$$

The shear modulus *G* depends on *E* and *v*

$$G = \frac{E}{2(1+\nu)} \;\; [MPa] \qquad (1)$$

Components of stress, strain and shear in the arbitrarily oriented Descartes coordinate system (*x, y* and *z*) are connected by the Hook law with the constants *E* and *v.*

$$\left.\begin{aligned}
\sigma_x &= \frac{E}{1-\nu-2\nu^2}\left[(1-\nu)\varepsilon_x + \nu\varepsilon_y + \nu\varepsilon_z\right] \\
\sigma_y &= \frac{E}{1-\nu-2\nu^2}\left[\nu\varepsilon_x + (1-\nu)\varepsilon_y + \nu\varepsilon_z\right] \\
\sigma_z &= \frac{E}{1-\nu-2\nu^2}\left[\nu\varepsilon_x + \nu\varepsilon_y + (1-\nu)\varepsilon_z\right] \\
\tau_{xy} &= \frac{E}{2(1+\nu)}\cdot\gamma_{xy} \\
\tau_{yz} &= \frac{E}{2(1+\nu)}\cdot\gamma_{yz} \\
\tau_{zx} &= \frac{E}{2(1+\nu)}\cdot\gamma_{zx}
\end{aligned}\right\} \qquad (2)$$

The rocks with layered structures, isotropic elastic properties of its deformations, in the best case, are unacceptable. The experiments have confirmed that the uniaxial compressive strength of rocks, with a layered structure in the direction normal to the plane of isotropy, is much greater than the strength in the direction of parallel planar isotropy. Stress and strain state in the plane of stratification has an isotropic character. This description of a methodology of behavior in the zone of elastic deformation consists in application the five independent elasticity constants. It can be said that the stress-strain state is characterized by transverse isotropy [1]. Independent constants are E_1 and E_2, normal and parallel to the plane of isotropy, v_1 and v_2, and shear modulus G_2 for the shear stress in the plane of isotropy.

Let us consider the unit volume of rock with the Descartes system of coordinates (x', y' and z'), wherein the axis z' matches with direction of the greatest deformability and x' and y' axes lie in the plane of isotropy, Figure 3.

From the conditions, Figure 3, the elastic constants are obtained from stress and linear and shear deformations of the unit volume, Figure 4.The values of the G_1 and v_3 dependent on E_1 and E_2, v_1 and v_2.

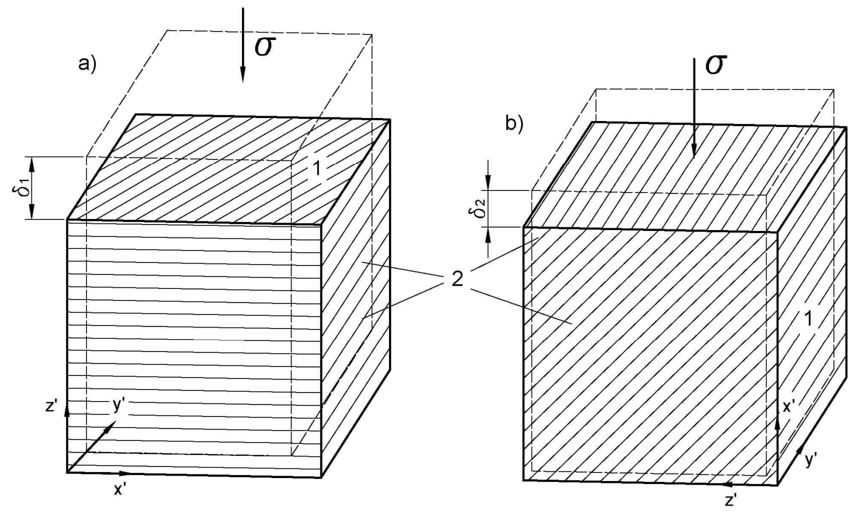

Figure 3 *Deformation anisotropy of rocks with a layered structure*

a - horizontal plane of isotropy, b - vertical plane of isotropy
1 - plane of isotropy
2 - stratification

It is important to say that, according to the transverse isotropy, the theory of elasticity does not specify maximum value of the Poisson ratio as in the case of full isotropy, where ν<0.5. From considered strain energy, the limitation of inequalities follows:

$$2\nu_2 \cdot \nu_3 < 1 - \nu_1 \tag{3}$$

$$\nu_2 \le \frac{E_2}{2E_1} \tag{4}$$

Based on the laboratory studies of deformation properties of rocks, ν_1 and ν_2 are always less than 0.5, and only ν_3 for transversely isotropic rocks in some cases may be higher than 0.5.

Figure 4, from *a* to *i*, shows determining the elastic constants of rock layered structure of transversely isotropic models.

a, b):

$$E_1 = \frac{\sigma_{x'}}{\varepsilon_{x'}} = \frac{\sigma_{y'}}{\varepsilon_{y'}};$$

c) $E_2 = \frac{\sigma'_z}{\varepsilon'_z}$

d, e i f):

$$G_1 = \frac{\tau_{x'y'}}{\gamma_{x'y'}} = \frac{E_1}{2(1+\nu_1)};$$

$$G_2 = \frac{\tau_{z'y'}}{\gamma_{z'y'}} = \frac{\tau_{x'y'}}{\gamma_{z'x'}}$$

g, h i i):

$$\nu_1 = \frac{\varepsilon_{y'}}{\varepsilon_{x'}};$$

$$\nu_2 = \frac{\varepsilon_{x'}}{\varepsilon_{z'}} = -\frac{\varepsilon_{y'}}{\varepsilon_{z'}};$$

$$\nu_3 = -\frac{\varepsilon_{z'}}{\varepsilon_{y'}} = \frac{E_1\nu_2}{E_2}$$

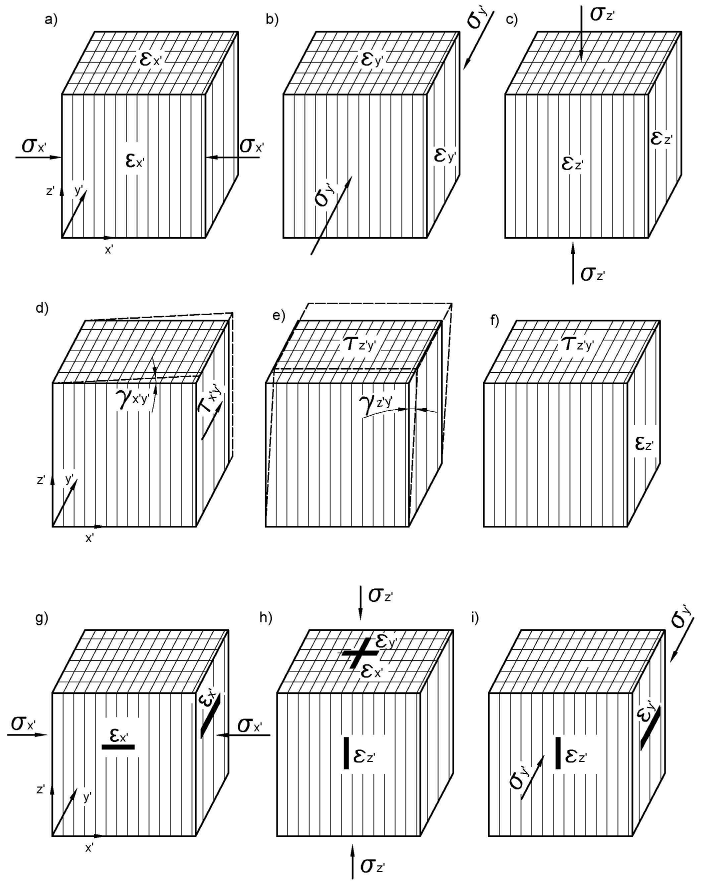

Figure 4 *Determination the elastic constants for rocks in the case of transverse complexion for isotropic layered structure*

a, b and c - modulus of elasticity and corresponding strains
d, e, and f - shear modulus
g, h and i – Poisson coefficient

The expression for determining the maximum value of independent shear modulus I. Kilj, proposes the following expression:

$$G_2 \leq \frac{E_2}{\left\{2\left[\nu_2(1+\nu_1)+\sqrt{\left(\frac{E_2}{E_1}-\nu_2^2\right)\left(1-\nu_1^2\right)}\right]\right\}} \quad (5)$$

Since the shear modulus G_2 is very difficult to determine "in-situ", various authors have suggested that this independent module can be determined approximately over other constants of elasticity.

L. Barden suggests the following relation [4]:

$$G_2 \cong \frac{E_2}{1+\frac{E_2}{E_1}+2\nu_2} \quad (6)$$

A less value can be obtained from the following relation:

$$G_2 \cong \frac{E_2}{2(1+\nu_2)} \quad (7)$$

REFERENCES

[1] Popović R., Ljubojev M., Contribution to Investigation the Mechanical Anisotropy of Rock Massive, International October Conference on Mining and Metallurgy, Bor, 2000.

[2] Ljubojev M., Popović R., Basics of Geomechanics, RTB Bor, Copper Institute, Bor, 2006.

[3] Popović R., Ljubojev M., Principles of Solving Problems in Geomechanics, Bor, 2007.

[4] Popović R., Cvetković M., Majstorović J., Anisotropy of Deformation Properties of Rock Salt, Proceedings, Faculty of Mining and Geology Belgrade, 2000.

[5] Popović R., Ljubojev M., Ignjatović D., Tašić D., Đurđevac-Ignjatović L., Determining the Shearing Parameters of Rocks per Preferential Planes, Mining Engineering 1/2012, Bor, 2012.

[6] V. Wittke, Felsmechnik Grundlagen Für Wirtschaftliches Bauen Im Fels, Berlin Heidelberg, 1984. (in German)

[7] G. Hadži-Nikovic, S. Ćorić, J. Gomilanović, Application of 3D Slope Stability Analysis in Defining the Excavation Conditions of Coal at the Open Pits, Mining and Metallurgy Engineering Bor 2/2013, p. 1-10

[8] V. Milić, I. Svrkota, D. Petrović, Analysis of Block Stability for Semi – Level Caving Method with Lateral Loading, Mining and Metallurgy Engineering Bor 2/2013, p. 21-26

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Ratomir Popović, Milenko Ljubojev*, Lidija Đurđevac-Ignjatović**

PARAMETRI DEFORMABILNOSTI ZA FORMIRANJE MODELA NAPONSKO-DEFORMACIJSKOG STANJA STENSKOG MASIVA**

Izvod

U radu je opisan princip razrade strukturnog modela stena, na osnovu kojeg se razrađuje geomehanički model stenskog masiva, na koji se mogu primeniti numeričke metode naponske analize pri rešavanju praktičnih zadataka u oblasti podzemne i površinske eksploatacije mineralnih sirovina.

Ključne reči: *deformabilnost, naponsko – deformaciono stanje, stenski masiv*

UVOD

Naponsko-deformacijsko stanje stena stenskog masiva ima veliki značaj pri projektovanju i izgradnji objekata i njihove stabilnosti. Pri izradi podzemnih prostorija, bez razlike na poprečni presek prostorije, stenski masiv je osnovni noseći elemenat. Deformacije stenskog masiva oko podzemne prostorije izazivaju napone u konstrukciji podgrade, odnosno obloge, tj. oba elementa uzajamno utiču jedan na drugi. Obzirom na veliku raznolikost građe stenskog masiva i njegovih svojstava, vrlo je teško razraditi model koji može opisati naponsko-deformacijsko stanje stenskog masiva. Takav model mora biti jednostavan kako bi se mogao široko primenjivati, a dobijeni rezultati biti prihvatljivi. Prvi korak u istraživanju mehanike stena je razrada strukturnog modela koji odražava sve osobenosti građe stena i njihova fizičko-mehanička i deformaciona svojstva.

Ta pitanja je detaljno razradio Walter Wittke. Praktično sve stene je svrstao u zrnastu strukturu, tj. stene sastavljene od pojedinih elemenata zrna. Gustina je određena upakovanim zrnima ili sastavljenih od njihovih agregata određene narušenosti pukotinama. Stena se idealizuje u vidu kvaziravnijskog i kvazijednorodnog elementa stenskog masiva. U zavisnosti od oblika i orijentacije zrna ili agregata u steni ovde ćemo razmatrati tri osnovna slučaja:

1. Stena sa neorijentisanom zrnastom strukturom, sl. 1.a.
2. Stena sa slojevitom strkturom, sl. 1.b.
3. Stena sa škriljavom strukturom, sl. 1.c.

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* *Institut za rudarstvo i metalurgiju Bor*

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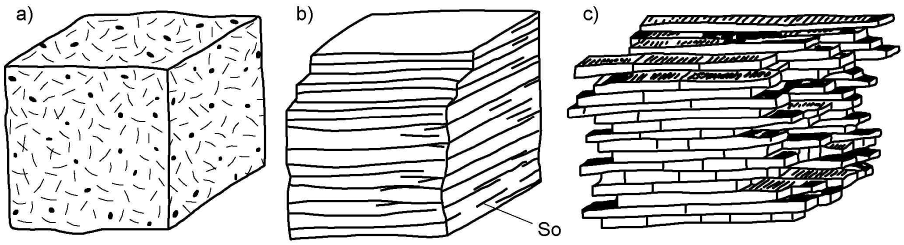
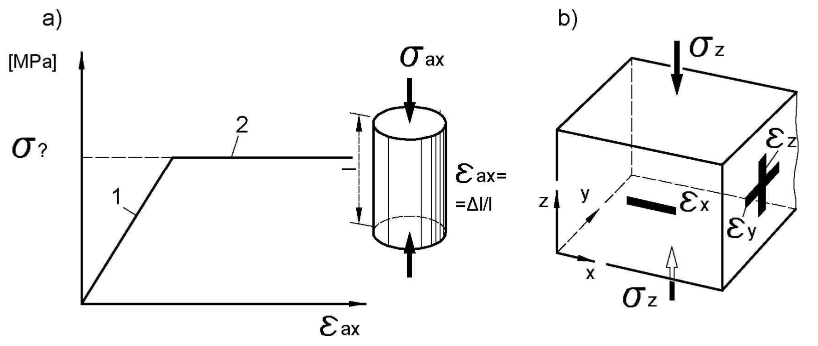


Sl. 1. *Strukturni model stene*

a – neorijentisana izotropna zrnasta struktura,
b – slojevita anizotropna struktura,
c – škriljava anizotropna strktura

Na osnovu strukturnog stenskog modela moguće je izraditi takav geomehanički model stenskog masiva na koji se mogu primeniti numeričke metode naponske analize pri rešavanju praktičnih zadataka u oblasti podzremne i površinske eksploatacije. Te numeričke metode se zasnivaju na pretpostavci o elasto-viskozno plastičnim deformacijama. Takav model omogućuje da se uzme u obzir mehaničko-deformaciona anizotropija uslovljena zrnastom strukturom i strukturom površina pukotina.

Pretpostavimo da se u delu opterećenja koje ne prevazilazi graničnu otpornost na jednoosni pritisak, razvijaju isključivo elastične deformacije nezavisne od vremena i proporcionalne su opterećenju, sl. 2. Kad opterećenje dostigne graničnu vrednost $\sigma_{gr.}$ tada nastaju neelastične nepovratne deformacije. Eksperimenti potvrđuju da nepovratne deformacije i povezano sa tim preraspodela napona, u vrlo visokom stepenu zavise od vremena. Te deformacije u geomehaničkom modelu zasnivaju se na viskozno-plastičnim svojstvima.



Sl. 2. *Deformabilnost izotropnih stena*

a – zavisnost elastičnih i idealno viskozno-plastičnih deformacija ε_{ax} *od napona* σ_{ax}
b – određivanje modula elastičnosti i koeficijenta Poissona ν stena
1 – elastična deformacija,
2 – viskozno-plastična deformacija

1. NAPONSKO-DEFORMACIJSKO STANJE STENA

1.1. Elastične deformacije

Opis elastičnih deformacija stena proizi-lazi iz modela njihove strukture. Stena sa neorijentisanom zrnastom strukturom pri jednoosnom ili troosnom opterećenju, koje je manje od granične čvrstoće, nastaju elastične deformacije nezavisno od pravca dejstva opterećenja. Deformabilne konstante, modul elastičnosti E i koeficijent Poisson-a ν se izražavaju na sledeći način:

$$E = \frac{\sigma_z}{\varepsilon_z}[MPa]; \ \nu = \frac{\varepsilon_x}{\varepsilon_z} = \frac{\varepsilon_y}{\varepsilon_z}$$

Modul smicanja G zavisi od E i ν:

$$G = \frac{E}{2(1+\nu)} \ [MPa] \qquad (1)$$

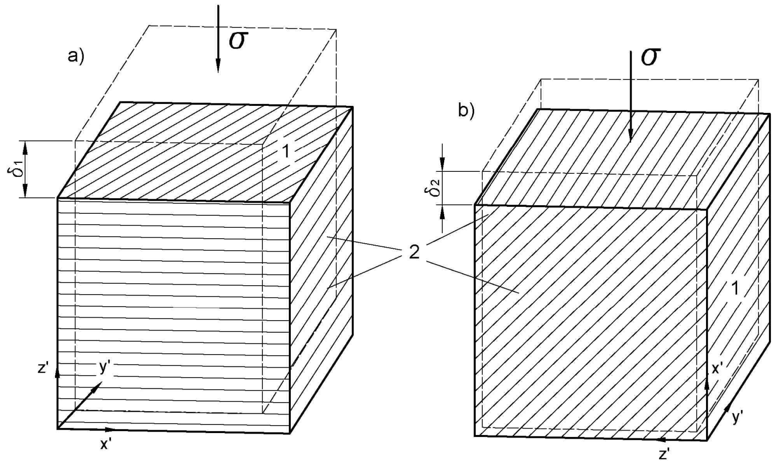
Komponente napona, deformacija i smicanja u proizvoljno orijentisanom Dekartovom koordinatnom sistemu (x, y i z) povezani su po Huk-ovom zakonu konstantama E i ν:

$$\left.\begin{aligned}
\sigma_x &= \frac{E}{1-\nu-2\nu^2}\left[(1-\nu)\varepsilon_x + \nu\varepsilon_y + \nu\varepsilon_z\right]\\
\sigma_y &= \frac{E}{1-\nu-2\nu^2}\left[\nu\varepsilon_x + (1-\nu)\varepsilon_y + \nu\varepsilon_z\right]\\
\sigma_z &= \frac{E}{1-\nu-2\nu^2}\left[\nu\varepsilon_x + \nu\varepsilon_y + (1-\nu)\varepsilon_z\right]\\
\tau_{xy} &= \frac{E}{2(1+\nu)}\cdot\gamma_{xy}\\
\tau_{yz} &= \frac{E}{2(1+\nu)}\cdot\gamma_{yz}\\
\tau_{zx} &= \frac{E}{2(1+\nu)}\cdot\gamma_{zx}
\end{aligned}\right\} \qquad (2)$$

Stene sa građom slojevite strukture, izotropne elastične karakteristike njenih deformacija u najboljem slučaju su nedopustive. Eksperimenti potvrđuju da jednoosna otpornost na pritisak stena sa slojevitom strukturom u pravcu normalnom na ravan izotropije znatno je veća od čvrstoće u pravcu paralelno ravno izotropije. Naponsko deformacijsko stanje u ravni slojevitosti poseduje izotropni karakter. Navedena metodologija opisa ponašanja u zoni elastičnih deformacija sastoji se u primeni pet nezavisnih jedne od drugih konstanti elastičnosti. Tada kažemo da naponsko-deformacijsko stanje karakteriše transverzalna izotropija [1]. Nezavisne konstante su E_1 i E_2, normalno i paralelno ravni izotropije, ν_1 i ν_2, i modul smicanja G_2 za napone smicanja u ravni izotropije.

Razmotrimo jediničnu zapreminu stene sa Dekartovim sistemom koordinata (x', y' i z'), pri čemu osa z' se poklapa sa pravcem najveće deformabilnosti, a ose x' i y' leže u ravni izotropije, sl. 3.

Iz uslova sl. 3 konstante elastičnosti se dobiju iz napona i linearnih i smičućih deformacija jedinične zapremine, sl. 4. Pri čemu su takođe veličine ν_3 i G_1 zavisne od E_1 i E_2, ν_1 i ν_2.



Sl. 3. *Anizotropija deformabilnosti stena sa slojevitom strukturom*

a – horizontalna ravan izotropije, b – vertikalna ravan izotropije
1 – ravan izotropije, 2 - slojevitost

Važno je reći, da pri transverzalnoj izotropiji, teorija elastičnosti ne određuje maksimalnu vrednost koeficijenta Poisson-a kao u slučaju pune izotropije, gde je $v < 0{,}5$. Iz razmatrane energije deformacija sledi samo ograničenje nejednačina:

$$2\nu_2 \cdot \nu_3 < 1 - \nu_1 \quad (3)$$

$$\nu_2 \leq \frac{E_2}{2E_1} \quad (4)$$

Na osnovu laboratorijskih istraživanja deformacionih svojstava stena ν_1 i ν_2 su uvek manji od 0,5, a samo ν_3 za transverzalno izotropne stene u pojedinim slučajevima može biti veći od 0,5.

Na sl. 4 od *a* do *i* prikazano je određivanje elastičnih konstanti stena slojevite strukture transverzalno izotropnog modela.

a, b):

$$E_1 = \frac{\sigma_{x'}}{\varepsilon_{x'}} = \frac{\sigma_{y'}}{\varepsilon_{y'}};$$

c) $E_2 = \frac{\sigma'_z}{\varepsilon'_z}$

d, e i f):

$$G_1 = \frac{\tau_{x'y'}}{\gamma_{x'y'}} = \frac{E_1}{2(1+\nu_1)};$$

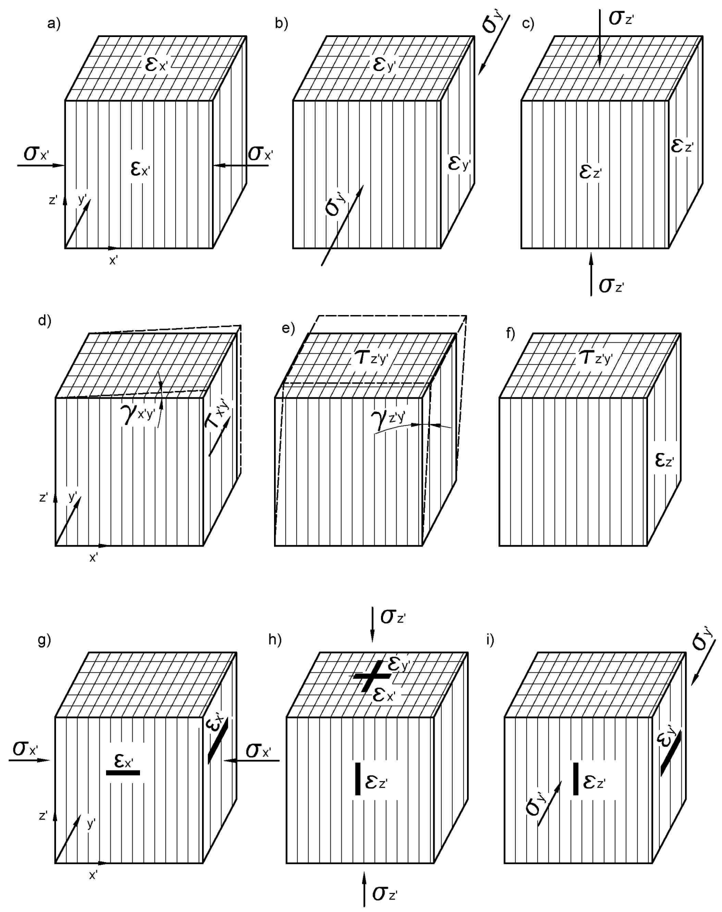
$$G_2 = \frac{\tau_{z'y'}}{\gamma_{z'y'}} = \frac{\tau_{x'y'}}{\gamma_{z'x'}}$$

g, h i i):

$$\nu_1 = \frac{\varepsilon_{y'}}{\varepsilon_{x'}};$$

$$\nu_2 = \frac{\varepsilon_{x'}}{\varepsilon_{z'}} = -\frac{\varepsilon_{y'}}{\varepsilon_{z'}};$$

$$\nu_3 = -\frac{\varepsilon_{z'}}{\varepsilon_{y'}} = \frac{E_1\nu_2}{E_2}$$



Sl. 4. *Određivanje elastičnih konstanti stena za slučaj transverzalno izotropni model slojevite strukture*

a, b i c – modul elastičnosti i odgovarajuće deformacije,
d, e i f – moduli smicanja,
g, h i i – koeficijenti Poisson-a

Izraz za određivanje maksimalne vrednosti nezavisnog modula smicanja I. Kilj, predlaže sledeći izraz:

$$G_2 \leq \frac{E_2}{\left\{2\left[\nu_2(1+\nu_1)+\sqrt{\left(\frac{E_2}{E_1}-\nu_2^2\right)(1-\nu_1^2)}\right]\right\}} \quad (5)$$

Obzirom da je modul smicanja G_2, vrlo teško odrediti „in-situ“ to razni autori su predložili za taj sam po sebi nezavisni modul da se odredi približno preko drugih konstanti elastičnosti.

L. Barden predlaže sledeću zavisnost [4]:

$$G_2 \cong \frac{E_2}{1+\frac{E_2}{E_1}+2\nu_2} \quad (6)$$

Nešto manja vrednost se dobije po sledećoj zavisnosti:

$$G_2 \cong \frac{E_2}{2(1+\nu_2)} \quad (7)$$

LITERATURA

[1] R. Popović, M. Ljubojev, Prilog istraživanju mehaničke anizotropije stenskog masiva, Međunarodno oktobarsko savetovanje rudara i metalurga, Bor, 2000.god.

[2] M. Ljubojev, R. Popović, Osnove geomehanike, RTB Bor, Institut za bakar, Bor, 2006.

[3] R. Popović, M. Ljubojev, Principi rešavanja problema u geomehanici, Bor, 2007.god.

[4] R. Popović, M. Cvetković, J. Majstorović, Anizotropija deformacionih svojstava kamene soli, Zbornik radova RGF Beograd, 2000.god.

[5] R. Popović, M. Ljubojev, D. Ignjatović, D. Tašić, L. Đurđevac-Ignjatović, Određivanje parametara smicanja stena po povlašćenim ravnima, Rudarski radovi 1/2012, Bor, 2012.god.

[6] V. Wittke, Felsmechnik grundlagen für wirtschaftliches Bauen im Fels, Berlin Heidelberg, 1984.

[7] G. Hadži-Niković, S. Ćorić, J. Gomilanović, Primena 3D analize stabilnosti kosina pri definisanju uslova iskopa uglja u površinskim kopovima, Mining and Metallurgy Engineering Bor 2/2013, str. 11-20

[8] 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

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Živko Sekulić, Božo Kolonja**, Dinko Knežević***

DEFINING THE SIZE CLASS AS THE QUALITY PARAMETER OF ZEOLITE ASSORTMENT OF PRODUCTS***

Abstract

Quality requirements for the product assortments, obtained from a large number of non-metallic mineral raw materials, are defined, and above all, they have the defined particle size. Are the quality requirements for zeolite assortments defined? Searching for the answer to this question, an internet research was done. The web pages of the most significant producers of materials based on natural zeolite were studied as well as the papers of a large number of prominent researchers whose experiments are focused on the natural zeolite. This paper presents the findings primarily with the aspect of particle size as the quality parameter of zeolite assortments. Based on this analysis, it is considered that it should define the quality requirements of zeolite assortments, especially the particle size for each product. In fact, it is important to know the particle size in mineral processing in order to choose less expensive procedure for obtaining the finall product.

Keywords: *natural zeolite, zeolite assortment, quality requirement, mineral processing, particle size of zeolite assortment*

1 INTRODUCTION

In order to investigate the possibility of use the non-metallic mineral raw material, i.e. to determine whether one or more useful products can be obtained from some non-metallic raw material, it is necessary to know the required quality of that product, i.e. which quality of that product is needed by the end users. This subject is most often regulated by standards for each material, obtained from non-metallic mineral raw material which has users and application. So, for example, there are standards for calcium carbonate raw materials which define the quality requirements for products used in a range of industries.

Quality requirements relate to the physical, chemical, mineralogic and other properties of given material. They define minimum or maximum values of specific parameters and the allowed discrepancies. The basic and initial parameter in this respect is the particle size, respectively size class, respectively range of products. Particle size is important from the aspect of its application since not all material sizes can be used for any application. There are similar standards for products obtained from quartz raw materials, clays, feldspars, phosphates, etc. There are standards of particular states, and there are some

* *Institute for Technology of Nuclear and Other Mineral Raw Materials, Franchet d`Esperey 86, 11 000 Belgrade, Serbia, z.sekulic@itnms.ac.rs*
** *University of Belgrade, Faculty of Mining and Geology, Djušina 7, 11 000 Belgrade, Serbia*
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standards for the EU countries. What is the state of affairs in this respect when it comes to one of the most significant non-metallic mineral raw materials-zeolite? It was searched for the answer to this question on web pages the most significant manufacturers of natural zeolite products, as well as by means the investigation of papers published by a large number of prominent researchers of natural zeolite. Only the certain aspect of the particle size range of products was studied. The observations and recommendations are presented in this paper.

2 OVERVIEW OF ZEOLITE PRODUCTION ASSORTMENTS

When zeolite production is in question, Robert L. Wirth presents the production and mine reserves [1]. Natural zeolite production was the highest in 2011 in China and it amounted to nearly 2,000,000 tons (including pozzolanic applications). Apart from China, the biggest producers are the United States, Japan, Jordan, South Korea, Slovakia and Turkey. All others produced around 5,500 tons in 2011. The world total (rounded) in 2011 was 2,800,000 T.

Speaking about the processes of obtaining the zeolite products for further application, it is interesting that F. A. Mumpton 1977[2] wrote about application and obtaining the products based on natural zeolite. This author, at the end of this consideration wrote: *"For many ion exchange applications, the desired size range is 20 x 50 mesh (850 to 300/am) which has been found to optimize the contact time and hydraulic characteristics of packed columns".*

The internet research provided data on companies in the business of manufacturing products from natural zeolite. In this paper, the most interesting data are present according to the evaluation from websites of the nine companies worldwide. These data relate to the assortments (i.e. particle size) and product use in the market, and details can be found on websites of these companies, which are present in Tables 1 and 2.The present data in Table 1 show a wide range of natural zeolite products. Those assortments (size classes) are different for the same application. Assortments are in the range from -32+16 to less than 20 micrometers.

Table 1 *Testing the production of zeolite assortments obtained from natural zeolite and their application*

<table>
<tr><th rowspan="2">Application of natural zeolite</th><th colspan="4">Company / website / and assortment, mm</th></tr>
<tr><th>USA
Bear River zeolite co., inc[3]</th><th>USA
St. Cloud Mining Co. [4]</th><th>USA
Steelhead Specialty Minerals[5]</th><th>USA
ZEO, Inc. [6]</th></tr>
<tr><td>1) Water Treatment</td><td></td><td rowspan="7">Powders
-0.044
-0.149
-0.42

Sands
-0.4+0.177
-1.41+0.4</td><td></td><td></td></tr>
<tr><td>Aquaculture</td><td>-12.7+4.76
-4.76+2.38
-4.76+1.41
-1.41+0.4</td><td></td><td></td></tr>
<tr><td>Wastewater treatment</td><td>-0.4+0</td><td>-4.76+2.38</td><td></td></tr>
<tr><td>Drinking water treatment</td><td>1.41+0.4</td><td>-1.41+0.4</td><td></td></tr>
<tr><td>Pool filters</td><td>1.41+0.4</td><td></td><td>SVZ 0.65
Ko 1.85</td></tr>
<tr><td>Flocculation</td><td></td><td></td><td></td></tr>
<tr><td>For fish ponds</td><td></td><td></td><td></td></tr>
</table>

Modified or combined zeolites		Granules -4.76+3.36 -3.36+2.38 -3.36+1.41 -.2.38+1.41 Aggregates -12.7+4.76 -19+12.7 -25.4+19		
2) Animal and Feed and Agricultural				
Complete feed mixture	-1.4+0.4			-0.5+0
Animal feeds mixture				Ultra, -45µm
Soil				
Soil remediation	-1.41+0.4 -0,4+0,25 -0,4+0			-1.4+0.25
For lawns	-2.38+1.41 -1.41+0.4 -0.595+0.25			
For pellets	-0.4+0			
For artificial fertilizers and substrate				
For golf courses				
3) Air Treatment				
Air Filtration	-9.51+6.35			
Removal of impurities				
4) Industry				
Concrete and pozzolanic for cement	-0.045+0			
Fillers in paper, cardboard, plastic, rubber, adhesives, asphalt	-0.4+0 -0.15+0			

Table 2 *Review the production of zeolite assortments obtained from natural zeoilite and their application*

Application of natural zeolite	**Company / website / and assortment, mm**				
	Australia Zeolite Australia Pty Ltd [7]	**South Africa Pratley (Pty) Ltd[8]**	**Turkey Rota Madencilik [9]**	**Slovakia ZEOCEM , a. s. [10]**	**Spain ZeoCat S.L.U[11]**
1) Water Treatment			**Grain Sizes We can produce any grain size according to your requirements.** Below there is a list of grain sizes in our standard production line:		
Aquaculture					-32+16; -16+8; -8+4; -2.5+2; -2+1; -1+0.5
Wastewater treatment					
Drinking water treatment		-0.84+0.25			
Pool filters					

Flocculation	-0.075+0		**-20 microns, -50 micron, -75 microns, -0.1 -0.225 -0.425 -1.18+0.7 -1.6+0.7 -2.5+1 -5+2.5 --9+5 -16+9**		
For fish ponds	-2+0.5				
Modified or combined zeolites					
2) Animal and Feed and Agrocultural					-8+4; -4+2.5; -2.5+1.2; -1.2+0.5
Complete feed mixture	-0.075+0 -0.5+0			-1+0; -1+0.5; -1+0.2; -0.5+0.2; -0.2+0	
Soil remediation	-1.6+0.5 -2+0.5				
For pellets	-0.075+0 -0.5+0				
For artificial fertilizers and substrate	-0.075+0 -0.5+0	-4+2 -4+0.25		-1+0.3; -8+4; -5+2.5; -5+1; -2.5+1	
For golf courses		-0.84+0.25			
3) Air Treatment					
Air Filtration					
Remove impurities					
4) Industry				-8+5; -4+2,5; -2.5+1; -1+0.5; -0.5+0.2	
Concrete and pozzolanic for cement					
5) Other Products					
Environment				-8+5; -4+2.5; -2.5+1; -1+0.5; -0.5+0.2	-5+2
Wide range					-0.7+0

3 REVIEW OF RESEARCH PAPERS FROM THE ASPECT OF NATURAL ZEOLITE

For the purpose of easier research, this paper presents the review of conditional classification according to theapplicability of natural zeolite. Three references were used for this list of application the zeolite products: website[1,12] and [10].

- Physical, chemical and mineralogical characterization

- Natural zeolite – water treatment
- Environmental application of natural zeolite
- Natural zeolite in agriculture and animal nutrition
- Natural zeolite in cement and ceramic bodies
- Biomedical and biotechnological applications of natural zeolite
- Ion exchange of natural zeolites/surface modified natural zeolites

3.1 Characterization of natural zeolite

Zeolite characterization is usually performed on samples taken in the beginning of preparation and processing, after that they are ground in laboratory into powder, for example <0.063mm [13-17]. However, O. Korkuna, et al. [18] in the paper *Structural and Physico-chemical properties of Natural Zeolites:Cclinoptilolite and Mordenite*, chose the fractions of clinoptilolite with the particle size ds = 0.355–0.5 mm and mordenite of ds = 0.2–0.315 mm for investigation.

3.2 Natural zeolites for water treatment

Researchers dealing with water treatment use the following natural zeolite size classes, obtained from the raw material: -2+0.5 mm; -1.5+0 mm; -0.2+0.15 mm; -0.16+0.04 mm; -0.075+0 mm and -0.02 mm. For example Denes Kallo[19] used particle size in the range of 40-160 µm , whereas Filippidis[20] tested the sample < 0.5 mm.

3.3 Environmental application of natural zeolite

Investigations are carried out on natural zeolite classes -2.4+1.4 mm; -1.4+0.4 mm; -0.4+0 mm. Zeocern company from Slovakia offers the following products of this kind: -8+5 mm; -4+2.5 mm; -2.5+1 mm; -1+0.5 mm; -0.5+0.2 mm. The authors Englert and Rubio [21] homogenized and sieved the sample below 149 µm (100 Mesh Tylerk) before characterization and experimentation. Saltali et al. [22] published the *Removal of Ammonium Ion from Aqueous Solution by Natural Turkish (Yıldızeli) Zeolite for Environmental Quality.* They used the commercial sample of natural Turkish zeolite (Yıldızeli town of Sivas) as an adsorbent in this study, supplied from Rota A.S¸ Mining Company, Istanbul, Turkey. The natural zeolite samples were crushed in a mortar and sieved using 200-mesh (0.075 mm) sieve. Godelitsas et al. [23] in the **report of investigation of uranium sorption from aqueous solutions used the HEU-type of zeolite crystals (particle-size <20 µm) by means of a batch-type method**. Godelitsasand associates dealt with the adsorption of Ni, Cu and Co-Heu using zeolite grains 20-90 microns. Misaelides [24] dealt with the application of surfactant-modified zeolites to the environmental remediation and use of natural zeolites in the permeable reactive barriers. Leyva-Ramos [25] in his paper *"Removal of Ammonium from Aqueous Solution by Ion Exchange on Natural and Modified Chabazite"* performed the investigations on samples of zeolitic rocks from the mineral deposit in the state of Sonora, Mexico. The zeolite samples were ground and sieved to the average particle diameter of 0.18mm (−70+100 US mesh). Results of investigations from this field were also published by Ming and Alen [26], Colella [27], Capelletti [28].

3.4 Natural zeolites in agriculture and animal nutrition

Researchers use -0.5+0 mm or 0.3+0 mm zeolite classes. The company "Australia zeolite" (Table 2) offers the following products: -0.075+0 mm; -0.5+0 mm; -1.6+0.5 mm; -2+0.5 mm. Zeocem Slovakia offers **complete feed mixture** for feed additives **(Table 2):** -1+0 mm; -1+0.5 mm; -1+0.2 mm; -0.5+0.2 mm; -0.2+0 mm.

Mumpton and Fishman in the paper „The Application of Natural Zeolites in Animal Science and Aquaculture"[2] say: "For many ionexchange applications the desired size range is 20 x 50 mesh (850 to 300/am) which has been found to optimize contact time and hydraulic characteristics of packed columns. Filippidis [29] presents the results of investigations on zeolite from Greece. The Hellenic Natural Zeolite (HENAZE) sample was used from a vertical profile. The sample was ground < 0.5 mm and homogenized.

3.5 Natural zeolites in cement and ceramic bodies

The following sizes are mentioned in the papers: -0.88+0.5 mm and production of pellets in sizes 23 to 27 mm or 11 to 13 mm. Zeocem company offers the following product classes for this purpose: -1+0 mm; -1+0.5 mm; -1+0.2 mm, -0.2+0 mm. Bear river zeolite co., inc offers class -0.4+0 mm and -0.15+0 mm**.**

Mertens et al. [30] **published in the study: "The grain size of all the samples after wet milling was determined in an aqueous suspension by laser diffraction using the Malvern Mastersizer S Long Bed with a 300RF optical lens for grain sizes between 880 µm and 0:05".** Dondi et al. [31] used eighteen zeolite bearing rocks from Sardinia; campaigns and Tuscany were taken into account, along with low densities (0.5-0.7 GCM-3) and fair technical characteristics (mass and strength loose particles). De Gennaro [32] for light aggregates used two different sizes of particles: one set was 23-27 mm, and other 11-13 mm. These sets are obtained starting from 3.36 and 0.31 cm^3 pellets, respectively. Lilkov [33,34] and Chipera and Bish [35] did not mention the size of the material they had used.

3.6 Biomedical and biotechnological applications of natural zeolites

Colella [36] wrote a critical reconsideration of biomedicaland veterinary applications of natural zeolites. The starting sample was not cited. Polat [37] in his doctoral thesis states that the sample was used in 75-150 micron sized particles. Orha et al. [38], state that the study used azeolite mineral from the Romanian region Mirsid with a grain diameter for experiments between 315-500 microns.

3.7 Ion exchange of natural zeolites / surface modified natural zeolite

Researchers have mostly experimented in this field on the basis of natural zeolite. The results of their investigations can be applied in several fields since the ion exchange occurs in any field of usage the natural zeolite.. However, the researchers are mainly focused on investigations the results that can be used in application of zeolite products for animal feed or water purification. Researchers use a range of size classes for this purpose: powder, -5+2 mm; -2+0,5 mm; -2+0 mm; -2.4+1.4 mm; -1.4+0.4 mm; -0.4+0 mm; -0.1+0 mm; -0.8+0.6 mm; -0.5+0 mm; -0.5+0.315 mm; -0.15+0.075 mm; -0.090+0.063 mm; -0.5+0.1 mm; -0.1+0.04 mm; -0.63+0 mm; -0.2+0 mm; -0.043+0 mm; -0.1+0.063 mm.

Tarasevic et al. [39], in the *Microcalorimetric Study of the Interaction between Water and Cation-Substituted Clinoptilolites,* used for experiments 0.25–0.5 mm fractions, too, when determining the Q 0 values of cation-substituted forms of clinoptilolite. Tomazović et al. [40] used for experiments the natural zeolite with sized particles of 0.090-0.063 mm. Trgo and Perić [41], **used for experiments the natural zeolite particle size of 0.1-0.5 mm** from the Croatian deposit Donje Jesenje. Misaelides et al. [42], used for investigations the homogenized materials, pulverized samples of zeolie ferous rocks from Georgia and Greece with grain size <2 mm or -10 mesh. Mendoza-Barron et al. [43], used the modified natural zeolite from the deposit located in San Luis Potosi, Mexico. The sample was ground and sieved to the average particle size of 0.42 mm (−20+30 US mesh).

Ćurković et al. [44], published a paper entitled *Kinetics and Thermodynamics Study of Copper Ions Removal by Natural Clinoptilolite***.** Natural clinoptilolite zeolite from Donje Jasinje was used in three size classes: -0.5 mm, -2+0.5 mm i -5+2 mm. Trgo et al. [45], used the natural zeolite sample with particle size of 0.04–0.10 mm. Simpson and Bowman [46], used zeolite in their investigations which was the natural clinoptilolite-rich tuff from the St. Cloud mine near Winston, New Mexico. The zeolite was crushed and sieved to 14–40 mesh size (1.4 - to 0.4 mm diameter). Faghihian and Bowman [47], used **in their investigations** two different size fractions, 0.4–1.4 mm and 1.4–2.4 mm. Sullivan et al., [48], prepared the SMZ from a clinoptilolite zeolite from New Mexico. The external cation exchange capacity of zeolite, determined by Ming and Dixon method (1987), was found to be approximately 70 to 90 mmolc/kg. Bowman [49] used the natural clinoptilolite-rich zeolitic tuff New Mexico with particle size <0.4 mm, 1.4–0.4 mm, or 2.4–1.4 mm. Tomašević-Canović et al. [50]: the starting material used in the experiments was raw zeolitic tuff sieved to yield particles <100 μm. Vujaković et al. [51], **Daković et al. [**52]: The starting material used in the experiments was raw zeolitic tuff sieved to yield particles <0.063 mm. Stanić et al. [53] used for experiments the raw zeolitic tuff zeolite from the Bala Mare deposit in Romania, and the sample was prepared under 0.2 mm in size. Krajišnik et al. [54]: The raw zeolitic tuff was sieved to yield particles below 43 μm. Cerjan Stefanović et al. [55] proved that the highest absorption of metallic cations on fraction of grain size of 0.1 to 0.063 mm, so that the reasons why they had chosen this fraction. Šiljeg et.al. [56] were chosen the fractions of grain size of 0.1 to 0.5 mm for experimental work.

4 OBSERVATIONS AND CONCLUSIONS

Based on the presented review, it can be concluded that there are no standardized physical, chemical or mineralogical parameters of quality for zeolite assortments for any field of application, unlike in the case of some other non-metallic mineral raw materials. There are regulations for pozzolanic additives of cement (which are applied on zeolite, too) used for those purposes (European Standard EN 197 and Italian Standard UNI 7549…). There are regulations defining the allowed impurities in the animal feed, so zeolite must conform with those regulations, too, but the minimum content of zeolite mineral, maximum harmful impurities, minimum CEC or the size of the product are not defined. Companies that process the natural zeolite in commercial products, as proof of the quality of these products, provide the tests for various application areas. Tests show that zeolite acts better than alternative materials. Researchers use a variety of particle size for the same purposes. For example, some researchers use classes -0.5+0 mm for water treatment and animal feed, while others use 0.063+0 mm etc. Frederick Mumpton, at the end of 1999, discussed the role of scientists in the study of mineral zeolite, and said that the role of scientists is multidisciplinary. The joint effort of scientists is essential to understand, for example, the zeolite functions in the digestive system of animals. He added that for further, besides all, the aspect **o**f mineral processing should be present. It was observed in this research that: the particle size of zeolite assortments is not standardized for any application. But, in mineral processing, it is essential to know: whether the zeolite assortments were obtained by crushing and sieving process or it is necessary to carry out the other complex mineral processing operations. Due to this, probably, in the future, the manufacturers of zeolitic product ranges and researchers, who work with natural zeolite, together with users have to define the quality requirements, and especially the particle size as the quality parameter of zeolite assortments.

REFERENCES

[1] http://minerals.usgs.gov/minerals/pubs/commodity/zeolites/

[2] F.A. Mumpton, P.H. Fishman, The Application of Natural Zeolites in Animal Science and Aquaculture.J. ANIM. SCI., 45(1977), p.1188

[3] www.bearriverzeolite.com

[4] http://www.stcloudmining.com

[5] www.steelheadspecialtyminerals.com

[6] www.zeoinc.com

[7] www.zeolite.com.au

[8] http://www.pratley.com

[9] http://www.rotamadencilik.com.tr/

[10] http://www.zeocem.com/

[11] http://www.zeocat.es

[12] F. A. Mumpton, Colloquium Paper, La rocamagica: Uses of natural zeolites in agriculture and industry. Proc. Natl. Acad. Sci. USA, 96(1999), p.3463

[13] O. Díaz Rizo, E.F. Herrera Peraza, Multi-elemental characterization of Cuban natural zeolites. J. Radioanal. Nucl. Chem. 212(1997), No 1-2, p.255

[14] T. Armbruster, Clinoptilotite-heulandite: applications and basic research, Zeolites and Mesoporous Materials at the dawn of the 21st century. Proceedings of the 13 International Zeolite Conference, Montpellier, France. Studies in Surface Science and Catalysis, 135(2001), p. 13

[15] L. S. Gadekar, S. S. Katkar, K. N. Vidhate, B. R. Arbad, M. K. Lande, Modification, characterization and catalytic potency of modified natural zeolite for Knoevenagel condensation reaction. Bulletin of the Catalysis Society of India, 7(2008), p. 76

[16] G. V.Tsitsishvili, N. S. Skhirtladze, T. G. Andronikashvili, V. G. Tsitsishvili, A. V. Dolidze, Natural zeolites of Georgia: Occurrences, properties, and application, Studies in Surface Science and Catalysis, 125(1999), p. 715

[17] D. L. Bish,and J.W. Carey, Thermal Behavior of Natural Zeolites, Rev. Mineral. Geochem., 45(2011), p. 403

[18] O. Korkuna, R. Leboda, J. Skubiszewska-Ziba, T. Vrublevs'ka, J. Gun'ko, V. M. Ryczkowski, Structural and physicochemical properties of natural zeolites: clinoptilolite and mordenite, Microporous Mesoporous Mater. 87(2006), p. 243

[19] D. Kalló, Wastewater purification in Hungary using natural zeolites, In: Natural Zeolites ’93: Occurrence, Properties, Use. Ming D W, Mumpton F A, editors. Brockport, NY: Int. Comm. Nat. Zeolites, (1995), p. 341

[20] A. A. Filippidis, Environmental, industrial and agricultural applications of Hellenic Natural Zeolite, Hellenic Journal of Geosciences, 45(2010), p. 91

[21] A. H. Englert, J. Rubio, Characterization and environmental application of a Chilean natural zeolite, Int. J. Miner. Process, 75(2005), No 1-2, p. 21

[22] K. Saltali, A. Sari, M. Aydin, Removal of ammonium ion from aqueous solution by natural Turkish (Yıldızeli) zeolite for environmental quality, J. Hazard. Mater, 141(2007) No.1, p. 258

[23] A. Godelitsas, P. Misaelides, A. Filippidis, D. Charistos, I. Anousis, Uranium sorption from aqueous solutions on sodium-form of HEU-type zeolite crystals, J. Radioanal. Nucl. Chem. 208(1996), No. 2, p. 393

[24] P. Misaelides, Application of natural zeolites in environmental remediation:

A short review, Microporous Mesoporous Mater. 44(2011), No.1-3, p. 15
[25] R. Leyva-Ramos, J.E. Monsivais-Rocha, A. Aragon-Piña, M.S. Berber-Mendoza, R.M. Guerrero-Coronado, P. Alonso-Davila, J. Mendoza-Barron, Removal of ammonium from aqueous solution by ion exchange on natural and modified chabazite, J. Environ. Manage., 91(2010), p. 2662
[26] D. W. Ming and E. R. Allen, Use of natural zeolites in agronomy, horticulture, and environmental soil remediation, Rev. Mineral. Geochem., 45(2001), p. 618
[27] C. Colella, Natural zeolites and environment, Stud. Surf. Sci. Catal., 2007, Chapter 27, p. 999
[28] P. Cappelletti, G. Rapisardo, B. de Gennaro, A. Colella, A. Langella, S.F. Graziano, D.L. Bish, M. de Gennaro, Immobilization of Cs and Sr in aluminosilicate matrices derived from natural zeolites, J. Nucl. Mater., 414(2011), p. 451
[29] A. Filippidis, G. Papastregios, N. Apostolidis, S. Filippidis, I. Paragios, C. Sikalidis, Purification of urban wastewaters by Hellenic natural zeolite, Bulletin of the Geological Society of Greece, 43(2010), No.5, p. 2597
[30] G. Mertens, R. Snellings, K. Van Balen, B. Bicer-Simsir, P. Verlooy, J. Elsen, Pozzolanic reactions of common natural zeolites with lime and parameters affecting their reactivity, Cem. Concr. Res., 39(2009), No.3, p. 233
[31] M. Doldi, P. Cappelletti, G.Cerri, M. Gennaro, R. Gennaro, A. Langella, Zeolitic tuffs as raw materials for lightweight aggregates., Key Eng. Mater., 2004, No. 264-268, p. 1431
[32] R. de' Gennaro, P. Cappelletti, G. Cerri, M. de' Gennaro, M. Doldi, A. Langella, Zeolitic tuffs as raw materials for lightweight aggregates, Appl. Clay Sci., 25(2004), No.1-2, p. 71
[33] V. Lilkov, O. Petrov, V. Petkova, N. Petrova, Y. Tzvetanova, Study of the pozzolanic activity and hydration products of cement pastes with addition of natural zeolites, Clay Miner., 46(2011), p. 241
[34] V. Lilkov, O. Petrov, Y. Tzvetanova, Rheological, porosimetric, and SEM studies of cements with additions of natural zeolites, Clay Miner., 46(2011) p. 225
[35] S. J. Chipera, D. L. Bish, Rehydration kinetics of a natural analcime, Eur. J. Mineral., 22(2010), p. 787
[36] C. Colella, A critical reconsideration of biomedical and veterinary applications of natural zeolites, Clay Miner., 46(2011), No. 2, p. 295
[37] Z. Polat, Integrated approach to whey utilization through natural zeolite adsorption/desorption and fermentation, [Dissertation], *The Graduate School of Engineering and Sciences, Izmir, 2009*, p. 209
[38] C. Orha, F. Manea, A. Pop, G. Burtica, I. F. Todea, Obtaining and Characterization of Zeolitic Materials with Antibacterial Properties, Rev. Chim., 59(2008), No. 2, p. 173
[39] Yu.I. Tarasevich, I. G. Polyakova, V. E. Polyakov, Microcalorimetric Study of the Interaction between Water and Cation-Substituted Clinoptilolites, Colloid J., 65(2003), No. 4, p. 493
[40] B. Tomazović, T. Ćeranić, G. Sijarić, The properties of the NH,-clinoptilolite, Zeolites, 16(1996) No.4, p. 301
[41] M. Trgo, J. Perić, Interaction of the zeolitic tuff with Zn-containing simulated pollutant solutions, J. Colloid Interface Sci., 260(2003), No. 1, p. 166
[42] P. Misaelides, V.A. Nikashina, A. Godelitsas, P.A. Gembitskii, E.M. Kats, Sorption of As(V)-anions from aqueous solutions by organo-modified natural zeolitic materials, J. Radioanal. Nucl. Chem. 227(1998), No. 1-2, p. 183

[43] J. Mendoza-Barrón, A. Jacobo-Azuara, R. Leyva-Ramos, M.S. Berber-Mendoza, R.M. Guerrero-Coronado, L. Fuentes - Rubio, J.M. Martínez-Rosales, Adsorption of arsenic (V) from a water solution onto a surfactant-modified zeolite, Adsorption, 17(2011), No. 3, p. 489

[44] L. Ćurković, M. Trgo, M. Rožić, N. V. Medvidović, Kinetics and thermodynamics study of copper ions removal by natural clinoptilolite, Indian J. Chem. Technol., 18(2011), No. 2, p. 137

[45] M. Trgo, J. Perić, N.V. Medvidović, A comparative study of ion exchange kinetics in zinc/lead-modified zeolite-clinoptilolite systems, J. Hazard. Mater., 136(2006), No. 3, p.938

[46] J. A. Simpson, R. S. Bowman, Non-equilibrium sorption and transport of volatile petroleum hydrocarbons in surfactant-modified zeolite, J. Contam. Hydrol., 108(2009), No. 1-2, p. 1

[47] H. Faghihian, R.S. Bowman, Adsorption of chromate by clinoptilolite exchanged with various metal cations,Water Res., 39(2005), No. 6, p. 1099

[48] E. J. Sullivan, R. S. Bowman, I. A. Legiec, Sorption of Arsenic from Soil-Washing Leachate by Surfactant-Modified Zeolite, J. Environ. Qual., 32(2003), No. 6, p. 2387

[49]. R. S. Bowman, Applications of surfactant-modified zeolites to environmental remediation, Microporous Mesoporous Mater., 61(2003), No. 1-3, p. 43

[50] M. Tomašević-Čanović, A. Daković, G. Rottinghaus, S. Matijašević, M. Duričić, Surfactant modified zeolites - new efficient adsorbents for mycotoxins, Microporous Mesoporous Mater.,61(2003), No. 1-3, p. 173

[51] A. Vujaković, M. Tomašević-Čanović, A. Daković, V. Dondur, The adsorption of sulphate, hydrogenchromate and dihydrogenphosphate anions on surfactant-modified clinoptilolite, Appl. Clay Sci., 17(2000), No. 5-6, p. 265

[52] A. Daković, M. Tomašević-Čanović, G. Rottinghaus, V. Dondur, Z. Mašić, Adsorption of ochratoxin A on octadecyldimethyl benzyl ammonium exchanged-clinoptilolite-heulandite tuff, Colloids Surf. B., 30(2003), No. 1-2, p. 157

[53] T. Stanić, A. Daković, A. Živanović, M. Tomašević-Čanović, V. Dondur, S. Milićević, Adsorption of Arsenic (V) by Iron (III)-Modified Natural Zeolitic Tuf, Environ. Chem. Lett., (2009), p. 161

[54] D. Krajišnik, A. Daković, M. Milojević, A. Malenović, M. Kragović, D.B. Bogdanović, V. Dondur, J. Milić, Properties of Diclofenac Sodium Sorption onto Natural Zeolite Modified with Cetylpyridinium Chloride, Colloids Surf. B , 83(2011), p. 165

[55] Š. Cerjan Stefanović, N. Logar Zabukovec, K. Margeta, N. Novak Tušar, I. Arčon, K. Maver, J. Kovač, J. Kaučič, Structural Investigation of Zn^{2+} Sorption on Clinoptilolite Tuff from the Vranjska Banja Deposit in Serbia, Microporous Mesoporous Mater., 105(2007), p. 251

[56] M. Šiljeg, S.C. Stefanović, M. Mazaj, N. Tušar, I. Arčon, J. Kovač, K. Margeta, N.Z. Logar, Structure investigation of As(III)- and As(V)-species bound to Fe-modified clinoptilolite tuffs, Microporous Mesoporous Mater. 118(2009), No. 1-3, p. 408

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Živko Sekulić[*], *Božo Kolonja*[**], *Dinko Knežević*[**]

DEFINISANJE KRUPNOĆE KAO PARAMETRA KVALITETA ZEOLITSKIH ASORTIMANA PROIZVODA[***]

Izvod

Zahtevi za kvalitet asortimana proizvoda koji se dobijaju iz velikog broja nemetaličnih mineralnih sirovina su definisani, a iznad svega, imaju definisanu veličinu čestica. Da li su zahtevi za kvalitet asortimana na bazi zeolita definisani? Tragajući za odgovorom na ovo pitanje izvršili smo internet istraživanje. Pregledali smo internet stranice najznačajnijih proizvođača materijala na bazi prirodnog zeolita, kao i radove velikog broja istaknutih istraživača čiji su eksperimenti fokusirani na prirodni zeolit. Ovaj rad predstavlja naše nalaze, pre svega sa aspekta veličine čestica kao parametra kvaliteta zeolitskih asortimana proizvoda. Na osnovu ove analize, smatramo da bi trebalo da se definišu zahtevi kvaliteta, posebno veličina čestica za svaki proizvod na bazi zeolita. U stvari, u pripremi mineralnih sirovina je važno da znate veličinu čestica, kako bi izabrali jeftiniji postupak za dobijanje konačnog proizvoda.

Ključne reči: *prirodni zeolite, zeolitski asortiman, uslovi kvaliteta, postupci pripreme, veličina čestice zeolitskih asortimana*

1. UVOD

U cilju ispitivanja mogućnosti upotrebe nemetalnih mineralnih sirovina, odnosno utvrđivanja da li se na bazi neke nemetaličnih mineralnih sirovina može dobiti jedan ili više korisnih proizvoda, potrebno je znati traženi kvalitet tog proizvoda, odnosno koji kvalitet tog proizvoda je potreban za krajnjeg korisnika. Ovo pitanje je najčešće regulisano standardima za svaki materijal dobijeno dnemetalnih mineralnih sirovina koja ima korisnika i primenu. Tako, na primer, za kalcijum-karbonat postoje standardi koji definišu zahteve za kvalitet proizvoda koji se koriste u različitim industrijama. Zahtevi kvaliteta se odnose na fizičke, hemijske, mineraloške i druge osobine datog materijala. Oni definišu minimalne i maksimalne vrednosti određenih parametara i dozvoljena odstupanja. Osnovni i početni parametar u tom smislu jeste veličina čestica, odnosno klasa krupnoće, odnosno asortiman proizvoda. Veličina čestica je važna sa aspekta njegove primene, jer ne mogu se koristiti sve veličine čestica za bilo koju aplikaciju. Postoje slični standardi za proizvode dobijene iz kvarcnih sirovina,

[*] *Institut za tehnologiju nuklearnih i drugih mineralnih sirovina, Franše d'Eperea 86, 11000 Beograd, Srbija, e-mail: z.sekulic@itnms.ac.rs*

[**] *Univerzitet u Beogradu, Rudarsko geološki fakultet, Đušina 7, 11000 Beograd, Srbija*

[***] *Ovaj rad je rezultat istraživanja u okviru projekta 034013 „Osvajanje tehnoloških postupaka dobijanja ekoloških materijala na bazi nemetaličnih mineralnih sirovina" i 172018 „Porozni materijali na bazi oksida u zaštiti životne sredine od genotoksičnih supstanci", koje finansira Ministarstvo prosvete, nauke i tehnološkog razvoja Republike Srbije od 2011-2014 .*

glina, feldspata, fosfata, itd. Postoje standardi pojedinih država, a postoje neki standardi za zemlje EU. Kakvo je stanje u tom pogledu, kada je u pitanju jedna od najznačajnijih nemetaličnih mineralnih sirovina - zeolit? Mi smo tražili odgovor na ovo pitanje na veb stranicama najznačajnijih proizvođača prirodnog zeolita proizvoda, kao i putem istraživanja objavljenih radova od strane velikog broja istaknutih istraživača prirodnog zeolita. Proučavali smo samo određeni aspekt opseg veličine čestica proizvoda. Naša zapažanja i preporuke su prikazani u ovom radu.

2. PREGLED PROIZVODNJE ZEOLITSKIH ASORTIMANA

Kada je u pitanju proizvodnja zeolita, Robert L. Virta predstavlja proizvodnju i rudne rezerve [1]. Proizvodnja prirodnih zeolita je najveća u Kini u 2011. godini i iznosila je skoro 2.000.000 tona (uključuje pucolanske aplikacije). Pored Kine, najveći proizvođači su SAD, Japan, Jordan, Južna Koreja, Turska i Slovačka. Svi ostali su proizveli oko 5.500 tona u 2011. godini. Svet je ukupno (zaokruženo) u 2011. godini proizveo 2.800.000 t.

F. A. Mumpton je još 1977 [2] pisao o primeni i dobijanju proizvoda na bazi priordnog zeolita. Naša istraživanja su na bazi podataka sa Interneta o kompanijama koje proizvode proizvoda od prirodnih zeolita. U ovom radu predstavićemo najinteresantnije podatke prema našim procenama iz sajtovima devet kompanija širom sveta. Ovi podaci odnose se na asortimane (odnosno čestica po krupnoći) i primenu proizvoda na tržištu, a detalje možete pronaći na sajtovima ovih kompanija, koje su prikazane u tabeli 1. i 2. .Podaci prikazani u tabeli 1 pokazuju širok spektar proizvoda na bazi zeolita. Ovi asortimani se razlikuju za istu aplikaciju. Asortimani su u rasponu od -32 do +16 i manje od 20 mikrometara.

Tabela 1. *Istraživanje proizvodnje zeolitskih asortimana dobijeni od prirodnog zeolita i njihove primene*

<table>
<tr><th rowspan="2">Primena prirodnog zeolita</th><th colspan="4">Kompanija / websajt / i asoriman, mm</th></tr>
<tr><th>USA
Bear river zeolite co., Inc [3]</th><th>USA
St. Cloud Mining Co. [4]</th><th>USA
Steelhead Specialty Minerals [5]</th><th>USA
ZEO, Inc. [6]</th></tr>
<tr><td>1) Tretman vode</td><td></td><td rowspan="8">Prah
-0.044
-0.149
-0.42

Pesak
-0.4+0.177
-1.41+0.4</td><td></td><td></td></tr>
<tr><td>Akva kultura</td><td>-12.7+4.76
-4.76+2.38
-4.76+1.41
-1.41+0.4</td><td></td><td></td></tr>
<tr><td>Tretman otpadne vode</td><td>-0.4+0</td><td>-4.76+2.38</td><td></td></tr>
<tr><td>Tretman vode za piće</td><td>-1.41+0.4</td><td>-1.41+0.4</td><td></td></tr>
<tr><td>Filteri za bazene</td><td>-1.41+0.4</td><td></td><td>SVZ 0.65
Ko 1.85</td></tr>
<tr><td>Flokulacija</td><td></td><td></td><td></td></tr>
<tr><td>Za ribnjake</td><td></td><td></td><td></td></tr>
<tr><td>Modifikovani ili kombinovani zeolit</td><td></td><td></td><td></td></tr>
</table>

2) Hrana za životinje i agrokultura		Granulat -4.76+3.36 -3.36+2.38 -3.36+1.41 -2.38+1.41 Agregat -12.7+4.76 -19+12.7 -25.4+19		
Kompletna mešavina	-1.4+0.4			-0.5+0
Mešavina stočne hrane				Ultra -45mM
Zemljište				
Remediacija	-1.41+0.4 -0,4+0,25 -0,4+0			-1.4+0.25
Za travnjake	-2.38+1.41 -1.41+0.4 -0.595+0.25			
Za pelete	-0.4+0			
Za golf terene				
3) Tretman vazduha				
Filtracija	-9.51+6.35			
Uklanjanje nečistoća				
4) Industrija				
Beton i pucolan za cement	-0.045+0			
Fileri papira, kartona, plastike, gume, lepila, asfalt	-0.4+0 -0.15+0			

Tabela 2. *Pregled istraživanja proizvodnje zeolitskih asortimana dobijenih od prirodnog zeolita i njihova primena*

Primena prirodnog zeolita	**Kompanija / websajt / i asoriman, mm**				
	Australia Zeolite Australia Pty Ltd [7]	**South Africa Pratley (Pty) Ltd [8]**	**Turkey Rota Madencilik [9]**	**Slovakia ZEOCEM, a. s. [10]**	**Spain ZeoCat S.L.U [11]**
1) Tretman vode			Mi možemo da proizvodimo bilo koju veličinu zrna u skladu sa vašim zahtevima. Ispod je spisak od veličine zrna u našoj standardnoj proizvodnoj liniji:		
Akvakultura					-32+16; -16+8; -8+4; -2.5+2; -2+1; -1+0.5
Tretman otpadne vode					
Tretman vode za piće		-0.84+0.25	**-20 mikrometara, -50 mikrometara -75 mikrometara -0.1**		
Filteri za bazene					
Flokulacija	-0.075+0				

Za ribnjake	-2+0.5				
Modifikovani ili kombinovani zeolit			**-0.225** **-0.425** **-1.18+0.7** **-1.6+0.7** **-2.5+1** **-5+2.5** **--9+5** **-16+9**		
2) Hrana za životinje i agrokultura					-8+4; -4+2.5; -2.5+1.2; -1.2+0.5
Kompletna mešavina	-0.075+0 -0.5+0			-1+0; -1+0.5; -1+0.2; -0.5+0.2; -0.2+0	
Mešavina stočne hrane	-1.6+0.5 -2+0.5				
Za pelete	-0.075+0 -0.5+0				
Za veštačka đubriva i podloge	-0.075+0 -0.5+0	-4+2 -4+0.25		-1+0.3; -8+4; -5+2.5; -5+1; -2.5+1	
Za golf terene		-0.84+0.25			
3) Tretman vazduha					
Filtracija					
Uklanjanje nečistoća					
4) Industrija				-8+5; -4+2,5; -2.5+1; -1+0.5; -0.5+0.2	
Beton i pucolanski dodatak cement					
5) Drugi proizvodi					
Zaštita				-8+5; -4+2.5; -2.5+1; -1+0.5; -0.5+0.2	-5+2
Širok opseg					-0.7+0

3. PREGLED ISTRAŽIVAČKIH RADOVA SA ASPEKTA PRIRODNOG ZEOLITA

Radi lakšeg istraživanja, ovaj rad predstavlja pregled prema uslovnoj podeli prirodnog zeolita na osnovu primenjivost.

Koristili smo tri reference za ovaj spisak primene zeolitskih proizvoda [1,12] i [10]:

- fizička, hemijska i mineraloška karakterizacija,
- prirodni zeolit - tretman vode,
- primena prirodnog zeolita u životnoj sredini,

- prirodni zeolit u poljoprivredi i ishrane životinja,
- prirodni zeolit u industriji cementa i keramike,
- biomedicinske i biotehnološke primene prirodnog zeolita,
- jonske izmena prirodnih zeolita/površinski modifikovani prirodni zeoliti.

3.1. Karakterizacija prirodnog zeolita

Karakterizacija zeolita se obično vrši na uzorcima uzetim u početku pripreme i obrade, nakon čega se u laboratoriji usitnjavaju u prah, na primer < 0,063 mm [13-17]. Međutim, O. Korkuna i drugi [18] u radu *Strukturne i fizičko-hemijske osobine prirodnih zeolita: klinoptilolita i mordenita*, za istraživanje su izabrali frakcije klinoptilolita veličine čestica ds=0.355-0.5 mm mordenite ds=0.2-0.315 mm.

3.2. Prirodni zeolit za tretman vode

Istraživači koji se bave tretmanom vode koriste sledeće klase krupnoće : -2 +0,5 mm; -1.5 -0.2 +0 mm; +0,15 mm; -0.16 +0,04 mm; -0.075 +0 mm i -0.02 mm. Na primer Denes Kallo [19] koristi veličinu čestica u opsegu 40-160 mikrometara, dok Filippidis [20] ispituje uzorak koji je <0.5 mm.

3.3. Primena prirodnog zeolita u životnoj sredini

Istraživanja se obavljaju na prirodnm zeolitu klase -2.4 +1,4 mm; -1.4 +0,4 mm, -0.4 +0 mm. Zeocem, Slovačka kompanija, nudi sledeće proizvode ove vrste: -8 +5 mm; -4 +2.5 mm; -2.5 mm; -1 +1 +0.5 mm; -0.5 +0,2 mm. Autori Englert i Rubio [21] homogenizuju i prosejavaju uzorak ispod 149 mikrometara (100 meša) pre karakterizacije i eksperimentisanja. Saltali i saradnici [22] su koristili komercijalni uzorak prirodnog zeolita kao adsorbent, koji se dobija iz rudarske kompanije. Prirodni uzorci su usitnjeni i prosejavani na 0,075 mm. Godelitsas i dr. [23] u Izveštaju o istraživanjima sorpcije uranijuma iz vodenih rastvora koriste Heu - tip zeolita (čestica veličine < 20 mkm). Godelitsas i saradnici za adsorpciju Ni, Cu i pomoću Heu zeolita koriste krupnoću 20-90 mikrometara. Misaelides [24] se bavi primenom površinski - modifikovanih zeolita u sanaciji životne sredine. Leiva-Ramos [25] u svom radu "*Uklanjanja amonijaka iz vodenog rastvora od jonske izmene na prirodni i modifikovani chabazite*" vrši istraživanje na uzorcima zeolitnih stena od mineralnih ležišta u državi Sonora u Meksiku. Uzorci su na terenu prosejavanja na čestice prečnika od 0.18 mm. Rezultate istraživanja iz ove oblasti su takođe objavili Ming i Alen [26], Colella [27], Capelletti [28].

3.4. Prirodnih zeolita u poljoprivredi i ishrane životinja

Istraživači koriste klase zeolita -0.5 + 0 mm ili 0,3 +0 mm. Kompanija "Australija zeolit" (Tabela 2) nudi sledeće proizvode: -0.075 +0 mm; -0.5 -1.6 +0 mm; +0,5 +0,5 mm; -2 mm. Zeocem Slovačka nudi kompletnu smešu za aditiv (Tabela 2): -1 + 0 mm; -1 +0,5 +0,2 mm; -1 mm; +0,2 mm; -0.5 -0.2 +0 mm.

Mumpton i Fishman u radu "Primena prirodnih zeolita u stočarstvu i akvakulturi" kažu: "Za mnoge aplikacije jonske izmene željeni opseg veličina je 0.850 do 0.300 mm. Filippidis [29] predstavlja rezultate istraživanja o zeolitu iz Grčke. Koristi se prirodni zeolit (HENAZE) krupnoće < 0,5 mm koji se homogenizuje

3.5. Prirodni zeolit u industriji cementa i keramike

U radovima se sledeće veličine pominju: -0.88 +0.5 mm i proizvodnju peleta u veličinama od 23 do 27 mm, ili 11 do 13 mm. Zeocem firma nudi sledeće proizvode za ovu svrhu: -1 +0 mm; -1 +0.5 mm; -1 +0,2 mm, -0.2 +0 mm. Bear River zeolit CO

Doo nudi klase -0.4 +0 mm i -0.15 +0 mm .Mertens i dr. [30] su u Studiji koristili čestice uzoraka, nakon mokrog mlevenja, veličine 0,880 mm i 0.05. Dondi i dr. [31] koriste osamnaest zeolitskih ležišta iz Sardinije, kampanije iz Toskane. Uzeti su u obzir uzorci male gustine (0.5-0.7 g/cm^3). De Đenaro [32] za lake agregate koristi dve različite veličine čestica: jedan set je 23-27 mm, i drugi 11-13 mm. Ovi skupovi su dobijeni polazeći od 3,36 do 0,31 cm^3-peleta, respektivno. Lilkov [33,34] i Chipera i Bish [35] nisu pominjali veličinu materijala koji su koristili.

3.6. Biomedicinska i biotehnološka primena prirodnih zeolita

Colella [36] je kritički preispitivao biomedicinsku i veterinarsku primenu prirodnog zeolita. Polazni uzorak nije bio defnisan. Polat [37] u svojoj doktorskoj tezi navodi koristi uzorak krupnoće 75-150 mikrometar. Orha i dr. [38], je naveo da u studiji koristi mineral zeolit iz oblasti Mirsid prečnika između 315-500 mikrometara.

3.7. Jonske izmene prirodnih zeolita / površinski modifikovani prirodni zeolit

Istraživači su u ovoj oblasti uglavnom eksperimentisali na bazi prirodnog zeolita. Rezultati njihovih istraživanja mogu se primeniti u nekoliko oblasti jonske izmene u kojoj se prirodni zeolit koristi. Međutim, istraživači su uglavnom fokusirani na istraživanja čiji rezultati se mogu koristiti za primenu zeolitskih asortimana za stočnu hranu, odnosno prečišćavanje vode. Istraživači koriste različite klase krupnoće za ovu namenu: prah, -5 +2 mm; -2 +0,5 mm; -2 +0 mm; -2.4 +1,4 mm, -1.4 +0,4 mm, -0.4 +0 mm ; -0.1 +0 mm; -0.8 +0,6 mm, -0.5 + 0 mm; -0.5 +0.315 mm; -0.15 +0.075 mm, -0,090 +0,063 mm, -0.5 +0,1 mm, -0.1 +0,04 mm; - +0 0,63 mm; -0.2 +0 mm; -0.043 + 0 mm; -0.1 +0.063 mm.

Tarasevič i dr. [39], u svom radu za eksperimente koristi frakciju 0.25-0.5 mm, Tomazović i dr. [40] za eksperimente na prirodni zeolitima koriste čestice veličine 0.090-0.063 mm. Trgo i Perić [41] su u svom eksperimentalnom radu koristili priordni zeolit krupnoće 0,1-0,5 mm, izležišta Donje Jesenje u Hrvatskoj. Misaelides i dr. [42], koriste homogenizovan materijal, mleveni uzorak stena iz Gruzije i Grčke granulacije <2 mm ili -10 mesh. Mendoza-Baron i drugi [43], za istraživanja koriste modifikovani zeolit iz ležišta koje se nalazi u San Luis Potosi, Meksiko. Uzorak je prosejavan na prosečnu veličinu čestica od 0,42 mm (-20 +30 US meša). Ćurković i dr. [44], objavili su rad pod nazivom *Istraživanje kinetike i termodinamike uklanjanja jona bakra prirodnim klinoptilolitom.* Prirodnog zeolita tipa Donje Jasinje je korišćen u tri veličine klase: -0.5 mm +0,5 mm, -2 i +2 -5 mm. Trgo i dr. [45], za istraživanje su koristili prirodni zeolit veličine čestica 0.04-0.10 mm. Simpson i Boumen [46] su koristili klinoptilolit-tuf iz St. Cloud kamenolomu kod Vinstona, Novi Meksiko koji je prirodno bogat. Zeolit je drobljen i prosejavan na 14 - 40 meša (1,4 - 0,4 mm). Faghihian i Boumen [47], u svojim istraživanjima koriste dve različite veličine frakcije: 0.4 - 1.4 mm, 1.4 - 2.4 mm. Sullivan i saradnici [48], pripremaju SMZ od zeolita iz Novog Meksika. Spoljni kapacitet katjonske izmene zeolita je 70 do 90 mmolc/kg. Bowman [49] koristi prirodni klinoptilolitom bogat zeolitni tuf iz Novog Meksika, veličine čestica <0,4 mm, 1.4 - 0.4 mm, ili 2.4 - 1.4 mm. Tomašević - Čanović i dr. [50]: *Polazni materijal koji se koristi u eksperimentima je zeolitni tuf koji se prosejava na veličinu čestica <100 mikrometara.* Vujaković i dr. [51], Daković i dr. [52] koriste polazni materijal koji se koristi u eksperimentima sirov zeolitni tuf prosejavan na čestice <0.063 mm. Stanić i dr. [53] za eksperimente su koristili sirov zeolitni tuf iz Bala Mare ležišta u Rumuniji, a uzorak je bio pripremljen na -0,2 mm. Krajišnik i dr.

[54] koriste sirov zeolitni tuf koji je prosejavan na čestice ispod 43 mikrometara. Cerjan - Stefanović i sar. [55]: Dokazano je da je najveća apsorpcija metalnih katjona na frakciji veličine zrna od 0,1 do 0.063 mm, pa su zato izabrali ovu frakciju. Šiljeg i saradnici [56] su izabrali frakcije veličine zrna od 0,1 do 0,5 mm za eksperimentalni rad.

4. ZAPAŽANJA I ZAKLJUČCI

Na osnovu prikazanog pregleda može se zaključiti da ne postoje standardizovani fizički, hemijski ili mineraloški parametri kvaliteta za zeolitske asortimane za bilo koju oblast primene, za razliku od nekih drugih nemetaličnih mineralnih sirovina. Postoje propisi za pucolanski dodatak cementu (koji se primenjuju na zeolit, takođe) koji se koriste u te svrhe (evropski standard EN 197 i UNI Italijanski standard 7549 ...). Postoje propisi koji definišu dozvoljene nečistoće u hrani za životinje, tako da zeolit mora u skladu sa tim propisima da ispunjava uslove, ali minimalni sadržaj minerala zeolita, najviše štetnih primesa, minimalni kapcitet katjonske izmene ili krupnoća proizvoda nisu definisani. Kompanije koje prerađuju prirodni zeolit u komercijalne proizvode, kao dokaz o kvalitetu ovih proizvoda daju testove za različite oblasti primene. Testovi pokazuju da zeolit deluje bolje od alternativnih materijala. Istraživači koriste različite veličine čestica za iste svrhe. Na primer, neki istraživači koriste klase -0.5 +0 mm za preradu vode i hrane za životinje, dok drugi koriste 0.063 +0 mm i dr.. Frederik Mumpton krajem 1999. godini, u studiji iz zeolita, kaže da je uloga naučnika multidisciplinarna. Zajednički napor naučnika je od suštinskog značaja ako želimo da razumemo, na primer, funkcije zeolita u digestivnom traktu životinja. On je dodao da za dalje, pored ostalih, i aspekt pripreme mineralnih sirovina treba da bude zastupljen. U našem istraživanju smo primetili: veličine čestica zeolitski asortimana nije standardizovan za bilo koju primenu. Ali, u pripremi mineralnih sirovina je važno da se zna: da li se asortimani dobijaju drobljenjem i prosejavanjem ili su potrebne druge složene operacije. Zbog toga, verovatno, u budućnosti, proizvođači zeolitnih asortiman i istraživači koji rade sa prirodnim zeolitom, zajedno sa korisnicima treba da definišu zahteve kvaliteta, a pre svega veličinu čestica kao parametar kvaliteta zeolita sortimenata.

LITERATURA

[1] http://minerals.usgs.gov/minerals /pubs /commodity/zeolites/

[2] F.A. Mumpton, P.H. Fishman, The Application of Natural Zeolites in Animal Science and Aquaculture. J. ANIM. SCI., 45(1977), p.1188

[3] www.bearriverzeolite.com

[4] http://www.stcloudmining.com

[5] www.steelheadspecialtyminerals.com

[6] www.zeoinc.com

[7] www.zeolite.com.au

[8] http://www.pratley.com

[9] http://www.rotamadencilik.com.tr/

[10] http://www.zeocem.com/

[11] http://www.zeocat.es

[12] F.A. Mumpton, Colloquium Paper, La roca magica: Uses of natural zeolites in agriculture and industry. Proc. Natl. Acad. Sci. USA, 96(1999), p.3463

[13] O. Díaz Rizo, E. F. Herrera Peraza, Multi-elemental characterization of Cuban natural zeolites. J. Radioanal. Nucl. Chem. 212(1997), No 1-2, p.255

[14] T. Armbruster, Clinoptilotite-heulandite: applications and basic research, Zeolites and Mesoporous Materials at the dawn of the 21st century. Proceedings of the 13 International Zeolite Conference, Montpellier, France. Studies in Surface Science and Catalysis, 135(2001), p. 13

[15] L. S. Gadekar, S. S. Katkar, K. N. Vidhate, B. R. Arbad, M. K. Lande, Modification, characterization and

catalytic potency of modified natural zeolite for Knoevenagel condensation reaction. Bulletin of the Catalysis Society of India, 7(2008), p. 76

[16] G. V. Tsitsishvili, N. S. Skhirtladze, T. G. Andronikashvili, V. G. Tsitsishvili, A. V. Dolidze, Natural zeolites of Georgia: Occurrences, properties, and application, Studies in Surface Science and Catalysis, 125(1999), p. 715

[17] D. L. Bish, and J. W. Carey, Thermal Behavior of Natural Zeolites, Rev. Mineral. Geochem., 45(2011), p. 403

[18] O. Korkuna, R.Leboda, J. Skubiszewska-Ziba, T. Vrublevs'ka, J. Gun'ko, V.M. Ryczkowski, Structural and physicochemical properties of natural zeolites: clinoptilolite and mordenite, Microporous Mesoporous Mater. 87(2006), p. 243

[19] D. Kalló, Wastewater purification in Hungary using natural zeolites, In: Natural Zeolites ’93: Occurrence, Properties, Use. Ming D W, Mumpton F A, editors. Brockport, NY: Int. Comm. Nat. Zeolites, (1995), p. 341

[20] A. A. Filippidis, Environmental, industrial and agricultural applications of Hellenic Natural Zeolite, Hellenic Journal of Geosciences, 45(20109, p. 91

[21 A. H. Englert, J. Rubio, Characterization and environmental application of a Chilean natural zeolite, Int. J. Miner. Process, 75(2005), No 1-2, p. 21

[22] K. Saltali, A. Sari, M. Aydin, Removal of ammonium ion from aqueous solution by natural Turkish (Yıldızeli) zeolite for environmental quality, J. Hazard. Mater, 141(2007) No.1, p. 258

[23] A. Godelitsas, P. Misaelides, A. Filippidis, D. Charistos, I. Anousis, Uranium sorption from aqueous solutions on sodium-form of HEU-type zeolite crystals, J. Radioanal. Nucl. Chem. 208(1996), No. 2, p. 393

[24] P. Misaelides, Application of natural zeolites in environmental remediation: A short review, Microporous Mesoporous Mater. 44(2011), No.1-3, p. 15

[25] R. Leyva-Ramos, J. E. Monsivais-Rocha, A. Aragon-Piña, M. S. Berber-Mendoza, R. M. Guerrero-Coronado, P. Alonso-Davila, J. Mendoza-Barron, Removal of ammonium from aqueous solution by ion exchange on natural and modified chabazite, J. Environ. Manage., 91(2010), p. 2662

[26] D. W. Ming and E. R. Allen, Use of natural zeolites in agronomy, horticulture, and environmental soil remediation, Rev. Mineral. Geochem., 45 (2001), p. 618

[27] C. Colella, Natural zeolites and environment, Stud. Surf. Sci. Catal., 2007, Chapter 27, p. 999

[28] P. Cappelletti, G. Rapisardo, B. de Gennaro, A. Colella, A. Langella, S. F. Graziano, D. L. Bish, M. de Gennaro, Immobilization of Cs and Sr in aluminosilicate matrices derived from natural zeolites, J. Nucl. Mater., 414(2011), p. 451

[29] A. Filippidis, G. Papastregios, N. Apostolidis, S. Filippidis, I. Paragios, C. Sikalidis, Purification of urban wastewaters by Hellenic natural zeolite, Bulletin of the Geological Society of Greece, 43(2010), No.5, p. 2597

[30] G. Mertens, R. Snellings, K. Van Balen, B. Bicer-Simsir, P. Verlooy, J. Elsen, Pozzolanic reactions of common natural zeolites with lime and parameters affecting their reactivity, Cem. Concr. Res., 39(2009), No.3, p. 233

[31] M. Doldi, P. Cappelletti, G.Cerri, M. Gennaro, R. Gennaro, A. Langella, Zeolitic tuffs as raw materials for lightweight aggregates., Key Eng. Mater., 2004, No. 264-268, p. 1431

[32] R.de' Gennaro, P. Cappelletti, G. Cerri, M. de' Gennaro, M. Doldi, A.

Langella, Zeolitic tuffs as raw materials for lightweight aggregates, Appl. Clay Sci., 25(2004), No.1-2, p. 71

[33] V. Lilkov, O. Petrov, V. Petkova, N. Petrova, Y. Tzvetanova, Study of the pozzolanic activity and hydration products of cement pastes with addition of natural zeolites, Clay Miner., 46(2011), p. 241

[34] V. Lilkov, O. Petrov, Y. Tzvetanova, Rheological, porosimetric, and SEM studies of cements with additions of natural zeolites, Clay Miner., 46(2011) p. 225

[35] S. J. Chipera, D. L. Bish, Rehydration kinetics of a natural analcime, Eur. J. Mineral., 22(2010), p. 787

[36] C. Colella, A critical reconsideration of biomedical and veterinary applications of natural zeolites, Clay Miner., 46(2011), No. 2, p. 295

[37] Z. Polat, Integrated approach to whey utilization through natural zeolite adsorption/desorption and fermentation, [Dissertation], The Graduate School of Engineering and Sciences, Izmir, 2009, p. 209

[38] C. Orha, F. Manea, A. Pop, G. Burtica, I. F. Todea, Obtaining and Characterization of Zeolitic Materials with Antibacterial Properties, Rev. Chim., 59(2008), No. 2, p. 173

[39] Yu. I. Tarasevich, I. G. Polyakova, V. E. Polyakov, Microcalorimetric Study of the Interaction between Water and Cation-Substituted Clinoptilolites, Colloid J., 65(2003), No. 4, p. 493

[40] B. Tomazović, T. Ćeranić, G. Sijarić, The properties of the NH,-clinoptilolite, Zeolites, 16(1996) No.4, p. 301

[41] M. Trgo, J.Perić, Interaction of the zeolitic tuff with Zn-containing simulated pollutant solutions, J. Colloid Interface Sci., 260(2003), No. 1, p. 166

[42] P. Misaelides, V.A. Nikashina, A. Godelitsas, P.A. Gembitskii, E.M. Kats, Sorption of As(V)-anions from aqueous solutions by organo-modified natural zeolitic materials, J. Radioanal. Nucl. Chem. 227(1998), No. 1-2, p. 183

[43] J. Mendoza-Barrón, A. Jacobo-Azuara, R. Leyva-Ramos, M.S. Berber-Mendoza, R. M. Guerrero-Coronado, L. Fuentes-Rubio, J.M. Martínez-Rosales, Adsorption of arsenic (V) from a water solution onto a surfactant-modified zeolite, Adsorption, 17(2011), No. 3, p. 489

[44] L. Ćurković, M. Trgo, M. Rožić, N. V. Medvidović, Kinetics and thermodynamics study of copper ions removal by natural clinoptilolite, Indian J. Chem. Technol., 18(2011), No. 2, p. 137

[45] M. Trgo, J. Perić, N. V. Medvidović, A comparative study of ion exchange kinetics in zinc/lead-modified zeolite-clinoptilolite systems, J. Hazard. Mater., 136(2006), No. 3, p.938

[46] J. A. Simpson, R. S. Bowman, Nonequilibrium sorption and transport of volatile petroleum hydrocarbons in surfactant-modified zeolite, J. Contam. Hydrol., 108(2009), No. 1-2, p. 1

[47] H. Faghihian, R. S. Bowman, Adsorption of chromate by clinoptilolite exchanged with various metal cations, Water Res., 39(2005), No. 6, p. 1099

[48] E. J. Sullivan, R. S. Bowman, I. A. Legiec, Sorption of Arsenic from Soil-Washing Leachate by Surfactant-Modified Zeolite, J. Environ. Qual., 32(2003), No. 6, p. 2387

[49]. R. S. Bowman, Applications of surfactant-modified zeolites to environmental remediation, Microporous Mesoporous Mater., 61(2003), No. 1-3, p. 43

[50] M. Tomašević-Čanović, A. Daković, G. Rottinghaus, S. Matijašević, M. Duričić, Surfactant modified zeolites - new efficient adsorbents for myco-

toxins, Microporous Mesoporous Mater.,61(2003), No. 1-3, p. 173

[51] A. Vujaković, M. Tomašević-Čanović, A. Daković, V. Dondur, The adsorption of sulphate, hydrogen-chromate and dihydrogenphosphate anions on surfactant-modified clinoptilolite, Appl. Clay Sci. , 17(2000), No. 5-6, p. 265

[52] A. Daković, M. Tomašević-Čanović, G. Rottinghaus, V. Dondur, Z. Mašić, Adsorption of ochratoxin A on octadecyldimethyl benzyl ammonium exchanged-clinoptilolite-heulandite tuff, Colloids Surf. B., 30(2003), No. 1-2, p. 157

[53] T. Stanić, A. Daković, A. Živanović, M. Tomašević-Čanović, V. Dondur, S. Milićević, Adsorption of arsenic (V) by iron (III)-modified natural zeolitic tuf, Environ. Chem. Lett., (2009), p. 161

[54] D. Krajišnik, A. Daković, M. Milojević, A. Malenović, M. Kragović, D. B. Bogdanović, V. Dondur, J. Milić, Properties of diclofenac sodium sorption onto natural zeolite modified with cetylpyridinium chloride, Colloids Surf. B , 83(2011), p. 165

[55] Š. Cerjan Stefanović, N. Logar Zabukovec, K. Margeta, N. Novak Tušar, I. Arčon, K. Maver, J. Kovač, J. Kaučič, Structural investigation of Zn2+ sorption on clinoptilolite tuff from the Vranjska Banja deposit in Serbia, Microporous Mesoporous Mater., 105(2007), p. 251

[56] M. Šiljeg, S.C. Stefanović, M. Mazaj, N. Tušar, I. Arčon, J. Kovač, K. Margeta, N.Z. Logar, Structure investigation of As(III)- and As(V)-species bound to Fe-modified clinoptilolite tuffs, Microporous Mesoporous Mater. 118(2009), No. 1-3, p. 408

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Radmilo Nikolić, Nenad Vušović*, Igor Svrkota*, Branislav Mihajlović***

POSITION OF SERBIAN COPPER PRODUCTION COMPLEX ON THE WORLD MARKET

Abstract

This paper presents the status, importance and role of copper in development the modern world economy. The main features of the world copper market are analyzed, such as: trends in consumption – cumulative and per capita, trends in production, exploitation reserves of copper – cumulative and by exploitation period, and finally the impact of new mining projects to projection of balance and imbalance of supply and demand on the world copper market. An analysis of the Serbian copper complex position on the world market is presented, along with comparison of copper resources between Serbia and the world. Also, the cost curve and position of the Serbian copper production complex are presented, accompanied by analysis of influencing factors that define the position of the Serbian copper production on the global market, as well as comparison with copper mining and processing companies in the world. Finally, a suggestion for possible routes of strategic activities is introduced, aiming to improve the existing position of the Serbian copper production on global market.

***Keywords**: market, strategy, copper, trends, reserves, resources*

INTRODUCTION

Copper production has a long history in Serbia. Excavation and processing of copper ore has lasted continuously for more than a century. Copper production complex went through different periods during that time, but it has always had very strong influence to industrial development in various social and political circumstances. In general, it could be said that copper production in Serbia had a constant growth till 70's of the last century. Then in 80's and 90's, there was stagnation, and finally a massive fall down in the first decade of this century. However, in the last couple of years, the Serbian Government took over the authority on copper production and started the process of reconstruction, modernization and stabilization of production facilities. In 2010, this program was started to apply through the massive technological and organizational improvements followed by huge investments. Due to the importance and influence of this program to entire Serbian development, this paper evaluates the current position of Serbian copper production complex on the world market and provides the projection of this position in the future based on current program.

IMPORTANCE OF COPPER FOR GLOBAL INDUSTRIAL DEVELOPMENT

The oldest objects made of copper come from 6,000 BC. The usage of copper for primitive tools and weapons is characteristic for entire epoch in the human history, known as the Copper Age. Also, in the next

* *University of Belgrade, Technical Faculty in Bor*
** *RTB - RBB Bor*

epoch, known as the Bronze Age, copper was an important factor since bronze is an alloy of copper and tin. The oldest known copper mines were situated in Sinai desert, Cyprus (that is why Latin name for copper was cuprum) and also Rudna Glava near Bor, eastern Serbia.

The New Age with its rapid scientific and industrial development brought a significant need for copper. Inventions of dynamo (1870) and AC motor (1887) started the era of electrical engineering, which made copper one of the most important and needed metals, up to the present day.

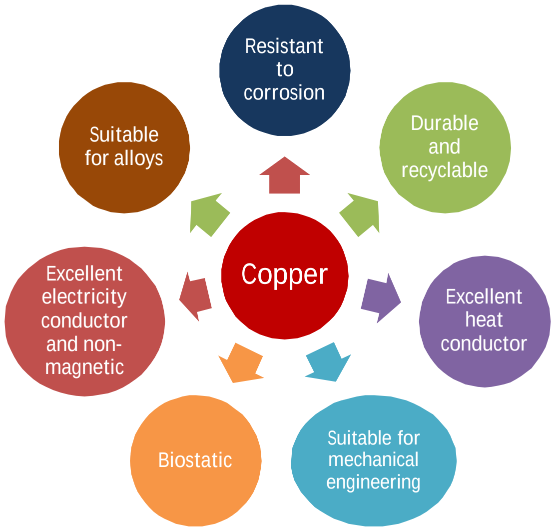

Figure 1 *Review of the most imortant properties of copper [1]*

Beside excellent electrical conductivity, copper has many other useful properties that make it very important ad irreplaceable in modern global industry. Figure 1 shows its main properties that make copper so usable.

WORLD COPPER MARKET

Trends of Consumption – Cumulative and per Capita

The twentieth century brought a huge development and expansion of industrial production. At the beginning of century, there was a global redistribution of power, which meant that big colonial forces were not the most powerful countries anymore; the new leaders were countries with the best developed capitalism of that time, such the US and Germany.

That was the period of strong industrial development which caused the urge for raw material. Copper production growth curve is almost exponential. At the beginning of 20th century, the global copper consumption was slightly below one million tons per year (Figure 2), while at the end of the century, it was almost twenty times higher. Such growth trend continued in the 21st century too, and in 2011 it almost reached 20 Mt per year, or per capita - 3 kg/year

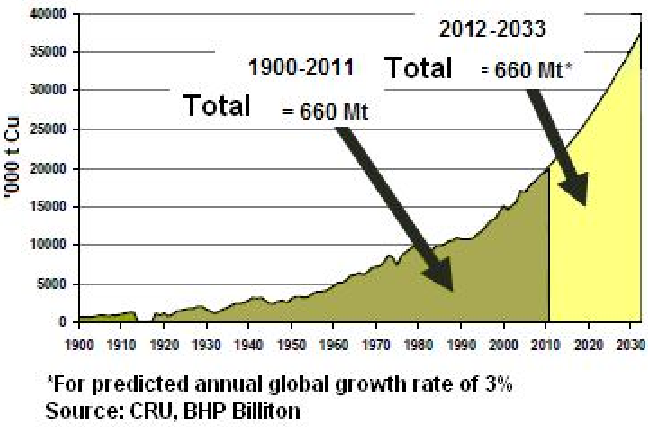

Figure 2 *Global copper consumption (cumulative) and projection till 2033 [2]*

Trends of Production

Copper production has very important position in the global industrial growth. Global need for raw material rises rapidly from the beginning of last century, especially for nonferrous metals and copper, as the most important of them. Such trend has even been boosted in the last decade, due to the industrial expansion of China, some Far East countries and BRICS countries.

Even with such growth trend, copper production managed to follow it. However, the projections of further growth lead to concerns about possible misbalance between the exponential consumption growth and limited production possibilities. The fact is that trends of global industrial and population growth superimpose, which would make an additional impact to demands on copper in the future. Figure 2 shows that predicted copper consumption in the next 22 years will almost match total consumption in the entire human history till today. The global copper production would not be able to follow such trends.

Exploitable Copper Reserves - Quantitative and per Years

Along with expansion of copper production, the copper ore reserves became exhausted. Such situation forced the new exploration works in order to find the new ore deposits. The main trend in properties of new deposits was a decrease of ore grades and an increase of deposit depths.

As a consequence, same amount of metal production required excessive mining and mineral processing works. Copper production industry had to follow the requirements regardless on circumstances, which meant that production costs had to be reduced. That was accomplished through the increase of productivity, technological innovations and organizational improvements.

As the result of intense exploration works, the global copper ore reserves had a constant increase. However, copper production also increased, which meant that in any moment the existing copper ore reserves provided 30 to 50 years of production. The current reserves reach 630 Mt of copper, which would be sufficient, according to the predictions, for the next 30 years.

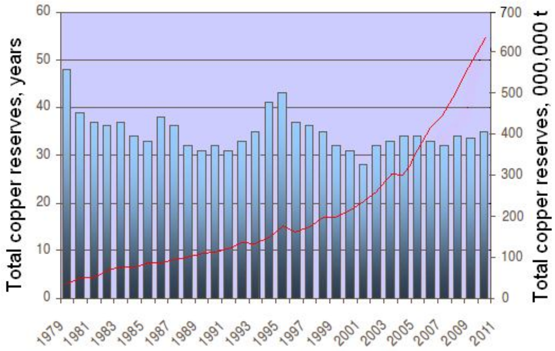

Figure 3 *Exploitable copper reserves – quantitative and per years [4]*

New Projects – Balance and Misbalance of Supply and Demand

The global level of mining and mineral processing output slightly exceeds 16 Mt of copper in 2011. Analysis of market flow shows that production will be able to match the demands for several more years, but then it will start to lag behind. Figure 4 shows that already in 2018 misbalance of supply and demand would reach 5 Mt of copper and 6 Mt in 2020. This means that the gap would have to be closed by the new copper mines, thus providing the global output increase of 1 Mt of copper annual rate.

The new projects and new mines are developed in unfavorable circumstances, because ore grades are reduced and amount of overburden is grown. This causes the increase of costs. Currently, majority of new mines are opened in deposits with 0.5 to 0.6% of Cu, with average cost price of 6,000 US$/t. There is also a trend of increase by – products share in total income.

One of the consequences of aggravation in basic copper production is a compromise between political and geological risks. It means that copper production will move to the developing countries, with higher business risk, more and more in the future. Another one is a compromise between capital and operational costs. It means that decreasing quality of available resources causes abandoning of principles like “high capital investments require low operational costs”.

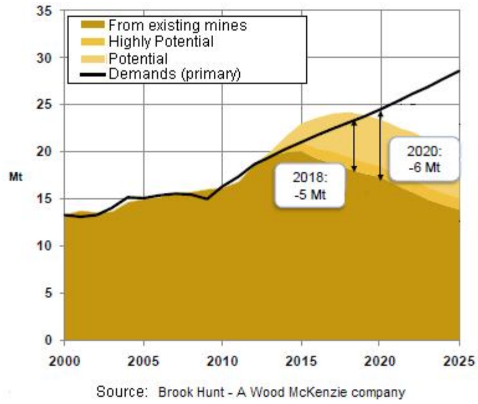

Figure 4 *Trend of global copper mining production [2]*

That is why there are the intense global activities in developing new projects for mining and mineral processing of copper ores. In total, there are some 7,000 of projects in progress. A distribution of projects by ten most important countries is given in Figure 5. It should be added that only several percent of total number of projects will be completely realized.

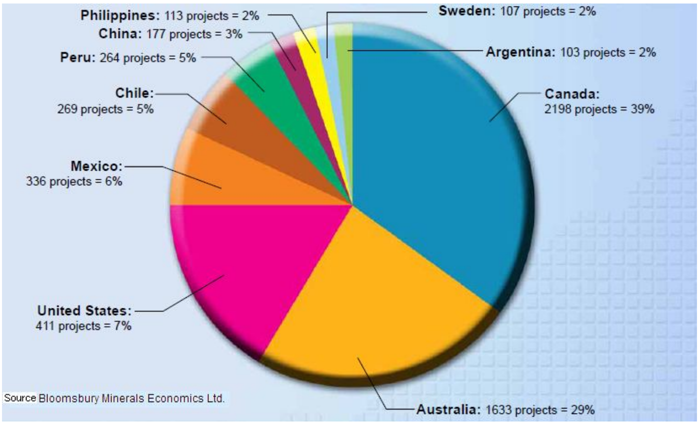

Figure 5 *Schedule of projects for exploitation and primary processing of copper in the top ten countries in the world [5]*

Long – term Predictions on position of copper at the world market

The expected increase of demand of copper on the world market reaches 10 Mt in the next 10 – 15 years (Figure 4). The estimations of leading analysts say that the existing level of reserves should be enough for that period. Some analysts even predict slight excess of supplies in the middle of decade. This situation is explained by increased utilization of scrap (recycled copper).

General assessments of leading analysts say that the predicted cost price of 6,000 US$/t (2.77 US$/lb) in next decade should be sufficient (and necessary) to match increasing market demands and consumption trends mentioned earlier. The lowest cost price in the new projects is 3,000 US$/t, the highest is 8,000 US$/t, while 6,000 US$/t price meets 75 % the future requirements.

It should be also kept in mind that increase of production costs is structural, with the following key components:

- Geographical factors – manpower,
- Geological factors-exhaustion of existing ore deposits, and
- Increasing energy crisis.

Increased industrialization of developing countries will increase the demands on copper on the world market, regardless to the prediction of substitution growth on some markets in the first part of decade.

Prediction of average direct production costs is 0.94 US$/lb, while intensity of capital investment is 12,000 US$/t (total investments / average annual output).

Projected Mean IRR (Internal Rate of Return) is 15%.

Analyses of sensibility of predicted cost price (2.77 US$/lb) show its high sensitivity to the market expectations of mining companies. Level of capital costs is also a key factor for the project economics. As it was mentioned before, their mean level is 12,000 US$/t, but globally it varies from 6,000 US$/t (for high – graded deposits) to 22,000 US$ (for huge porphyry low – graded deposits).

If the global trends of copper consumption growth are compared with the global GDP growth, it can be concluded that this relation was approximately 0.6 till 90's, then it reached 1.03 between 1990 and 2000, and it stabilized at 0.64 afterwards.

The estimations say that approximately 20% of the global copper consumption should be covered by recycling in the future. The share of recycled copper will vary from 14% to 21% and it would be dependable on absolute values of prices of copper and scrap on the market, as well as their relative relation.

POSITION OF THE SERBIAN COPPER PRODUCTION COMPLEX ON THE WORLD MARKET

Serbia has a long term history of existence on the global copper market. As it was mentioned before, until 70's the position of Serbia was very important, with 2% share of global production. Serbian copper resources were well known by their ore grades and participation of precious metals. Serbian copper production complex was globally highly appreciated at that time.

The end of golden era of Serbian copper production came with decrease of ore grades in ore deposits, increasing depths of ore deposits and many other factors, such as increase of waste in copper mining and falling of prices on the world market. All these factors had a negative influence to the business economy.

Comparison of Serbian and Global Mining and Mineral Processing Resources

After nearly 80 years of copper production in mainly comfortable circumstances, the ore grades started to reduce rapidly. At the end of 70's, content of copper in the ore has fallen down below 1% and such trend is a constant. Currently, the excavated ore has 0.25 to 0.28% of copper, while projections for the next decade predict 0.33% Cu as the mean value. It was mentioned before that the global trend for new projects is approximately 0.5 to 0.6% of Cu, which means that the quality of Serbian resources planned for next decade is twice lower than global resources. The mean ore grades in Serbian copper mining are shown in Figure 6.

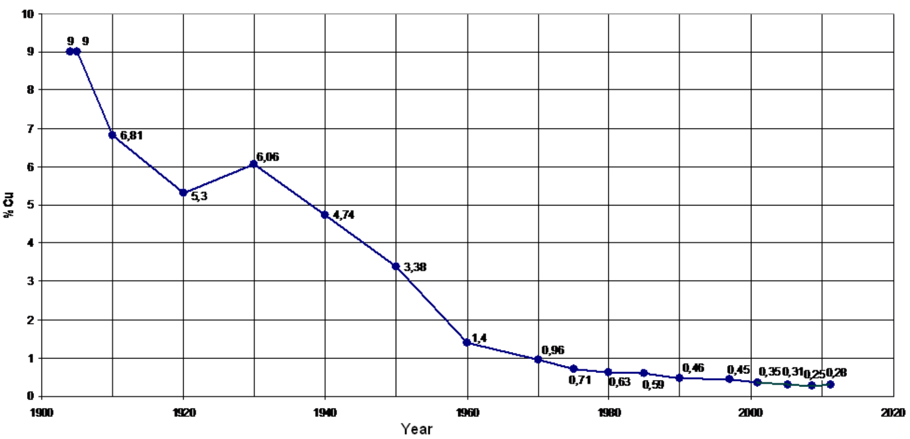

Figure 6 *Mean ore grades in the Serbian copper mining [10]*

When the new copper mines are designed, usual amount is 400 to 800 t of excavated bulk material for 1 t of copper. In Serbia, it exceeds 1,000 t. If the amount of excavations per ton of produced copper is compared in the world and in Serbia, based on projections for the next decade, it can be concluded that the Serbian copper produc tion would require 2.5 times more excavations than others. Consequently, this means that the ore reserves included in the Serbian projections of copper mining in the next ten years will not be able to provide a competitive position of Serbian copper production on the world market.

While there are the new projects and mine designs with projected 6,000 US$/t cost price around the world, at the same time the Serbian estimations of cost price reach 8,000 US$/t. This is a serious risk in terms of future existence the Serbian copper production complex on the world market.

Cost Price Curve and Position of Serbian Copper Production Complex in it

If mining company wants to survive on the world market (and provide profitability), it needs to place itself and be competitive with the other mining companies. Price of metal on the world market is not valid for evaluation the company competitiveness.

Price of metal is unstable and mainly out of the producer control. However, the costs are controllable. Position on the cost price curve defines the competitiveness and business risks for any company, which means that efforts have to be made in order to cut the costs. Cost price curve for 2011 is shown in Figure 7.

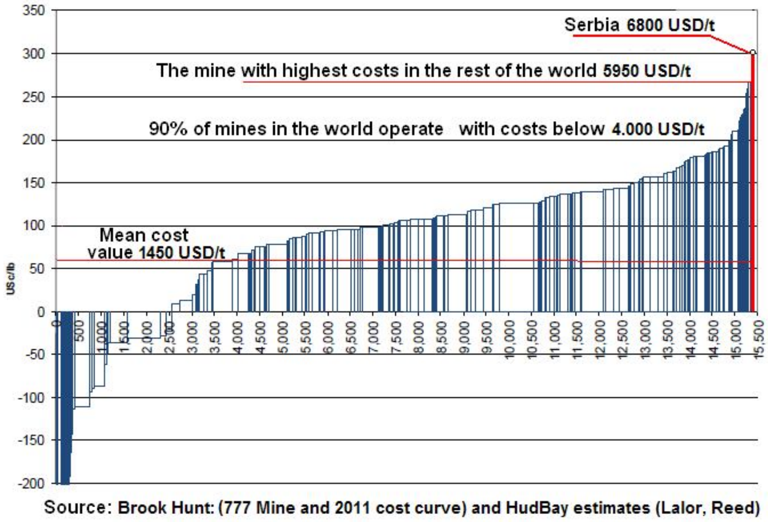

Figure 7 *Position of the Serbian copper production complex in the global cost curve [3]*

The main strategy or long term projection for each mine ore mining company is to provide a good position on the cost curve. The aim is to reach lower left part of curve. Figure 7 shows that position of Serbia is at the right end, with costs reaching 6,800 US$/t, which is extremely uncompetitive. Figure 7 also shows that 17% of the global copper production comes as a byproduct, where the main product is usually gold, that the mean cost value is 1,450 US$/t and 90% of companies in the world produce copper with the cost price lower than 4,000 US$/t. The highest recorded cost price in the world, apart from Serbia, is 5,950 US$/t.

CONCLUSION

Problems that the Serbian copper production complex has had to deal with for a long time are the poor quality of ore reserves, increasing depth of ore deposits and bulk of excavations needed to produce a ton of copper. That is why its competitiveness on the world market is poor. In order to improve such position, it is necessary to raise the quality of ore reserves and reduce bulk of excavations. This is possible to achieve through the intense exploration works, in order to discover the new deposits and also through including some existing ore deposits into programs of strategic development. The Borska Reka is an example of ore body whose properties are more favorable than properties of the currently active ore deposits.

There are some other issues to be solved, too. The most important are determination of permanent company status, definition of internal organization model and financial stability. Defining of these strategic issues, along with the improved production management, technological discipline and more rational business decisions should enable profitable production and long – term sustainable development and finally more competitive position on the world market.

REFERENCES

[1] AQM Copper Inc, Copper fundamentals, 2010.

[2] Boliden Group, Update and Market Outlook, CMD 2011.

[3] Brook Hunt, 777 Mine and 2011 Cost Curve, 2011.

[4] Indian Bureau of Mines, Market Survey on Copper, Ngapur, 2011.

[5] Interra Resource Intelligence, Copper – The New Fundamentals, Mineral Exploration Roundup, 2011.

[6] Mihajlović, B., Exploration of Possibilities for Economic Underground Mining of Existing Ore Reserves. PhD Thesis, Bor, 2003 (In Serbian).

[7] Operative Production Documentation of RTB Bor Group (In Serbian).

[8] Page, C., Steffen, O., Adding Shareholder Value By Strategic Mine Planning, SRK, October, 1998.

[9] Rio Tinto, Exploration and Acquisition in the Global Mining Industry, World Mining Investment Congress, London, 2010.

[10] Stamenković, Đ., Copper From Bor, Past – Present - Future, Bor 1997 (In Serbian).

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Radmilo Nikolić, Nenad Vušović*, Igor Svrkota*, Branislav Mihajlović***

POLOŽAJ SRPSKOG KOMPLEKSA PROIZVODNJE BAKRA NA SVETSKOM TRŽIŠTU

Izvod

U radu je dat komparativni prikaz položaja, značaja i uloge bakra u razvoju moderne svetske privrede i u Srbiji. Analizirane su glavne karakteristike svetskog tržišta bakra: trendovi potrošnje – kumulativni i po stanovniku, trendovi proizvodnje, eksploatacione rezerve bakra – kumulativne i po veku trajanja, kao i uticaj novih rudarskih projekata na projekciju balansa, odnosno debalansa ponude i tražnje bakra na svetskom tržištu. Izvršena je analiza i dat je prikaz položaja kompleksa proizvodnje bakra Republike Srbije na svetskom tržištu, zatim upoređenje resursa Srbije sa resursima bakra u svetu. Dat je prikaz krive cene koštanja i položaj kompleksa proizvodnje bakra u Srbiji na njoj, izvršena analiza uticajnih faktora koji definišu položaj Srpskog kompleksa proizvodnje bakra na svetskom tržištu kao i upoređenje sa kompanijama za otkopavanje i preradu bakra u svetu. Na kraju je dat predlog mogućih pravaca strateških aktivnosti usmerenih na popravljanje postojećeg položaja kompleksa proizvodnje bakra Republike Srbije na svetskom tržištu bakra.

Ključne reči: *tržište, strategija, bakar, trendovi, rezerve, resursi.*

UVOD

Proizvodnja bakra u Srbiji ima dugogodišnju istoriju. Eksploatacija i prerada ruda bakra kontinuirano se vrše već više od sto godina. U tom periodu kompleks proizvodnje bakra je prolazio kroz različite periode i imao je snažan uticaj na impozantan privredni razvoj koji se odvijao u vrlo burnim društveno – socijalnim okolnostima. Generalno gledajući, do kraja sedamdesetih godina prošlog veka može se oceniti da je proizvodnja bakra u Srbiji imala rast, osamdesetih i devedesetih godina je došlo do stagnacije, dok je tokom prve decenije dvadeset prvog veka došlo do značajnog pada proizvodnje i urušavanja nekada moćnog sistema za proizvodnju i preradu bakra. Početkom druge decenije ovog veka, odnosno u poslednjih nekoliko godina, Republika Srbija je preuzela nadležnost nad proizvodnjom bakra i započela program rekonstrukcije, modernizacije i stabilizacije njenih proizvodnih kapaciteta. Taj program je 2010. god. započeo da se konkretizuje kroz jedan sveobuhvatan tehnološki i organizacioni zahvat, uz vrlo obiman nivo investicija. Zbog značaja i uticaja pomenutog programa na ukupan razvoj Republike Srbije u celini, u radu je data stručna ocena sadašnjeg položaja kompleksa proizvodnje bakra na svetskom tržištu, kao i projekcija budućeg položaja u skladu sa navedenim razvojnim programom.

* *Univerzitet u Beogradu, Tehnički fakultet u Boru*
** *RTB - RBB Bor*

ULOGA BAKRA U RAZVOJU MODERNE SVETSKE PRIVREDE

Najstariji nađeni predmeti od bakra datiraju iz vremena oko 6.000 godina pre Nove ere. Njegova primena za izradu primitivnih alata i oružja karakteriše čitavu jednu epohu u razvoju čovečanstva, poznatu kao bakarno doba. I u sledećoj epohi, bronzanom dobu, koje je nastupilo oko 3.000 godina Nove ere, bitan činilac je bio bakar, od koga je napravljena tvrda legura – bronza. U bronzanom dobu je potpuno istisnuta upotreba kamenih alatki, a smatra se da je ovo doba završeno tek u Srednjem veku. Najstariji rudnici bakra su u to vreme bili u Sinajskoj pustinji, zatim na Kipru, odakle potiče i latinski naziv bakra – cuprum. Među najstarije rudnike bakra spada i Rudna Glava u okolini Bora.

Sl. 1. *Pregled najvažnijih osobina bakra [4]*

Novi vek sa naglim razvojem u nauci i industriji doveo je do velikih potreba za bakrom. Pronalaskom dinamo mašine (1870. god.) i motora naizmenične struje (1887. god.), počela je era elektrotehnike, koja je bakar učinila neophodnim metalom, što traje do današnjih dana.

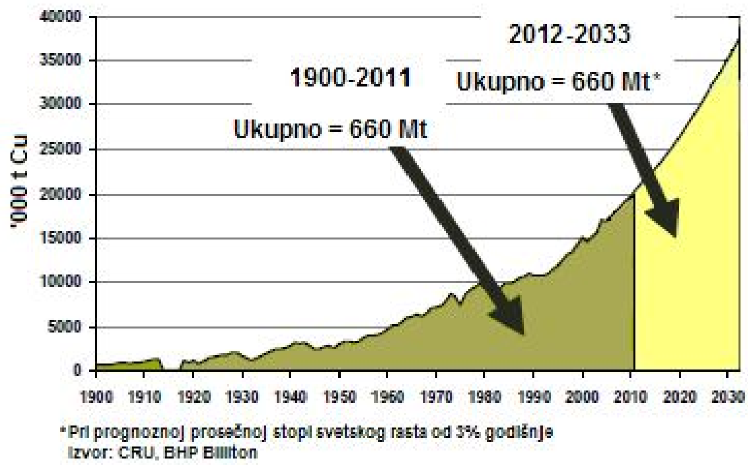
Osim odlične elektroprovodljivosti, bakar ima još niz drugih korisnih osobina koje ga čine jednim od nezamenljivih metala u modernoj svetskoj industriji. Na Sl. 1 dat je prikaz njegovih glavnih osobina zbog kojih se primenjuje u industriji.

KARAKTERISTIKE SVETSKOG TRŽIŠTA BAKRA

Trendovi potrošnje - kumulativni i po stanovniku

Dvadesti vek karakteriše snažan razvoj i ekspanzija industrijske proizvodnje. Globalna preraspodela moći početkom veka se sa nekada moćnih kolonijalnih sila prelila na stranu najsnažnije razvijenih kapitalističkih zemalja toga doba, koje su predvodile Sjedinjene Države i Nemačka.

U tom periodu sve snažniji zamah industrijskog razvoja je stvorio glad za sve većim količinama sirovina. Bakar beleži eksponencijalnu krivu rasta potrošnje. Početkom dvadesetog veka svetska potrošnja bakra je bila na nivou nešto manjem od milion tona godišnje (vidi sl. 2), da bi se na njegovom kraju skoro dvadeset puta uvećala. Trend takvog rasta potrošnje se nastavio i u XXI veku, te je na kraju 2011. god. potrošnja dostigla nivo od 20 miliona tona godišnje, što po stanovniku zemlje iznosi približno 3 kg/god.



Sl. 2. *Kumulativna potrošnja bakra u svetu i prognoza do 2033. god. [2]*

Trendovi proizvodnje

Industrija proizvodnje bakra u svetu zauzima visoku stratešku poziciju u ukupnom privrednom rastu. Tokom čitavog prethodnog veka i do današnjih dana u svetu je prisutna velika potreba za sirovinama, a naročito za obojenim metalima, gde bakar zauzima vodeće mesto. Taj trend je u zadnjih desetak godina značajno pojačan eksplozivnom ekspanzijom privrednog razvoja Kine, pojedinih dalekoistočnih zemalja Azije i BRIK-a.

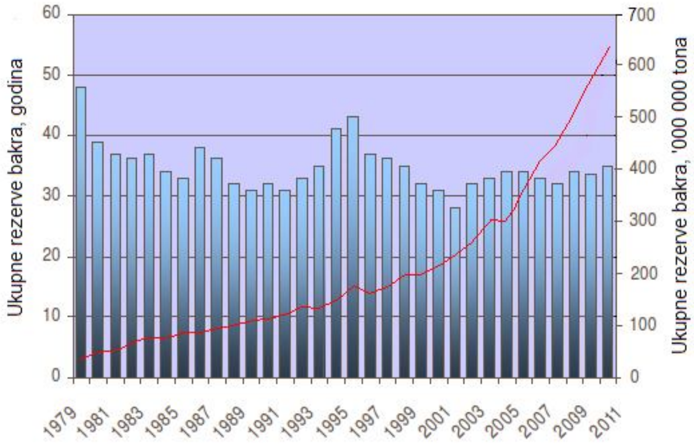
I pored takvog trenda, proizvodnja bakra je uspevala da vrlo uspešno prati eksponencijalni rast potrošnje. Međutim, napred pomenuti eksplozivan rast potrošnje bakra u pojedinim zemljama i prognoze njegovog daljeg rasta, po prvi put su dovele do toga da se već nagoveštava pojava debalansa između eksponencijalno rastuće potrošnje i ograničenih mogućnosti proizvodnje. Naime, trendovi ubrzanog industrijskog rasta i porasta stanovništva u svetu se superponiraju i u budućnosti će još više pojačati pritisak tražnje na tržište bakra. Sa Sl. 2 se može videti da je projekcija potrošnje bakra u svetu takva da se predviđa da se u narednih 22 god. potroši maltene ista količina bakra kao u ukupnoj istoriji čovečanstva do danas. Proizvodnja bakra u svetu te trendove neće moći da prati.

Eksploatacione rezerve bakra - količinski i po godinama

Paralelno sa ekspanzijom proizvodnje bakra u svetu postojeće rezerve rude su se intenzivno i sve ubrzanije iscrpljivale. To je imperativno nalagalo da se stalno istražuju nove rezerve koje bi nadomestile trošenje postojećih. Karakteristika takvog kretanja je bio sve niži kvalitet novih resursa, sa sve nižim sadržajima korisnih komponenti i na sve većim dubinama.

Takav trend je neminovno nametao potrebu da se za istu količinu metala otkopava i prerađuje sve veća količina iskopina. Industrija proizvodnje i prerade bakra je u tim okolnostima morala da stalno traži rešenja kojima bi parirala takvom trendu, odnosno morala je da stalno snižava jedinične troškove proizvodnje, kroz dizanje produktivnosti, tehnološke inovacije i organizaciona poboljšanja.

Kao rezultat intenzivnih geoloških radova na istraživanju, svetske rezerve bakra su se stalno povećavale, ali je njihov vek trajanja održavan na nivou od 30 do 50 godina. Trenutne eksploatacione rezerve iznose oko 630 miliona tona metala, što prema projekcijama rasta predstavlja rezerve za narednih tridesetak godina (vidi sl. 3).

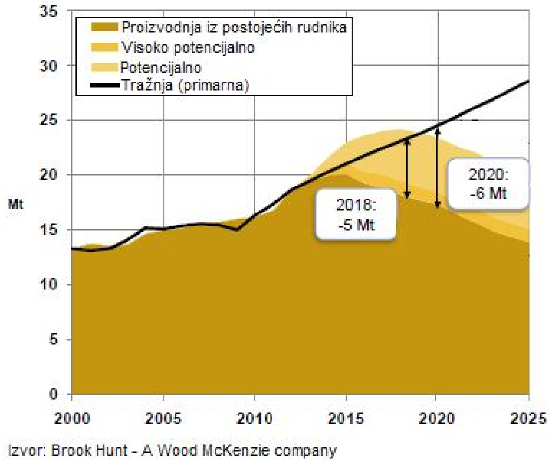


Sl. 3. *Ukupne rezerve bakra u svetu, količinski i po veku trajanja [9]*

Novi projekti – balans/debalans ponude i tražnje

Trenutni nivo rudničke proizvodnje i primarne prerade bakra u svetu iznosi nešto manje od 17 miliona tona godišnje. Analiza kretanja na svetskom tržištu pokazuje da će još nekoliko godina proizvodnja bakra iz postojećih rudnika moći da prati trend potrošnje, a onda će doći do njenog zaostajanja. Sa sl. 4 se vidi da će već 2018. godine debalans ponude i tražnje biti 5 miliona tona bakra, a 2020. godine biće 6 miliona tona. To praktično znači da će uključivanjem novih rudnika u proces proizvodnje u tom periodu morati da se popunjava kapacitet proizvodnje po dinamici od oko 1 milion tona bakra godišnje.

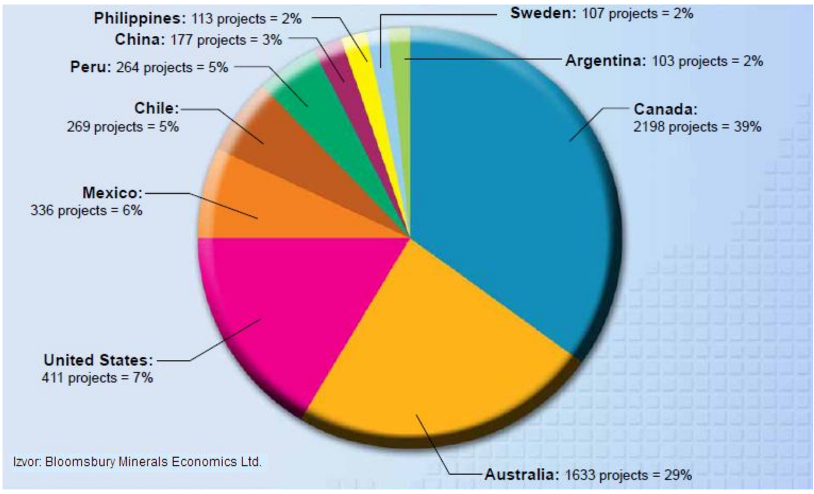
Razvoj novih projekata se odvija u uslovima sve manjeg sadržaja bakra i korisnih metala u rudi, sa sve većom količinom iskopina po toni dobijenog bakra. To podiže cenu koštanja proizvodnje bakra u takvim rudnicima. Trenutno u svetu novi rudarski projekti se rade sa prosečnim sadržajem bakra od 0.5 do 0.6 % i sa prosečnom cenom koštanja od 5.500 USD/t. Pritom planirani prihodi od nus-proizvoda postaju sve uticajniji na ukupnu ekonomiku projekata.



Sl. 4. *Trend rudničke proizvodnje bakra u svetu [2]*

Takođe je karakteristično da u uslovima kada se sve teže obezbeđuju profiti iz bazne proizvodnje bakra, neminovno dolazi do kompromisa između političkih i geoloških rizika. To znači da će se buduća proizvodnja bakra sve više seliti u zemlje u razvoju sa većim rizikom poslovanja. Takođe je sve više prisutan kompromis između kapitalnih i operativnih troškova. To znači da se u uslovima sve nižeg kvaliteta raspoloživih resursa sve više napušta princip po kome visoki nivo kapitalnih investicija automatski traži niži nivo operativnih troškova.

Zbog toga se u svetu intenzivno radi na razradi novih projekata za eksploataciju i primarnu preradu bakra. Ukupno je trenutno u razradi oko 7.000 projekata. Raspored projekata (za deset glavnih zemalja) je dat na sl. 5.



Sl. 5. *Raspored projekata za eksploataciju i primarnu preradu bakra u deset glavnih zemalja u svetu [5]*

POLOŽAJ KOMPLEKSA PROIZVODNJE BAKRA SRBIJE NA SVETSKOM TRŽIŠTU

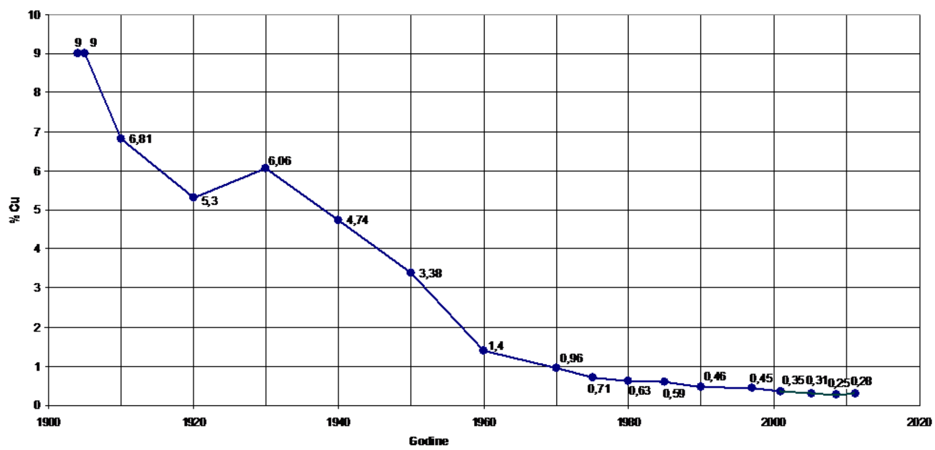
Kompleks proizvodnje i primarne prerade bakra u Srbiji je dugo godina prisutan na svetskom tržištu. Kao što je ranije u ovom radu pomenuto, sve do kraja sedamdesetih godina prošlog veka, taj položaj je bio vrlo konkurentan. Srbija je u to vreme u ukupnoj proizvodnji bakra u svetu učestvovala sa 2 %. Njeni resursi su se isticali po sadržaju bakra i učešću pratećih plemenitih metala. U to vreme kompleks proizvodnje bakra u Srbiji je u svetu imao izuzetan respekt.

Po isteku tog vremena došlo je do sve većeg osiromašenja postojećih rezervi bakra - sve nižeg sadržaja bakra i pratećih metala u eksploatacionim rezervama na sve većim dubinama. Paralelno sa time, uslovi poslovanja u postojećim rudnicima su bivali sve teži. Sve veća količina iskopina po toni proizvedenog bakra i njegova niska cena na svetskom tržištu su sve više pritiskali ekonomiku poslovanja.

Upoređenje resursa za proizvodnju i primarnu preradu bakra Srbije sa resursima u svetu

Posle skoro osamdeset godina eksploatacije i rada u uslovima relativnog blagostanja, krajem sedamdesetih godina prošlog veka srednji sadržaj bakra u proizvedenoj rudi je sišao ispod 1 % i nastavio permanentan dalji pad. Trenutno se eksploatiše ruda sa srednjim sadržajem bakra na nivou od 0.25 do 0.28 %, dok se u planovima za narednih deset godina planira sa srednjim sadržajem bakra od 0.33 %. Napred je navedeno da se u razvoju novih projekata u svetu računa sa srednjim sadržajem od 0.5 do 0.6 % Cu. To znači da su eksploatacioni resursi sa kojima se u Srbiji ulazi u plan za narednih deset godina duplo nižeg kvaliteta od svetskih. Srednji sadržaj bakra u rudi proizvedenoj u Srbiji je dat na sl. 6.

U svetu se pri projektovanju novih rudnika računa sa količinom od 400 do maksimalno 800 tona iskopina po toni proizvedenog bakra. U Srbiji taj odnos iznosi 1.000 t iskopina po toni bakra. Ako se uporede količine iskopina po toni proizvedenog bakra sa kojima se vrše projekcije buduće

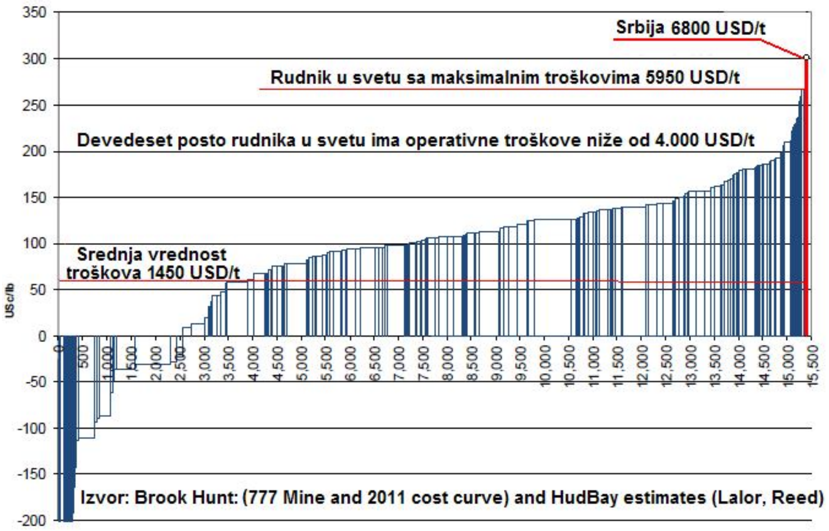


Sl. 6. *Srednji sadržaj ostvaren pri eksploataciji rude bakra u Srbiji [10]*

proizvodnje u svetu i u Srbiji, onda se dolazi do zaključka da će se za proizvodnju tone bakra u Srbiji otkopavati od 1.25 do 2.5 puta više iskopina nego u svetu. To znači da eksploatacione rezerve sa kojima Srbija ulazi u program razvoja za narednih deset godina ne mogu da omoguće njen konkurentan položaj u svetu. Dok svet sa pouzdanom dozom sigurnosti vrši projekcije novih rudnika sa cenom koštanja od 5.500 USD/t, u Srbiji je ta projekcija izvršena sa visokih 8.000 USD/t, što značajno povećava rizik budućeg opstanka njenog kompleksa proizvodnje bakra na svetskom tržištu.

Kriva cene koštanja i položaj kompleksa proizvodnje bakra Srbije na njoj

Da bi neka rudarska kompanija opstala na tržištu (što podrazumeva njenu profitabilnost), mora se pozicionirati tako da bude konkurentna sa drugim rudarskim kompanijama. Upotreba cene metala za



Sl. 7. *Položaj kompleksa proizvodnje bakra u Srbiji na krivoj cene koštanja (konkurentnosti) [3]*

potrebe planiranja ništa ne govori o konkurentnosti kompanije. Cena metala je neizvesna i uglavnom izvan kontrole proizvođača. Ali troškovi (cena koštanja) su podložni kontroli. Pozicija na krivoj cene koštanja proizvodnje identifikuje konku-rentnost poslovanja i rizik od gubitka, što znači da bi cenu koštanja trebalo smanjivati. Kriva cene koštanja (konkurentnosti) u svetu za 2011. god je prikazana na sl. 7.

Ključna strategija ili dugoročna vizija za jedan rudnik ili kompaniju je da obezbedi što bolju poziciju na krivoj cene koštanja proizvodnje bakra. Njena primarna strategija treba da bude stalna težnja da se što bolje pozicionira u donjem (levom) delu krive. Sa sl. 7 se vidi da je položaj kompleksa proizvodnje bakra u Srbiji skroz desno na krivoj, sa cenom operativnih troškova od 6.800 USD/t, što mu daje izuzetnu nekonkurentnost na tržištu. Sa sl. 7 se takođe vidi da se 17 % bakra u svetu dobija iz rudnika kao nus-proizvod, koji povećava prihod od osnovnog proizvoda, obično zlata, da je srednja vrednost troškova proizvodnje bakra 1.450 USD/t a da čak 90 % svetskih kompanija bakra trenutno radi sa cenom koštanja nižom od 4.000 USD/t, dok najviši evidentirani nivo operativnih troškova u svetu iznosi 5.950 USD/t.

ZAKLJUČAK

Osnovni problem koji već duže vreme opterećuje položaj kompleksa proizvodnje bakra u Srbiji predstavlja nizak kvalitet eksploatacionih rezervi rude, njihova sve veća dubina i velika količina iskopina potrebnih za proizvodnju jedne tone bakra. Zbog toga je vrlo nizak stepen njegove konkutentnosti sa ostalim kompanijama u svetu. Sa tog aspekta preporuka je da se učini maksimalan napor za iznalaženje mogućnosti dizanja kvaliteta eksploatacionih rezervi i smanjenje opterećenosti velikim količinama iskopina. To se može postići tako što kompleks proizvodnje bakra u Srbiji treba najozbiljnije razmotriti dosta istraženo i delimično pripremljeno rudno ležište "Borska Reka", koje je u sagledavanjima strategije razvoja nepravedno zapostavljeno. Kvalitet njegovih ukupnih i overenih rudnih rezervi je na znatno višem nivou od onih koje su obuhvaćene u razvojnim programima i nije opterećeno velikim okoličinama iskopina po toni proizvedenog bakra.

LITERATURA

[1] AQM Copper Inc, Copper fundamentals, 2010.

[2] Boliden Group, Update and Market Outlook, CMD 2011.

[3] Brook Hunt, 777 Mine and 2011 Cost Curve, 2011.

[4] Indian Bureau of Mines, Market Survey on Copper, Ngapur, 2011.

[5] Interra Resource Intelligence, Copper – The New Fundamentals, Mineral Exploration Roundup, 2011.

[6] Mihajlović, B., Istraživanje mogućnosti ekonomične podzemne eksploatacije postojećih rezervi bakra. Doktorska disertacija, Bor, 2003.

[7] Operativna dokumentacija

[8] Page, C., Steffen, O., Adding Shareholder Value By Strategic Mine Planing, SRK, October, 1998.

[9] Rio Tinto, Exploration and Acquisition in the Global Mining Industry, World Mining Investment Congress, London, 2010.

[10] Stamenković, Đ., Borski bakar, prošlost–sadašnjost–budućnost, Bor 1997.

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Radmilo Rajković, Mile Bugarin*, Vladan Marinković**

STABILITY ANALYSIS OF THE WASTE DUMP "OŠTRELJSKI PLANIR" OF THE OPEN PIT "BOR" IN A FUNCTION OF WATER QUANTITY**

Abstract

Stability analysis of the waste dump "Oštreljski Planir" was carried out using the Geostudio2007 software for critical profiles determined on 3D model of the site in Gemcom 6 software. The influence of water on the stability of dump is defined by varying the coefficient of pore water in disposed material.
Keywords: *Stability, GeoStudio2007 software, Gemcom 6 software, coefficient of pore water*

INTRODUCTION

In the period from 1975 to 1980, the waste from the open pit "Bor" was dumped in several locations in the vicinity of the open pit, where the external dumps were formed. One of them is the waste dump "Oštrelj" which is also called the "East Dump" or "Cyanidation". It is located in the far east of the open pit Bor next to the former plant Cyanidation which is no longer in operation, because a part of landfill slope for leaching slided in the eighties of the last century and disablee this facility. It is also the highest dump of the open pit "Bor", with the final plane at K +475 m, and foot at level K +375 m. Height of formed landfill is 100 m with slope of 38^0. The lake Robule is situated on the base of this dump on the southeastern side. During the period of dumping on the "Oštrelj" waste dump, the cut-off grade of copper in the ore was much higher than it is today, so there is the possibility of this dump exploitation by leaching or classical excavation. The amount of material in this waste dump is 95 million m^3.[5, 10, 11]

SELECTION OF COMPUTATIONAL PARAMETERS AND CHARACTERISTIC PROFILES

Based on the existing map data, the 3D model of the waste dump "Oštreljski Planir" was developed in the software Gemcom 6 [1, 3, 4, 8, 9, 15], Figure 1. Critical profiles for calculation the stability were defined on this model. 1-1 'passes through a part of the waste dump near the lake "Robule", and profile 2 - 2' passes through a part of the waste dump with maximum height of disposed material. The position of the profile 2 is shown in Figure 2.

The values of the physical - mechanical characteristics of disposed material and background of waste dump sites defined in the project documentation for mining the open pit "Bor" [5, 10] and they are shown in Table 1.

* *Mining and Metallurgy Institute Bor, e-mail: radmilo.rajkovic@irmbor.co.rs*
** *This work is the result of the Project No. 37001 "Impact of Mining Waste from RTB to Pollution of Waterways with a Proposal of Measures and Actions to Reduce Harmful Effects on the Environment", funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia*

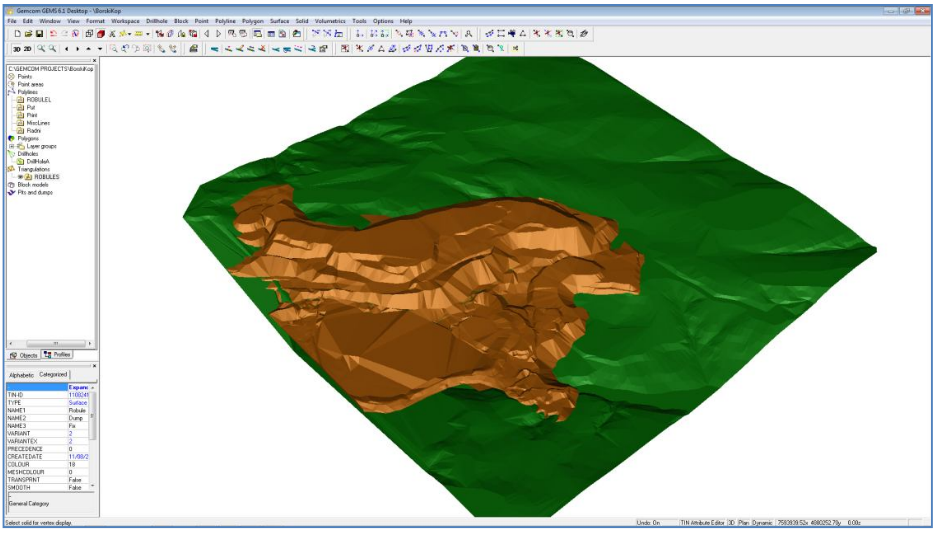

Figure 1 *3D model of waste dump in the software Gemcom 6*

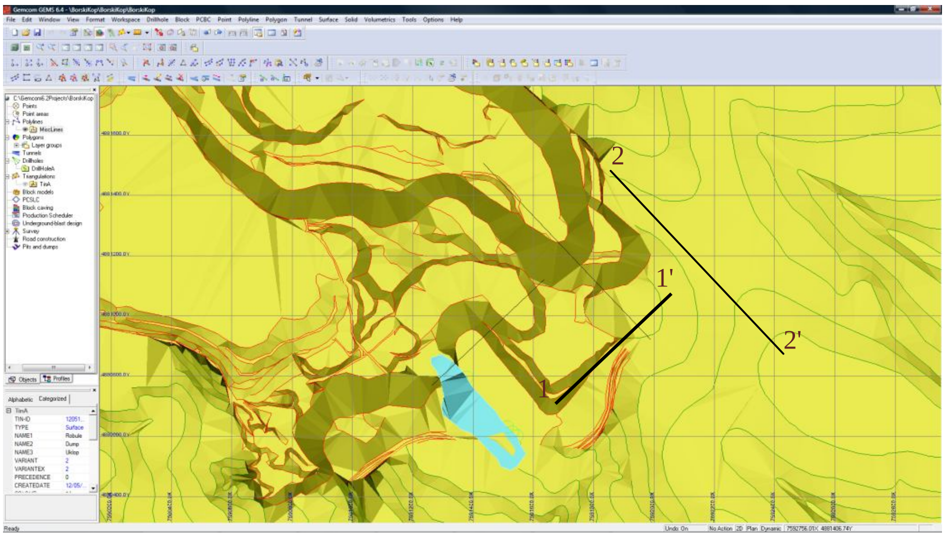

Figure 2 *Position of profiles for stability analysis*

Table 1 *Computational values of physico-mechanical parameters for calculation of stability*

Type of rock	**Angle of internal friction, φ, °**	**Gravity, γ, kN/m³**	**Cohesion, C kN/m²**
Background of waste dump	42.0	26.5	300
Disposed material	30.0	19.0	100

STABILITY CALCULATION

Stability calculation was made by the software GeoStudio 2007, or its subprogram SLOPE/W designed for stability calculation by the limit equilibrium condition, license no. 99803. The program includes methods of stability calculation by the limit equilibrium condition which are used today in the world: Bishop, Janbu, Spencer, Morgenstern - Price, Sarma et al. The impact of ground water on the stability in the software GeoStudio 2007 SLOPE/W can be modeled in several ways: piezometric water level, coefficient of pore water pressure r_u and pressure of pore water B-bar. The impact of surface loads on background could be also modeled by software as well as seismic effect [2, 6, 7, 12, 13, 14].

Stability calculation was made by the methods of Bishop and Morgenstern – Price. The impact of ground water on stability was modeled by the coefficient of pore water r_u, which is varied from 0.1 to 0.8. Stability analysis was carried out using the tool je Entry and Exit which defining the area where sliding plane cuts the field surface and radius area of potential sliding planes, Figures 3 – 5.

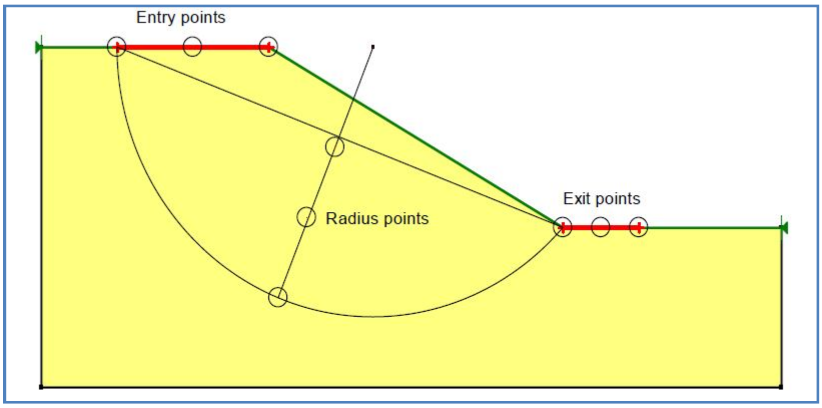

Figure 3 *Tool Entry and Exit*

Figure 4 *Radius area of potential sliding planes in tools Entry and Exit*

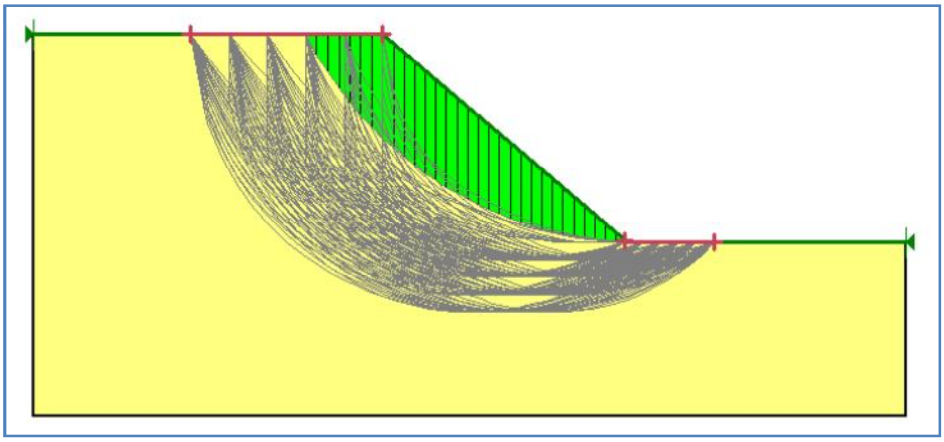

Figure 5 *View of potential sliding planes in tools Entry and Exit*

Stability calculation using the software GeoStudio 2007 on profiles 1 – 1' and 2 – 2' for the coefficient of pore water r_u = 0.1 is shown in Figures 6 – 9, and complete calculation results in Figure 10.

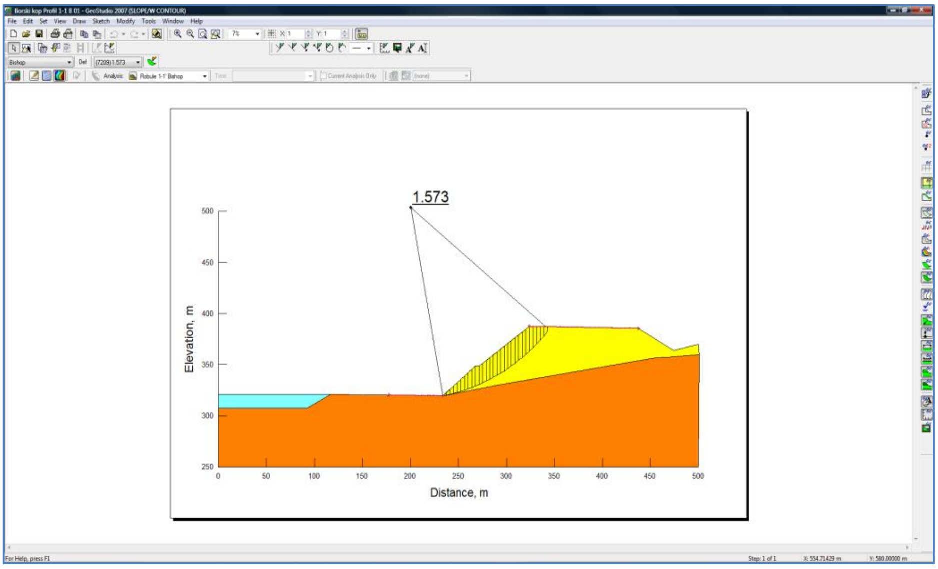

Figure 6 *Stability calculation for profile 1 – 1' by the Bishop method*

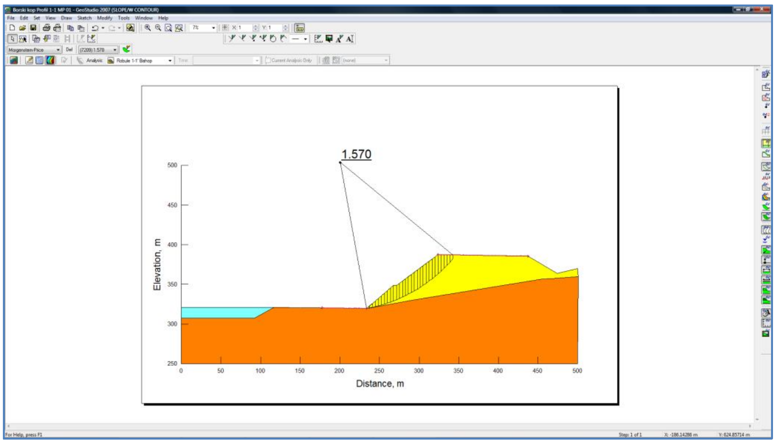

Figure 7 *Stability calculation for profile 1 – 1' by the Morgenster – Price method*

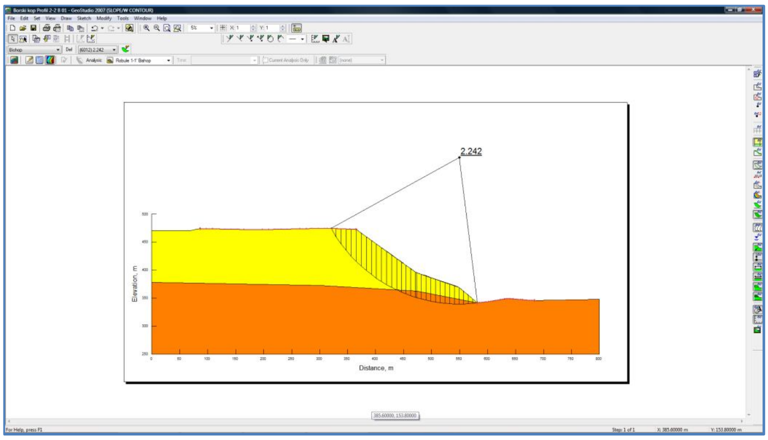

Figure 8 *Stability calculation for profile 2 – 2' by the Bishop method*

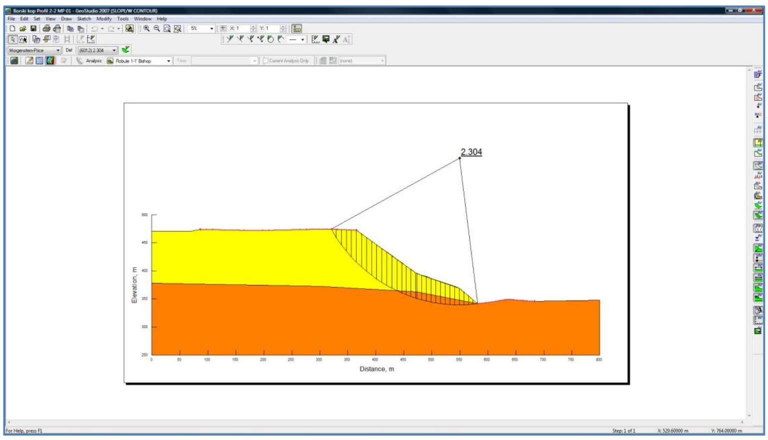

Figure 9 *Stability calculation for profile 2 – 2' by the Morgenster – Price method*

	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
Profil 1 – 1' Bishop	1.708	1.573	1.439	1.304	1.169	1.035	0.902		
Profil 1 – 1' Morgenstern-Price	1.705	1.570	1.435	1.301	1.167	1.036	0.903		
Profil 2 – 2' Bishop	2.327	2.242	2.039	1.837	1.635	1.435	1.236	1.041	0.849
Profil 2 – 2' Morgenstern-Price	2.385	2.304	2.106	1.906	1.710	1.517	1.328	1.144	0.965

r_u

Figure 10 *Graphical view of stability calculation results*

ANALYSIS OF STABILITY CALCULATION RESULTS

Dependence of change the stability coefficient could be seen from graphical view with increasing coefficient of pore water for both analyzed profiles. The current Rulebook on technical requirements for surface mining of mineral resources (Official Gazette RS No. 96/2010) has stipulated the following minimum stability coefficients for waste dumps:

- Working slopes of partial individual floors: 1.05 to 1.10.
- Working slopes of partial individual floors and floor slope system: 1.10 to 1.15.
- Final slopes of waste dump: 1.30 to 1.50.
- Fracture of background and sliding along background: 1.50 to 2.00.

Maximum allowable values of pore water coefficient could be read from graph of stability calculation results, which meet the prescribed values of stability coefficient. If there is larger water quality than allowed, it is necessary to reduce the level of groundwater below the contact of disposed masses and background in possible exploitation. The waste dump must be regularly drained from surface water.

CONCLUSION

Softver GeoStudio 2007 – SLOPE/W is a program that can very accurately determine all relevant conditions for calculation the slope stability of open pits, waste dumps and earth dams. Each lithological member on a profile can be realistically modeled by spatial position and physico-mechanical characteristics. It is also possible to model the effect of ground water on stability by several ways as well as the surface loads on background. Using of this software significantly reduces the time of calculation regarding to the classical design.

For realistic assessment the problems of stability in the software GeoStudio 2007, the most important is a selection of reliable input parameters.

Since the data on physic-mechanical characteristics are older than three decades, in the case of this waste dump exploitation by leaching or classical excavation, it is necessary to check the geomechanical and hydrogeological characteristics of the background and disposed material. For calculation the stability in exploitation, a load of machinery have to be taken into account and determine minimum distance from the edge of the waste dump for its operation.

REFERENCES

[1] R. Rajković, V. Marinković, M. Mikić, D. Kržanović: Development of 3D model of the Southeastern Waste Dump; Minig 2013, Plans for Development and Improvent of Mining; 28-31 May 2013 Veliko Gradište, Srebrno jezero; pp. 224 – 226; ISBN 978-86-80809-78-6.

[2] R. Rajković, D. Kržanović, M. Mikić, V. Marinković: Stability of Ash and Slag Dump on Thermal Power Plant Gacko with Software GeoStudio 2007; Minig 2013, Plans for Development and Improvent of Mining; 28-31 May 2013 Veliko Gradište, Srebrno jezero; pp. 227 – 231; ISBN 978-86-80809-78-6.

[3] M. Ignjatović, R. Rajković, S. Ignjatović, L. Đurđevac Ignjatović, L. Kričak, R. Pantović: Determination of Optimal Contours of Open Pit Mine during Oil Shale Exploitation by Minex 5.2.3. Program; Journal of Process Management - New Technologies, Volume 1 Issue 2, April 2013; pp. 1 - 9; ISSN 2334-735X.

[4] M. Bugarin, Lj. Obradović, R. Rajković, V. Marinković, Z. Stevanović: Technical Solution: 3D Model of the Oštreljskog Planir in a Function of Analyzing the Effects of Acid Waste Water on the Environment; Project MNTR TR-37001 TR-1, IRM Bor, 2012; Decision of the Scientific Council, MMI Bor No. X/7.1 of 09.10.2012.

[5] R. Lekovski, M. Bugarin, M. Mikić, R. Rajković, Lj. Obradović: Remediation on the Flotation Tailing Dump Bor Using the Categories of Semiremediation and Auroremediation; Project MNTR TR-37001 TR-3, IRM Bor, 2012; Decision of the Scientific Council, MMI Bor No. X/7.5 of 09.10.2012.

[6] M. Ignjatović, S. Ignjatović, M. Negovanović, R. Rajković, L. Đurđevac Ignjatović, D. Ignjatović: Determination of the Final Slope Angle of the Open Pit Mine during Exploitation of Oil Shale from Aleksinac dDposit during GeoStudio 2007 – SLOPE/W Program; TTEM - Technics Technologies Education Management 2011/3; pp. 615 – 621; ISSN 1840-1503.

[7] M. Ignjatović, R. Rajković, B. Rajković, D. Milanović, M. Popović; Stability Analysis of Open Pit ’’Progorelica“ by Bishop Method and Program Plan Failure Analysis; II International Symposium “Mining 2011“ Mining Present State and Future Prospects and Sustainable Development; Vrnjačka banja 10 – 13 maj 2011; pp. 599 – 603; ISBN 978-86-80809-61-8.

[8] R. Rajković, V. Marinković, R. Lekovski: Digital 3D Terrain Model; Mining Engineering 3/2011; pp. 25 – 40; ISSN: 1451-0162 (M51).

[9] R. Rajković, V. Marinković, R. Lekovski: 3D Model of the Waste Dump Oštrelj in the Software Gemcom 6; Mining Engineering 3/2011; ISSN 1451-0162.

[10] R. Lekovski, R. Rajković, Lj. Obradović: Formation of the East Waste Dump in Bor and Review of Previous Activities on the Environmental Protection; Mining Engineering 2/2011; pp. 125 – 136; ISSN 1451-0162.

[11] D. Milanović, Z. Stojanović, R. Rajković; The Preparation of Copper Ore in Serbia; Monograph: Status and Perspective of Mineral Processing in Serbia, Serbian Academy of Engineering 2011; p. 9 – 37; ISBN 978-86-7747-430-0. (in Serbian)

[12] M. Ignjatović, R. Rajković, M. Maksimović, D. Ignjatović: A Technical Solution: The Determination of the Final Angles in Newly Open Pit Mine in the Exploatation of ol Shale Deposits from the Location Aleksinac - Software GeoStudio 2007. - Slop/W, Project MNTR-TR-17005 TR-1, IRM Bor No. 543, 2010; Solution of Director MMI Bor No. 543 - 27.04.2010. (in Serbian)

[13] R. Rajković, D. Kržanović, R. Lekovski: Stability Analysis of Innner Waste Dump "Kutlovaca" of The Coal Open Pit Mine "Potrlica"– Pljevlja Using the GeoStudio 2007 Software; Mining engineering 1/2010; Pages 69 – 80; ISSN 1451-0162.

[14] R. Rajković, D. Kržanović, B. Rajković; Analysis of Stability During the Cleaning of Cassettes 1 and 2 of Setting Pond Filter of Waste Water Purification Facilities of Kolubara – PreradaVreoci by Software Geostudio 2007; 42. International October Conference on Mining and Metallurgy; pages 33-40, 2010; ISBN 978-86-80987-79-8.

[15] V. Marinković, R. Rajković, D. Kržanović, G. Pačkovski, D. Mitić, 2D and 3D Models, Similarity and Diferences, Bakar 34 (2009) 1; ISSN 0351-0212

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Radmilo Rajković, Mile Bugarin*, Vladan Marinković**

ANALIZA STABILNOSTI ODLAGALIŠTA JALOVINE "OŠTRELJSKI PLANIR" POVRŠINSKOG KOPA "BOR" U FUNKCIJI OVODNJENOSTI**

Izvod

Analiza stabilnosti odlagališta jalovine "Oštreljski planir" urađena je programom GeoStudio 2007, za kritične profile određene na osnovu 3D modela lokaliteta u program Gemcom 6. Uticaj vode na stabilnost odlagališta definisan je variranjem koeficijenta porne vode u odloženom materijalu.

Ključne reči: *stabilnost, program GeoStudio 2007, program Gemcom 6, koeficijent porne vode.*

UVOD

U period od 1975 do 1980 godine, jalovina sa površinskog kopa "Bor" odlagana je na više lokacija u blizini površinskog kopa, pri čemu su formirana spoljna odlagališta. Jedno od njih je i odlagalište "Oštrelj" koje se još naziva i "Istočno odlagalište", ili "Cijanizacija". Nalazi se na krajnjem istoku od površinskog kopa Bor pored bivšeg pogona Cijanizacije koji nije više u funkciji, jer je deo kosine odlagališta za luženje kliznuo osamdesetih godina prošlog veka i onesposobio ovo postrojenje. To je ujedno i najviše odlagalište površinskog kopa „Bor", čija je završna ravan na K +475 m, a nožica na koti K +375 m. Visina formiranog odla-gališta iznosi 100 m sa nagibom kosine 38^0. U podnožju ovog odlagališta na jugoistočnoj strani nalazi se jezero Robule. Tokom perioda odlaganja na odlagalištu "Oštrelj", granični sadržaj bakra u rudi bio je znatno veći nego danas, tako da postoji mogućnost eksploatacije ovog odlagališta luženjem ili klasičnim otkopavanjem. Količina materijala na ovom odlagalištu iznosi oko 95 miliona m^3materijala. [5, 10, 11]

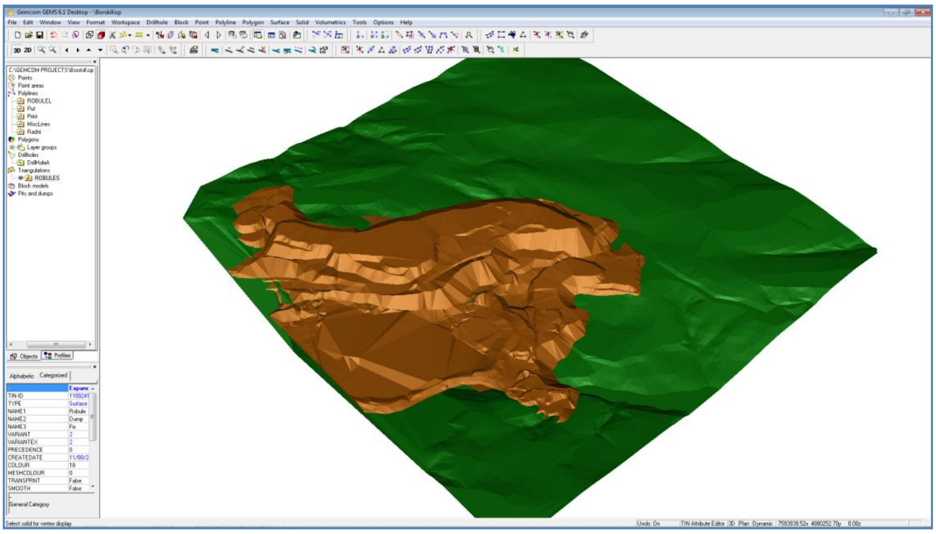
IZBOR RAČUNSKIH PARAMETARA I KARAKTERISTIČNIH PROFILA

Na osnovu postojećih kartografskih podataka urađen je 3D model odlagališta "Oštreljski planir" u program Gemcom 6 [1, 3, 4, 8, 9, 15], slika 1. Na ovom modelu definisani su kritični profile za proračun stabilnosti. Profil 1 – 1' prolazi kroz deo odlagališta u neposrednoj blizini jezera "Robule", a profil 2 – 2' prolazi kroz deo odlagališta sa najvećom visinom odloženog materijala. Položaj profila prikazan je naslici 2.

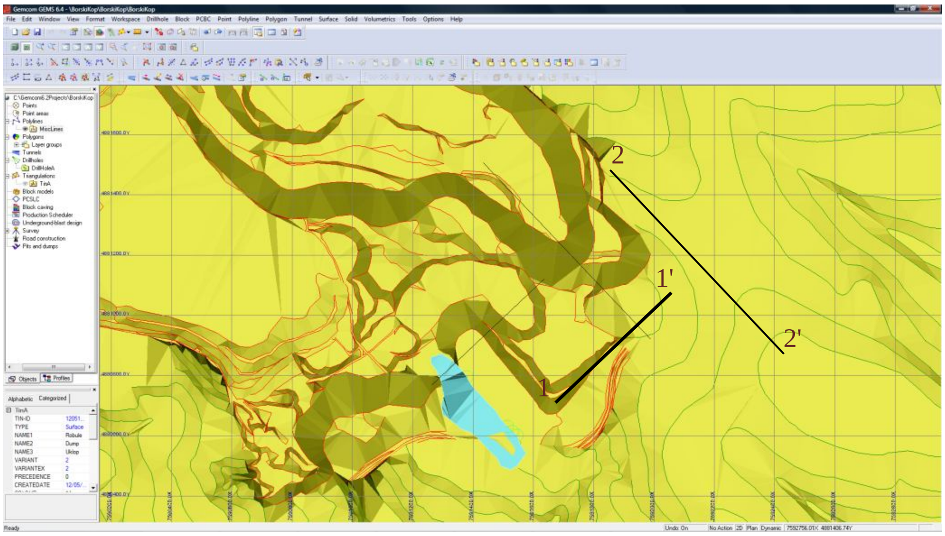
Vrednosti fizičko - mehaničkih karakteristika odloženog materijala i podloge odlagališta, definisane su u projektnoj dokumentaciji za eksploataciju na površinskom kopu „Bor" [5, 10] i prikazane su u tabeli 1.

* *Institut za rudarstvo i metalurgiju Bor, e-mail: radmilo.rajkovic@irmbor.co.rs*

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



Sl. 1. *3D model odlagališta u programu Gemcom 6*



Sl. 2. *Položaj profila za analizu stabilnosti*

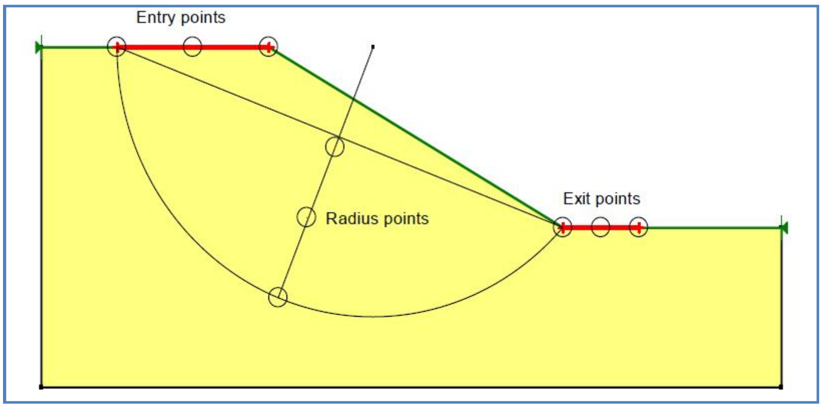
Tabela 1. *Računske vrednosti fizičko-mehaničkih parametara za proračun stabilnosti*

Vrsta stene	Ugao unutrašnjeg trenja, φ, °	Zapreminska težina, γ, kN/m^3	Kohezija, C kN/m^2
Podloga odlagališta	42,0	26,5	300
Odloženi materijal	30,0	19,0	100

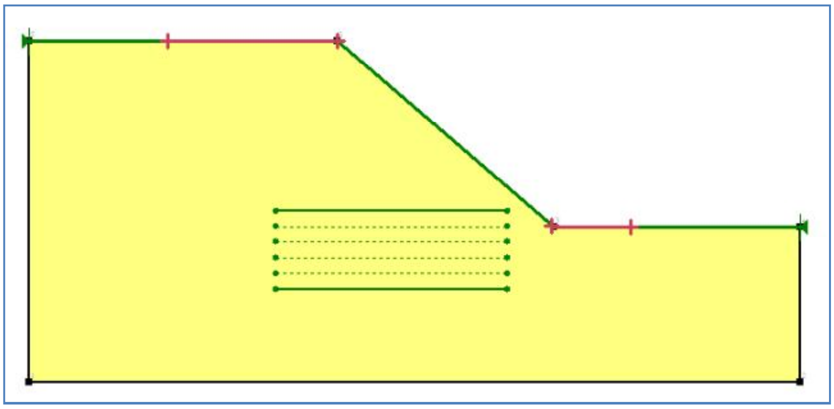
PRORAČUN STABILNOSTI

Proračun stabilnosti izvršen je programom GeoStudio 2007, odnosno njegovim potprogramom SLOPE/W namenjenim za proračun stabilnosti uslovom granične ravnoteže, licenca br. 99803. Program sadrži metode proračuna stabilnosti uslovom granične ravnoteže koje se danas koriste u svetu: Bishop, Janbu, Spenser, Morgenstern – Price, Sarma i dr. Uticaj podzemnih voda na stabilnost u softveru GeoStudio 2007 SLOPE/W može da se modelira na više načina: piezometrijskim nivoom vode, koeficijentom porne vode r_u i pritiskom porne vode B-bar. Softverom se takođe može modelirati uticaj površinskih opterećenja na podlogu, kao i seizmički uticaj [2, 6, 7, 12, 13, 14].

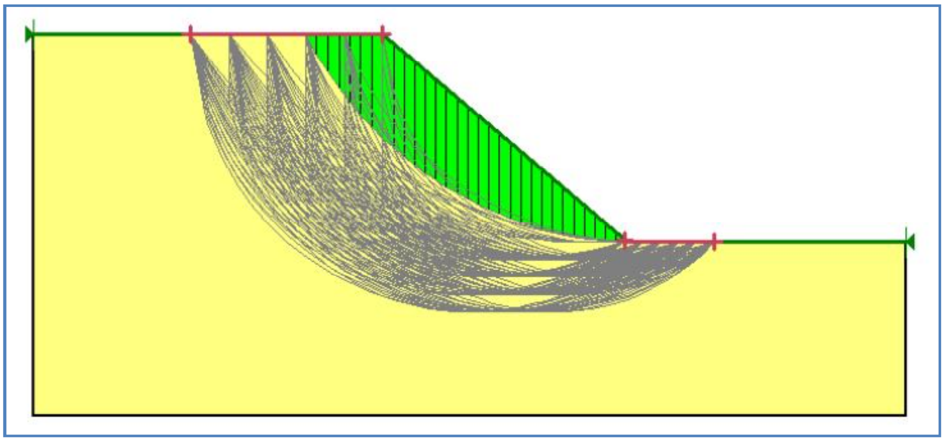
Proračun stabilnosti urađen je metodama Bishop i Morgenstern – Price. Uticaj podzemnih voda na stabilnost modeliran je koeficijentom porne vode r_u, koji je variran od 0,1 do 0,8. Analiza stabilnosti rađena je alatom Entry and Exit kojim se definiše oblast u kojoj klizna ravan seče površinu terena, i oblast radijusa potencijalnih kliznih ravni, slike 3 – 5.



Sl. 3. *Alat Entry and Exit*

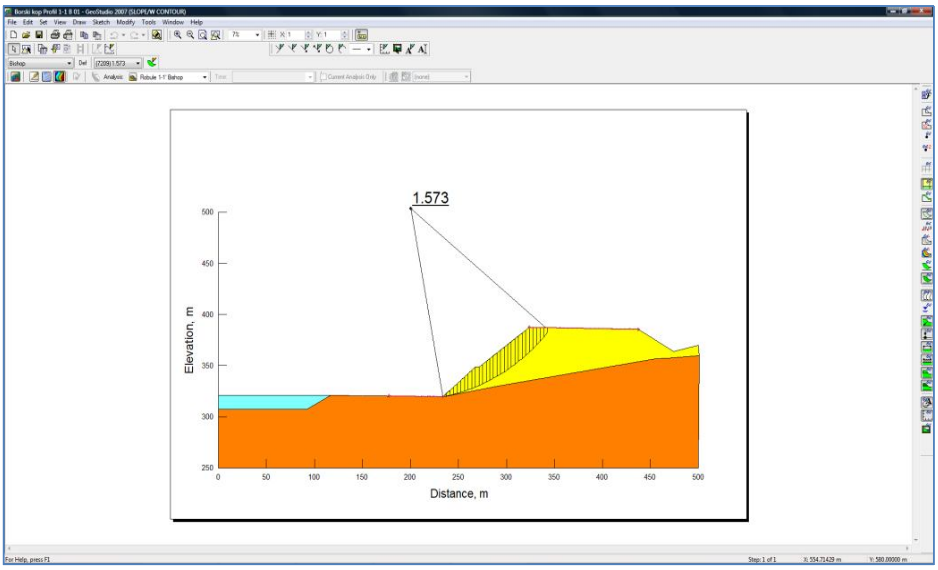


Sl. 4. *Oblast radijusa potencijalnih kliznih ravni kod alata Entry and Exit*

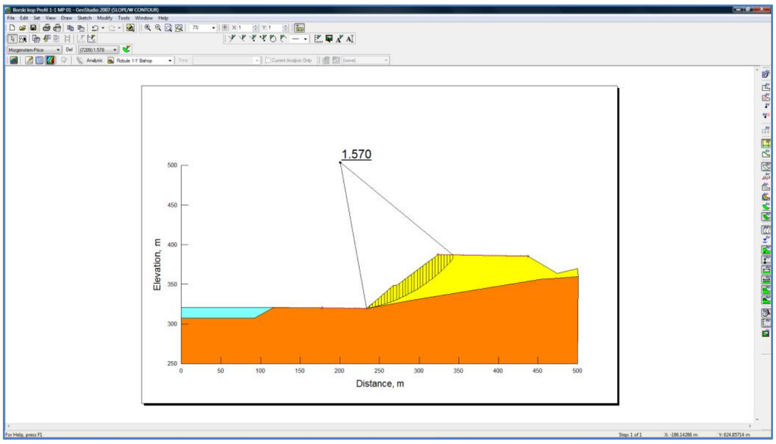


Sl. 5. *Prikaz potencijalnih kliznih ravni kod alata Entry and Exit*

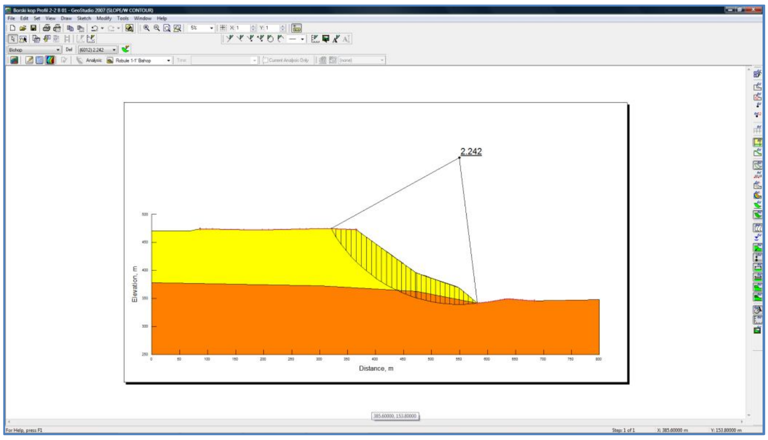
Proračun stabilnosti programom GeoStudio 2007 na profilima 1 – 1' i 2 – 2' za koeficijent porne vode r_u = 0,1 prikazan je na slikama 6 – 9, a kompletni rezultati proračuna na slici 10.



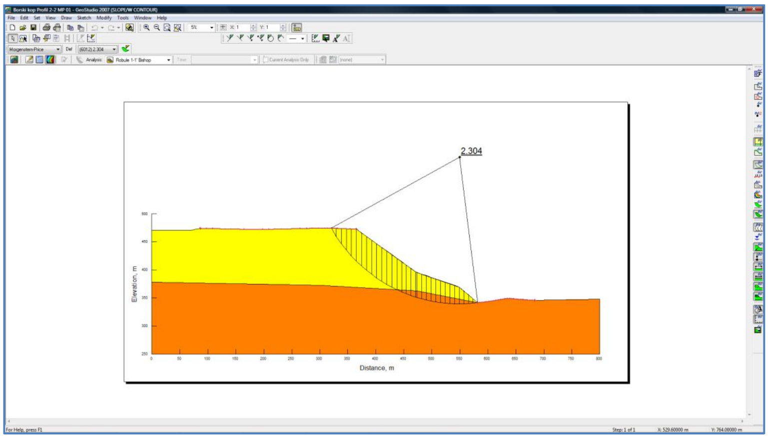
Sl. 6. *Proračun stabilnosti za profil 1 – 1' po metodi Bishop*



Sl. 7. *Proračun stabilnosti za profil 1 – 1' po metodi Morgenster – Price*



Sl. 8. *Proračun stabilnosti za profil 2 – 2' po metodi Bishop*



Sl. 9. *Proračun stabilnosti za profil 2 – 2' po metodi Morgenster – Price*

Sl. 10. *Grafički prikaz rezultata proračuna stabilnosti*

ANALIZA REZULTATA PRORAČUNA STABILNOSTI

Sa grafičkog prikaza rezultata proračuna stabilnosti može se videti zavisnost promene koeficijenta stabilnosti sa povećanjem koeficijenta porne vode za oba analizna profila. Važećim Pravilnikom o tehničkim zahtevima za površinsku eksploataciju mineralnih sirovina (Sl. glasnik RS br. 96/2010) propisani su sledeći minimalni koeficijenti stabilnosti za odlagališta jalovine:

- Radne kosine parcijalnih pojedinačnih etaža: 1,05 do 1,10.
- Radne kosine parcijalnih pojedinačnih etaža i sistema kosina etaža: 1,10 do 1,15.
- Završne kosine odlagališta: 1,30 do 1,50.
- Lom podloge i klizanje po podlozi: 1,50 do 2,00.

Sa grafika rezultata proračuna stabilnosti mogu se očitati maksimalne dozvoljene vrednosti koeficijenta porne vode za koje su ispunjene propisane vrednosti koeficijenta stabilnosti. Ako postoji veća ovodnjenost od dozvoljene, pri eventualnoj eksploataciji potrebno je izvršiti smanjenje nivoa podzemne vode ispod kontakta odloženih masa i podloge. Takođe se odlagalište mora redovno odvodnjavati od površinskih voda.

ZAKLJUČAK

Softver GeoStudio 2007 – SLOPE/W je program kojim veoma precizno mogu da se determinišu svi relevantni uslovi za proračun stabilnosti kosina površinskih kopova, odlagališta jalovine i zemljanih brana. Svaki litološki član na profile može biti realno modeliran prostornim položajem i fizičko – mehaničkim karakteristikama. Takođe je moguće na više načina modelirati uticaj podzemnih voda na stabilnost, kao i površinska opterećenja na podlogu. Korišćenjem ovog softvera značajno se skraćuje vreme proračuna u odnosu na klasično projektovanje.

Za realno sagledavanje problematike stabilnosti u program GeoStudio 2007 najvažniji je izbor pouzdanih ulaznih parametara.

Kako su podaci o fizičko - mehaničkim karakteristikama stariji od tri decenije, u slučaju eksploatacije ovog odlagališta luženjem ili klasičnim otkopavanjem, potrebno je proveriti geomehaničke i hidrogeološke karakteristike podloge i odloženog materijala. Za proračun stabilnosti pri eksploataciji mora se uzeti u obzir opterećenje od mehanizacije i odrediti minimalno rastojanje od ivice kosine odlagališta za njen rad.

LITERATURA

[1] R. Rajković, V. Marinković, M. Mikić, D. Kržanović: Development of 3D model of the southeastern waste dump; Minig 2013, Plans for development and improvent of mining; 28-31 may 2013 Veliko Gradište, Srebrno jezero; Pages 224 – 226; ISBN 978-86-80809-78-6.

[2] R. Rajković, D. Kržanović, M. Mikić, V. Marinković: Stability of ash and slag dump on thermal power plant Gacko with software GeoStudio 2007; Minig 2013, Plans for development and improvent of mining; 28-31 may 2013 Veliko Gradište, Srebrno jezero; Pages 227 – 231; ISBN 978-86-80809-78-6.

[3] M. Ignjatović, R. Rajković, S. Ignjatović, L. Đurđevac Ignjatović, L. Kričak, R. Pantović: Determination of optimal contours of open pit mine during oil shale exploitation by Minex 5.2.3. program; Journal of Process Management - New Technologies, Volume 1 Issue 2, April 2013; Pages 1 - 9; ISSN 2334-735X.

[4] M. Bugarin, Lj. Obradović, R. Rajković, V. Marinković, Z. Stevanović: Tehničko rešenje: Trodimenzionalni model Oštreljskog planira u funkciji analize uticaja kiselih otpadnih voda na životnu sredinu; Projekat MNTR TR-37001 TR-1, IRM Bor, 2012; Odluka Naučnog veća IRM Bor br. X/7.1 od 09.10.2012.

[5] R. Lekovski, M. Bugarin, M. Mikić, R. Rajković, Lj. Obradović: Remedijacija na flotacijskom jalovištu Bor primenom kategorija polurekultivacije i autorekultivacije; Projekat MNTR TR-37001 TR-3, IRM Bor, 2012; Odluka Naučnog veća IRM Bor br. X/7.5 od 09.10.2012.

[6] M. Ignjatović, S. Ignjatović, M. Negovanović, R. Rajković, L. Đurđevac Ignjatović, D. Ignjatović: Determination of the final slope angle of the open pit mine during exploitation of oil shale from Aleksinac deposit during GeoStudio 2007 – SLOPE/W program; TTEM - Technics Technologies Education Management 2011/3; Pages 615 – 621; ISSN 1840-1503.

[7] M. Ignjatović, R. Rajković, B. Rajković, D. Milanović, M. Popović; Stability analysis off open pit „Progorelica“ by Bishop method and program plan failure analysis; II international symposium „Mining 2011“ Mining presents state and future prospects and sustainable development; Vrnjačka banja 10 – 13 maj 2011; Pages 599 – 603; ISBN 978-86-80809-61-8.

[8] R. Rajković, V. Marinković, R. Lekovski: Digital 3D terrain model; Mining engineering 3/2011; Pages 25 – 40; ISSN: 1451-0162 (M51).

[9] R. Rajković, V. Marinković, R. Lekovski: 3D model of the waste dump Oštrelj in the software Gemcom 6; Mining engineering 3/2011; ISSN 1451-0162.

[10] R. Lekovski, R. Rajković, Lj. Obradović: Formation of the East Waste dump in Bor and review of previous activities on the environmental protection; Mining engineering 2/2011; Pages 125 – 136; ISSN 1451-0162.

[11] D. Milanović, Z. Stojanović, R. Rajković; Priprema ruda bakra u Srbiji; Monografija:Stanje i perspektive pripreme mineralnih sirovina u Srbiji; Inženjerska akademija Srbije 2011; Str. 9 – 37; ISNB 978-86-7747-430-0.

[12] M. Ignjatović, R. Rajković, M. Maksimović, D. Ignjatović: Tehničko rešenje: Određivanje završnih uglova novoprojektovanog površinskog kopa pri eksploataciji uljnih škriljaca sa lokaliteta Aleksinačkog ležišta programom GeoStudio 2007 – Slope/W, Projekat MNTR TR-17005 TR-1, IRM Bor br. 543, 2010; Rešenje direktora IRM Bor br. 543 od 27.04.2010.

[13] R. Rajković, D. Kržanović, R. Lekovski: Stability analysis of innner waste dump "Kutlovaca" of the coal open pit mine "Potrlica"– Pljevlja using the GeoStudio 2007 software; Mining engineering 1/2010; Pages 69 – 80; ISSN 1451-0162.

[14] R. Rajković, D. Kržanović, B. Rajković; Analysis of stability during the cleaning of cassettes 1 and 2 of setting pond filter of waste water purification facilities of Kolubara – PreradaVreoci by software Geostudio 2007; 42. International October Conference on Mining and Metallurgy; pages 33-40, 2010; ISBN 978-86-80987-79-8.

[15] V. Marinković, R. Rajković, D. Kržanović, G. Pačkovski, D. Mitić, 2D i 3D modeli, sličnosti i razlike, Bakar 34 (2009) 1; ISSN 0351-0212.

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Salko Ćosić, Mevludin Avdić*, Amir Sušić**, Milenko Ljubojev****

FINITE ELEMENT ANALYSIS OF DEEP UNDERGROUND SALT CAVERNS****

Abstract

In this paper, the process of finite element analysis of deep underground salt caverns was described with geometry and material properties related to caverns in the salt mine Tetima-Tuzla, B&H. The 3D model was built based on ultrasound measurement and CAD modelling of planar geometry data. Nonlinear finite element analysis was performed resulting in stresses and deformations data necessary for assessment of cavern stability and time dependent behaviour.

Keywords: *finite element analysis, CAD model, stress and deformation fields, plasticity and creep*

1 INTRODUCTION

Besides the many advantages, there are also some drawbacks related to leaching exploitation of deep underground salt caverns. Leaching process leads to enlargements of caverns and subsequently to reducing of its stability. Due to high litho-static pressure at cavern depth, failure of cavern walls is possible if its dimensions are above certain limit. In order to maintain stability, it is necessary to stop leaching process when cavern reaches some critical dimensions. Exploited cavern must be filled with water and sealed. The leaching process has to be continued at new cavern(s) usually in the vicinity of previous one. The position, dimensions and leaching dynamics of the new cavern is influenced with other caverns in the vicinity. There are protective pillars between caverns that are necessary to maintain the stability of caverns. The pillars are highly loaded with internal (litho-static) pressure at cavern depth. The calculation of geometrical disposition of caverns and its critical diameters is a complex task. Up to now, some recommendations were usually used on the basis of elasticity theory models and empirical data from previous years of exploitation. The theory of elasticity allows stress-strain calculation in the case of ideal, homogeneous, isotropic, linearly elastic material and cylindrical, spherical or elliptical shape of caverns. Unfortunately, in the real-world conditions, the rock salt deposit are layered with non-homogeneous layers, the rock materials are anisotropic; the constitutive behaviour is nonlinear and inelastic. Also, the cavern shape is usually far away from the ideal, cylindrical or spherical case for which analytical models can be useful. Therefore, the analytical models, based on elasticity theory, have limited usefulness in the practical stress state calculations. It is

* *University of Tuzla, Bosnia and Herzegovina*
** *d.d. Rudnik soli Tetima, Tuzla, Bosnia and Herzegovina*
*** *Mining and Metallurgy InstituteBor, Serbia*
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therefore, necessary to have larger coefficients of safety related to the critical caverns diameters and its mutual axial distance. It leads to stopping of leaching before it is really necessary at the moment when cavern is fully formed and gave its maximum production and transfer to a new cavern with small size and small capacity. Also, the axial distance between caverns must be larger, that means, lot of salt material is permanently lost.

High improvement in this field came with the finite element analysis. It allows nonlinear analysis of stress-strain state with advanced material models and realistic geometry (shape) of caverns and layers of rock materials. The result is more reliable prediction of caverns behaviour and its mutual interactions. Such analysis with geometrical and material parameters, related to the rock salt mine “Tetima” in the vicinity of Tuzla, Bosnia and Herzegovina, is given in this work.

2 THE FEM MODEL OF SALT CAVERNS

The first step in FEM analysis is development of CAD model with realistic caverns geometry and positions in salt deposit. The stress-strain state will be analyzed for the group of five caverns and pillars between them, situated at the Tetima mine, near Tuzla, Bosnia and Herzegovina. The actual geometry of cavern walls is obtained by ultrasonic measurement. The ultrasonic measuring head is down warded, from the surface to the bottom of cavern, taking series of flat scans (2D) in the plane normal to cavern axis, shown in Figure 1. Contour lines are modeled as splines allowing smooth cavern surface and solid model to be generated by 3D modelling software. Caverns are between 80 and 100 meters high and with diameters up to 40 meters. All caverns are situated at 500-700 meters from the surface. The volume of one entirely developed cavern is approximately 100,000 m^3.

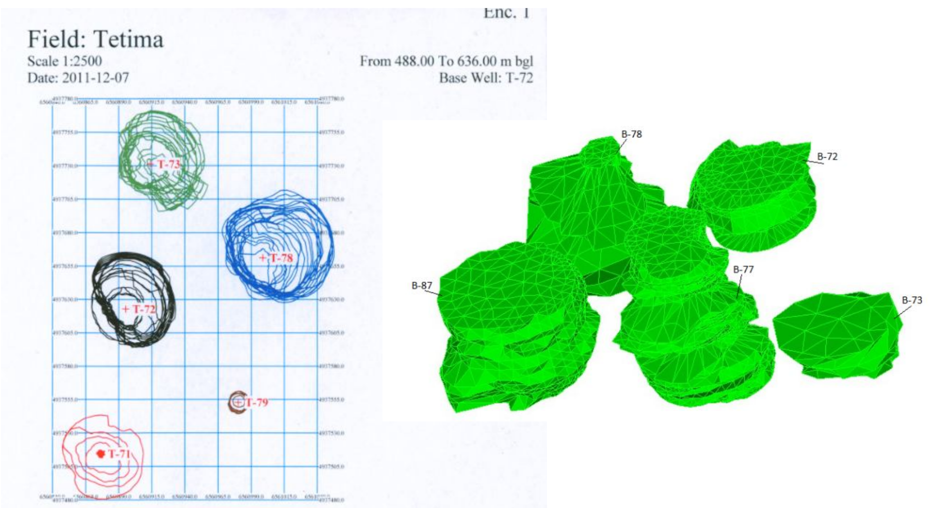

Figure 1 *Caverns cross-sections by ultrasonic measurements(a) and appropriate 3D solid models (b)*

3D solid model of individual caverns is shown in Figure1 (b). Caverns are obtained by subtraction of previously generated 3D solids from layered deposit model (Figure 2.a). Model dimensions are 300 x 200 x 600 m. It is adequate to include all five caverns and to exclude influence of the rest of salt deposit. In order to reduce model height (depth 500-700 m) at upper surface, a uniformly distributed external pressure equivalent to litho-static pressure at appropriate depth is applied. It leads to significant reduction of DOF in FEM analysis with minor reduction of accuracy. All layers are modelled based on geophysical measurements and geological maps.

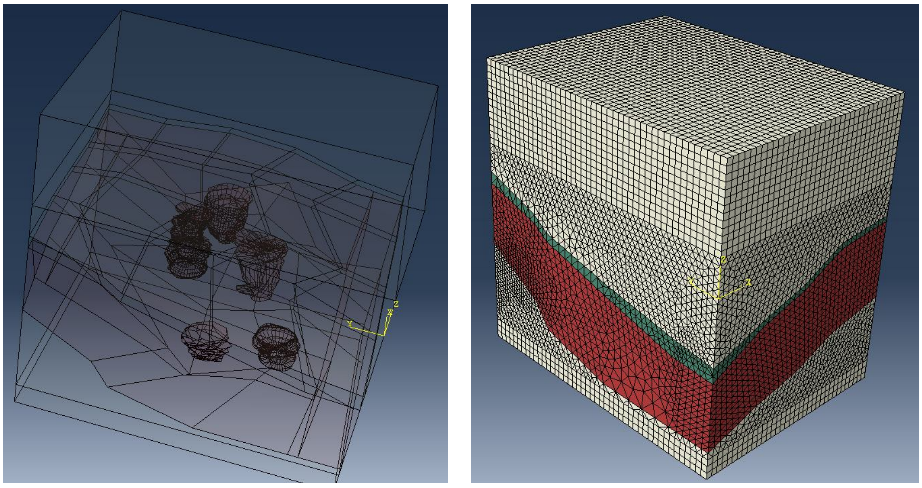

Figure 2 *3D layered CAD model of caverns and its disposition in the Tetima mine(a), discretized domain (b)*

3 PREPROCESSING

3.1 Model Partitioning and Mesh Generation

Before discretization on finite elements, it is necessary to do domain partitioning in order to allow better mesh generation. The complicated curved parts of domain (salt cavern walls) are discretized on standard linear tetrahedral elements but large part of domain is discretized on more advanced hexahedral elements, Figure 2. In this way, there is a compromise between the mesh quality, number of degrees of freedom in problem and hardware (computing) capacity of our computers. Total number of degrees of freedom for entire model is around 380,000. After defining caverns geometry and automatic mesh generation, the material model, loads, boundary conditions and interface between cavern and surrounding material are defined.

3.2 Material Modelling

In the real conditions, the domain is layered with many different rock materials. The base material (rock salt) under high pressure has the elasto visco-plastic behaviour. Therefore, the FEM analysis is nonlinear, time dependent, with many increments of loads and many iterations steps. The parameters for material model are determined by fitting the experimental measurement results on many salt samples, according to the standardised procedures. Another rock material is modeled as linearly elastic by the Drucker-Pragger plasticity model. In the space of principal stresses, the D-P model is given as (1) and salt creep model is given by (2):

$$\sqrt{J_2} = a + b \cdot I_1 \text{ ili}$$

$$\sqrt{\frac{1}{6}}[(\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_3)^2 =$$

$$= a + b \cdot (\sigma_1 + \sigma_2 + \sigma_3) \qquad (1)$$

$$\overline{\varepsilon_{cr}} = (A \cdot \sigma^n [(m + 1)\overline{\varepsilon_{cr}}]^m)^{\frac{1}{m+1}} \qquad (2)$$

The constants (material parameters) a, b, A, n and m in equations (1) and (2) are found experimentally.

3.3 Boundary Conditions

Dimensions of model are taken sufficiently large so we can apply standard geomechanical boundary conditions shown in Figure 3 (b) for the 2D case. The lowest surface of the model is fixed in vertical directions and vertical lateral surfaces are fixed in normal to surface directions. In this way, the whole model is properly fixed in space.

3.4 External Loads

The external loads are due to evenly distributed gravity force and defined by gravity acceleration level and directions and material density. On top surface of model that is at 180 m from free surface, the apply external pressure is applied that is equivalent to the internal rock pressure at depth of 180 meters, with rock material density of 2100 kg/m^3. Internal salt water pressure in caverns is linearly related with depth, beginning from the free surface (ordinary hydrostatic pressure p=ρgh).

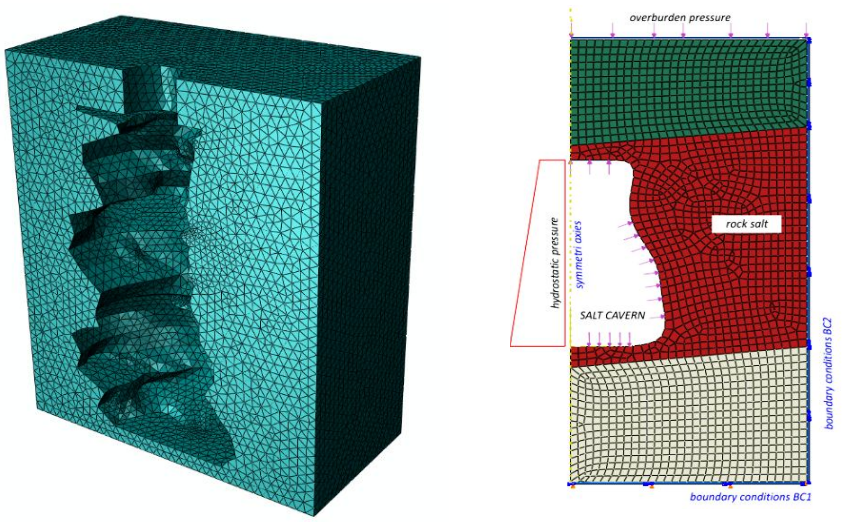

Figure 3 *Discretized cavern model (a), standard boundary conditions (b)*

4 DISCUSION OF RESULTS

Resulting system of equations in discrete form were solved in approximately 200 min. of PC time. Due to intense plastic deformation of several elements, the analysis was performed in several increments of load (30) and approximately 5-6 iteration steps in every increment. The most interesting result variables are displacement field, during leaching process and after. The magnitude of displacement field is shown in Figure 4. Maximum vertical displacement is about 1.3 m. and it is located at free surface above cavern no. 73. Due to visco-plastic behaviour of rock salt, it is assumed that vertical displacements shall rise in cavern surrounding with time. Vertical displacements in another cross section are much smaller. Also, the effect of rising of bottom for all caverns can be seen. It is easy to explain, because the internal pressure at cavern bottom is hydrostatic, $p=\rho_{water}gh$, but the external pressure is much higher, equal to $p=\rho_{rock}gh$.

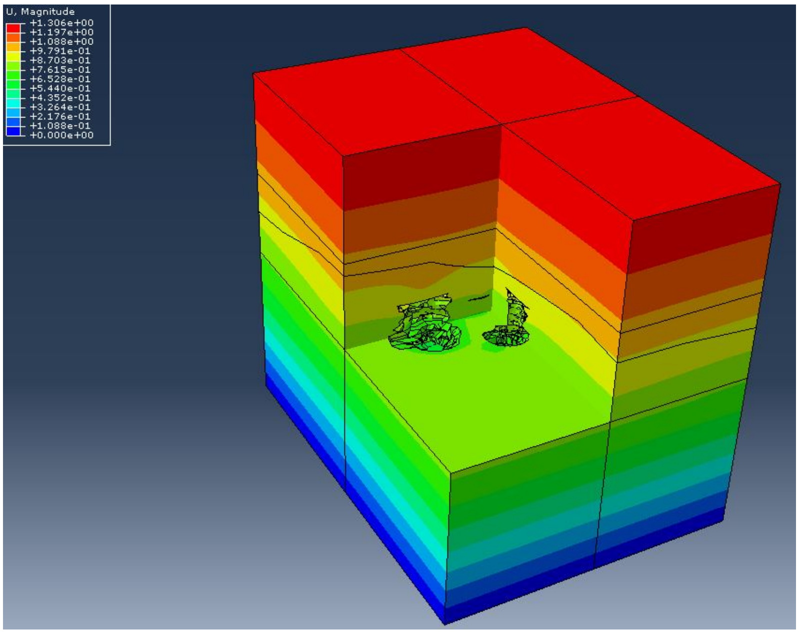

Figure 4 *Magnitude of displacements in cavern cross section*

In Figure 5, We can see displacements distribution in horizontal cross section (u_2). High pressure outside of cavern and lower pressure inside, and reduced horizontal stiffness due to caverns (cavity in material) leads to horizontal displacements of magnitude ± 2 10^{-2} m. In a case when internal hydrostatic pressure is re duced to zero (empty caverns), the stress equilibrium is lost due to non-symmetric shape of cavern and it leads to collapse of cavern walls. In the simulation process, this is related with loss of convergence. Layered material and uneven distribution of pillar thickness between caverns also contribute to this effect.

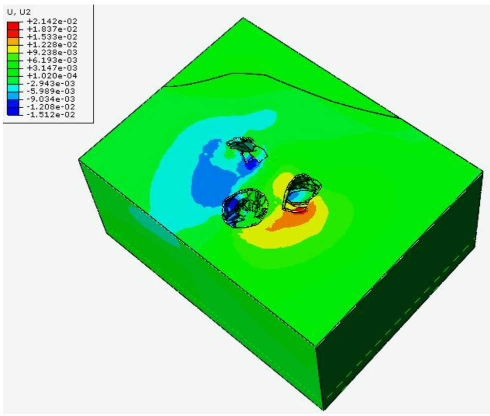

Figure 5 *Distribution of horizontal displacement, u_2*

For stress analysis, the most important is the effective stress related to the Drucker-Praggerplasticity criterion. The nodal point's effective stress can be compared with uniaxial stresses leading to the plastic deformation, obtained experimentally at rock samples. The analysis shows stresses higher the 20 MPa that are beyond the layered materials yield stresses. The most severe stress concentrations are at sharp corners in cavern walls, but number of such situations is relatively small with respect to the cavern dimensions. Also, such places are disjoined, far away one from another. In the real conditions, the geometry changes and sharp corners are not so severe, it can be assumed that plastic deformations will remain loca-lised and corresponding plastic zones will be separated. Also, the local plastic deformation will lead to decreasing of stress gradients in the local zone. In whole model, for given geometrical and material parameters, any larger plastic zone was not found, only small, disconnected local plastic zones.

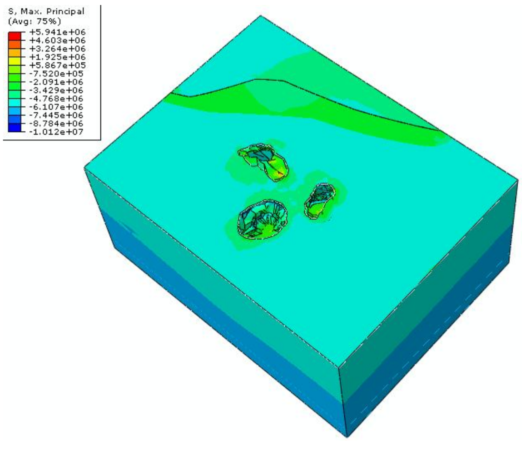

Figure 6 *First principal stress distribution (σ_{P1})*

As rock materials have reduced strength with respect to the extension stress, distribution of the first principal stress, σ_{p1} is shown in Figure 6. It shows maximum extension stress in every nodal point. Checking many cross sections of a model in three perpendicular planes, it is realized that extension stresses σ_{p1} are relatively small, except in already mentioned areas with high stress concentrations. In such points, the plastic deformations occur, leading to equalisation and decreasing of extension stresses. The high magnitude of another principal stresses that are compressive (σ_{p1} and σ_{p1}) improves the global model stability.

CONCLUSIONS

The general conclusion obtained by described nonlinear finite element analysis is that the model is in stabile elastic state, with localised stress concentrations and correspondding plastic deformation at sharp corners in cavern walls. There is no any larger plastic zone and horizontal displa-cements are relatively small. The tangential stresses are little bit larger in pillars between caverns, but there is no severe plastic deformation there. The stresses in the upper protective plate have caused local plastic deformations at several places, but it is still in stabile state. In the first layer above the salt, the local potential possibility has cracks due to low ultimate extension stress for that material. The material parameters of rock materials are highly scattered, so the average values are used in numerical analysis. With such material parameters, there is no any indicator of global cavern instability or global instability of pillars between caverns. The zones with plastic deformations are strictly localised and separated. Visco-plastic effect will lead to spreading of plastic zones, but also to stress reduction and equalisation of its distribution. The cavern volume will decrease with time. Maximum value of vertical displacement includes displacement due to the historical terrain subsidence and excavation by leaching. Magnitude of the last one is approximately 0.3 m at depth of 200 m from free surface. It is relatively small related to the cavern dimensions. So, the main conclusion is that the cavern group is still in stabile state, but many local plastic zones indicate that it can reach its ultimate dimensions. Therefore, it is compulsory to watch surface settling, to have regular ultrasound measurements of caverns geometry and to perform subsequent nonlinear finite element analysis.

REFERENCES

[1] Bobet A.: „Numerical Methods in Geomechanics“, The Arabian Journal for Science and Engineering, Volume 35, Number 1B, 2010

[2] Dowling, N. E., “Mechanical Behavior of Materials. Engineering Methods for Deformation, Fracture, and Fatigue” Second Editon, 1999.

[3] F. Kočar: The Rheological Properties of Rock Salt from Tuzla Basin, Bosnia and Herzegovina, FMGC Tuzla, 1971 (in Bosnian)

[4] Hartmut von Trayller, LorencoMusso: „Controlled Cavern Leaching in Bedded Salt Without Blanket in Timpa del Salto’’ Spring 2006 Conference, Brussels, Belgium

[5] Jeremic M. L.: "Rock mechanics in salt mining", Springer ISBN-10: 9054101032, 1994

[6] K. L. De Vries, K. D. Mellegard, G. D. Callahan, W. M. Goodman: "Cavern Roof Stability for Natural Gas Storage in Bedded Salt, Topical Report RSI-1829 DE-FG26-02NT41651, prepared for the United States Department of Energy, Mill Road Pittsburgh, Pennsylvania June 2005

[7] Minkley W., Menzel W.: "A Visco-elasto-plastic Softening Model and its

Application for Solving Static and Dynamic Stability Problems in Potash Mining", Institut für Gebirgsmechanik GmbH, Leipzig, Germany

[8] Munson, D. E.; Devries, K. L., “Development and Validation of a Predictive Technology for Creep Closure of Underground Rooms in Salt” Seventh International Congress on Rock Mechanics. Vol 1, pp 127-134, Aachen/Deutschland, 1991.

[9] Munson, D. E. Analysis of Multistage and Other Creep Data for Domal Salts, SAND98-2276, Sandia National Laboratories, Albuquerque, NM, January 1998.

[10] Otossen N. S.: "Viscoelastic-Visco-plastic Formulas for Analysis of Cavities in Rock Salt, Int. J. Rock Mech. Min. Sci and Geomech, Vol 23, No3, pp 201-212, 1986

[11] Steven R. Sobolik, Brian L. Ehgartner: "3D Cavern Enlargement Analysis" Sandia National Laboratories Report SAND2001-0526, Albuquerque, USA, April 2000

[12] G. Hadži-Nikovic, S. Ćorić, J. Gomila-nović, Application of 3D Slope Stability Analysis in Defining the Excavation Conditions of Coal at the Open Pits, Mining and Metallurgy Engineering Bor 2/2013, p. 1-10

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Salko Ćosić[*], Mevludin Avdić[*], Amir Sušić[**], Milenko Ljubojev[***]

NAPONSKO-DEFORMACIONA ANALIZA SONIH KOMORA METODOM KONAČNIH ELEMENATA[****]

Izvod

U ovom radu opisujemo proces naponsko-deformacione analize dubokih sonih komora metodom konačnih elemenata. Geometrijske i geomehaničke osobine komora i stijenskih slojeva odgovaraju istima na rudniku soli "Tetima" u Tuzli, BiH. 3D model je izrađen na osnovu serije ravnih ultrazvučnih snimaka duž ose svake komore. Izvođenjem nelinearne MKE analize došlo se do naponsko-deformacionog stanja masiva u zoni eksploatacije,neophodnog za procjenu stabilnosti i ponašanja komora.

Ključne reči: *MKE analiza, CAD model, sona komora, distribucija napona i deformacija*

1. UVOD

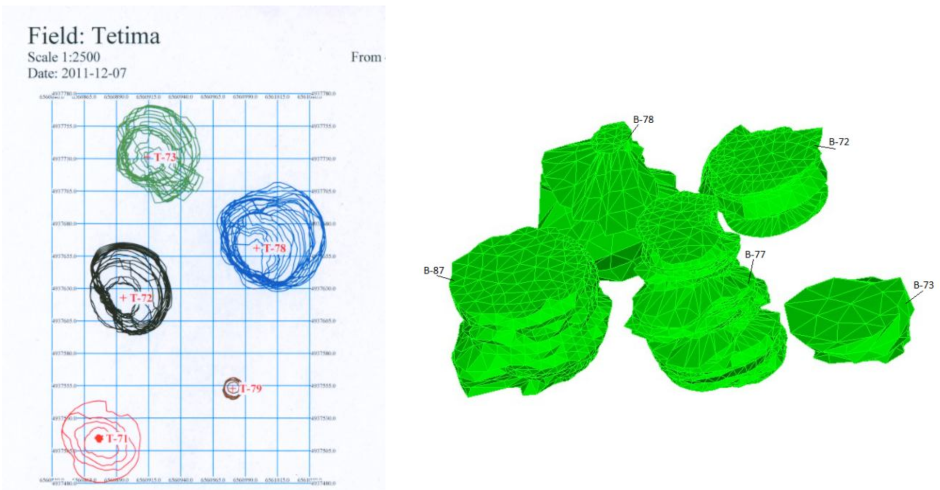
Eksploatacija ležišta kamene soli metodom izluživanja osim prednosti vezana je i za niz poteškoća. Širenje podzemnih komora (kaverni) velikih dimenzija u ležištu soli vezano je za povećanje opasnosti od gubitka stabilnosti komore. Kolaps izaziva litostatički pritisak kome je komora na velikoj dubini izložena. U cilju održanja stabilnosti tj. izbjegavanja kolapsa neophodno je zaustaviti ekspolataciju kada se veličina komore približi kritičnoj granici, istu hermetički zatvoriti i preći na izluživanje nove, susjedne komore. Položaj i dinamika izluživanja nove komore takođe imaju veliki uticaj na već zatvorenu komoru. Potrebno je osigurati da zaštitni stubovi od kamene soli između komora mogu nositi visoke vrijednosti spoljnih (litoloških) pritisaka na dubini komore. Određivanje potrebnih geometriskih parametara (prečnici komora i rastojanja između osa istih) je složen zadatak. U dosadašnjim istraživanjima i praksi uglavnom su se koristili ili empirjski ili obrasci teorije elastičnosti. Ovi drugi omogućavaju da se za homogen, izotropan, linearno elastičan materijal odredi naponsko stanje pri postojanju cilindričnih, eliptičnih ili sferičnih šupljina i njihovih kombinacija pri odgovarajućim graničnim uslovima [11]. Na žalost, u realnim uslovima, ležište kamene soli je daleko od homogenog, izotropnog, linearno-elastičnog materijala. Ono je najčešće slojevito, sa različitim, nehomogenim slojevima, stijenski materijal (kamena so, mineral halit) je u opštem slučaju anizotropan i njegova konstitutivna relacija je nelinearna i neelastična. Takođe, oblik (geometrija) stvarne komore bitno odstupa od cilindričnog ili sferičnog oblika za koji su razvijeni analitički modeli. Jasno je da prethodno spomenuti analitički modeli mogu dati samo približnu sliku naponskog stanja te da se zbog složenosti i nepouzdanosti mora raditi

[*] *Univerzitet u Tuzli, Bosna i Hercegovina*
[**] *d.d.Rudnik soli Tetima, Tuzla, Bosna i Hercegovina*
[***] *Institut za rudarstvo i metalurgiju Bor*
[****] *Ovaj rad je realizovan u okviru projekta broj 36014 koji se finansira od strane Ministarstva prosvete, nauke i tehnološkog razvoja Republike Srbije, za period 2011 – 2014.*

sa većim stepenima sigurnosti. Ovo se u praktičnom smislu ogleda kroz zatvaranje komore (prestanak eksploatacije) možda i znatno prije nego što je to zaista neophodno, u fazi kada ista ima najveću produktivnost, prelazak na novu komoru koja u početnoj fazi izluživanja zbog malih dimenzija ima i vrlo malu produktivnost kao i ostavljanje znatno većeg zaštitnog stuba između stare i nove komore čime je taj mineralni materijal trajno izgubljen. Pojava FEM metode analize napona i deformacija dovela je do bitnog napretka u ovom području. Ista omogućava nelinearnu analizu napona i deformacija u zoni komore sa naprednijim modelima materijala i realističnom geometrijom koja uzima u obzir slojevitost materijala i stvarni oblik komore. Time se omogućava pouzdanija procjena stanja i ponašanja pojedinačne komore kao i međusobne interakcije više komora u ležištu. Proceduru takve analize na primjeru komora rudnika „Tetima“ u Tuzli dajemo u nastavku rada.

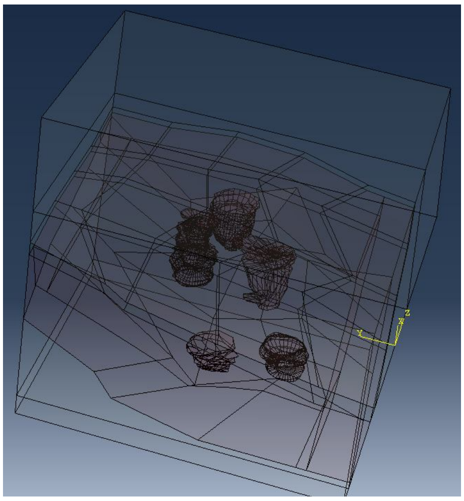
2. MKE MODEL SONIH KOMORA

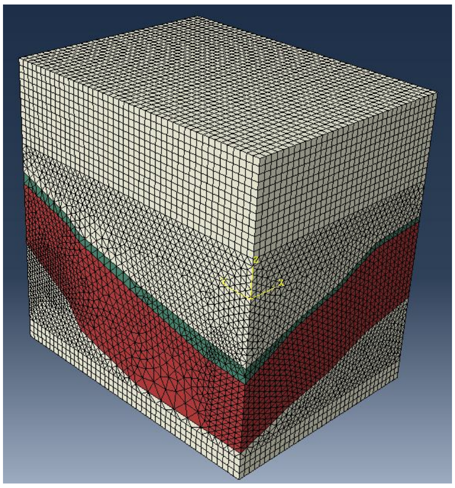
Početna faza FEM analize podrazumijeva izradu realističnog CAD modela ležišta sa komorama. U nastavku će mo prikazati naponsko-deformacionu analizu zaštitnih stubova između više (5) komora na rudniku „Tetima“ u Tuzli, Bosna i Hercegovina. Geometrija stvarnih komora utvrđena je ultrazvučnim snimanjem. Sonda se spušta po osi komore sa površine do dna i daje niz ravnih (2D) ultrazvučnih snimaka, u ravni normalnoj na osu komore, sl. 1 (a). Konturni presjeci se opisuju spline funkcijama koje se koriste za generisanje 3D solida. Komore su orjentaciono 80-100 m. visoke, prečnika do 40 m i na dubini od 500-700 m. Zapremina jedne komore orijentaciono iznosi 100.000 m^3.



Sl. 1. *Ultrazvučni snimak, presjek na odgovarajućoj visini komore (a), 3D solid modeli (b)*

3D solidmodel pojedinačne komore prikazan je na slici 2 (a). CAD model obuhvata 5 komora koje su modelirane na osnovu serije ultrazvučnih snimaka. Komore (šupljine) su dobijene "oduzimanjem" 3D modela punih komora od prethodno pripremljenog modela sloja kamene soli, sl. 2 (b). Dimenzije modela (300 x 200 x 600) m. su takve da se obuhvate sve komore od interesa te da se bočni uticaji ostatka masiva svode na standardne što podrazumijeva da se fiksiraju pomaci svih tačaka u pravcu normale na površinu. S obzirom na dubinu na kojoj se nalazi gornja površina komora, da bi se smanjila veličina modela, izostavlja se stijenski materijal (sloj laporca), a njegov uticaj se kompenzira dodavanjem ravnomjerno raspoređenog pritiska po litostatičkom zakonu po gornjoj površini modela. Slojevi (litološki članovi) su modelirani na osnovu raspoloživih geoloških podataka i karata.





Sl. 2. *3D slojeviti CAD model komora u ležištu rudnika „Tetima" (a), diskretizirana domena (b)*

3. PRE-PROCESIRANJE

3.1. Generisanje MKE mreže

Prije diskretizacije na konačne elemente je izvršeno je particioniranje modela kako bi se omogućila izrada naprednije heksagonalne mreže elemenata tamo gdje je to moguće. Zakrivljeni dijelovi komore sa složenom geometrijom modeliraju se pomoću standardnih linearnih tetraedarskih elemenata. Na ovaj način (particioniranjem) postignut je kompromis između broja elemenata (broj stepeni slobode) u modelu, kvaliteta aproksimacije i računske mogućnosti hardvera na kome se obavlja FEM analiza. Na sl. 2 (b) prikazan je diskretizirani model. Ukupan broj stepeni slobode modela iznosi oko 380.000.

Nakon definisanja geometrije modela, preprocesiranje obuhvata automatsko generisanje mreže, definisanje modela materijala, opterećenja, graničnih uslova i eventualnih interakcija između dijelova modela i okoline.

3.2. Modeliranje materijala

U razvijenom modelu, domena je slojevita i sastoji se od više litoloških članova. Osnovni materijal domene, kamena so, pod dejstvom dugotrajnog pritiska pokazuje visko-elastoplastične efekte što FEM analizu čini nelinearnom i podrazumijeva iterativno rješavanje sa većim brojem iteracija. Parametri potrebni za izabrani reološki model materijala određeni fitovanjem rezultata utvrđenih eksperimentalno na uzorcima, prema standardiziranim procedurama. Ostali stijenski slojevi su modelirani kao linearno elastični sa Drucker-Pragger-ovim uslovom tečenja u oblasti plastičnosti. U prosturu glavnih napona, Drucker-Prager uslov loma dat je sa (1) dok je efekt puzanja modeliran sa (2):

$$\sqrt{J_2} = a + b \cdot I_1 \text{ ili}$$

$$\sqrt{\frac{1}{6}[(\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_3)^2} =$$

$$= a + b \cdot (\sigma_1 + \sigma_2 + \sigma_3) \qquad (1)$$

$$\overline{\varepsilon_{cr}} = (A \cdot \sigma^n [(m+1)\overline{\varepsilon_{cr}}]^m)^{\frac{1}{m+1}} \qquad (2)$$

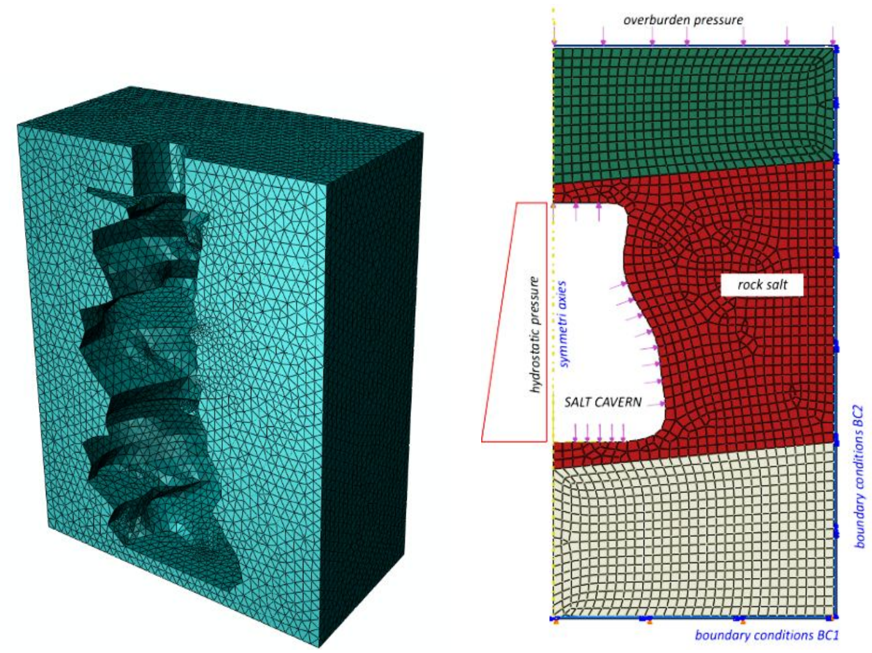
Konstante a, b, A, n i m u (1) i (2) su određene eksperimentalno.

3.3. Granični uslovi

Dimenzije modela su izabrane dovoljno velike tako da se na stranama mogu primijeniti standardni geomehanički granični uslovi prikazani na sl. 3 (b) za slučaj 2D analize. Za površinu koja odgovara donjoj bazi modela je usvojeno da je vertikalni pomak jednak nuli. Za bočne površine modela je usvojeno da su pomaci u pravcu normalom na bočne ravni jednaki nuli. Time je model pravilno i dovoljno fiksiran u prostoru.

3.4. Opterećenje

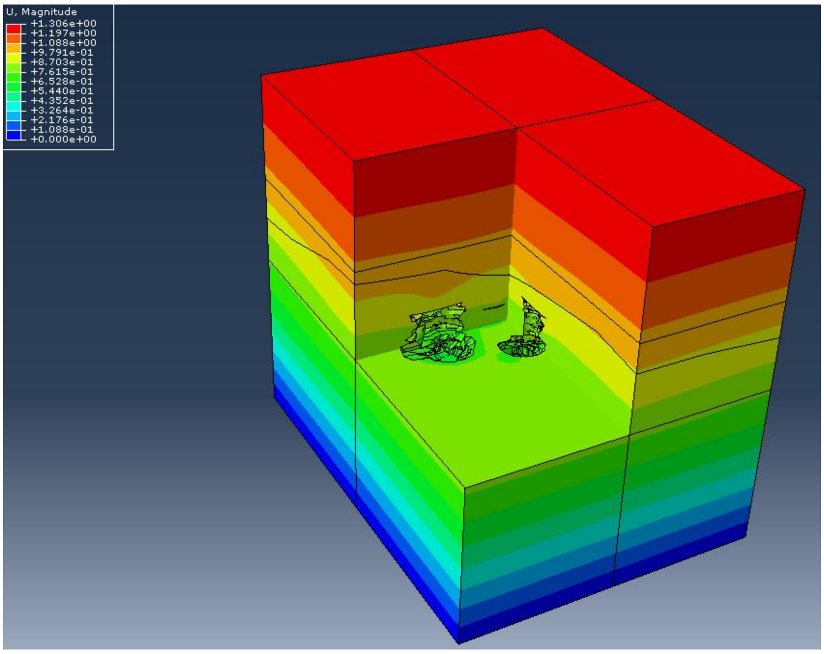
Opterećenje potiče od sopstvene težine i zadaje se preko faktora gravitacije i gustoće materijala. Na gornju površinu dodat je eksterni pritisak koji kompenzira odgovarajuću visinu stijenskog masiva od gornje plohe modela do slobodne površine. Veličina eksternog pritiska jednaka je pritisku na dubini od 180 m pri gustoći materijala od 2100 kg/m^3. Pritisak u unutrašnosti komora se mijenja linearno sa dubinom i jednak je vrijednosti hidrostatičkog pritiska na odgovarajućoj dubini, p=ρgh.



Sl. 3. *Diskretizirani MKE model komore (a), standardni granični uslovi (b)*

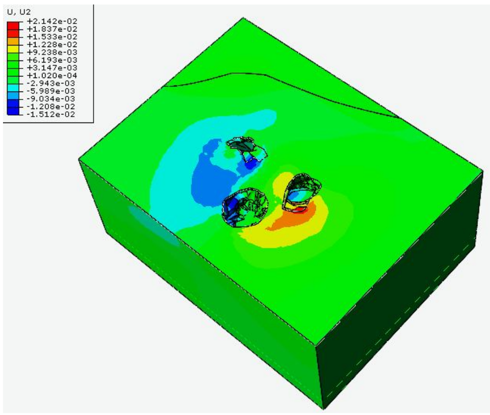
4. ANALIZA REZULTATA

Rezultujući diskretni sistem (nelinearnih) jednačina se rješava za cca 200 minuta rada PC računara. Zbog izrazito lokalizovanog plasticifiranja nekoliko elemenata, analiza se vrši u više inkremenata opterećenja (max. 30) sa 2-6 iteracija po inkrementu. U praktičnom smislu, od interesa su polja pomaka koji nastaju u toku i nakon eksploatacije. Distribucija magnitude pomaka za date parametre prikazan je na sl. 4. Maksimalno utvrđeno vertikalno pomjeranje iznosi oko 1.306 m i locirano je na površini u zoni projekcije komore br. 73. S obzirom na visko-elasto-plastične efekte koje pokazuje ruda soli, očekuje se blagi porast vertikalnog pomaka s vremenom, u čitavoj zoni. Vertikalni pomaci u ostalim presjecima su bitno manji. Uočljivo je i podizanje dna komore što je sasvim razumljivo s obzirom na znatno više vrijednost pritiska u masivu soli izvan nego u slanoj vodi unutar komore.



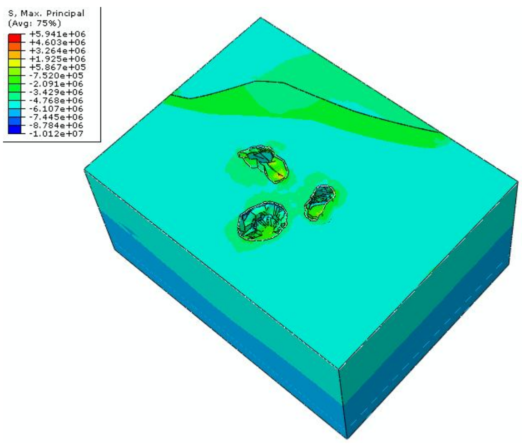
Sl. 4. *Magnituda pomaka u poprečnom presjeku*

Na sl. 5 prikazano je polje horizontalnog pomjeranja (u_2) u horizontalnom presjeku kroz komore. Visoke vrijednosti pritisaka unutar i izvan komora te smanjena krutost materijala u horizontalnoj ravni uslijed postojanja šupljina dovode do bočnih pomaka reda veličine od -2 do + 2 cm. U slučaju da se neutrališe unutrašnji hidrostatički pritisak (prazna komora) bočni pomaci postaju bitno veći i dovode do kolapsa komore (u numeričkom smislu gubi se konvergencija nakon velikog broja iteracija). Tome doprinose i neravnomjerno raspoređeni bočni pritisci koji nastaju uslijed neravnomjerne debljine i mehaničkih osobina materijala slojeva.



Sl. 5. *Distribucija horizontalnog pomaka*

Za analizu napona najmjerodavniji je efektivni napon koji se u ovom slučaju računa prema Drucker-Prager kriteriju plastičnog tečenja. Izračunate vrijednosti napona u čvornim tačkama (skalarne veličine) pružaju mogućnost poređenja sa eksperimentalno utvrđenim jednoosnim naponima koji dovode do plastične deformacije. Analizom su utvrđeni naponi reda veličine 20 MPa koji prekoračuju granice tečenja materijala slojeva. Najveći naponi se javljaju na izolovanim mjestima na površini komora u presjecima koji imaju nagle i oštre promjene geometrije. Broj takvih mjesta je relativno mali i ista su udaljena jedno od drugoga. U stvarnim uslovima, promjena geometrije nije tako izrazita i konture nisu tako „oštre” kao što je to prikazano na modelu, tako da se smatra da se ovdje radi o lokalnim plastičnim deformacijama. Plastična deformacija tih elementa će dovesti do ravnomjernije distribucije napona i rasterećenja tih presjeka. U modelu, za zadate parametre materijala i opterećenja, nije utvrđena pojava nastanka i širenja plastificirane zone većih dimenzija.



Sl. 6. *Prvi glavni napon (sP1)*

Budući da stijenski materijali ne podnose istezanje, na slici 6. je prikazana distribucija maksimalnog glavnog napona. Analizom distribucije ovog napona sa promjenom položaja presjeka modela utvrđeno je da isti ima relativno malu vrijednost u čitavom modelu osim u nekoliko kritičnih tačaka koje se nalaze na mjestima nagle promjene geometrije komore (oštre ivice ili uglovi). U takvim tačkama dolazi do lokalne plastične deformacije čime se naponi istezanja smanjuju i uravnotežavaju sa okolinom. Visoka vrijednost druga dva glavna napona (kompresivni) povoljno djeluje na stabilnost komore tako da osim lokalnih plastičnih deformacija u blizini oštrih uglova ili ivica, u cjelini model se nalazi u elastičnom stanju sa umjerenim vrijednostima napona i deformacija.

ZAKLJUČAK

Generalni zaključak dobijen analizom pomaka kroz čitav model je da nema intenzivnih pomjeranja u zoni komora. Tangencijalni naponi koji su i najveći uzročnik pojave plastičnih deformacija pokazuju nešto veću vrijednost u dijelu materijala između komora što je i razumljivo obzirom na već spomenuto kod analize pomaka. Analizom naponsko - deformacijskog stanja u području predviđene zone zaštitne ploče uočavaju se pojave plastičnih deformacija, ali njihov intenzitet nije u toj mjeri izražen da bi dao pokazatelj eventualnog proloma zaštitnog stuba. Rezultati naponske analize i plastičnih deformacija za materijal iznad soli ukazuju na tačke potencijalne zone pojave pukotina i narušavanja homogenosti sloja. U proračunu su uzete srednje dobijene vrijednosti geomehaničkih parametara. Podaci dobijeni ovom analizom ukazuju da nema pokazatelja o spajanju komora i narušavanju postojećih međukomornih stubova. Utvrđene plastične deformacije su male magnitude i obuhvataju mala područja. Visko-plastični efekat koji ispoljava so će dovesti do širenja ovog područja ali sa opadanjem napona i povećanjem ravnomjernosti distribucije. Dobijena veličina maksimalnog vertikalnog pomaka, a koja je navedena u radu sadrži pored uticaja slijeganja terena usljed eksploatacije i "istorijsku" vrijednost pomaka koji je bio prije početka eksploatacije. Ako se uzme u obzir i ovaj parametar onda se ta vrijednost kreće u granicama do 0.3 metra na dubini od 200 metara od površine. Opšti je zaključak da je naponsko stanje stabilno, naponi u glavnini materijala su još uvijek u elasticčnom području ali i da je blizu granica plastificiranja i velikih deformacija jer su neka najnepovoljnija područja već zahvaćena istom.

LITERATURA

[1] A. Bobet: „Numerical Methods in Geomechanics“, The Arabian Journal for Science and Engineering, Volume 35, Number 1B, 2010

[2] N. E. Dowling, “Mechanical Behavior of Materials. Engineering Methods for Deformation, Fracture, and Fatigue” Second Editon, 1999.

[3] F. Kočar, Reološke osobine kamene soli Tuzlanskog basena, RGGF Tuzla, 1971 (in Bosnien)

[4] H. von Trayller, L. Musso, „Controlled Cavern Leaching in Bedded Salt Without Blanket in Timpa del Salto“ Spring 2006 Conference, Brussels, Belgium

[5] M. L. Jeremic: "Rock mechanics in salt mining", Springer ISBN-10: 9054101032, 1994

[6] K. L. De Vries, K. D. Mellegard, G. D. Callahan, W. M. Goodman: "Cavern Roof Stability for Natural Gas Storage in Bedded Salt“, Topical Report RSI-1829 DE-FG26-02NT41651, prepared for United States Department of Energy, Mill Road Pittsburgh, Pennsylvania, June 2005.

[7] W. Minkley, W. Menzel, "A Visco-elasto-plastic Softening Model and its Application for Solving Static and Dynamic Stability Problems in Potash Mining", Institut für Gebirgsmechanik GmbH, Leipzig, Germany

[8] D. E. Munson, K. L. Devries, "Development and Validation of a Predictive Technology for Creep Closure of Underground Rooms in Salt" Seventh International Congress on Rock Mechanics. Vol 1, pp 127-134, Aachen/Deutschland, 1991.

[9] D. E. Munson, Analysis of Multistage and Other Creep Data for Domal Salts SAND98-2276, Sandia National Laboratories, Albuquerque, NM, January 1998.

[10] N. S. Otossen, "Viscoelastic-Viscoplastic Formulas for Analysis of Cavities in Rock Salt, Int. J. Rock Mech. Min. Sci and Geomech, Vol 23, No3, pp 201-212, 1986

[11] S. R. Sobolik, B. L. Ehgartner: "3D Cavern Enlargement Analysis" Sandia National Laboratories Report SAND2001-0526, Albuquerque, USA, April 2000.

[12] G. Hadži-Niković, S. Ćorić, J. Gomilanović, Primena 3D analize stabilnosti kosina pri definisanju uslova iskopa uglja u površinskim kopovima, Mining and Metallurgy Engineering Bor 2/2013, str. 11-20

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Nebojša Vidanović[*]*, Rade Tokalić*[*]*, Ljubinko Savić*[**]*, Suzana Lutovac*[*]

JUSTIFICATION OF RENEWED COAL EXPLOITATION FROM THE DEPOSIT "BAJOVAC"[**]

Abstract

Coal presents the basic energy potential of the Republic of Serbia. More than half of electric energy production in our country comes from this resource. This causes a need for activation the new seams of raw material which are potentially exploitable. This work presents an extract from the research results, published within the Project TR 33029 "Study of Possibilities for Valorization the Remaining Coal Reserves with a View to Provide the Stability of Energy Sector of the Republic of Serbia", financed by the Ministry of Education and Science. This work treated the problems of future coal exploitation from the West Morava Basin, with special review to the activation of the closed mine "Bajovac".

Keywords: *coal, exploitation, deposit, seam, capacity, method*

1 GENERAL DATA ON DEPOSIT AND ITS PREVIOUS EXPLOITATION

The West Morava coal seam presents the unique coal bearing location in the area of Bresnica – Tavnik – Ladjevci. The mine "Bajovac" is located in the north-east part of the Basin (Cacak – Kraljevo). Total surface of the Basin is 1000 km^2 , while the production coalbearing area of the mine "Bajovac" has surface of 1.5 km^2.

For many years, the coal has been exploited in the area of Bresnica - Tavnik - Ladjevci from four coal mines, as well as: "Bresnica", "Voljace", "Tavnik" and "Bajovac".

1.1 LOCATION AND SPREADING

The mine "Bajovac" is located near the village of Ladjevac in the vicinity of the town of Kraljevo. Based on data from exploration drill holes in the panon-pontic coal series, the reserves of two coal zones were determined the upper with two coal seams and the lower with five, from which only upper one has the economic value.

In the upper coal zone, the highest coal seam is marked as the upper-roof A_1 seam with the average thickness of 6-8 m of pure coal in the seam, with barren interseams of 15 m. The seam A_1 presents the main coal seam, which only was in exploitation in the mentioned pit field. It has a regular development in largerarea and it is mined quite steeply in the direction of southwest under angle of 49°, regarding that in the vicinity of Mrcajevci-Ladjevci cleavage falling angle

[*] *University of Belgrade, Faculty of Mining and Geology, Djusina 7, 11000 Beograd, Srbija, e-mail: vidanovic@rgf.bg.ac.rs, tokalic@rgf.bg.ac.rs, lutovac@rgf.bg.ac.rs*
[**] *FTS Kosovka Mitrovica*
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rises up to 85°, so it lies in different depths in the eastern part about 30 m, and in the western part about 400 m. The lower layer was never under exploitation. Exploitation of coal in the mine “Bajovac” started in 1958. And with high efforts, it was maintained by the end of 1986. Production of coal was low, in the interval from 7,000 to 17,000 t annually, although conditions for mining in this pit are very favorable, and conditions of coal placement and entire climate did not enable better results.

1.1.2 Tectonic Review of the Basin

Based on geological and geophysical testing in the West Morava Basin, intensive tectonic movements were noticed, represented by cleavages of different intensity. The main role in forming of the West Morava valley had the longitudinal the West Morava fault of high intensity with direction SE-NW.

Due to strong tectonic intensity, a part of depression sunk in depth, so the thickness of Neogene sediments in that part is the largest. According to data of exploration drilling in the area of the village of Katrge, the thickness of Neogene sediments in the lowered part is 1910 m, and in the south raised part is about 1200 m, so the jump along this cleavage is about 700 m, meaning that north part is much more lowered.

Little more to the north, parallel to the previous one, the ‘’Mrcajevci-Ladjevci’’ fault is stretched, which on length of over 20 km cuts down the productive series, so across its length south wing together with coal seams has lowered for about 350 m. This fault has a special significance for exploitation, because it is possible to perform excavation by mining works only to its border in all coal areas.

Between these two faults, the medium parts went very low, so one secondary tectonic trench is formed inside the valley, going in length to the east outside of the West Morava Basin to the Krusevac Basin.

Besides mentioned longitudinal faults, several cross faults of significantly lower intensity were determined in the north and north-east part of Basin, inside which the coal series is shared into blocks. So, the existence of faults was determined along the Dicina River, then the Banjska River and the Bresnicka River and others.

Along these faults, some blocks significantly went lower in depth, and some remained to stick out like horsts, so later due to erosion part of roof and upper coal zone were taken away, and in some places the coal seam too.

1.2 RAW MATERIAL BASE

1.2.1 Limitation of the Coal Bearing Area

The coal bearing area of the West-Morava Basin includes the north-east part, and it is separated in the area Bresnica – Tavnik – Ladjevci. That is where the upper roof coal seam was exploited for many years in the mining districts: Bresnica, Voljavca, Tavnik and Bajovac, with surface area of 2.8 km^2.

The former mining district of the mine “Bajovac” which has surface of app. 1.3 km^2, in the east side is limited with offspring zone of direction NW-SE, while the west lower border is separated by Mrcajevci-Ladjevci fault that cuts the coal seam in two parts, so the lower west wing went down about 350 m. Southeast border is profiled line of drill holes T-8 and T-12 where the coal seam of smaller thickness is determined, while the northwest border is old works of the earlier mines of Tavnik and Bajovac. By direction of stretching, the length of exploitation area is 900 to 1000 m.

1.2.2 Coal Reserves in the Mining District of the Mine “Bajovac”

Since coal reserves in the mine “Bajovac” are important for this work, the following Table 1 shows the reserves of this mining district.

Table 1

Geological reserves of upper A_1 coal seam in the mining district "Bajovac" (t)			
Category	**Balance**	**Out of balance**	**Total**
A	5,373,470	137,280	5,510,750
B	2,039,550	-	2,039,550
Total A+B	7,413,020	137,280	7,550,300
Geological reserves of lower B_2 coal seam in the mining district "Bajovac" (t)			
A	-	-	-
B	2,704,970	-	2,704,970
C_1	168,880	-	168,880
Total A+B+C_1	7,413,020	-	7,550,300
Total Bajovac	**10,286,870**	**137,280**	**10,424,150**

1.2.3 Geological Characteristics of the Coal Seam and Associated Rocks

Coal bearing field of the mining district of the mine "Bajovac" was explored with seven exploration drill holes, while two cuts, k + 115.6 m were opened by the former exploration works. Drill holes are located on parallel profile lines, in distances, per stretching of coal seams of 250 to 600 m, and per fall from 200 to 250 m. All mining premises are also oriented per stretching.

On the basis of received data, it was determined that two coal zones are present in this coal bearing field, but in economic view, only the upper zone is significant with two regular developed coal seams, separated as A_1 and B_2, with space development, similar thickness and continuous quality. Distance between these two layers is in the range from 50 to 60 m.

In the lower zone, the coal seams are irregular with small thickness, poor quality, so they do not have an economic value from the mining point of view.

The roof A_1 of coal seam has regular development in larger space on the area of Bresnica, Tavnik, Bajovac and Ladjevci. The real thickness of coal seam in the mining district of the mine Bajovac is in the range from 2.60 m to 11.90 m, or on the average of 8.5 m. Coal seam is ho mogenous with uniform composition of xylite-vitrite type, with scattered seamsof detrital (clay-marl) type.

Coal seam stretches quite steeply in the southwest direction with angle of about 49^0, while in the vicinity of Mrcajevci-Ladjevci fault falling angle increases up to 85^0 and lies down on different thicknesses, in the east part about 30 m, and in the west part about 400 m. Direct bottom and roof part of coal seams are coalish sebaceous clays and marl gray stratified clays.

Bottom B_2 coal seam in the frame of this coal field is regularly developed and it lies beneath the roof one in the distance of 50 to 60 m. It is separated by dirt bands, and divided into three thinner coal seams. Its total thickness with dirt bands is from 3.0 m to 12.0 m, and without dirt bands is from 1.5 to 5.3 m. Dirt bands are made of coalish and gray thin layered clays.

Generally, it also stretches, as the previous one towards southwest, under approximate angle, so it is stretched from 20 m on the east to 480 m on the west. Roof level and bottom level are made of coalish sebaceous and marlish clay and marl itself.

This coal layer has never been exploited, so all data about it are based on the exploration drill holes and offsprings on the surface. It was entered from the shaft “Strmuzak“ at k + 165 m, but there were no more mining works on the seam.

1.2.4 Quality of Coal

Testing the coal quality was done in the laboratory of the Mining Institute – Zemun, so there are enough data for review of coal quality and its wide application.

Coal from the mine “Bajovac“ has good physical characteristics, because roof A_1 seam is quite compact and sinewy, although there are smaller lens of friable and soft earthy-detrital coal. It has band structure, partially lenticular, brown to dark color, dark scratch, slope and lenticular stratification, irregular fracture.

Coal loses moisture during standing and storage, so the total loss of moisture under longer storage is up to 24%, therefore it cannot be stored for a long period of time, except under special conditions.

Petrographic tests showed that coal belongs to the vitrite-clarite and clarite type, and it is made of vitrite, clarite, durite and fasite. Due to quite low level of gelification, wooden components of vitrite prevails, and they amount from 11 to 35% and clarite from 37 to 70%, while the level of vitrite participates with smaller amount from 3 to 10%.

Inorganic impurities in coal are singenetic terigene ingredients, presented by coalish clays from 9 to 61%, and from authigenic minerals in coal there are pyrites, marcasite, and siderite, with highest participation of pyrites, from 1 to 5%. From epigenetic ingredients in coal, only plaster is present.

Based on these petrographic analyses, coal from the mine „Bajovac“ belongs to the group of hard brown-lignite coals.

Laboratory tests of chemical-physical characteristics of raw coal from roof A_1 seam, taken from the pit of the mine “Bajovac“, have shown the following results:

Technical analysis:

• Moisture	35.30%
• Ash	16.28%
• S total	1.65%
• S in ash	0.59%
• Coke	57.84%
• C-fix	21.36%
• Combustible	48.42%
• Volatile	26.86%
• DTE	12.050 kJ/kg
• GTE	13.574 kJ/kg

Elemental analysis:

• Carbon	32.64%
• Hydrogen	2.82%
• Oxygen + Nitrogen	11.90%
• S combustible	1.06%

Laboratory tests of chemical-physical characteristics of raw coal from roof B_2 seam, taken from works in the mining districtt Tavnik-Strmuzak have shown the following results:

Technical analysis:

• Moisture	36.15%
• Ash	15.25%
• S total	1.49%
• S in ash	0.76%
• Coke	38.83%
• C-fix	23.58%
• Combustible	48.60%
• Volatile	25.02%
• DTE	12,050 kJ/kg

Elemental analysis:

• Carbon	70.20%
• Hydrogen	5.66%
• Oxygen + Nitrogen	22.41%
• S combustible	1.50%

It could be seen from the present data that data for both seams are similar, what for coals from these two seams means that they are practically the same.

As another data from the literature, there is a successful attempt to dry coal with steam under pressure of 20 atm. According to data, this treatment gave the excellent results and that the fuel of very good quality was obtained:

• Moisture	12.70%
• Ash	14.80%
• S total	1.30%
• S in ash	0.70%
• Coke	46.80%
• C-fix	32.00%
• Combustible	72.40%
• Volatile	40.40%
• DTE	18.130 kJ/kg
• Carbon	50.00%
• Hydrogen	4.20%

Also, the experiments of dry distillation and gasification were carried out, and it was determined that coal from this basin could be used for production of metallurgical products, which in quality completely satisfies the needs of the metallurgy.

Coal could also be successfully used for production of high-caloric gas for industrial and thermal needs.

2 TECHNICAL-TECHNOLOGICAL CONDITIONS OF EXPLOITATION

2.1 PRODUCTION CAPACITY

In calculation the production capacity in the pit of the mine "Bajovac", the following facts have to be considered:

1. Production requested by investors is 200.000 t.c.c. (tons of commercial coal);
2. For coal excavation, both coal seams have to be foreseen;
3. Liquidation of protection pillars of previous opening premises will be performed at the first horizon;
4. Four excavation methods would be applied in the pit, and only one of them was used in this mine.

Production capacity at the I horizon (k+240 – k+160 m)

In the roof coal seam A_1 at the I horizon only 112,000 t of geological reserves or cca 100.000 t.c.c. will be included. Coal reserves will be in liquidation and the excavation method will be applied that was already used in this pit, and that is the **modified pillar-chamber method.** In such conditions, the annual production could not be expected at the level larger than 50,000 t.c.c.

Regarding to the characteristics of bottom coal seam (thickness of coal seam from 3 to 12 m with coal participation in seam (in three thin seams) of 50%, i.e. 1.5 to 6.0 m, due to larger quantity of waste in the excavated coal in this seam, the production from this seam must not exceed 30% of total production, so in this phase, the production of total 20,000 t.c.c. could be planned.

Total production at the I horizon will amount 70,000 t.c.c./year in the first two years. This dynamics of production will lead to imbalance, because after two years all coal in the roof seam of this horizon will be excavated, with only 10% of reserves in the bottom one. This imbalance fill be fixed in later exploitation, when the production in the roof seam will be significantly increased.

Production capacity at the II horizon (k+160 – k+80 m)

In the roof coal seam A_1 at the II horizon 829,000 t of geological reserves or cca 790,000 t.c.c. will be included, but the excavation will be organized with one sub-level which would divide this sub-level per altitude in two equal parts. In the upper sublevel, cca 340,000 t.c.c would be. From this amount in the south wing, cca 130,000 t.c.c. would be located, and the excavation method that was already in use in this mine, would be applied. Yearly capacity would be 65,000 t.c.c. and the excavation would last for two years. At the same time, the excavation by friction pillars would be introduced in the north wing, in the amount of 210.000 t.c.c. With capacity of over 80.000 t.c.c., the excavation would last just over 2.5 years. A part of coal reserves will be in liquidation of the previous protection pillars of opening premises (cca 40,000 t.c.c.) and the excavation method that was already in use in this pit would be applied, and that is the **modified pillar-chamber method.** In these conditions, the yearly production at the level larger than 50,000 t.c.c. could not be expected, so in the upper sub-level, the excavation would last for 2.5 years, and cca 380,000 t.c.c. would be excavated. In the second sub-level, the production would be cca 400,000 t.c.c. Since in this part there is no liquidation of the old protection pillars, this sub-level would be divided in two asymmetric wings, in the south in length of 420 m and in the north north in length of

510 m. From total quantities of reserves in the south cca 180,000 t.c.c. would be, where the excavation method that was already in use in this pit would be applied. Yearly capacity would be 65,000 t.c.c. and the excavation would last cca 3 years. At the same time, the excavation by friction pillars would be introduced to the north wing in the amount of cca 220.000 t.c.c. With capacity of 80.000 t.c.c., the excavation would last also cca 3 years, and cca 400.000 t.c.c. would be excavated.

As it was said that production from the bottom seam must not exceed 30% from total production, in this phase yearly production of 234.000 t.c.c. or cca 42.000 t.c.c. could be planned.

Total production at the II horizon will amount 167,000 t.c.c. per year in 5.5 years. This dynamics of production would correct inequality, regarding that after 5.5 years about 260,000 t.c.c. would be excavated in the bottom seam of the I horizon and cca 40.000 t.c.c. in the bottom seam of the II horizon.

Production capacity at the III horizon (k+80 – k+0 m)

In roof coal seam A_1 at the III horizon, 856,000 t of geological reserves or cca 810.000 t.c.c. will be included. Coal reserves are in ideal position and after 5.5 years the modern excavation method could be introduced, i.e. the excavation by wide frontal mechanized complex. In these conditions, the yearly production at the level larger than 180,000 t.c.c. could be expected. Excavation would be carried out in the entire deposit in length of 940 m and it would last for 4.5 years or with the average advancing of front of 22 m/month.

Production from the bottom seam in this horizon also must not exceed 30% of total production, so in this phase the production of total 60,000 t.c.c. or 270,000 t.c.c. for 4.5 years could be planned, so a delay in excavation in the bottom seam for one entire horizon would be practically achieved.

Production capacity at the IV horizon (k+0 – k-80 m)

Semi-horizon (k-80 – k-100 m) – Liquidation

Excavation would be carried out in this semi-horizon in the roof seam using the modified pillar-chamber method with capacity of 2 x 50,000 t.c.c., two-wings, and it would last cca 1.5 years. Regarding that with starting the excavation in this semi-horizon about 450,000 t would be left in the roof seam, the same would be excavated in that period at the level of 30,000 t.c.c./year, so total production in this period would be 130,000 t.c.c..

The remaining 400,000 t.c.c. in the bottom seam could be excavated, if the market would be found or if some other mines of this basin would be opened. Independently, it could be possible to organize the excavation at the level of 2 x 40,000 t.c.c., also two-wings, in time of 5 years.

2.2 PRODUCTION DYNAMICS AND LIFETIME

In accordance to the suggested technical solution, the exploitation of this deposit would be carried out for 22 years. Yearly production in this period would be of 70,000 t/year in the first and second year, then it would be increased successively in the following six years and, in the ninth year, it could be possible to reach maximum capacity of 240,000 t/year which would be maintained in the following seven years. In the last six years, the production would be gradually decreased due to the deposit structure, and in the last year, it would amount 40,000 t/year.

CONCLUSION

This work presents an extract from the research results, published within the Project TR 33029 "Study of Possibilities for Valorization the Remaining Coal Reserves with a View to Provide the Stability of Energy Sector of the Republic of Serbia", financed by the Ministry of Education and Science. This work treated the problems of future coal exploitation from the West Morava Basin, with special review to the activation of the closed mine "Bajovac".

The basic idea that was a guide to the authors was to activate this deposit as a replacing capacity for the Ibar mines until finding the adequate solutions. For analysis of possibilities the coal exploitation from this deposit, all available technical documentation was used with simultaneous consultation of all relevant experts dealing with these problems.

Very detailed techno-economic analysis of the deposit "Bajovac" unequivocally has determined a justification of its reopening. The basic technical solutions were suggested in the frame of research, according to this Project, for opening, excavation methods, necessary work force per number and structure and necessary equipment. Economic analysis of this investment, which included the costs, market prices, and other relevant indicators also gave the positive results, therefore generally this project could get a positive evaluation.

REFERENCES

[1] N. Vidanovic et al., Justification Study of Exploitation Deposits "Cerje" of Despotovac Coal Basin and "Bajovac" of The West Morava' Coal Basin, FMG Belgrade, 2011; (in Serbian)

[2] P.Nikolic, D. Dimitrijevic, Coal of Yugoslavia, Pronalazastvo, Belgrade 1990, (in Serbian)

[3] N. Vidanovic, R. Tokalic, S. Mitic, Justification of Coal Explitation from Deposit "Cerje – Jovacko Polje, Journal "Underground Works", number 221, ISSN 03542904, p. 9-15, FMG Belgrade, 2012. (in Serbian)

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Nebojša Vidanović[*]*, Rade Tokalić*[*]*, Ljubinko Savić*[**]*, Suzana Lutovac*[*]

OPRAVDANOST PONOVNE EKSPLOATACIJE UGLJA IZ LEŽIŠTA „BAJOVAC“[**]

Izvod

Ugalj predstavlja osnovni energetski potencijal Republike Srbije. Više od polovine električne energije koja se proizvede u našoj zemlji je iz ovog resursa. To uslovljava potrebu aktiviranja novih potencijalno eksploatabilinh ležišta ove sirovine. Ovaj rad predstavlja izvod iz rezultata istraživanja koja su objavljena u okviru projekta TR 33029 "Izučavanje mogućnosti valorizacije preostalih rezervi uglja u cilju obezbeđenja stabilnosti energetskog sektora Republike Srbije" a koje finasira Ministarstvo prosvete i nauke. U njemu je tretirana problematika buduće eksploatacije uglja iz Zapadno-moravskog basena, sa posebnim osvrtom na aktiviranje zatvorenog rudnika "Bajovac".

Ključne reči: *ugalj, eksploatacija, ležište, sloj, kapacitet, metoda*

1. OPŠTI PODACI O LEŽIŠTU I NJEGOVOJ DOSADAŠNJOJ EKSPLOATACIJI

Zapadno - moravski ugljeni sloj sačinjava jedinstveni ugljonosni lokalitet na području Bresnica - Tavnik - Lađevci. Rudnik "Bajovac", se nalazi u severoistočnom delu basena (Čačak – Kraljevo). Ukupna površina basena iznosi 1000 km^2, dok produktivno ugljonosno područje rudnika ''Bajovac'' zahvata prostor od 1,5 km^2.

Dugi niz godina ugalj je eksploatisan u području Bresnica – Tavnik – Lađevci sa četiri ugljenokopa i to: "Bresnica", "Voljače", "Tavnik" i "Bajovac".

1.1. POLOŽAJ I RASPROSTRANJENJE

Rudnik "Bajovac" nalazi se kod sela Lađevac blizu Kraljeva. Na bazi podataka iz istražnih bušotina u panonsko-pontijskoj ugljonosnoj seriji utvrđene su dve ugljonosne zone, gornja sa dva ugljena sloja i donja sa pet, od kojih je samo gornja od ekonomske vrednosti.

U gornjoj ugljonosnoj zoni najviši ugljeni sloj označen kao gornji-krovinski A_1 sloj ima prosečnu debljinu od 6-8 m čistog uglja u sloju, a sa jalovim proslojcima i do 15 m. Sloj A_1 pretstavlja glavni ugljeni sloj, koji je do sada jedini bio u eksploataciji u navedenim revirima. Ima regularno razviće

[*] *University of Belgrade, Faculty of Mining and Geology, Djusina 7, 11000 Beograd, Srbija, e-mail: vidanovic@rgf.bg.ac.rs, tokalic@rgf.bg.ac.rs, lutovac@rgf.bg.ac.rs*
[**] *FTN Kosovska Mitrovica*
[**] *Ovaj rad predstavlja izvod iz rezultata istraživanja koja su objavljena u okviru projekta TR 33029 "Izučavanje mogućnosti valorizacije preostalih rezervi uglja u cilju obezbeđenja stabilnosti energetskog sektora Republike Srbije" a koje finasira Ministarstvo prosvete, nauke i tehnološkog razvoja Republike Srbije.*

na većem prostoru i zaleže dosta strmo u pravcu jugozapada pod uglom od 49°, stim što u blizini mrčajevačko - lađevačkog raseda padni ugao se povećava i do 85°, tako da leži na različitim dubinama i to u istočnom delu oko 30 m, a u zapadnom na oko 400 m. Podinski sloj nije nikada eksploatisan. Eksploatacija uglja u rudniku "Bajovac" otpočela je 1958. godine i uz velike napore održavala se do kraja 1986. godine. Proizvodnja uglja bila je skromna i kretala se godišnje od 7.000 do 17.000 t, mada su uslovi za rudarenje u ovoj jami veoma povoljni, tadašnji uslovi plasmana uglja i celokupna klima nisu omogućavali bolje rezultate.

1.1.2. Tektonski prikaz basena

Na osnovu geoloških i geofizičkih ispitivanja u zapadno moravskom basenu uočeni su intezivni tektonski pokreti pretstavljeni rasedima različitog inteziteta. Glavnu ulogu u formiranju zapadno-moravske kotline imao je uzdušni "zapadno-moravski" rased, velikog stepena inteziteta, pravca pružanja JI-SZ.

Usled jake tektonske intezivnosti deo depresije je potonuo u dubinu, tako da je i debljina neogenih sedimenata u tom delu najveća. Prema podacima istražnog bušenja u ataru sela Katrge debljina neogenih sedimenata u spuštenom delu je 1910 m, a u južnom izdignutom oko 1200 m, tako da je skok duž ovog raseda oko 700 m, odnosno da je za toliko spušteno severno krilo.

Nešto severnije, paralelno sa prethodnim pruža se drugi mrčajevačko-lađevački rased, koji na dužini preko 20 km preseca produktivnu seriju, tako da je duž njega južno krilo zajedno sa ugljenim slojevima potonulo za oko 350 m. Ovaj rased je od posebnog značaja za eksploataciju, jer se rudarskim radovima može vršiti otkopavanje samo do njegove granice u svim ugljonosnim područijma.

Između ova dva raseda, središnji delovi su duboko potonuli, tako da je unutar same kotline formiran jedan sekundarni tektonski rov, koji se prema istoku produžuje i van granica Zapadno moravskog basena u Kruševački basen.

Pored pomenutih uzdužnih u severnom i severoistočnom delu basena utvrđeno je prisustvo i nekoliko poprečnih raseda znatno manjeg inteziteta, kojima je ugljonosna serija iskomadana u blokove. Tako je utvrđeno postojanje raseda duž reke Dičine, zatim Banjske i Bresničke reke i drugi.

Duž ovih raseda neki blokovi su znatno potonuli u dubinu, a neki su ostali visoko da strče u vidu horstova, tako da je kasnije erozijom odnešen deo krovine i gornja ugljenosna zona, a mestimično i ugljeni slojevi.

1.2. SIROVINSKA BAZA

1.2.1. Ograničenje ugljonosnog prostora

Ugljonosno područije zapadno moravskog ugljenog basena zahvata severoistočni deo, a izdvojen je u predelu Bresnica - Tavnik - Lađevci. U njemu je gornji krovinski ugljeni sloj eksploatisan dugi niz godina u revirima: Besnica, Voljavča, Tavnik i Bajovac, zahvativši površinu cca 2,8 km^2.

Nekadašnji Revir rudnika "Bajovac" koji zahvata površinu od cca 1,3 km^2, ograničen sa istočne strane izdanačkom zonom pravca pružanja SZ-JI, dok je zapadna donja granica izdvojena mrčajevačko-ladjevačkim rasedom, kojim je ugljeni sloj presečen na dva dela, tako da je donje zapadno krilo potonulo oko 350 m. Jugoistočnu granicu čini profilska linija bušotina T-8 i T-12, gde je utvrđen ugljeni sloj manje debljine, dok severozapadnu granicu čine stari radovi ranijih rudnika Tavnik i Bajovac. Po pružanju dužina eksploatacionog prostora iznosi 900 do 1000 m.

1.2.2. Ugljene rezerve u reviru rudnika "Bajovac"

Kako su za ovaj rad bitne rezerve uglja rudnika „Bajovac" u sledećoj tabeli prikazaće se rezerve ovog revira.

Tabela 1.

Geološke rezerve gornjeg A_1 ugljenog sloja u reviru jame ''Bajovac'' (t)			
Kategorija	**Bilansne**	**Vanbilansne**	**Ukupne**
A	5.373.470	137.280	5.510.750
B	2.039.550	-	2.039.550
Ukupno A+B	7.413.020	137.280	7.550.300
Geološke rezerve gornjeg B_2 ugljenog sloja u reviru jame ''Bajovac'' (t)			
A	-	-	-
B	2.704.970	-	2.704.970
C_1	168.880	-	168.880
Ukupno A+B+C_1	7.413.020	-	7.550.300
Ukupno Bajovac	**10.286.870**	**137.280**	**10.424.150**

1.2.3. Geološke karakteristike ugljenog sloja i pratećih stena

Ugljonosno polje revira rudnika „Bajovac“ istraženo je sa sedam istražnih bušotina, dok je nekadašnjim eksploatacionim radovima otvoreno da kote k +115,6 m. Bušotine su locirane na paralelnim profilnim linijama, na rastojanjima, po pružanju ugljenih slojeva od 250 do 600 m, a po padu od 200 do 250 m. Sve rudarske prostorije orijentisane su takođe po pružanju.

Na bazi dobijenih podataka utvrđeno je da su u ovom ugljonosnom polju prisutne dve ugljonosne zone, ali je u ekonomskom pogledu značajna samo gornja zona, u kojoj se nalaze dva regularna razvijena eksploataciona ugljena sloja izdvojena kao A_1 i B_2, prostornog razvića, približne debljine i ujednačenog kvaliteta. Rastojanje između ova dva sloja kreće se od 50 do 60 m.

U donjoj zoni ugljeni slojevi su neregularni, male debljine, veoma lošeg kvaliteta, tako da sa rudarskog gledišta nemaju praktičnu ekonomsku vrednost.

Krovinski A_1 ugljeni sloj ima regularno razviće na većen prostoru područja Bresnice, Tavnika, Bajovca i Lađevaca. Prava debljina ugljenog sloja u reviru polja Bajovac kreće se od 2,60 m do 11,90 m, odnosno u proseku od 8,5 m. Ugljeni sloj je homogen, ujednačenog sastava, ksilitskivitritskog tipa, sa mestimičnim proslojcima detruitusnog (glinovito-laporovitog) tipa.

Ugljeni sloj zaleže dosta strmo u pravcu jugozapada pod uglom od oko $49^{0,}$ stim što se u blizini mrčajevačko lađevačkog raseda padni ugao povećava i do 85^0 te leži na različitim dubinama i to u istočnom delu oko 30 m, a u zapadnom na oko 400 m. Direktnu podinu i krovinu ugljenog sloja čine ugljevite masne gline i laporovite sive uslojene gline.

Podinski B_2 ugljeni sloj u okviru ovog ugljonosnog polja je regularno razvijen i leži ispod povlatnog na rastojanju od 50 do 60 m. Raslojen je jalovim proslojcima, tako da je podeljen u tri tanja ugljena sloja. Ukupna njegova debljina sa jalovim proslojcima kreće se od 3,0 do 12,0 m, dok bez proslojaka varira od 1,5 do 5,3 m. Jalovi proslojci jalovi proslojci su od ugljevitih i sivih tanko uslojenih glina.

Generalno takođe zaleže, kao i prethodni u pravcu jugozapada, pod približnim uglom, tako da se nalazi ovaj sloj kreću od 20 m na istoku do 480 m na zapadu. Krovinu i podinu ovog sloja je kao i kod povlatnog izgradjena od ugljevitih masnih i laporovitih glina i lapora.

Ovaj ugljeni sloj nikada nije eksploatisan, pa se svi podaci o njemu baziraju na osnovu istražnih bušotina i izdanaka na površini. Iz okna „Strmužak“ u ovaj sloj ušlo se sa kote k +165 m, ali se nije dalje išlo rudarskim radovima po sloju.

1.2.4. Kvalitet uglja

Utvrđivanje kvaliteta uglja vršena su uglavnom u laboratoriji Rudarskog instituta – Zemun, tako da postoji dovoljno podataka za sagledavanje kvaliteta uglja i njegovu široku primenu.

Ugalj iz rudnika „Bajovac“ ima dobre fizičke osobine, jer je krovinski A_1 sloj prilično kompaktan i žilav, mada ima manjih sočiva trošnog i mekanog zemljasto-detritusnog uglja. Strukture je trakaste, delimično sočivaste, braon do mrke boje, ogreba mrkog, kose i sočivaste slojevitosti, nepravilnog preloma.

Pri stajanju i skladištenju ugalj gubi vlagu, tako da ukupan gubitak vlage pri dužem lagerovanju iznosi i do 24%, tako da se ne može vremenski duže lagerovati, osim pod specijalnim uslovima.

Petrografskim ispitivanjima utvrđeno je da ugalj pripada vitritsko-klaritskom i klaritskom tipu, a sastavljen je od vitrita, klarita, durita i fasita. Usled prilično niskog stepena gelifikacije preovlađuju drvenaste komponente vitrita, koje se kreću od 11 do 35% i klarita od 37 do 70%, dok je ditrita znatno manje od 3 do 10%.

Anorganske primese u uglju predstavljene su singenetskim terigenim sastojcima, zastupljeni ugljevitim glinama od 9 do 61%, a od autigenih minerala u uglju se nalaze pirit, markasit i siderit, gde je najviše zastupljen pirit od 1 do 5%. Od epigenetskih sastojaka u ovom uglju je jedino zastupljen gips.

Na osnovu ovih petrografskih analiza ugalj iz revira rudnika ’’Bajovac’’ pripada grupi tvrdih mrko-lignitskih ugljeva.

Laboratorijska ispitivanja hemijsko-tehničkih osobina rovnog uglja iz krovinskog A_1 sloja uzetog iz jame rudnika „Bajovac“ pokazale su sledeće rezultate:

Tehnička analiza:

- Vlaga 35,30%
- Pepeo 16,28%
- S ukupan 1,65%
- S u pepelu 0,59%
- Koks 57,84%
- C-fix 21,36%
- Sagorljivo 48,42%
- Isparljivo 26,86%
- DTE 12.050 kJ/kg
- GTE 13.574 kJ/kg

Elementarna analiza:

- Ugljenik 32,64%
- Vodonik 2,82%
- Kiseonik + Azot 11,90%
- S sagorljiv 1,06%

Laboratorijska ispitivanja hemijsko-tehničkih osobina rovnog uglja iz krovinskog B_2 sloja uzetog iz radova u reviru Tavnik - Strmužak pokazale su sledeće rezultate:

Tehnička analiza:

• Vlaga	36,15%
• Pepeo	15,25%
• S ukupan	1,49%
• S u pepelu	0,76%
• Koks	38,83%
• C-fix	23,58%
• Sagorljivo	48,60%
• Isparljivo	25,02%
• DTE	12.050 kJ/kg

Elementarna analiza:

• Ugljenik	70,20%
• Vodonik	5,66%
• Kiseonik + Azot	22,41%
• S sagorljiv	1,50%

Iz navedenih podataka može se videti da su podaci iz obadva sloja slični, što za ugljeve iz ova dva sloja znači da su praktično isti.

Kao još jedan podatak iz literature postoji uspešan pokušaj da se ugalj suši parom pod pritiskom od 20 atm. Ovakvo tretiranje je prema podacima dalo odlične rezultate i da je dobijeno gorivo vrlo dobrog kvaliteta i to:

• Vlaga	12,70%
• Pepeo	14,80%
• S ukupan	1,30%
• S u pepelu	0,70%
• Koks	46,80%
• C-fix	32,00%
• Sagorljivo	72,40%
• Isparljivo	40,40%
• DTE	18.130 kJ/kg
• Ugljenik	50,00%
• Vodonik	4,20%

Takođe su vršeni opiti švelovanja i gasifikacije, gde je utvrđeno da se ugalj iz ovog basena može upotrebljavati za proizvodnju komadnog metalurškog polukoska, koji po dobijenim kvalitetnim osobinama u potpunosti može zadovoljiti potrebe metalurgije.

Isto tako ugalj se veoma uspešno može primeniti za proizvodnju visokokaloričnog gasa za industrijske i termičke potrebe.

2. TEHNIČKO-TEHNOLOŠKI USLOVI EKSPLOATACIJE

2.1. KAPACITET PROIZVODNJE

Kod proračuna kapaciteta proizvodnje u jami rudnika „Bajovac“ treba imati u vidu sledeće činjenice.

1. Tražena proizvodnja od strane Investitora iznosi 200.000 t.k.u.
2. Za otkopavanje uglja mora se predvideti oba ugljena sloja;
3. Na prvom horizontu će se vršiti praktično likvidacija zaštitnih stubova nekadašnjih prostorija otvaranja;
4. U jami bi se primenilo četiri metode otkopavanja, od kojih je samo jedna imala primenu u ovom rudniku.

Kapacitet proizvodnje u I horizontu (k+240 – k+160 m)

U krovinskom ugljenom sloju A_1 u I horizontu zahvatiće se svega 112.000 t geoloških rezervi ili cca 100.000 t.k.u. Rezerve uglja će biti u likvidaciji i primenjivala bi se otkopna metoda koja je već bila u primeni u ovoj jami, a to je **modifikovana stubno-komorna metoda.** U ovakvim uslovima ne može se očekivati godišnja proizvodnja na nivou većem od 50.000 t.k.u.

S obzirom na karakteristike podinskog ugljenog sloja (moćnost ugljenog sloja od 3 do 12 m sa učešćem uglja u sloju (u tri tanja sloja) od 50% tj. od 1,5 do 6,0 m. Zbog veće količine jalovine u uglju otkopanom u ovom sloju, proizvodnja iz ovog sloja ne sme preći 30% od ukupne proizvodnje pa se u ovoj fazi može planirati proizvodnja od ukupno 20.000 t.k.u.

Ukupna proizvodnja u I horizontu iznosiće u toku prve dve godine 70.000 t.k.u./ god. Ovakvom dinamikom prizvodnje pojaviće se neujednačenost, zato što će se posle dve godine otkopati sav ugalj u krovinskom sloju ovog horizonta i samo do 10 % rezervi u podinskom. Ovaj disbalans će se ispraviti tokom kasnije eksploatacije, kada će se bitno povećati proizvodnja u krovinskom sloju.

Kapacitet proizvodnje u II horizontu (k+160 – k+80 m)

U krovinskom ugljenom sloju A_1 u II horizontu zahvatiće se 829.000 t geoloških rezervi ili cca 790.000 t.k.u., ali bi se otkopavanje organizovalo sa jednim međuhorizontom, koj bi po visini podelio ovaj horizont na dva jednaka dela. U gornjem međuhorizontu bi bilo cca 340.000 t.k.u. Od ove količine u južnom krilu bi se nalazilo cca 130.000 t.k.u. gde bi se primenjivala otkopna metoda koja je već bila u primeni u ovoj jami. Godišnji kapacitet bi bio 65.000 t.k.u. i otkopavanje bi trajalo 2 godine. Istovremeno bi se u severnom krilu uvelo otkopavanje frikcionim stupcima, koji bi zahvatio cca 210.000 t.k.u. Sa kapacitetom od 80.000 t.k.u. otkopavanje bi trajalo nešto preko 2,5 godine. Deo rezervi uglja će biti u likvidaciji nekadašnjih zaštitnih stubova prostorija otvaranja (cca 40.000 t.k.u.) i primenjivala bi se otkopna metoda koja je već bila u primeni u ovoj jami, a to je **modifikovana stubno-komorna metoda.** U ovakvim uslovima ne može se očekivati godišnja proizvodnja na nivou većem od 50.000 t.k.u. tako da bi u gornjem međuhorizontu otkopavanje ukupno trajalo 2,5 godina, pri čemu bi se iskopalo cca 380.000 t.k.u. U drugom međuhorizontu bi bilo cca 400.000 t.k.u. Kako u ovom delu nema likvidacija starih zaštitnih stubova, ovaj međuhorizont bi se podelio na dva asimetrična krila i to južno u dužini od 420 m i severno u dužini od 510 m. Od ukupne količine rezervi u ježnom krilu bi se nalazilo cca 180.000 t.k.u. gde bi se primenjivala otkopna metoda koja je već bila u primeni u ovoj jami. Godišnji kapacitet bi bio 65.000 t.k.u. i otkopavanje bi trajalo cca 3 godine. Istovremeno bi se u severnom krilu uvelo otkopavanje frikcionim stupcima, koji bi zahvatio cca 220.000 t.k.u. Sa kapacitetom od 80.000 t.k.u. otkopavanje bi trajalo takođe cca 3 godine, pri čemu bi se iskopalo cca 400.000 t.k.u.

Kako smo rekli da proizvodnja iz podinskog sloja ne sme preći 30% od ukupne proizvodnje pa se u ovoj fazi može planirati proizvodnju od ukupno 234.000 t.k.u. ili cca 42.000 t.k.u. godišnje.

Ukupna proizvodnja u II horizontu iznosiće u toku 5,5 godine 167.000 t.k.u./god. Ovakvom dinamikom prizvodnje delimično bi se ispeglala neujednačenost, zato što bi se posle 5,5 godina otkopalo oko 260.000 t.k.u. u podinskom sloju I horizonta i cca 40.000 t.k.u. u podinskom II horizonta.

Kapacitet proizvodnje u III horizontu (k+80 – k±0 m)

U krovinskom ugljenom sloju A_1 u III horizontu zahvatiće se 856.000 t geoloških rezervi ili cca 810.000 t.k.u. Rezerve uglja su u idealnom položaju i posle 5,5 godina može se uvesti savremena otkopna metoda, a to je otkopavanje širokočelnim mehanizovanim kompleksom. U ovakvim uslovima može se očekivati godišnja proizvodnja na nivou većem od 180.000 t.k.u. Otkopavanje bi se odvijalo u celom ležištu u dužini od 940 m i trajalo bi 4,5 godina ili sa prosečnim napredovanjem fronta od 22 m/mesec.

Proizvodnja iz podinskog sloja ni u ovom horizontu ne sme preći 30% od ukupne proizvodnje pa se u ovoj fazi može planirati proizvodnja od ukupno 60.000 t.k.u. ili za 4,5 godina 270.000 t.k.u., tako da bi se praktično ostvarilo kašnjenje otkopavanja u podinskom sloju za jedan celi horizont.

Kapacitet proizvodnje u IV horizontu (k±0 – k-80 m)

Poluhorizont (k-80 – k-100 m)-Likvidacija

U ovom poluhorizontu bi se vršilo u krovinskom sloju otkopavanje modifikovanom stubno-komornom metodom sa kapacitetom od 2 x 50.000 t.k.u. dvokrilno i trajalo bi cca 1,5 godina. S obzirom da bi početkom otkopavanja u ovom poluhorizontu preostalo oko 450.000 t u krovinskom sloju, isti bi se u ovom slučaju otkopavao u tom periodu na nivou 30.000 t.k.u./god., tako da bi ukupna proizvodnja u ovom periodu bila 130.000 t.k.u.

Preostalih 400.000 t.k.u. u podinskom sloju bi se moglo otkopavati, ako se nađe tržište ili ako se otvore neki drugi rudnici ovog basena. Nezavisno bi moglo da se organizuje otkopavanje na nivou 2 x 40.000 t.k.u. takođe dvokrilno u trajanju od 5 godina.

2.2. DINAMIKA PROIZVODNJE I VEK TRAJANJA

Prema predloženim tehničkim rešenjima eksploatacija ovog ležišta bi se obavljala 22 godine. Godišnja proizvodnja u ovom periodu kretala bi se od 70.000 t/god. u prvoj i drugoj godini, zatim bi se povećavala sukcesivno narednih šest godina a u devetoj godini je moguće dostići maksimalni kapacitet od 240.000 t/god. koji bi se održavao narednih sedam godina. U poslednjih šest godina proizvodnja bi se zbog strukture ležišta polako smanjivala, do poslednje godine eksploatacije kada bi iznosila 40.000 t/god.

ZAKLJUČAK

Ovaj rad predstavlja izvod iz rezultata istraživanja koja su objavljena u okviru projekta TR 33029 "Izučavanje mogućnosti valorizacije preostalih rezervi uglja u cilju obezbeđenja stabilnosti energetskog sektora Republike Srbije" a koje finasira Ministarstvo prosvete i nauke. U njemu je tretirana problematika buduće eksploatacije uglja iz zapadno moravskog basena, sa posebnim osvrtom na aktiviranje zatvorenog rudnika"Bajovac"

Osnovna ideja kojom su se autori rukovodila je bila da se ovo ležište aktivira kao zamenski kapacitet za Ibarske rudnike do momenta iznalaženja adekvatnijih rešenja. Za analizu mogućnosti eksploatacije uglja iz ovog ležišta korišćena je raspoloživa tehnika dokumentacija uz istovremeno konsultovanje relevantnih stručnjaka koji su se bavili ovom problematikom.

Veoma detaljna tehno-ekonomska analiza ležišta "Bajovac" nedvosmisleno je utvrdila opravdanost njegovog ponovnog otvaranja. U okviru istraživanja po ovom projektu predložena su osnovna tehnička rešenja otvaranja, metode otkopavanja, potrebna radna snaga po broju i strukturi, potrebna oprema. Ekonomska analiza jedne ovakve investicije koja je obuhvatila troškove, tržište cene i ostale relevantne pokazatelje je takođe dala pozitivne rezultate, pa se stoga može generalno dati pozitivna ocena jednog ovakvog projekta.

LITERATURA

[1] N. Vidanović i drugi, Studija opravdanosti eksploatacije u ležištima „Cerje" Despotovačkog ugljenog basena i „Bajovac", zapadnomoravskog ugljenog basena, RGF Beograd, 2011.

[2] P. Nikolić, D. Dimitrijević, Ugalj Jugoslavije, Pronalazaštvo, Beograd 1990,

[3] N. Vidanović, R. Tokalić, S. Mitić, Opravdanost eksploatacije uglja iz ležišta „Cerje-Jovačko polje", Časopis „Podzeni radovi", broj 21, ISSN 03542904, str. 9-15, RGF Beograd, 2012.

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Vitomir Milić, Igor Svrkota*, Dejan Petrović**

DETERMINATION OF OPTIMAL PARAMETERS FOR SUBLEVEL STOPPING METHOD**

Abstract

This paper presents a design and parameters of the new variant of sublevel stopping method. The proposed new variant is the result of combination the theoretic considerations, field experience using the application of similar methods and researches on models. The idea of new design was to include most of advantages from several variants of sublevel stopping. The new variant is called “Semi-level stopping” [1]. Determination of optimal parameters for this method was performed using physical similarity model.

Keywords: *underground mining, mining methods, new method design*

INTRODUCTION

Underground mining in some Serbian mines is performed at depth that exceeds 500 m. The new ore deposits, planned for mining in the future, are even deeper. For instance, the ore body Borska Reka, in the copper mine Jama Bor, lies between 500 and 1,200 meters below ground surface. The ore reserves in this ore body exceed 600 Mt of ore, with copper content of about 0.6% [2].

So, the future of underground mining in the Bor ore deposit relays on huge ore reserves on very significant depths. This is a very serious task, both for RTB Bor and experts in the underground mining, to find the way to excavate these ore reserves economically and continue 110 year long tradition of the underground mining.

Mining method design, presented in this paper, is the result of long year investigation in the area of sublevel caving and sublevel stopping mining methods. The field data from sublevel caving method, applied in the ore bodies Tilva Ros and P_2A of Jama Bor, were very helpful. The idea was to design a new, improved method, suitable for application in this copper mine. A part of investigation related to the optimization of method parameters, and the results will be present in this paper.

INVESTIGATION THE OPTIMUM PARAMETERS IN LABORATORY CONDITIONS

The new method design, called the semi-level stopping with single-sided lateral loading, was tested and analyzed in laboratory, on a physical similarity model. Main principles of modeling and testing were followed, including geometric, kinematic and dynamic similarity principles. The model is shown in Figure 1.

* *University of Belgrade, Technical Faculty in Bor*

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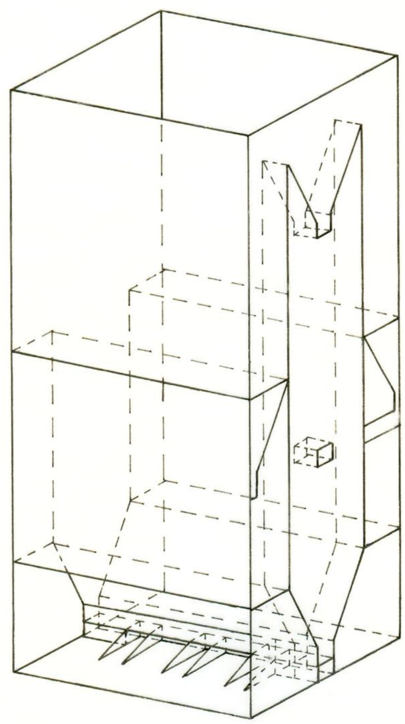

Figure 1 *Axonometric view of the mine design model M-1*

FIXED AND VARIABLE PARAMETERS

Laboratory testing was performed based on the following, previously determined, fixed parameters:

- Dimensions of sublevel drifts,
- Dimensions of drilling drifts,
- Spacing between drifts,
- Semi-level height,
- Particle size distribution for ore and overburden,
- Density of ore and overburden and looseness factor,
- Angle of blasting plane α,
- Angle of final blastholes β.

Variable parameters were:

- Thickness of blasting zone, which has influence on number of loading rooms and their mutual spacing ($m_1 = n\ W\ K_r$);
- Blasting block width (B).

Many combinations and tests can be derived with two variables (m = 2), which would have numerous different values. In order to optimize the number of tests, variation of blasting block width was reduced to three values, B = 12, 14 and 16 m. Also, there were three values of spacing between lateral loading rooms, l = 8, 10 and 12 m.

These values were defined based on investigations in the ore drawing dynamics and preliminary investigations the method of design parameters.

Variation of parameters enables defining the optimal parameters, in order to achieve maximum ore recovery, along with satisfying ore dilution.

ORE DRAWING

Ore drawing was performed on M-1 model, from three lateral loading rooms. The obtained data were stored, analyzed and used for evaluation the method parameters. Data on ore recovery and ore dilution were used to create graphs of functional relation $O_r = f(I_r)$.

The experimental laboratory testing was performed in several stages.

1 Stage one – preliminary testing

The first task was to determine the suitable geometric parameters for designned mining method. Variable parameters were: blasting block width (B), spacing between lateral loading rooms (l) and thickness of blasted ore ($n \times m_1$). Block height, or level height, or double semi-level height was fixed at 80 m during testing (H = 2h = 80 m), since this height was suitable as the level height in this case.

2 Stage two – the first series of tests

Based on preliminary testing and determination the shape of draw solid (draw ellipsoid eccentricity), the limits of variable parameters were defined. Each test was carried out for all possible combinations of variable parameters and repeated three times.

3 Stage three – second series of tests

The pairs of parameters with unsatisfying results were excluded from further testing. For instance, the results for 8 m spacing between lateral loading rooms were much worse for any block width (12, 14, or 16 m) than the results for 10 and 12 m spacing.

For parameters with satisfying results, tests were continued. Further tests were performed with two draw points on model M-1. These additional tests were ran in order to confirm results from first series of tests.

4. Stage four – third series of tests

This was the last series of tests, with parameters that provided the best relations between ore recovery and ore dilution. Last series of tests included inserting of markers. A total of 175 markers were inserted into M-1 model. Markers provide very accurate results in analyses of drawing, and also better insight in phenomena which takes place in the model during the tests.

Ore drawing in the model was performed in specified dosages. The first dosage is drawn till the appearance of waste in one of the loading rooms. The first appearance of waste occurs in the third loading room, which is logical, considering the fact that the third room has frontal contact with waste. The area of this contact is equal to the area of blasted block. The following dosages were exactly 2.5 kg each, drawn equally from each room, till waste appears in all of the remaining rooms. Drawing goes on till ore dilution exceeds 50%. At that point, drawing was supposed to stop, but, in order to provide more points for graphical illustration of relation between the ore dilution and ore recovery, the ore drawing went a little further.

Interpretation of results was created using tables and graphs. Each table, for each test, includes a detailed test balance, with data on quantity of bulk ore (Q_{rm}), clean ore ($Q_{čr}$) and waste (Q_j) per kg of each dosage. Tables also contain their cumulative values, along with values of ore recovery and ore dilution, per dosage and in total.

Ore recovery is a quotient of clean ore ($Q_{čr}$, kg) and total ore (Q_r, kg). Ore recovery was calculated for each test, where values of $Q_{čr}$ were measured from each dosage, while Q_r is quantity of ore used in the test:

$$I_r = \frac{Q_{čr}}{Q_r} \cdot 100, \% \quad (1)$$

Total ore recovery is a quotient of cumulative value of $Q_{čr}$ and total ore in model, Q_r.

Ore dilution (O_r), calculated for each dosage, is a quotient of waste in dosage (Q_j) and bulk ore in dosage (Q_{rm}):

$$O_r = \frac{Q_j}{Q_{rm}} \cdot 100, \% \quad (2)$$

Total ore dilution is gained as a quotient of cumulative values of waste and bulk ore.

INTERPRETATION OF THE OBTAINED RESULTS

Testing data were stored particularly for each loading room and each dosage, which enabled data interpretation by test and draw point, for each series of testing.

Interpretation of results was performed through tables and graphs. Tables show data of ore recovery and dilution for each test, each dosage and in total. Based on these data, the next step was to create graphs, with lines of interdependence between the ore dilution and ore recovery. Beside the graphs, the interdependence was also expressed via equations. Equations were created based on minimum squares theory. Line correlation ratio was used to determine the accuracy of approximation, i.e. deviation of equation from relation curve.

High values of correlation ratio show high accuracy of approximation of functions Or = f (Ir) and Or' = f (Ir) with regression equations. This means that it is possible, with satisfying accuracy, to calculate ore dilution (O_r) if the value of ore recovery (I_r) is known, and vice versa.

As it was mentioned before, the quantity of drawn ore and waste were recorded for each test and each draw point. It enabled partial interpretation of the results by single draw points. Also, determination the relations between parameters enables comparison of results for different positions of draw points and loading rooms.

ANALYSIS OF THE OBTAINED RESULTS

Values of ore recovery and dilution were calculated based on the results of testing, according to the measurements of drawn ore and waste for each dosage and in total. The calculated values were present graphically and functional dependences were established.

During testing on model M-1, the first series included 27 tests [6]. There were three variations of values for block width (B = 12, 14 and 16 m) and spacing between lateral loading rooms (l = 8, 10 and 12 m). Test was repeated three times for each pair of values. Quantity of ore, stored into model, varied along with variations of width and spacing. The obtained data show clearly that quantity of clean ore strongly depends on spacing of the loading rooms. Consequently, the values of ore recovery also vary along with spacing.

Analysis of the results from the first series of tests has shown that best results were obtained with 12 m spacing. In this case, the quantity of clean ore exceeds 22%. For total ore recovery of 89.94%, the ore dilution reaches 10.68% [1].

In the second series of tests, there were two draw points. Since 8 m spacing caused the worst results again, these results were excluded from further considerations. Again, the best results were obtained for B = 12 m and l = 12 m pair of values, so the results from the first series of tests were confirmed.

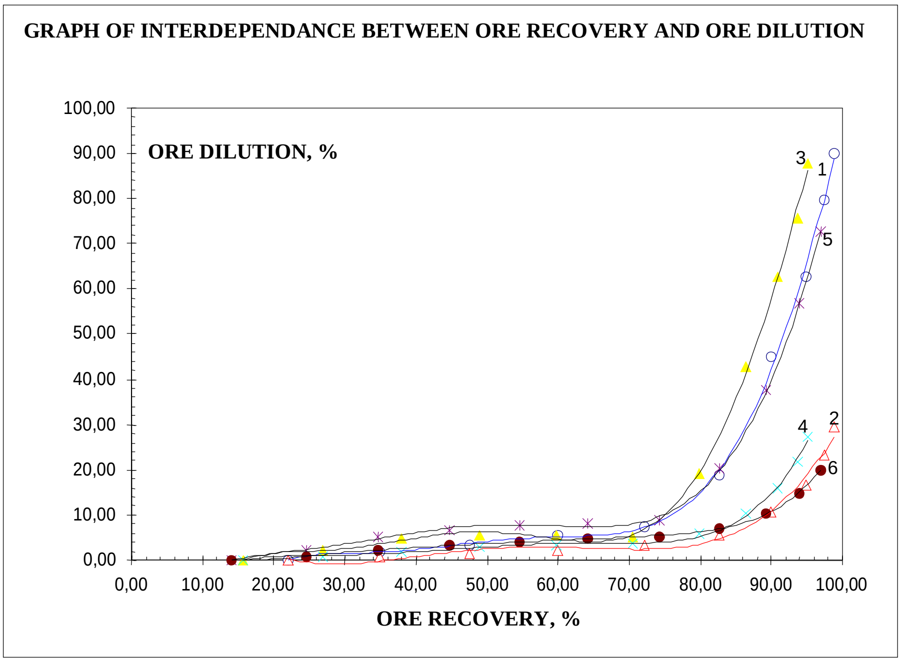

Figure 2 *Ore drawing results for the first series of tests (with three loading rooms)*
Values of parameters: H = 80 m, B = 12, 14 and 16 m and l = 12 m

1, 2. B = 12m; l = 12m (1 in a dosage; 2 in total)
3, 4. B = 14m; l = 12m (3 in a dosage; 4 in total)
5, 6. B = 16m; l = 12m (5 in a dosage; 6 in total)

The results obtained in the second series of tests are shown in Figure 3. After reviewing the results of both the first and second series of tests, it was obvious that the best results were obtained for maximum value of spacing and minimum value of block width. This means that it is necessary to continue with testing with different values of variable parameters, in order to define the optimum parameter values.

So, in the third series of tests, there were several additional pairs of values (B = 12 m; l = 14 m and B = 14 m; l = 14 m). Also, markers were installed in the model in some tests. Comparison of the new results with the best results from previous series provided final answer: B = 12 m and l = 8 m are optimal values of variable parameters for designed method, according to testing on model M-1. These values of parameters provide maximum of clean ore and ore recovery with minimum ore dilution.

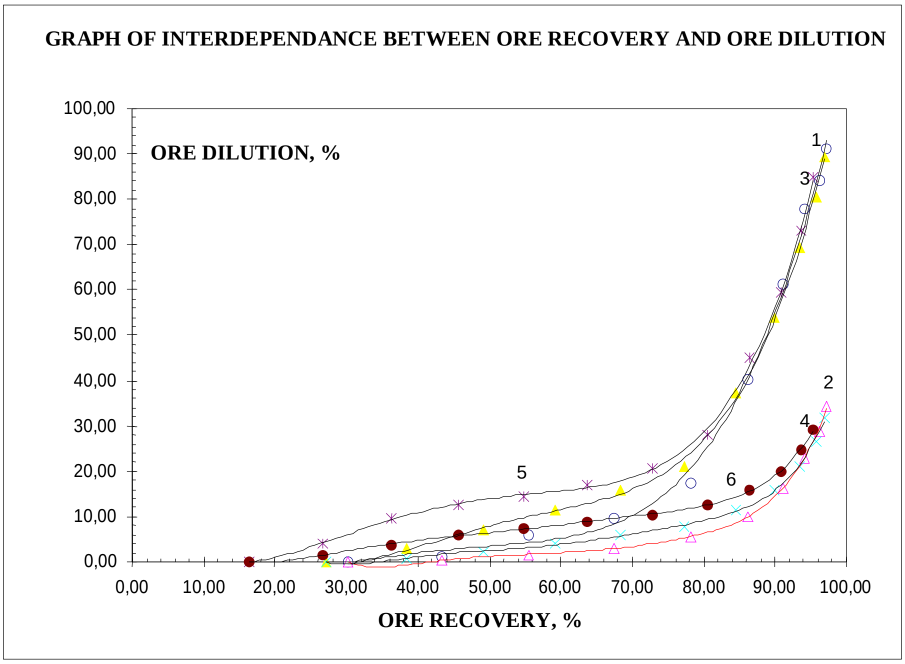

Figure 3 *Ore drawing results for the second series of tests (with two loading rooms)*

Values of parameters: H = 80 m, B = 12, 14 and 16 m and l = 12 m

1, 2. B = 12m; l = 12m (1 in a dosage; 2 in total)

3, 4. B = 14m; l = 12m (3 in a dosage; 4 in total)

5, 6. B = 16m; l = 12m (5 in a dosage; 6 in total)

Based on data gained from testing on model M-1, from the first and second series of tests (with three and two loading rooms), the most optimal parameters were determined for designed mining method, named the Semi-level stopping with single side lateral loading. The values of optimal parameters are:

- Block height, H = 80 m;
- Block width, B = 12 m;
- Spacing between lateral loading rooms, l = 12 m.

Comparison between the first and second series of tests, with the results filtered in order to present only the most favorable values of parameters, is shown in Figure 4.

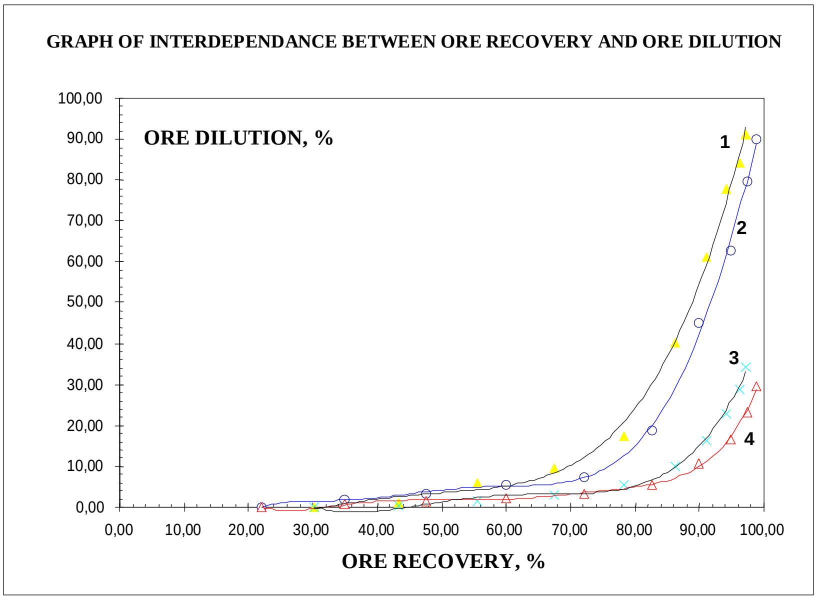

Figure 4 *Relation between the ore recovery and ore dilution in case of ore drawing from two and three draw points, with optimal values of method parameters*

Line 1 – two loading rooms (in a dosage); Line 2 – three loading rooms (in a dosage); Line 3 – two loading rooms (in total); Line 4 – three loading rooms (in total)

Tests results have shown that more draw points enable better results. In Figure 4, Lines 2 and 4 (flatter lines) confirm such conclusion, both in a dosage and total. The most important thing in the process of drawing is discipline, which means that the schedule of drawing has to be obeyed strictly. It is obvious that better results are achieved in the case of more draw points. This was confirmed in the analysis of results by draw points, too.

CONCLUSION

Model testing, with variation of parameters, enabled an optimization of mining method geometry, aiming to provide the best results in the ore recovery and ore dilution, both in the stope and entire deposit.

Designed mining method generally provides high values of ore recovery (80 – 90%) with 10 – 15% of ore dilution, which was proved on a model testing. In order to provide maximum ore recovery and minimum ore dilution, several parameters were varied during the model testing. The final results are the following: for B = 12 m wide and H = 80 m high stope and l = 12 m lateral spacing between loading rooms, the ore recovery ratio is K_{ir} = 0.9, while the ore dilution ratio is K_{or} = 0.1.

In order to achieve these results, it is necessary to manage the ore drawing process carefully and provide even amount of drawn ore from each draw point. Testing has also shown that more draw points enable better results.

REFERENCES

[1] V. Milić, The Research Basic Parameters of New Methods Semilevel Caving for Excavation Deep Parts of the Bor Deposit, Ph D. Thesis, Bor, 1996. (in Serbian)

[2] R. Kojdić, Contribution of the Determination the Most Appropriate Parametars of Excavation Methods, with the Techno-economic Aspects of Bor Copper Deposits in the Deep, Ph D. Thesis, Bor, 1991. (in Serbian)

[3] V. Milić, Ž. Milićević, N. Atanasković, Determination of Parameters Blowing Down Method by Modeling, Underground Mining Engineering, Belgrade, 1994. (in Serbian)

[4] V. Milić, Ž. Milićević, Determination of the Eccentricity of the Ellipsoid Flow of ore from the Bor Ore Deposits, Journal of Mining and Metallurgy, Bor, 1995. (in Serbian)

[5] V. Milić, Ž. Milićević, The Basis of Exploitation Mineral Deposits, The University book, Bor, 2005. (in Serbian)

[6] M. M. Protodjakonov, P. I. Teder. Metodika racionalnogo planirovanija eksperimentov fizičko-mehaničeskie gornye problemy, Moskva, ”Nauka”, 1971. (in Russian)

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

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Vitomir Milić, Igor Svrkota*, Dejan Petrović**

ODREDJIVANJE OPTIMALNIH PARAMETARA METODE BLOKOVSKOG OTKOPAVANJA**

Izvod

U ovom radu govori se novoj konstrukciji metode blokovskog otkopavanja sa zarušavanjem rude. Predložena varijanta metode otkopavanja je istaživana u okviru teorijskog razmatranja korišćenjem iskustva u praktičnoj primeni tehnologija otkopavanja iz iste grupe metoda. Sve prednosti metoda sa podetažnim zarušavanjem u velikom broju varijantnih rešenja spojeni su u novu konstrukciju koja nosi naziv "Metoda sa poluetažnim zarušavanjem" [1]. Određivanje optimalnih parametara novopredložene konstrukcije izvršeno je u laboratroijskim uslovima na fizičkom modelu sličnosti.

Ključne reči: *podzemna eksploatacija, metode otkopavanja, nove konstrukcije*

UVOD

Podzemna eksploatacije rude u rudnicima u Srbiji obavlja se na dubinama koje iznose i više od 500 m. Ležišta koja su za buduću eksploataciju nalaze se na znatno većim dubinama, a u borskom ležištu rude bakra rudno telo „Borska Reka", koje je perspektiva podzemne eksplotacije, zaleže na dubini od 500 do 1200 m. Rudno telo ima rezerve rude od preko 600 milona tona rude sa sadžajem bakra od oko 0,6 % [2].

Izuzetno velike rezerve rude, na velikoj dubini predstavljaju glavni preduslov za nastavak podzemne eksploatacije u jami Bor. Za rudarske stručnjake iz oblasti podzemne eksploatacije to je veliki izazov, a za RTB Bor neophodnost nastavka tradicije rudarenja koja iznosi 110 godina.

Tehnologija otkopavanja koja se predlaže u ovom radu rezulatat je dugogodičnjeg istraživanja, koja su sprovedena u cilju usavršavanja novih konstrukcija metoda otkopavanja iz grupe metoda sa zarušavanjem rude i krovinskih stena. Korišćenjem rezultata iz primene podetažnih metoda u rudnim telima „Tilva Roš" i „P_2 A" isvršeno je usavršavanje konstrukcija i predložena nova. Rezultati istraživanja optimalnih prametara, za najpovoljne pokazatelje daju se u ovom radu.

ISTRAŽIVANJE OPTIMALNIH PARAMATARA METODE OTKOPAVANJA U LABORATORIJSKIM USLOVIMA

Istraživanje parametara metode „Poluetažnog prinudnog zarušavanja sa jednostranim bočnim utovarom rude" izvršeno je u laboratorijskim uslovima na fizičkom modelu sličnosti. Pri izvodjenju ogleda ispoštovani su osnovni principi modeliranja i izvodjenje ogleda; geometrijska, kinematička i dinamička sličnost [3].

Izgled modela prikazan je na slici br. 1.

* *Univerzitet u Beogradu, Tehnički fakultet u Boru*

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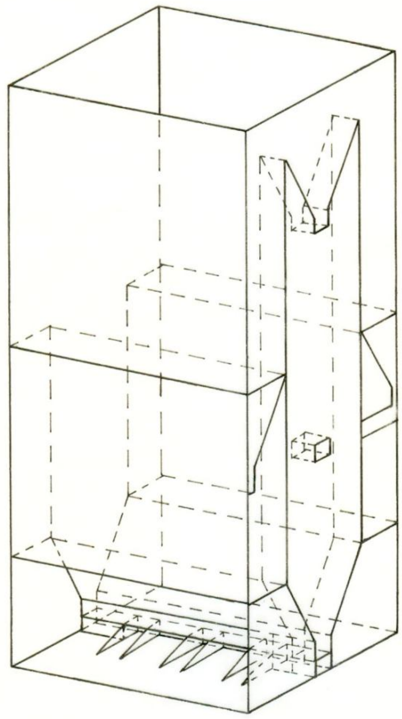


Sl. 1. *Aksonometrijski izgled modela M-1 metode otkopavanja*

STALNI I PROMENLJIVI PARAMETRI PRI ISPITIVANJU

U toku izvodjenja ogleda operiše se sa sledećim usvojenim parametrima i veličinama:

- dimenzije podetažnih hodnika,
- dimenzije hodnika za bušenje,
- njihovo medjusobno rastojanje,
- dimenzije utovarnih komora,
- visina poluetaže (podetaže),
- granulometrijski sastav rude i jalovine,
- zapreminska masa rude i jalovine sa odgovarajućim faktorom rastresitosti,
- nagibni ugao ravni miniranja α,
- ugao krajnjih bušotina β.

Promenljive veličine su:

- Moćnost pojasa miniranja, koja uslovljava broj utovarnih komora, odnosno njihovo medjusobno rastojanje ($m_1 = n\ W\ K_{r-}$)
- Širina bloka miniranja (B).

Sa dve promenljive (m = 2), koje mogu imati veliki broj različitih vrednosti, može se izvesti veliki broj kombinacija, a samim tim i veliki broj ogleda. Radi svodjenja ogleda na manji broj uzete su po tri vrednosti širine bloka miniranja: B = 12, 14, 16 m. Osna rastojanja izmedju bočnih utovarnih komora iznose: l = 8, 10, 12 m.

Ovako izabrane vrednosti dobijene su na osnovu izučavanja zakonitosti istakanja rude na modelima i na osnovu preliminarnih istraživanja parametra razmatrane metode.

Izmenom promenljivih veličina moguće je utvrditi pri kojim se parametrima postiže najveće iskorišćenje i zadovoljavajuće osiromašenje rude.

ISTAKANJE RUDE

Istakanje rude iz modela vršeno je na modelu M-1 iz tri utovarne komore sa jedne strane. Rezultati dobijeni iz izvedenih ogleda prikazani su tabelarno, a na osnovu sračunatih vrednosti iskorišćenja i osiromašenja formirani su grafici funkcionalne zavisnosti $O_r = f(I_r)$.

Eksperimantalna laboratorijska istraživanja, koja se nalaze u osnovi ovoga rada, obavljena su u više etapa - serija.

1. Prva etapa istraživanja - preliminarana istraživanja

Za predloženu konstrukciju metode otkopavanja potrebno je bilo odrediti odgovarajuće geometrijske parametre otkopne metode. Parametri čije su vrednosti tokom istraživanja menjane su: širina otkopnog bloka (B), osno rastojanje izmedju bočnih utovaranih komora (l), odnosno moćnost pojasa minirane rude (n x m_1). Visina bloka (etaže, poluetaže (H = 2h = 80 m) u svim ogledima je imala istu vrednost od 80 m i zadržana je kao konstantna jer odgovara visini horizonta.

2. I serija ogleda

Na osnovu preliminarnih istraživanja [4] i utvrdjivanja oblika figure istakanja (ekscentriciteta elipsoida istakanja) odredjene su granice u kojima će se kretati promenljivi paramatri predložene konstrukcije metode otkopavanja. Svaki ogled je radjen za sve moguće kombinacije parametara i po tri puta.

3. II serija ogleda

Parovi ispitivanih parametara gde su dobijeni loši rezultati su izbačeni iz daljih istraživanja:

- Analizom dobijenih rezultata utvrdjeno je da su rezultati, kod razmatrane varijante (model M-1), za osna rastojanja utovarnih komora od 8 m i bilo koje razmatrane širine bloka od 12, 14 i 16 m lošiji od rezultata za osna rastojanja utovarnih komora od 10 i 12 m i bilo koje razmatrane širine bloka.

Povoljni parametri, koji su dali zadovoljavajuće rezultate su dalje istraživani. Dalja istraživanja su vršena sa dva ispusna otvora na modelu M-1. Ovi dopunski ogledi radjeni su sa ciljem da se potvrde rezultati iz prve serije ogleda.

4. III serija ogleda

U ovoj poslednjoj seriji ogleda ponovljeni su ogledi sa parametrima gde su dobijeni najpovoljniji odnosi iskorišćenja i osiromašenja rude. Ovi ogledi su radjeni sa žetonima i to na modelu M-1 sa 175 ugradjenih žetona. Ugradjeni žetoni omogućuju vrlo preciznu interpretaciju rezultata istakanja kao i pojava koje se dešavaju u modelu pri istakanju.

Istakanje rude vršeno je u odredjenim dozama, redom iz svake utovarne komore. Prva doza istakanja izvlači se do pojave jalovine u jednoj od utovarnih komora. Jalovina će se prvo pojaviti u trećoj utovarnoj komori. Ovo je potpuno logično jer treća komora imaja čeoni kontakt sa jalovinom. Površina ovog kontakta jednaka je površini bloka rude koji se minira. Sledeće doze istakanja su po 2,5 kg (ravnomerno iz svake komore) do pojave jalovine u ostalim utovarnim komorama. Istakanje se dalje vrši sve do momenta kada osiromašenje u komorama predje 50 %. Medjutim, gotovo u svim ogledima istočena je i neka doza više da bi se dobio dovoljan broj tačaka za grafičko prikazivanje osiromašenja u zavisnosti od iskorišćenja rude u analizama koja se odnose na ispusne otvore.

Pri interpretaciji rezultata formirani su tabelarni i grafički prikazi. U svakoj tabeli, za svaki izvedeni ogled, prikazan je bilans jednog ogleda iz kojeg se vidi, po dozama istakanja, količina istočene rudne mase (rovne rude) Q_{rm} , čiste rude $Q_{čr}$, i jalovine Q_j u kg. Takodje, u tabeli je data i njihova kumulativna vrednost, kao i iskorišćenje rude I_r (%) i osiromašenje rude (%) u dozi i ukupno.

Na osnovu dobijene čiste rude $Q_{čr}$ (kg) iz svake doze deljenjem sa količinom ugradjene rude Q_r (kg) u modelu, za taj ogled dobija se iskorišćenje za svaku dozu [5] tj.

$$I_r = \frac{Q_{\sim r}}{Q_r} \cdot 100 \text{ , \%} \qquad (1)$$

Ukupno iskorišćenje dobija se iz odnosa čiste rude $Q_{čr}$ i to kumulativno, prema ugradjenoj količini rude Q_r u modelu.

Osiromašenje za svaku dozu predstavlja odnos količine jalovine Q_j za svaku dozu posebno, prema ukupnoj količini rovne rude Q_{rm}, za tu dozu [5] tj.

$$O_r = \frac{Q_j}{Q_{rm}} \cdot 100 \text{ , \%} \qquad (2)$$

Ukupno osiromašenje dobija se iz odnosa količina jalovine Q_j kumulativno, prema količini rudne mase Q_{rm} kumulativno za tu dozu.

INTERPRETACIJA DOBIJENIH REZULTATA

Pri izvodjenju ogleda dobijeni podaci su parcijalno upisivani za svaku utovarnu komoru i u dozama što omogućuje interpretaciju rezultata ukupno za svaki ogled i parcijalno po ispusnim otvorima (za sve serije ispitivanja).

Interpretacija rezultata je izvršena tabelarno i grafičkim prikazima. U tabelama su, za svaki izvedeni ogled, dati dobijeni rezultati i sračunate vrednosti iskorišćenja i osiromašenja u dozi istakanja i ukupno. Na osnovu računatih vrednosti formirane su grafičke zavisnosti iskorišćenja i osiromašenja rude. Za svaku zavisnost data je jednačina, na osnovu teorije najmanjih kvadrata, kojom je opisana promena kao i koeficijent krivolinijske korelacije. Koeficijentom krivolinijske korelacije je odredjen stepen tačnosti aproksimacije krivih nadjenim jednačinama regresije.

Visoke vrednosti koeficijenta krivolinijske korelacije ukazuju na visok stepen tačnosti aproksimacije zavisnosti Or = f (I_r) i Or’ = f (I_r), jednačinama regresije. To znači da je pomoću jednačina moguće, sa dovoljno tačnosti, za svaku poznatu vrednost ″I_r″ izračunati odgovarajuću vrednost za ″O_r″ i obrnuto.

Za svaki izvedeni ogled posebno su upisivane vrednosti istočene količine rude i jalovine po ispusnim otvorima. To omogućuje da se izvrši i interpretacija parcijalno po ispusnim otvorima. Takodje, na osnovu ovako prikazanih zavisnosti moguće je izvršiti uporedjenje dobijenih rezultata u zavisnosti od položaja ispusnih otvora (utovarnih komora).

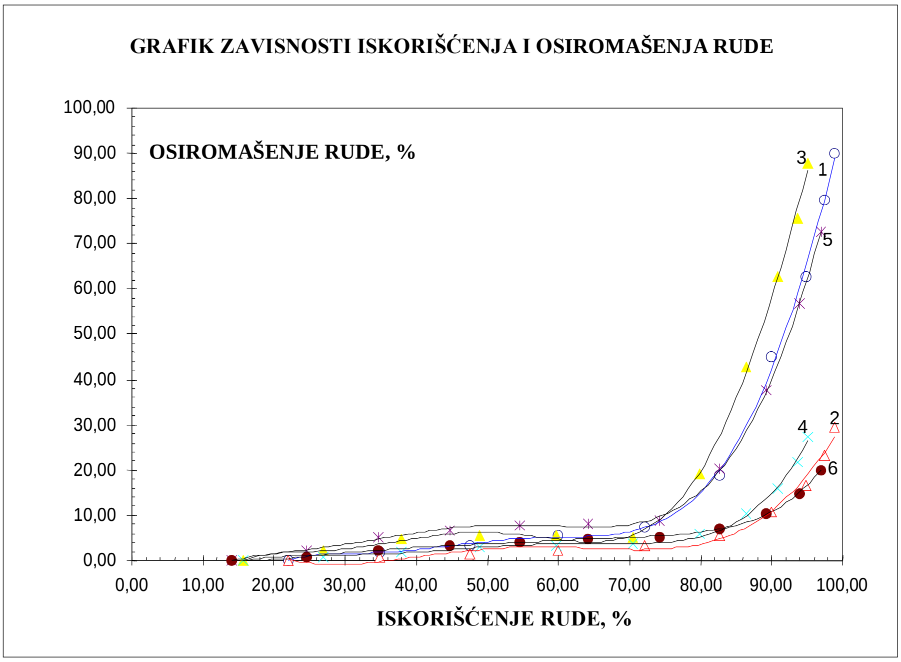
ANALIZA DOBIJENIH REZULTATA

Na osnovu izmerenih količina čiste rude i jalovine pri istakanju (u dozama istakanja), za svaki ogled, izračunate su vrednosti iskorišćenja i osiromašenja rude u dozi i ukupno. Sračunate vrednosti su predstavljene grafički i dobijene su funkcionalne zavisnosti.

Na modelu M-1 u prvoj seriji ogleda uradjeno je 27 ogleda /6/. Tri puta su širina bloka miniranja (B = 12, 14, 16 m) i osno rastojanje izmedju bočnih utovarnih komora (l = 8, 10, 12 m) menjale svoju vrednost. Za svaki izabrani par ovih parametara ogled je ponavljan po tri puta. U zavisnosti od osnog rastojanja, znači i od moćnosti pojasa minirane rude, u model je ugradjivana različita količina rude. Dobijeni rezultati jasno ukazuju da se pri promeni osnih rastojanja izmedju utovarnih komora dobijaju različite količine čiste rude. Isto tako za odgovarajuću vrednost osiromašenja različito je iskorišćenje rude kako u dozi tako i ukupno.

Dakle, očigledno je da u I seriji ogleda pri bilo kojoj promeni parametara najpovoljniji se rezultati dobijaju kada je osno rastojanje l = 12 m. Pri ovim vrednostima parametara dobija se količina čiste rude od preko 22 %. Za ukupno osiromašenje od 89,94 % dobija se osiromašenje od 10,68 % /1/.

U drugoj seriji ogleda na modelu M-1 radjeni su ogledi za iste vrednosti parametara koji su menjani, ali sa dva ispusna otvora. Osna rastojanja od l = 8 m, zbog očigledno najlošijih rezultata u ovoj seriji nisu razmatrana. I u ovoj seriji ogleda dobijeni su najpovoljniji rezutati za B = 12 m i l = 12 m, što je potvrdilo zaključke iz prve serije ogleda.



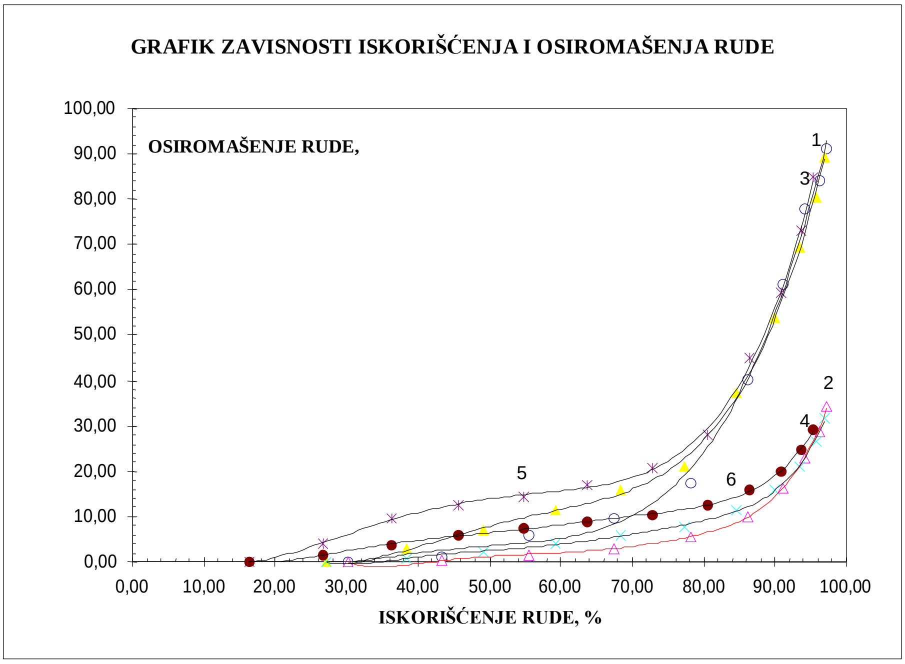
Sl. 2. *Uporedni rezultati istakanja rude iz modela M-1 u I seriji (tri utovarne komore) za odnose parametara H = 80 m, B = 12, 14 i 16 m i l = 12 m*

1, 2. B = 12m; l = 12m (1 u dozi; 2 ukupno)
3, 4. B = 14m; l = 12m (3 u dozi; 4 ukupno)
5, 6. B = 16m; l = 12m (5 u dozi; 6 ukupno)

Rezultati istraživanja (uporedni za različite širine bloka) za osno rastojanje od l = 12 m pri istakanju u II seriji, gde je radjeno sa dve bočne utovarne komore prikazani su na sl. br. 3.

Na osnovu ogleda iz I i II serije na modelu M-1 dobijeni su najpovoljniji rezultati za najveću ispitivanu vrednost osnog rastojanja "l" i najmanju vrednost širine bloka "B" koja je ispitivana. Sve ovo ukazuje da je neophodno nastaviti sa istraživanjima u cilju odredjivanja optimalnih parametara.

Iz tog razloga u III seriji ogleda uradjeni su dopunski ogledi (B = 12; l = 14 m i B = 14; l = 14 m), kao i ogledi sa ugradnjom žetona. Uporedjenjem ovih rezultata sa najboljim iz prve serije dobijen je konačan odgovor da su za varijantu metode "Poluetažnog prinudnog zarušavanja" koja je ispitivana na modelu M-1 optimalne vrednosti parametara B = 12 m i l = 12 m. Pri ovim vrednostima parametara dobija se najveća količina čiste rude i najveće iskorišćenje uz minimalno osiromašenje rude.



Sl. 3. *Uporedni rezultati istakanja rude iz modela M-1 u II seriji (dve utovarne komore) za odnose parametara H = 80 m, B = 12, 14 i 16 m i l = 12 m*

1, 2. B = 12m; l = 12m (1 u dozi; 2 ukupno)

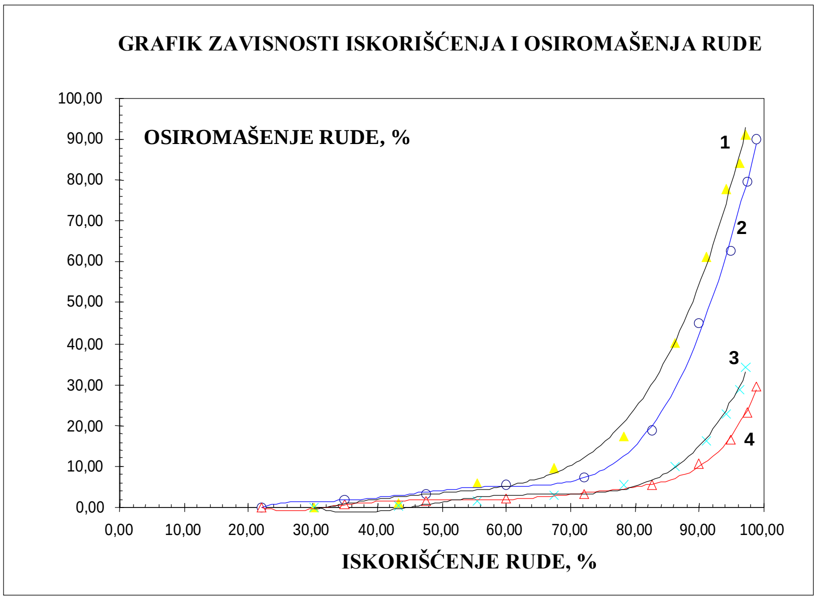
3, 4. B = 14m; l = 12m (3 u dozi; 4 ukupno)

5, 6. B = 16m; l = 12m (5 u dozi; 6 ukupno)

Na osnovu uporedjenja dobijenih rezultata na modelu M-1 iz I serije ogleda, kada je radjeno iz tri utovarne komore, i II serije, kada je radjeno sa dve utovarne komore dobijeni su optimalni parametri metode Poluetažnog prinudnog zarušavanja sa jednostranim bočnim utovarom. To su:

- visina bloka H = 80 m,
- širina otkopnog bloka B = 12 m,
- osno rastojanje izmedju bočnih utovarnih komora l = 12 m

Uporedni rezultati I i II serije ogleda (sa tri i dva ispusna otvora), a za najbolje dobijene vrednosti parametara prikazani su na slici br. 4.



Sl. 4. *Uporedni rezultati istakanja rude sa dve i tri utovarne komore za najbolje odnose parametara (H = 80 m, B = 12 m, l = 12 m).*
1. Dve utovarne komore (u dozi); 2. Tri utovarne komore (u dozi);
3. Dve utovarne komore (ukupno); 4. Tri utovarne komore (ukupno)

Za optimalne odnose parametara mnogo bolji pokazatelji se dobijaju pri primeni metode otkopavanja sa većim brojem ispusnih otvora. Na slici 4. krive 2 i 4 (koje su položenije) potvrdjuju upravo te zaključke, bilo da se funkcionalne zavisnosti posmatraju u dozi istakanja ili ukupno. Najvažnija stvar pri istakanju rude iz pojasa velike moćnosti je disciplinovan rad koji podrazumeva, pre svega, ravnomernost pri istakanju iz utovarnih komora koje su aktivne.

Očigledno je na osnovu prikazanih uporednih grafika, ukupnih i parcijalnih, da se mnogo bolji rezultati dobijaju pri primeni metode Poluetažnog prinudnog zarušavanja sa većim brojem ispusnih otvora. Tu konstataciju potvrdjuju i rezultati koji se odnose na parcijalnu interpretaciju po ispusnim otvorima.

ZAKLJUČAK

Analizom rezultata, koja je izvršena u predhodnom poglavlju, došlo se do parametara otkopnih blokova, odnosno do geometrije bloka koji obezbedjuju maksimalno iskorišćenje toga bloka, a samim tim, primenom ove konstrukcije otkopne metode i čitavog ležišta.

Sama konstrukcija otkopne metode obezbedjuje velika iskorišćenja (80 - 90%) uz osiromašenje od 10 - 15 %, što su ispitivanja na modelima i pokazala. Za razmatranu varijantu metode poluetažnog prinudnog zarušavanja dobijeni su najbolji rezultati za sledeće parametre otkopnog bloka: širina B = 12 m, visina H = 80 m, osno rastojanje izmedju bočnih utovarnih komora l = 12 m. Za ovako izabrane parametre dobijeni su i najbolji pokazatelji metode otkopavanja i oni iznose: K_{ir} =0,90; K_{or}=0,10, Da bi se ostvarila ovakva iskorišćenja, neophodno je pridržavati se režima utovara iz utovarnih komora, odnosno treba utovarati iste ili približno iste količine rude iz svih utovarnih komora iz kojih se vrši utovar rude.

U ispitivanjima kod varijante razmatrane metode istakanje rude obavljano je iz dve i tri utovarne komore. Medjusobni odnos rezultata ukazuje da treba ići sa većim brojem utovarnih mesta. Na taj način postižu se bolji efekti odnosno dobijaju se veća iskorišćenja.

LITERATURA

[1] V. Milić, Istraživanje osnovnih parametara novih metoda poluetažnog prinudnog zarušavanja za otkopavanje dubokih delova borskog ležišta. Doktorska disertacija, Bor, 1996.

[2] R. Kojdić, Prilog odredjivanju najpovoljnijih parametara otkopne metode, sa tehno-ekonomskog aspekta, u uslovima eksploatacije bakarnog ležišta Bor na velikim dubinama, Doktorska disertacija, Bor, 1991.

[3] V. Milić, Ž. Milićević, N. Atanasković, Odredjivanje parametara metode poluetažnog prinudnog zarušavanja modeliranjem. Podzemni radovi. Beograd, 1994.

[4] V. Milić, Ž. Milićević, Odredjivanje ekscentriciteta elipsoida točenja rude iz Borskog ležišta. Glasnik rudarstva i metalurgije. Bor, 1995.

[5] V. Milić, Ž. Milićević, Osnovi eksploatacije ležišta mineralnih sirovina, Bor, 2005.

[6] M. M. Protodjakonov, P. I. Teder, Metodika racionalnogo planirovanija eksperimentov fizičko-mehaničeskie gornye problemy, Moskva, ”Nauka”, 1971.

[7] V. Milić, I. Svrkota, D., 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

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Ljubiša Obradović, Jelena Stanković*, Mile Bugarin**

DISPOSAL OF HAZARDOUS MINING WASTE - THE CURRENT SERBIAN AND EU LEGISLATION**

Abstract

By adoption the first Law on Waste Management of the Republic of Serbia in 2009 ("Official Gazette RS", No. 36/09), the necessary preconditions for introduction the order into the subject area were created. The Law on Waste Management was amended in 2010 ("Official Gazette RS", No. 88/2010). According to the guidelines of the amended Law on Waste Management, the Government of the Republic of Serbia has adopted the Regulation on disposal of hazardous waste on landfills ("Official Gazette RS", No. 92/2010). The Government has defined with this Law, for the first time, three categories of waste disposal and all parameters necessary for selection appropriate location, design and monitoring of future waste disposal. The Government regulation on landfills represents a harmonization of domestic legislation with the European Union in the field of environmental protection and waste management and with actual Directive 1993/31/EU.

***Keywords**: Regulation 92/2010, hazardous waste*

INTRODUCTION

Disposal of waste on landfill provides and ensures the conditions to prevent or reduce as far as possible negative effects on the environment, in particular the pollution of surface water, groundwater, soil and air, and on the global environment, including the greenhouse effect. In order to avoid these negative effects, the aim is the harmonization of the national legislation of the Republic of Serbia in the field of air quality, water, waste and industrial pollution with the EU acquis, which makes a significant progress in this area.

The environmental field, in addition, is the most voluminous and constantly in development, so that under the appropriate legal regulation in this area, the volume of EU legislation is constantly increased, what requires the constant monitoring of development the EU legislation regarding to comply with the national regulations. In the NPI document (National Program for Integration), this area is divided into the following chapters: horizontal legislation, air quality and climate changes, waste management, water protection and management, nature protection, chemicals, industrial pollution control and risk management, genetically modified organisms, noise protection, forestry and civil protection.

Since 1992, a selection of site and regulation of waste landfills in Serbia have

* *Mining and Metallurgy Institute, Bor*

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been carried out according to the Rulebook on criteria for determining the location and regulation of waste landfills from 1992 ("Official Gazette RS", No. 54/92). In accordance with this Rulebook, the general definition of landfill is: *a landfill of waste is the sanitary technical landscaped area where the solid waste is disposed as waste material generated in the public areas, households, production process or work, traffic or use, and which has no properties of hazardous substances and cannot be processed or rationally use as industrial raw material or energy fuel.* This Rulebook classifies all types of waste in one category, so the same rules and methodologies are used in designing the future municipal and industrial landfills.

Adoption the Law on Waste Management ("Official Gazette RS", No. 36/09) has provided the legal framework for establishment the integrated waste management system. A completion of all by-laws would be expected in the next periods that will completely regulate the waste management system (various rules and regulations). One of this regulation is the Regulation on disposal of hazardous waste ("Official Gazette RS", No. 92/2010) which is in accordance with the European Union Directive on the Landfills of Waste, No. 1999/31/EC. This Regulation shall prescribe more closely the conditions and criteria for determining the location, technical and technological conditions for designing, construction and operation of waste landfills, types of waste whose disposal on the landfill is prohibited, quantity of biodegradable waste that can be disposed, criteria and procedures for acceptance and non-acceptance, i.e. disposal of waste on landfill, method and procedures of operation, contents and monitoring of landfill operation as well as subsequently maintenance upon closure of landfill. This is particularly important because the landfill in accordance with the Rulebook from 1992 is designed as a watertight with the coefficient of terrain permeability on which the landfill is built of at least: k= 0.00001 m/s ($k=10^5$ cm/s), or the coefficient in meters is: k= 0.0000001 m/s ($k=10^{-7}$ m/s). This coefficient is insufficient because it does not satisfactorily prevent pollution of groundwater and surface water due to the uncontrolled movement of leachate from the landfill into the surrounding space, but by the adoption of new Regulation, a demand for water resistance has been considerably tightened.

The problem of hazardous industrial waste is in its improper storage that does not comply with the law as well as the lack of systemic solution to this problem. Partial solution is in export of hazardous waste for permanent disposal in other countries, which accounts for only 6%. The Republic Government has adopted, in December 2008 the Conclusion on construction the facilities for physical-chemical treatment of hazardous wastes, and in June 2009, the Conclusion on temporary storage the hazardous waste of unknown owner. Separation of components that can be recycled from waste is also regulated by the law. Development of recycling industry in Serbia, with the support of the ministry, creates the conditions for opening the new job positions in the new industry. Incineration of waste with the energy evaluation does not exist at this moment, because there are no facilities for waste incineration. A part of waste, presented by the waste tires, has started to be used as the energy resource/substitutes in the cement factories in Serbia.

LEGISLATION OF EU AND SERBIA ON DISPOSAL OF HAZARDOUS WASTE AT THE LANDFILLS WITH A VIEW TO THE DANGEROUS MINING WASTE

The Law on Waste Management ("Official Gazette RS", No. 36/09 and 88/2010) has provided the legal framework for establishment the integrated waste management system. In the frame of integrated system, the permanent and safe disposal of waste takes very important or the most important place.

European Union Directive on the Landfills of Waste, No. 1999/31/EC

When the EU legislation concerning the disposal of different types of waste on landfills is in question, it is officially regulated since 1999 by the Landfill Directive No. 1999/31/EC. The Landfill Directive is binding to all member states of the European Union and the countries that are candidates or in future pretend to join the EU. This Directive defines the three basic types of landfills for inert, non-hazardous and hazardous waste.

All necessary parameters are individually defined for every landfill, relevant to the selection of appropriate locations for future landfill during its construction, operation and after termination the exploitation of landfill and its closure and remediation. During the life of the construction, operation and post-operation of the landfill, the appropriate auscultation works - monitoring of landfill are defined. Continuous monitoring and monitoring of the landfill is very important because as a rule, all landfills, particularly the hazardous waste landfill, are large potential causes of pollution to all environmental factors (air, water and earth). Timely reacting and well/timed detection of irregularities in the work and exploitation of landfills, can prevent occurence of accident situations which are usually large scale, with unforeseeable consequences.

Regulation of the Government of RS on disposal of hazardous waste („Official Gazette RS“, No. 92/2010).

Thanks to the legal framework established by the Act on Waste Management 2009 and its first amendment 2010, the Government of RS in 2010 has adopted the Decree on the disposal of waste at landfills (" Official Gazette of RS", No. 92/2010). This Decree of the Government of RS, in fact, represents the harmonization of national legislation with the European and EU Directive on the landfill No. 1999/31/EC. In practice, the domestic regulation of landfills (92/2010) is mostly translated into the EU Directive on landfills (1999/31/EC) with some minor amendments.

With Regulation on disposal of hazardous waste of the Government of the Republic of Serbia (as like in the European Union Directive), the landfill has been classified for the first time into three types of landfills instead of one type that was previously present. The basic types of landfill are:

- landfills for inert waste,
- landfills for non-hazardous waste, and
- landfills for hazardous waste.

Landfills for hazardous waste are objects used for disposal of waste, which are, according to their characteristics (at least one or more features), hazardous waste, according to the Rulebook on categories, controling and classification of waste (“Official Gazette RS”, No. 56/10).

Mining waste disposal

The current Law on Waste Management in its Article 4 defines several types of waste to which the law does not apply. Paragraph 6 of Article 4 states that the provisions of the Act do not apply to:

- *“waste generated from mining exploration, excavation, processing and storage of mineral resources and overburden from mines and quarries“.*

According to definition of the current law on waste management, the overburden is excluded from its application. Project TR 37001, financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia, has provided recycling of flotation tailings from the old flotation tailing dump to the aim of recovery the useful components contained in this tailings. Copper, as a useful component, recovered from flotation tailings by hydrometallurgical processes, after which the acid waste material remains that should be permanently and safely disposed on landfill.

For the purpose of classification the waste obtained after leaching, the acid waste is subjected to the standard leaching test SRPS EN 12457-2. The study obtained by elution is according to the Rulebook on categories, controling and classification of waste ("Official Gazette RS", No. 56/10). According to this Rulebook, the waste material after leaching can be stored on hazardous waste landfill.

GENERAL REQUIREMENTS OF LANDFILL FOR HAZARDOUS WASTE

With regulation on disposal of hazardous waste ("Official Gazette RS", No. 92/2010), the important parameters are more precisely determined for defining the location of hazardous waste disposal, precise guidelines for design and construction of this type of landfill are given, especially technical and technological conditions, content and method of monitoring and maintenance the landfill after closure.

Landfill is located, as a rule, in sheltered coves of side relief, the former land borrow pits and flat terrains that are without current and stagnant water. Steep terrain with a slope of 25% may be used for landfills with adequate application of appropriate technical measures (planning, sidewise support, supporting, etc.). The landfill cannot be located on very cracked rocky substrate, with high water permeability and undefined movement directions of groundwater in the area affected by sliding, collapse, subsidence or other earth moving mass, if such phenomena cannot be prevented by technical measures.

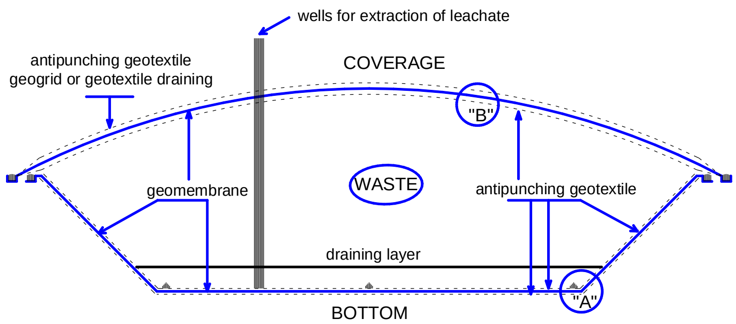

Figure 1 *A typical cross section of the hazardous waste landfill*

On the landfill, base and side are regulated; the lateral sides that will ensure the stability of the landfills provide sealing and waterproofing, which together with a system for admission and disposal of leachate prevent its penetration into the subsoil landfills. The landfill base and side shall consist of a mineral layer which satisfies permeability and thickness requirements with a combined effect in terms of protection of soil, groundwater and surface water at least equivalent to $K \leq 1{,}0x10^{9}$ m/s and thickness ≥ 5 m.

When the geological barrier does not naturally meet the above conditions, it can be completed artificially and reinforced by others means giving equivalent protection. An artificially established geological barrier should be no less than 0.5 m thick.

In addition to the geological barrier described above, the leachate collection and sealing system must be added in accordance with the following principles as to ensure that leachate accumulation at the base of the landfill is kept to minimum:

Table 1 *Leachate collection and bottom sealing*

Sealing and drainage of waste landfill bottom	For hazardous waste
Artificial sealing liner (geomembrane)	required
Drainage layer ≥0.5 m	required

The other methods and techniques can be used for sealing of landfill base and sides, if the requirements in Table 1 are provided.

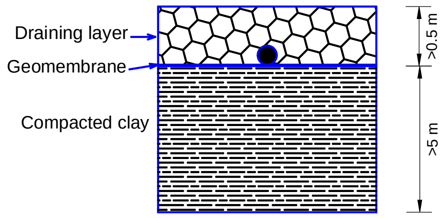

Figure 2 *Detail "A" - Sealing/drainage structure of bottom and slopes*

Project of drainage layer, drainage pipes and drainage channels shall be made on calculation the water balance in order to enable system operation of drainage and treatment of leachate, operation control and maintenance of the landfill. On the landfill of hazardous waste, it is necessary to provide a separate system for collection and drainage of leachate through the drainage layer in which drainage pipes are placed for transferring to designed system and treatment. Penetration of waste into the drainage system is prevented with appropriate technical solutions. For the maintenance and control of drainage pipes for collecting leachate, it is necessary to built up the sufficient number of shafts, which must be stable and rely on subsoil. For temporary retention of leachate, which is collected from the landfill body, it is necessary to set up a collecting shaft, which is resistant to the chemical influences.

After completion the period of exploitation, the landfill will be closed to further disposal formation a coverage layer, which meets the following technical conditions:

Table 2 *Required measures for designing a coverage layer of hazardous waste landfill*

Required measures for designing a coverage layer	**Landfill category**
	For hazardous waste
Artificial sealing liner	required
Impermeable mineral layer ≥0.5 m	required
Top soil cover≥0.5 m	required

For the layer of remediation (top soil cover), the waste, made by other biological treatment technologies, can be also used with satisfying limit values of parameters for waste disposal.

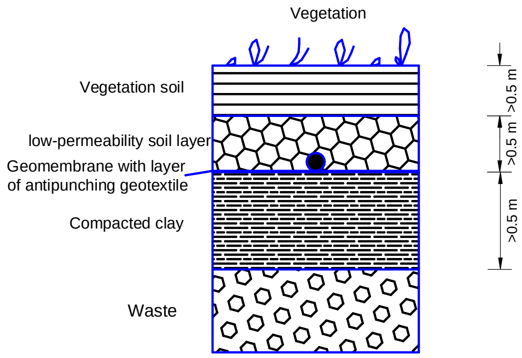

Figure 3 *Detail "B" - Design of coverage layer*

After closure the landfill and until its decay, the operator takes measures relating to the maintenance, supervision, control and monitoring of landfills, in accordance with this Regulation and the Law.

CONCLUSION

By adoption the Law on Waste Management of the Republic of Serbia in 2009 and its amendment in 2010, the legal framework was provided for establishment the integrated waste management system in Republic of Serbia.

As a part of an integrated waste management system, the permanent and safe disposal of waste to landfill takes an important place, or the most important one. In order to synchronize the national legislation with the European and EU Directive, the Government of the Republic of Serbia 2010 has adopted the Decree on the disposal of waste at landfills. In practice, the domestic regulation of landfills (92/2010) is mostly translated into EU Directive on landfills (1999/31/EC) with some minor amendments. With the Regulation on disposal of hazardous waste of the the Government of the Republic of Serbia (as like in the European Union Directive), the landfill has been classified for the first time into three types of landfills instead of one type that was previously present. The basic types of landfill are:

- landfills for inert waste,
- landfills for non-hazardous waste, and
- landfills for hazardous waste.

The waste generated from mining exploration, excavation, processing and storage of mineral resources, as well as the waste rock from mines and quarries is excluded from the current Law on waste management. This means that the flotation tailings, which was disposed at the Old Bor Flotation Tailing Dump are excluded from the above laws, but if the same flotation tailings is subjected to the recycling process in order to recover the remaining useful components, the law can be applied. Copper, as a useful component, recovered from flotation tailings by hydro metallurgical processes, after which the acid waste material remains that should be permanently and safely disposed on landfill.

For the purpose of classification the waste obtained after leaching, the acid waste is subjected to the standard leaching test SRPS EN 12457-2. The study obtained by elution is according to the Rulebook on categories, controling and classification of waste (“Official Gazette RS”, No. 56/10). According to this Rulebook, the waste material after leaching can be stored on hazardous waste landfill.

As there are no constructed landfills for hazardous waste in the Republic of Serbia, in order to better introduce them, their basic characteristics and structural elements are shown, according to the Regulation on disposal of hazardous waste (“Official Gazette RS”, No. 92/2010) and European Union Directive on the Landfill of Waste 1999/31/EC.

REFERENCES

[1] Law on Environmental Protection ("Official Gazette RS", No. 135/04, 36/09);

[2] Law on the Waste Management, (“Official Gazette RS”, No. 36/09 i 88/2010);

[3] European Union Directive on the Landfill of Waste, No. 1999/31/EC;

[4] Regulation on Disposal of Hazardous Waste (“Official Gazette RS”, No. 92/2010).

[5] Rulebook on Categories, Controlling and Classification of Waste (“Official Gazette RS”, No. 56/10);

[6] Stevanović Z., Obradović Lj., Marković R., et all: Chapter 2: "Mine Waste Water Management in the Bor Municipality in Order to Protect the Bor River Water", Book: Advances in Waste Water-Treatment Technologies and Recent Analytical Developments, Edited by Fernando Sebastian García and Luciano Carlos, Published by InTech, First Published January, 2013, (ISBN 980-953-307-598-8), 41-63.

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Ljubiša Obradović[*], Jelena Stanković[*], Mile Bugarin[*]

DEPONOVANJE OPASNOG OTPADA IZ RUDARSTVA - AKTUELNA ZAKONSKA REGULATIVA EU I SRBIJE[**]

Izvod

Usvajanjem prvog Zakona o Upravljanju otpadom Republike Srbije 2009. godine ("Sl. glasnik RS", broj 36/09), stvoreni su neophodni preduslovi za uvođenje reda u predmetnoj oblasti. Zakon o Upravljanju otpadom je dopunjen 2010. godine ("Sl. glasnik RS", br. 88/2010). U skladu sa smernicama dopunjenog Zakona o Upravljanju otpadom Vlada RS 2010. godine donosi Uredbu o odlaganju otpada na deponije ("Sl. glasnik RS", br. 92/2010). Ovom uredbom Vlade definišu se po prvi put tri kategorije deponija kao i svi parametri neophodni za izbor odgovarajuće lokacije, projektovanje i monitoring buduće deponije otpada. Uredba Vlade o deponijama predstavlja usaglašavanje domaće zakonske regulative sa regulativom EU i njenom aktuelnom Direktivom o deponijama br. 1999/31/EC.

Ključne reči: *Uredba o deponijama br. 92/2010, opasan otpad*

UVOD

Odlaganjem otpada na deponiju obezbeđuju se i osiguravaju uslovi za spečavanje i smanjenje štetnih uticaja na zdravlje ljudi i životnu sredinu u toku celog životnog ciklusa deponije, posebno zagađenja površinskih i podzemnih voda, zemlje i vazduha, uključujući i efekat staklene bašte. Kako bi se ovi štetni uticaji sprečili, teži se usaglašavanju nacionalnog zakonodavstva Republike Srbije iz oblasti kvaliteta vazduha, voda, otpada i industrijskog zagađenja sa pravnim tekovinama EU, koja je u ovoj oblasti dosta napredovala. Oblast životne sredine osim što je najobimnija u stalnom je razvoju, pa se shodno potrebi pravnog regulisanja ove oblasti, obim EU propisa konstantno povećeva, što zahteva stalno praćenje razvoja EU zakonodavstva radi usaglašavanja sa domaćim propisima. U NPI dokumentu (Nacionalni program za integraciju), ova oblast je podeljena na sledeća poglavlja: horizontalno zakonodavstvo, kvalitet vazduha i klimatske promene, upravljanje otpadom, zaštita i upravljanje vodama, zaštita prirode, hemikalije, kontrola industrijskog zagađenja i upravljanje rizikom, genetički modifikovani organizmi, zaštita od buke, šumarstvo i civilna zaštita.

Od 1992. godine izbor lokacije i uređenje deponija otpadnog materijala se u Srbiji vršio prema Pravilniku o kriterijumima za određivanje lokacije i uređenje deponija otpadnih materijala iz 1992. godine ("Sl. glasnik RS", br. 54/92). U skladu sa navedenim Pravilnikom opšta definicija deponije je: *deponija otpadnih materija jeste sanitarno-tehnički uređen prostor na kome se odlaže čvrst otpad koji kao otpadni materijal nastaje na javnim površinama, u domaćinstvima, u procesu proizvodnje*

[*] *Institut za rudarstvo i metalurgiju Bor*

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odnosno rada, u prometu ili upotrebi, a koji nema svojstva opasnih materija i ne može se prerađivati, odnosno racionalno koristiti kao industrijska sirovina ili energetsko gorivo. Ovaj pravilnik sve otpade svrstava u jednu kategoriju, tako da se za projektovanje budućih komunalnih i industrijskih deponija koriste ista pravila i metodologija.

Usvajanjem Zakona o upravljanju otpadom ("Sl. glasnik RS", broj 36/09 i 88/2010) obezbeđen je pravni okvir za uspostavljanje integralnog sistema upravljanja otpadom. U narednom periodu treba očekivati završetak svih podzakonskih akata koji će u potpunosti urediti sistem upravljanja otpadom (razni pravilnici i uredbe). Jedna od tih uredbi je i Uredba o odlaganju otpada na deponije ("Sl. glasnik RS", broj 92/2010) koja je u skladu sa Direktivom Saveta EU o deponijama otpada br. 1999/31/EC. Ovom uredbom se bliže propisuju uslovi i kriterijumi za određivanje lokacije, tehnički i tehnološki uslovi za projektovanje, izgradnju i rad deponija otpada, vrste otpada čije je odlaganje na deponiji zabranjeno, količine biorazgradivog otpada koje se mogu odložiti, kriterijumi i procedure za prihvatanje ili neprihvatanje, odnosno odlaganje otpada na deponiju, način i procedure rada i zatvaranja deponije, sadržaj i način monitoringa rada deponije, kao i naknadnog održavanja posle zatvaranja deponije. Ovo je posebno bitno iz razloga što se deponije u skladu sa pravilnikom iz 1992. godine projektuju kao vodonepropusne sa koeficijentom propustljivosti terena na kome se deponija izgrađuje od najmanje: k= 0,00001 m/s (k=10^{5}cm/s), odnosno u metrima koeficijenat iznosi: k= 0,0000001 m/s (k=10^{-7} m/s). Ovaj koeficijenat je nedovoljan jer ne sprečava na zadovoljavajući način zagađenje podzemnih i površinskih voda usled nekontrolisanog kretanja procednih voda iz deponije u okolni prostor, a donošenjem nove uredbe zahtev za vodonepropusnost je znatno pooštren.

Problem opasnog industrijskog otpada, a tu spada i otpad iz rudnika, je u njegovom nepropisnom skladištenju koji nije u skladu sa zakonom, kao i nepostojanje sistemskog rešenja za taj problem. Delimično rešenje je izvoz opasnog otpada na trajno zbrinjavanje u drugim zemljama koji je zastupljen sa svega 6%. Republička vlada je u decembru 2008. usvojila Zaključak o izgradnji postrojenja za fizičko-hemijski tretman opasnog otpada, a u junu 2009. Zaključak o privremenom skladištenju opasnog otpada nepoznatog vlasnika. Izdvajanje komponenti koje se mogu reciklirati iz otpada je takođe uređeno zakonom. Razvojem reciklažne industrije u Srbiji uz podršku ministarstva stvaraju se uslovi za otvaranje novih radnih mesta u novoj industrijskoj grani. Spaljivanje otpada u Srbiji uz energetsku valorizaciju u ovom trenutku ne postoji, jer ne postoje pogoni za insineraciju (spaljivanje) otpada. Deo otpada koje predstavljaju otpadne gume je počeo da se koristi kao energetski resurs/supstituenat u cementarama u Srbiji.

ZAKONSKA REGULATIVA EU I SRBIJE O ODLAGANJU OTPADA NA DEPONIJE SA OSVRTOM NA OPASAN RUDNIČKI OTPAD

Zakon o upravljanju otpadom ("Sl. glasnik RS", broj 36/09 i 88/2010) je obezbedio pravni okvir za uspostavljanje integralnog sistema upravljanja otpadom. U okviru integralnog sistema trajno i sigurno zbrinjavanje otpada zauzima veoma važno ako ne i najvažnije mesto.

Direktiva EU o deponijama 1999/31/EC

Kada je u pitanju zakonska regulativa EU koja se odnosi na odlaganje različitih vrsta otpada na deponijama ona je od 1999 godine zvanično uređena Direktivom o deponijama br. 1999/31/EC. Direktiva o deponijama je obavezujuća za sve države članice Evropske unije kao i za države koji su kandidati ili u budućnosti pretenduju na članstvo u EU. Ovom direktivom se definišu tri osnovna tipa deponija za inertan, neopasan i opasan otpad.

Za svaku deponiju pojedinačno su definisani svi neophodni parametri bitni kako za izbor adekvatne lokacije za buduću deponiju, tokom njene izgradnje, eksploatacije kao i po prestanku eksploatacije deponije, njenom zatvaranju i rekultivaciji. Tokom celog životnog veka izgradnje, eksploatacije i post-eksploatacije deponije definisani su i odgovarajući oskultacioni radovi - monitoring deponije. Kontinualno praćenje i monitoring deponije je veoma bitan jer su po pravilu sve deponije a naročito deponije opasnog otpada, veliki potencijalni zagađivači svih činilaca životne sredine (vazduh, voda i zemlja). Pravovremeno reagovanje i blagovremeno uočavanje svih nepravilnosti u radu i eksploataciji deponije, može sprečiti nastanak akcidentnih stuacija koje su po pravilu širih razmera sa nesagledivim posledicama.

Uredba Vlade RS o odlaganju otpada na deponije ("Sl. glasnik RS", br. 92/2010)

Zahvaljujući pravnom okviru koji je uspostavljen donošenjem Zakona o upravljanju otpadom 2009 godine kao i njegovom prvom dopunom 2010 godine, Vlada RS 2010 godine donosi Uredbu o odlaganju otpada na deponije ("Sl. glasnik RS", br. 92/2010). Ova uredba Vlade RS u stvari predstavlja usaglašavanje domaćeg zakonodavstva sa evropskim, odnosno usaglašavanje sa EU direktivom o deponijama br. 1999/31/EC. U praksi domaća uredba o deponijama (92/2010) predstavlja u najvećoj meri prevedenu Direktivu EU o deponijama (1999/31/EC) sa nekim manjim dopunama.

Uredbom Vlade RS o deponijama se (kao i u direktivi EU) po prvi put definišu tri osnovna tipa deponija umesto jednog koji je ranije postojao. Osnovni tipovi deponija su:

- deponije za inertan otpad,
- deponije za neopasan otpad i
- deponije za opasan otpad.

Deponije opasnog otpada predstavljaju objekte na kojima se odlaže otpad koji po svojim karakteristikama (najmanje jedna ili više karakteristika) predstavljaju opasan otpad, prema Pravilniku o kategorijama, ispitivanju i klasifikaciji otpada ("Sl. glasnik RS", br. 56/10).

Odlaganje rudničkog otpada

Aktuelni Zakon o upravljanju otpadom u svom članu 4 definiše više vrsta otpada na koje se zakon ne primenjuje. U tački 6 člana 4 piše da se odredbe zakona ne primenjuju i na:

- *"Otpad iz rudarstva koji nastaje istraživanjem, iskopavanjem, preradom i skladištenjem mineralnih sirovina, kao i jalovina iz rudnika i kamenoloma".*

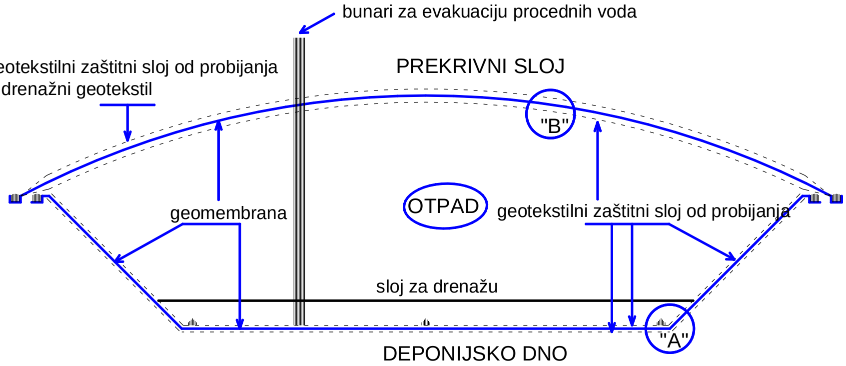
Prema definiciji aktuelnog zakona o upravljanju otpadom flotacijska jalovina je izuzeta od njegove primene. Projektom TR 37001 finansiranog od strane Ministarstva za nauku i tehnološki razvoj planom i programom je predviđeno recikliranje flotacijske jalovine iz starog flotacijskog jalovišta, u cilju valorizacije korisnih komponenti koju ova jalovina sadrži. Bakar kao korisna komponenta se iz flotacijske jalovine valorizuje hidrometalurškim putem. Nakon izdvajanja bakra preostaje otpadni materijal veoma kiselog karaktera koji je potrebno trajno zbrinuti na odgovarajućoj deponiji.

U cilju definisanja i karakterizacije otpada dobijenog nakon luženja, kiseli otpad je podvrgnut standardnom testu luživosti SRPS EN 12457-2. Nakon luženja izvršeno je ispitivanje eluata u skladu sa Pravilnikom o kategorijama, ispitivanju i klasifikaciji otpada ("Sl. glasnik RS", br. 56/10). Prema navedenom pravilniku otpadni materijal nakon luženja je svrstan u kategoriju opasnog otpada i može se skladirati na deponiju opasnog otpada.

OSNOVNE KARAKTERISTIKE DEPONIJE OPASNOG OTPADA

Uredbom o odlaganju otpada na deponije ("Sl. glasnik RS", br. 92/2010) bliže se određuju parametri važni pri definisanju lokacije deponije opasnog otpada, daju se precizne smernice za projektovanje i izgradnju ovog tipa deponije, posebno tehnički i tehnološki uslovi, sadržaj i način monitoringa rada deponije i održavanje posle zatvaranja.

Deponija se locira, po pravilu, u uvalama zaklonjenim bočnim reljefom, bivšim pozajmištima zemlje i ravnim terenima koji su bez tekućih i stagnirajućih voda. Strmi tereni sa nagibom preko 25% mogu se koristiti za deponije uz primenu adekvatnih tehničkih mera (planiranje, škarpiranje, podgrađivanje i dr.). Deponija se ne može locirati na terenu sa jako ispucalom stenovitom podlogom sa visokom vodopropustljivošću i nedefinisanim pravcima kretanja podzemnih voda i na području ugroženom klizanjem, urušavanjem, sleganjem tla ili drugim pomeranjem zemljine mase, ukoliko se takva pojava ne može sprečiti tehničkim merama.



Sl. 1. *Tipičan presek kroz deponiju opasnog otpada*

Na deponiji se uređuje deponijsko dno i nagibi, tj. bočne strane na način koji će osigurati stabilnost deponije, obezbediti zaptivanje, odnosno vodonepropusnost koja zajedno sa sistemom za prijem i odvođenje procedne vode sprečava njeno prodiranje u podtlo deponije. Dno i bočne strane tela deponije opasnog otpada treba da se sastoje od prirodne geološke barijere koja zadovoljava zahteve u vezi propustljivosti i debljine sa kombinovanim dejstvom u smislu zaštite tla, podzemnih i površinskih voda od $K \leq 1{,}0 \times 10^{-9}$ m/s i sa debljinom sloja ≥ 5 m.

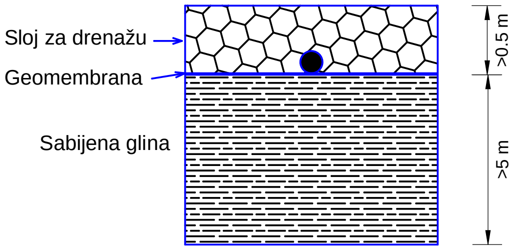
Kada prirodna geološka barijera ne zadovoljava propisane vrednosti, ona se obezbeđuje oblaganjem deponijskog dna sintetičkim materijalima ili prirodnim mineralnim tamponom koji mora biti tako konsolidovan da se dobije ekvivalentna vrednost dna u smislu njegovih vodopropusnih svojstava. Prirodni mineralni tampon ne sme biti manji od 0,5 metara.

Na deponiji je potrebno obezbediti i dodatnu zaštitu dna deponije kako bi se sprečila migracija procedne vode u podtlo deponije i to na sledeći način:

Tabela 1. *Zahtevani nivo zaštite dna deponije za opasni otpad*

Zaptivanje i drenaža dna deponije	**Za opasan otpad**
Veštačka zaptivna obloga-folija (geomembrana)	zahteva se
Drenažni sloj $\geq$0.5 m	zahteva se

Za zaptivanje deponijskog dna i bočnih strana deponije mogu se koristiti i druge metode i tehnike, ako obezbeđuju uslove iz Tabele 1.



Sl. 2. *Detalj "A" - Struktura zaptivanja/drenaže dna i padine*

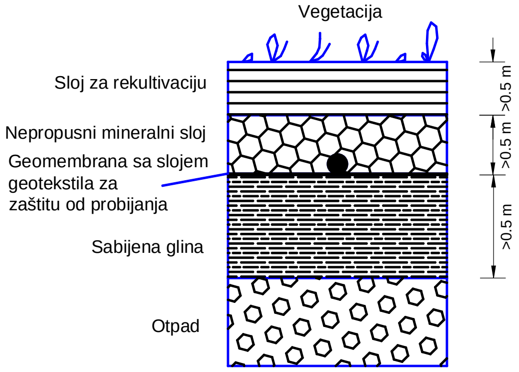
Projekat drenažnog sloja, drenažnih cevi i odvodnih kanala izrađuje se na osnovu proračuna bilansa voda kako bi se omogućilo delovanje sistema za dreniranje i prečišćavanje procedne vode, kontrola rada i održavanje deponije. Na deponiji opasnog otpada potrebno je obezbediti poseban sistem za sakupljanje i odvođenja procedne vode kroz drenažni sloj u koji su položene drenažne cevi za njeno odvođenje u projektovani sistem za njen tretman. Prodiranje otpada u drenažni sistem sprečava se odgovarajućim tehničkim rešenjima. Za održavanje i kontrolu drenažnih cevi za prikupljanje procedne vode potrebno je da se izgradi dovoljan broj šahtova, koji moraju biti stabilni i oslonjeni na podtlo. Za privremeno zadržavanje procedne vode koja se prikupi iz tela deponije potrebno je postaviti i sabirni šaht, koji je otporan na hemijske uticaje.

Nakon završenog perioda eksploatacije, deponija se zatvara za dalje odlaganje formiranjem gornjeg prekrivnog sloja koji ispunjava sledeće tehničko-tehnološke uslove:

Tabela 2. *Zahtevane mere pri formiranju gornjeg prekrivnog sloja deponije za opasan otpad*

Primenjene mere u smislu formiranja gornjeg prekrivnog sloja	**Klasa deponije**
	Za opasan otpad
Veštačka vodonepropusna obloga-folija	zahteva se
Nepropusni mineralni sloj $\geq$0.5 m	zahteva se
Sloj za rekultivaciju$\geq$0.5 m	zahteva se

Za sloj za rekultivaciju može se koristiti i otpad dobijen drugim tehnologijama biološkog tretmana, koji po sastavu zadovoljava granične vrednosti parametara za odlaganje otpada.



Sl. 3. *Detalj "B" - Projektovanje prekrivnog sloja*

Nakon zatvaranja deponije sve do njenog odumiranja operater na deponiji preduzima mere koje se odnose na održavanje, nadzor, kontrolu i monitoring prostora deponije, u skladu sa ovom uredbom i Zakonom.

ZAKLJUČAK

Usvajanjem Zakona o upravljanju otpadom 2009. godine i njegovom dopunom 2010. godine stvoren je pravni okvir za postepeno uspostavljanje integralnog sistema upravljanja otpadom u R. Srbiji.

U okviru integralnog sistema upravljanja otpadom veoma važno mesto, ako ne i najvažnije zauzima trajno i sigurno zbrinjavanje otpada na deponiji. U cilju sinhronizacije domaće zakonske regulative sa regulativom EU, Vlada Republike Srbije 2010. godine donosi Uredbu o odlaganju otpada na deponiji ("Sl. glasnik RS", br. 92/2010). Ova uredba Vlade RS se praktično veoma malo razlikuje od Direktive EU o deponijama 1999/31/EC. Uredbom se po prvi put uvodi klasifikacija deponija pri čemu su sve deponije podeljene u tri osnovne kategorije i to:

- deponije inertnog otpada,
- deponije neopasnog otpada i
- deponije opasnog otpada.

Otpad iz rudarstva koji nastaje istraživanjem, iskopavanjem, preradom i skladištenjem mineralnih sirovina, kao i jalovina iz rudnika i kamenoloma je izuzet iz važećeg Zakona o upravljanju otpadom. To znači da je flotacijska jalovina koja je odložena na starom Borskom flotacijskom jalovištu izuzeta iz navedenog zakona, međutim ukoliko se ista flotacijska jalovina podvrgne procesima reciklaže u cilju valorizacije preostalih korisnih komponenti, zakon se može primeniti. Bakar kao korisna komponenta se iz flotacijske jalovine izdvaja hidrometalurškim putem nakon čega preostaje kiseli otpadni materijal koji treba trajno i sigurno zbrinuti na deponiji.

U cilju klasifikacije otpada dobijenog nakon luženja, kiseli otpad je podvrgnut standardnom testu luživosti SRPS EN 12457-2. Ispitivanjem dobijenog eluata prema Pravilniku o kategorijama, ispitivanju i klasifikaciji otpada ("Sl. glasnik RS", br. 56/10), otpadni materijal nakon luženja može se skladirati na deponiju opasnog otpada.

Kako u Srbiji ne postoje izgrađene deponije za odlaganje opasnog otpada, u cilju boljeg upoznavanja sa njima prikazane su njihove osnovne karakteristike i konstruktivni elementi, saglasno Uredbi Vlade o deponijama ("Sl. glasnik RS", br. 92/2010) i Direktivi EU o deponijama 1999/31/EC.

LITERATURA

[1] Zakon o zaštiti životne sredine ("Sl. glasnik RS", 135/04, 36/09).

[2] Zakon o Upravljanju otpadom ("Sl. glasnik RS", broj 36/09 i 88/2010).

[3] Direktiva EU o deponijama br. 1999/31/EC.

[4] Uredba Vlade RS o odlaganju otpada na deponijama ("Sl. glasnik RS", br. 92/2010).

[5] Pravilnik o kategorijama, ispitivanju i klasifikaciji otpada ("Sl. gl. RS", br. 56/10).

[6] Stevanović Z., Obradović Lj., Marković R., at all: Chapter 2: "Mine Waste Water Management in the Bor Municipality in order to Protect the Bor River Water", Book: Advances in Waste Water-Treatment Technologies and Recent Analytical Developments, Edited by Fernando Sebastian García and Luciano Carlos, Published by In Tech, First published January, 2013, (ISBN 980-953-307-598-8), 41-63

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Prvoslav Trifunović, Nada Miličić***

DEFINING OF MODEL FOR DETERMINING THE SERVICE LIFE OF HOISTING ROPES IN MINING***

Abstract

The aim of this paper is to create an adequate model of relationship between the tensile strength and tearing force of the rope and its exploitation time. Analyzing the obtained laboratory data a mathematical model is chosen in order to achieve a good agreement with data. Using this model, it is possible to compute (approximately) the values of average tensile strength $\overline{R}$ *and tearing forces sum F of the rope at arbitrary time moment t. Consequently, the values of these parameters can be predicted in the given time interval, as well as the exploitation time of rope.*

***Keywords**: average tensile strength, tearing forces sum, exploitation time of rope*

1 INTRODUCTION

The service life of steel hoisting ropes is defined by complex conditions of mechanical and corrosive wear prevailing in a mine shaft. Mechanical wear is the result of static and dynamic stress affecting the rope during its service life (tensile strain, bending, torsion and other). Corrosive wear is the result of specific working conditions prevailing in a mine shaft, such as: acid mining water with pH<4, aggressive mining gases (oxygen, carbon dioxide, hydrogen sulfide and other), airborne dust, high humidity, high temperature, absence of daylight, etc.

During service life of the rope, there are changes at the rope itself, demonstrated by occurrence of broken wires and reduction of cross-sectional area. The occurrence of broken wires occurs at the base due to the fatigue of wire material, and less often due to the effect of tensile forces onto reduced cross-section. The reduction of cross-section of the rope occurs as the result of mechanical wear and due to the effect of corrosion. Both factors, mechanical and corrosive wear, may occur independently or together, what depends on prevailing conditions in the shaft, rope quality, lubrication and maintenance quality, etc.

During service life, the rope is the most exposed to stresses at the joint with hoisting vessel due to the dynamic stresses born by the rope at the beginning of drive, as well as due to the abrupt change in velocity. Therefore, every 5 to 6 months (as

* *University of Belgrade, Faculty of Mining and Geology, Belgrade, Serbia*
** *University of Belgrade, Faculty of Technology and Metallurgy, Belgrade, Serbia*

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provided by the Mining regulations), pieces of rope, with length of 1 to 2 m are cut in this part of the rope for the purpose of laboratory tests.

Some authors believe that the performed laboratory tests on a part of the rope at the joint with hoisting vessel cannot be taken as absolute criterion for determination of rope condition. Therefore, it is necessary to carry out the additional "in situ" test along the whole rope using the magnetic-inductive method in order to establish the condition of the whole rope and register changes, occurred due to deterioration and wear of the rope.

Taking all those above mentioned facts into account, the authors of this paper have proposed a mathematical model, which enables to predict a moment of reaching limiting values of the average tensile strength $\overline{R}$ and aggregate breaking force of the rope F, and thereby to predict a service life of the rope.

2 RESULTS OF LABORATORY TESTS ON STEEL HOISTING ROPE

Steel hoisting ropes for the purposes of mining are produced of high quality steel, with nominal tensile strength of wire material 1570 MPa or 1770 MPa, depending on construction and rope type. At the same time, those are also minimum tensile strengths, up to which the strength of wires is allowed to be reduced during service life of the rope.

When carrying out the laboratory tests of the rope, breaking force $F_m[N]$ and tensile strength of wire material $R_m[MPa]$ have to be established. Thereby, the aggregate breaking force of the rope, as well as the average tensile strength of wire material has to be calculated. Based on the results obtained, the evaluation on further usability of the rope, pursuant to the SRPS C.H1.030 Standard and the Rulebook on Technical Standards for Transportation of People and Material through the Mine Shaft, has to be given.

In order to evaluate the quality of wire material as well as the whole rope, the results of laboratory tests for the steel hoisting rope, which was used for about 10 years, and is still in use, were taken into consideration. During this period of time, 9 laboratory tests (approximately one test annually) were carried out. The results of tests are given in Table 1. [1]

Table 1 *Results of laboratory tests on hoisting rope*

Test serial number	Aggregate breaking force of the rope ΣF [N]	Average tensile strength of wire material $\overline{R}\,[MPa]$
1. (a new rope)	358786	1886.88
2. (I test)	352650	1864.38
3. (II test)	351139	1860.25
4. (III test)	357751	1886.05
5. (IV test)	357339	1879.95
6. (V test)	354144	1873.76
7. (VI test)	352847	1866.23
8. (VII test)	354180	1871.19
9.(VIII test)	352866	1861.40

Steel hoisting rope that was examined, with structure wj+6(9+9+1) Seale, has the computationally obtained breaking force $F_{computational}$=332390 N and nominal tensile strength of wire material R_m=1770 MPa.

Pursuant to the SPRS C.H1.030 Standard and the Rulebook on Technical Standards for Transportation of People and Material through the Mine Shaft, the rope has satisfactory quality if the aggregate breaking force of the rope, measured in a laboratory is higher than the computational breaking force of the rope ($F_{measured}$>$F_{computational}$) and if the average tensile strength of wire material is higher than the nominal tensile strength of wires ($\overline{R}$ >R_m).

Analyzing the laboratory test results after ten years of rope utilization in a mine shaft, it was established that the measured values of the aggregate breaking force of the rope and average strength of wires are still slightly higher than minimum prescribed values of $F_{computational}$ and R_m, so the rope may be used in the mine for a brief period of time. Due to small differences between measured and allowed values, the service life of the rope is at the very end, and therefore the rope must be replaced by the new one.

3 MATHEMATICAL MODEL FOR DETERMINING THE SERVICE LIFE OF HOISTING ROPE

By testing the rope at specific time intervals, the breaking force and tensile strength are followed. Based on the obtained measurement results, it is possible to find the type of dependency between breaking force and tensile strength and time. As breaking force equals the product of tensile strength and cross-sectional area, wherefrom follows that the dependencies of the average breaking force F on average tensile strength $\overline{R}$ is of the following type:

$$F = k \cdot \overline{R}$$

The value of k parameter is found in a condition that the linear function $F = k \cdot \overline{R}$ approximate the most optimally the data from Table 1 in the sense of method of the smallest squares, and it amounts *k=189.42.* Hence, it is

$$F = 189.42\overline{R} \qquad (1)$$

whereby the index of curvilinear dependency is $\rho_F = 0.940383487$, which means that the dependency is "very strong".

Analyzing the obtained data, it can be concluded that the best compliance with laboratory data for $\overline{R}$ depending on time was given by a cubic regression model. [2], [4]

In order to apply the method of the smallest squares for obtaining regression model, we shall take the data from the Table 1 in such a way, that we shall consider the first year of testing as zero and take into account only the year in which the rope was tested, and instead of average tensile strength $\overline{R}$ we shall observe the variable $Z = \overline{R} - \overline{\overline{R}}$, where $\overline{\overline{R}}$ =1872.233MPa is arithmetic mean of the obtained average strengths. In this way we obtain dependency Z on t as shown in Table 2.

Table 2 *Dependency of the variable Z on the time t*

t	1	2.667	3.5	4.583	5.5	6.75	7.833	8.333	8.833
Z	14.647	-7.85	-11.986	13.820	7.715	1.527	-6.003	-1.040	-10.830

Based on the data from Table 2, the following cubic regression model is obtained:

$$Z=46.75 – 40.69t + 8.95t^2 – 0.58t^3 \quad (2)$$

whose graph is shown in Figure 1.

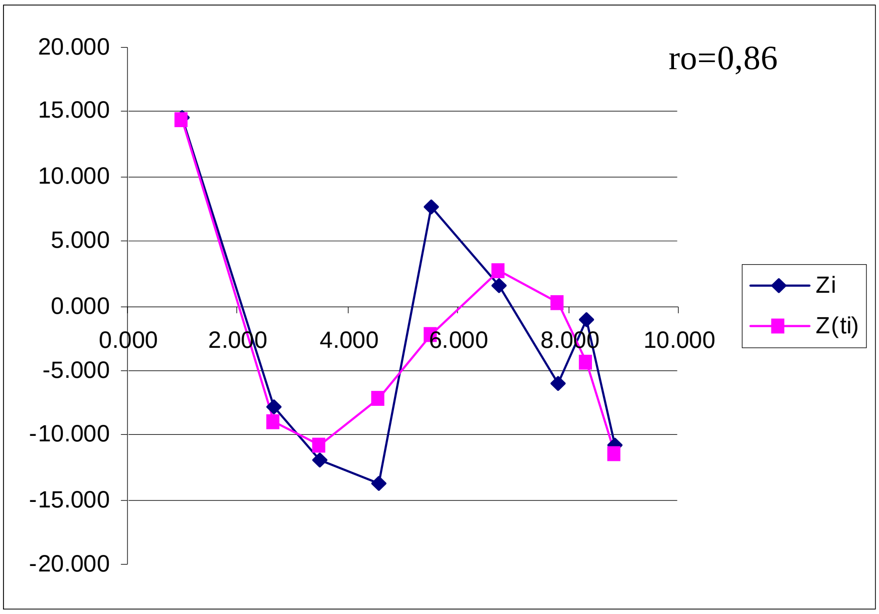

Figure 1 *Curve of tensile strength dependency on time*

Index of curvilinear dependency is ρ_z=0.86, which indicates that there is a "strong" dependency among data from Table 2, which is expressed by equation (2). [3]

By applying equation (2), it is possible to find the values of variable *Z*, i.e. values of the average tensile strength $\overline{R}$ within the arbitrary time moment *t*, and then by using equation (1) to find the values of aggregate breaking force *F* as well.

3.1 Verification the model on tested rope

The checkup of proposed mathematical model was made on the steel hoisting rope, which was in use for about 10 years, with structure wj+6(9+9+1) Seale, with computationally found breaking force $F_{computational}$= =332390 N and nominal tensile strength of wire material of R_m=1770 MPa.

By applying the proposed mathematical model, the following indicators result:

If the time period of rope usage is t=9.5 years, it follows that it is Z=-29.345, i.e. the average tensile strength of wires is $\overline{R}$ = =1872.233-29.345=1842.887 MPa, and the aggregate breaking force of the rope is $F_{aggregate}$=349079.66 N.

For the time period of the rope usage of t=10 years, it is obtained that it is Z=-45.15, i.e. the average tensile strength of wires is $\overline{R}$ =1872.233-45.15=1827.082 MPa, and the aggregate breaking force of the rope is $F_{aggregate}$=346085.87 N.

The obtained values are close to the measured values in laboratory and they are higher than minimum prescribed values $F_{computational}$ and R_m, which indicate that the rope may be used further in the mine. By this, the accuracy of the model and its conformity with the laboratory results and actual condition on site are confirmed.

Accordingly, by the use of the proposed model, the time moment *t* can be determined when limiting values, allowed by the Standard and Mining Regulations, have to be reached, which are: $F_{computational}$=332390 N and R_m=1770 MPa.

Namely, for $F_{computational}$=332390 N from equation (1), $\overline{R}$ =1754,78 MPa is obtained, and then Z=-117.455; then from the equation (2),the time of the rope usage is obtained that amounts t=11.47 years.

For R_m=1770 MPa, firstly Z=-102.233, is obtained and then from the equation (2), the time of the rope usage is obtained that amounts amounting t=11.21 years.

Predicted service life of the rope, obtained by this model, amounts approximately 11 years, which corresponds to the actual service life of the rope in the mine.

Based on the aforementioned statements, it can be concluded that the service life of rope in the mine can be predicted with considerably large reliability using the proposed model, and thereby the expensive laboratory and field "in situ" tests on ropes can be avoided.

4 CONCLUSION

The evaluation of the rope quality, based on the results, obtained from laboratory tests on a part of rope at its joint with hoisting vessel was proved to be insufficient, which is the reason why the periodical additional field tests and controls of installed steel ropes have to be carried out, in order to establish the resistivity condition of the whole rope and changes, caused by deterioration and wear of the rope. All of this complicate and raise the costs of test procedure and evaluation or quality of the steel hoisting ropes.

The authors of this paper have proposed a mathematical model, based on which it is possible to predict the service life of used rope with considerably large reliability and to determine the moment of its replacement.

Analyzing the obtained data, it is concluded that the best compliance with laboratory data for the average tensile strength $\overline{R}$ depending on the time *t*, is given by the cubic regression model, as shown by the following equation:

$$Z=46.75 - 40.69t + 8.95t^2 - 0.58t^3 \quad (2)$$

Applying the proposed model, it is possible to find the value of average tensile strength $\overline{R}$ within the arbitrary time period *t*, and then indirectly the value of aggregate breaking force *F* as well and then, based on them, to establish the service life of rope.

REFERENCES

[1] Zeković, M., Trifunović, P., Đukanović, N.: The Results of Periode Testing the Steel Export Cables from Serbian Mines, The Laboratory for Technology Mterials in Mining Industry, Faculty of Mining and Geology Belgrade, 1980-2010 (in Serbian);

[2] Miličić, N., Trifunović, P., Miličić, M.: The assessment of Life Time of the Hoisting Cable Based on the Results of Periodic Laboratory tests, Underground Mining Engineering, FMG

Belgrade 12 (2003), p. 55-60, (in Serbian);

[3] Jevremović, V., Mališić, J.: Statistical Methods in Metrology and Engineering, Belgrade, 2002 (in Serbian);

[4] Trifunović, P., Miličić, N., Miličić, M.: Attachment of the Methodology for Quality Evaluation of Export Cable in Mining, Underground Mining Engineering, FMG Belgrade 13 (2004), p. 49-55, (in Serbian);

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Prvoslav Trifunović, Nada Miličić***

DEFINISANJE MODELA ZA ODREĐIVANJE RADNOG VEKA IZVOZNIH UŽADI U RUDARSTVU***

Izvod

Cilj ovog rada je da se napravi odgovarajući matematički model zavisnosti zatezne čvrstoće i sile kidanja užeta od vremena njegove eksploatacije. Analizom dobijenih laboratorijskih podataka bira se matematički model koji ima dobru saglasnost sa merenim podacima.

Koristeći ovaj model moguće je odrediti vrednosti prosečne zatezne čvrstoće $\overline{R}$ i zbirne prekidne sile užeta F u proizvoljnom vremenskom monentu t, pa na osnovu njih prognozirati vek eksploatacije užeta.

Ključne reči: *prosečna zatezna čvrstoća žica, zbirna prekidna sila užeta, vek eksploatacije užeta*

1. UVOD

Radni vek čeličnih izvoznih užeta definisan je vrlo složenim uslovima mehaničkog i korozionog habanja koji vladaju u oknu rudnika. Mehaničko habanje je posledica statičkih i dinamičkih naprezanja koja deluju na uže u toku njegove eksploatacije (naprezanja na zatezanje, savijanje, torziju i dr.). Koroziono habanje je posledica specifičnih radnih uslova koji vladaju u oknu rudnika, kao što su: kisele rudničke vode sa pH<4, agresivni rudnički gasovi (kiseonik, ugljendioksid, sumporvodonik i dr.), lebdeća prašina, visoka vlažnost, povišena temperatura, odsustvo dnevne svetlosti i dr.

U toku eksploatacije užeta dolazi do promena na samom užetu, koje se manifestuju pojavom prekinutih žica i smanjenjem površine poprečnog preseka. Pojava prekinutih žica javlja se u osnovi zbog zamora materijala žica, ređe zbog dejstva zateznih sila na oslabljeni presek. Smanjenje poprečnog preseka užeta javlja se kao posledica mehaničkog habanja i dejstva korozije. Oba faktora, mehaničko i koroziono habanje, mogu se pojaviti samostalno ili zajedno, što zavisi od uslova koji vladaju u oknu, kvaliteta užeta, kvaliteta podmazivanja i održavanja i dr.

Za vreme rada uže je najviše izloženo naprezanjima kod spoja sa izvoznim sudom, zbog dinamičkih naprezanja koje uže trpi pri započinjanju vožnje, kao i usled nagle promene brzine kretanja. Zbog toga se svakih 5 do 6 meseci (kako predviđaju rudarski propisi) na tom delu užeta odsecaju komadi užeta dužine od 1 do 2 m radi laboratorijskog ispitivanja.

Neki autori smatraju da izvršena laboratorijska ispitivanja na delu užeta kod spoja sa izvoznim sudom ne mogu biti uzeta kao apsolutni kriterijum za utvrđivanje stanja užeta. Zbog toga je potrebno povremeno izvršiti dodatna “in situ” ispitivanje duž celog užeta magnetno-induktivnom meto-

* *Univerzitet u Beogradu, Rudarsko geološki fakultet, Beograd, e-mail: prvoslav.trifunovic@rgf.bg.ac.rs*
** *Univerzitet u Beogradu, Tehnološko metalurški fakultet, Beograd, Srbija*
*** *Ovaj rad je proistekao kao rezultat projekta br. 33029 „Izučavanje mogućnosti valorizacije preostalih rezervi uglja u cilju obezbeđenja energetske stabilnosti Republike Srbije“ finansiranog od strane Ministarstva prosvete, nauke i tehnološkog razvoja Republike Srbije.*

dom, kako bi se utvrdilo stanje kompletnog užeta i evindentirale nastale promene usled istrošenosti i habanja užeta.

Uzimajući u obzir napred pomenute činjenice, autori ovog rada su predložili matematički model kojim je moguće predvideti vremenski moment postizanja graničnih vrednosti prosečne zatezne čvrstoće $\overline{R}$ i zbirne prekidne sile užeta F, i shodno tome, prognozirati vek eksploatacije užeta.

2. REZULTATI LABORATORIJSKIH ISPITIVANJA ČELIČNOG IZVOZNOG UŽETA

Čelična izvozna užad za potrebe rudarstva proizvode se od izuzetno kvalitetnih čelika, nazivne zatezne čvrstoće materijala žica 1570 MPa ili 1770 MPa, zavisno od konstrukcije i vrste užeta. Istovremeno to su i minimalne zatezne čvrstoće do kojih sme opasti čvrstoća žica u toku eksploatacije užeta.

Prilikom laboratorijskog ispitivanja užeta utvrđuje se *sila kidanja F_m [N]* i *zatezna čvrstoća materijala žica R_m [MPa]*. Pri tome se računa zbirna prekidna sila užeta, kao i prosečna zatezna čvrstoća materijala žica. Na osnovu dobijenih rezultata daje se ocena o daljoj upotrebljivosti užeta na osnovu standarda SRPS C.H1.030 i Pravilniku o tehničkim normativima pri prevozu ljudi i materijala oknom rudnika.

Za ocenu kvaliteta materijala žica, kao i kompletnog užeta, uzeti su u razmatranje rezultati laboratorijskih ispitivanja čeličnog izvoznog užeta koje je bilo u upotrebi oko 10 godina i još se nalazi u eksploataciji. U tom periodu urađeno je 9 laboratorijskih ispitivanja (približno jednom godišnje). Rezultati ispitivanja dati su u tabeli 1. [1]

Tabela 1. *Rezultati laboratorijskih ispitivanja izvoznog užeta*

Redni broj ispitivanja	Zbirna prekidna sila užeta ΣF [N]	Prosečna zatezna čvrstoća materijala žica $\overline{R}\,[MPa]$
1. (novo uže)	358786	1886,88
2. (I ispitivanje)	352650	1864,38
3. (II ispitivanje)	351139	1860,25
4. (III ispitivanje)	357751	1886,05
5. (IV ispitivanje)	357339	1879,95
6. (V ispitivanje)	354144	1873,76
7. (VI ispitivanje)	352847	1866,23
8. (VII ispitivanje)	354180	1871,19
9. (VIII ispitivanje)	352866	1861,40

Ispitivano čelično izvozno uže, konstrukcije wj+6(9+9+1) Seale, ima računsku prekidnu silu $F_{računsko}$=332.390 N i nazivnu zateznu čvrstoću materijala žica R_m=1.770 MPa.

Prema standardu SRPS C.H1.030 i Pravilniku o tehničkim normativima pri prevozu ljudi i materijala oknom rudnika uže je zadovoljavajućeg kvaliteta ako je izmerena laboratorijski zbirna prekidna sila užeta veća od računske prekidne sile užeta ($F_{mereno} > F_{računsko}$) i ako je prosečna zatezna čvrstoća materijala žica veća od nazivne zatezne čvrstoće žica ($\overline{R} > R_m$).

Analizirajući laboratorijske rezultate ispitivanja posle deset godina korišćenja užeta u oknu rudnika konstatovali smo da su izmerene vrednosti zbirne prekidne sile užeta i prosečne zatezne čvrstoće žica i dalje nešto veće od minimalno propisanih vrednosti $F_{računsko}$ i R_m, pa se uže može još neko vreme koristiti na rudniku. S obzirom na male razlike između izmerenih i dozvoljenih vrednosti radni vek užeta je sasvim pri kraju, zbog čega se uže uskoro mora zameniti novim.

3. MATEMATIČKI MODEL ZA ODREĐIVANJE RADNOG VEKA IZVOZNOG UŽETA

Ispitivanjem užeta u određenim vremenskim intervalima, mi pratimo promenu sile kidanja i zatezne čvrstoće od vremena. Na osnovu dobijenih rezultata merenja, moguće je naći oblik zavisnosti sile kidanja užeta i zatezne čvrstoće od vremena. Kako je sila kidanja jednaka proizvodu zatezne čvrstoće i površine poprečnog preseka žice, sledi da je zavisnost prosečne sile kodanja F od prosečne zatezne čvrstoće $\overline{R}$ oblika:

$$F = k \cdot \overline{R}$$

Vrednost parametra *k* nalazimo iz uslova da linearna funkcija $F = k \cdot \overline{R}$ najbolje aproksimira podatke iz tabele 1. u smislumetode najmanjih kvadrata i ona iznosi *k=189,42*. Pa je,

$$F = 189{,}42\overline{R} \qquad (1)$$

pri čemu je indeks krivolinijske zavisnosti $\rho_F = 0{,}940383487$, što znači da je zavisnost "vrlo jaka".

Analizom dobijenih podataka zaključujemo da najbolju saglasnost sa laboratorijskim podacima za $\overline{R}$ u zavisnosti od vremena daje kubni regresioni model. [2], [4]

Da bismo primenili metodu najmanjih kvadrata za dobijanje regresionog modela, podatke u tabeli 1., ćemo uzeti tako što ćemo prvu godinu ispitivanja uzeti kao nultu i uzeti u obzir samo godinu u kojem je uže ispitivano, a umesto prosečne zatezne čvrstoće $\overline{R}$ posmatraćemo promenljivu $Z = \overline{R} - \overline{\overline{R}}$, gde je $\overline{\overline{R}}$ =1872,233 MPa aritmetička sredina dobijenih prosečnih čvrstoća. Na ovaj način dobijamo zavisnost *Z* od *t* datu u tabeli 2.

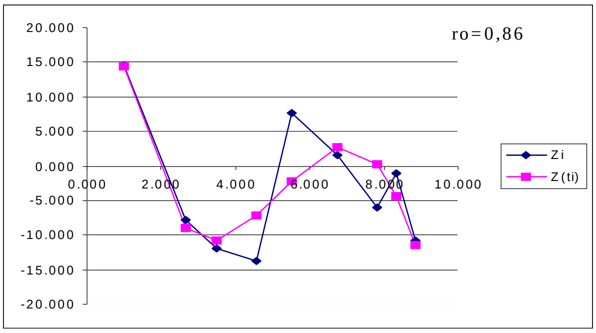
Tabela 2. *Zavisnost promenljive Z od vremena t*

t	1	2,667	3,5	4,583	5,5	6,75	7,833	8,333	8,833
Z	14,647	-7,85	-11,986	13,820	7,715	1,527	-6,003	-1,040	-10,830

Na osnovu podataka iz tabele 2. dobijamo sledeći kubni regresioni model:

$$Z = 46{,}75 - 40{,}69t + 8{,}95t^2 - 0{,}58t^3 \quad (2)$$

čiji grafik je dat na sl. 1.



Sl. 1. *Kriva zavisnosti zatezne čvrstoće od vremena*

Indeks krivolinijske zavisnosti je $\rho_z = 0{,}86$, što ukazuje da između podataka u tabeli 2. postoji "jaka" zavisnost izražena jednačinom (2). [3]

Primenom jednačine (2) moguće je naći vrednosti promenljive *Z*, tj. vrednosti prosečne zatezne čvrstoće $\overline{R}$ u proizvoljnom vremenskom monentu *t*, a zatim korišćenjem jednačine (1) i vrednosti zbirne prekidne sile *F*.

3.1. Provera modela na ispitivanom užetu

Provera predloženog matematičkog modela urađena je na čeličnom izvoznom užetu koje je bilo u eksploataciji oko 10 godina, konstrukcije wj+6 (9+9+1) Seale, sa računskom prekidnom silom $F_{računsko}$ = 332.390 N i nazivnom zateznom čvrstoćom materijala žica R_m = 1770 MPa.

Primenom predloženog matematičkog modela dolazimo do sledećih pokazatelja:

Ako je vremenki period korišćenja užeta t=9,5 godina, tada je Z =-29,345, tj. prosečna zatezna čvrstoća žica $\bar{R}$ =1.872,233-29,345 = 1.842,887 MPa, a zbirna prekidna sila užeta F_{zbirno} = 349079,66 N.

Za vremenski period korišćenja užeta od t=10 godina, dobijamo da je Z = -45,15, tj. prosečna zatezna čvrstoća žica je $\bar{R}$ = 1.872,233 - 45,15 = 1827,082 MPa, a zbirna prekidna sila užeta F_{zbirno} = 346085,87 N.

Dobijene vrednosti bliske su laboratorijski izmerenim vrednostima i veće su od minimalno propisanih vrednosti $F_{računsko}$ i R_m, što ukazuje da se uže može i dalje koristiti na rudniku. Ovim potvrđujemo tačnost modela i njegovo poklapanje sa laboratorijskim rezultatima i stvarnim stanjem na terenu.

Isto tako, predloženim modelom možemo odrediti vremenski moment *t* u kome se postižu granične vrednosti koje dozvoljava standard i rudarski propisi, a koje iznose: $F_{računsko}$ = 332.390 N i R_m = 1.770 MPa.

Naime, za $F_{računsko}$ = 332.390 N iz jednačine (1) dobijamo $\bar{R}$ = 1.754,78 MPa, a zatim Z=-117,455, pa iz jednačine (2) dobijamo vreme korišćenja užeta od t=11,47 godina.

Za R_m = 1770 MPa dobijamo prvo Z = -102,233, a zatim iz jednačine (2) dobijamo vreme korišćenja užeta od t=11,21 godina.

Prognozirani vek eksploatacije užeta dobijen ovim modelom iznosi oko 11 godina, što se poklapa sa stvarnim periodom eksploatacije užeta na rudniku.

Na osnovu svih prethodnih konstatacija možemo zaključiti da se predloženim modelom sa dosta velikom pouzdanošću može odrediti vek eksploatacije užeta na rudniku i time izbeći skupa laboratorijska i terenska "in situ" ispitivanja užadi.

4. ZAKLJUČAK

Ocena kvaliteta užeta na osnovu rezultata laboratorijskih ispitivanja na delu užeta kod spoja sa izvoznim sudom pokazala se nedovoljnom, zbog čega se povremeno moraju vršiti dodatna terenska ispitivanja i kontrole ugrađenih čeličnih užeta kako bi se utvrdilo stanje otpornosti kompletnog užeta i nastale promene usled istrošenosti i habanja užeta. Sve ovo jako usložnjava i poskupljuje proceduru ispitivanja i ocenu kvaliteta čeličnih izvoznih užadi.

Autori ovog rada predložili su matematički model na osnovu kojeg je moguće sa dosta velikom pouzdanošću prognozirati vek trajanja užeta u eksploataciji i odrediti trenutak njegove zamene.

Analizom dobijenih podataka zaključujemo da najbolju saglasnost sa laboratorijskim podacima za prosečnu zateznu čvrstoću $\bar{R}$ u zavisnosti od vremena *t* daje kubni regresioni model, dat sledećom jednačinom:

$$Z=46,75 - 40,69t + 8,95t^2 - 0,58t^3 \quad (2)$$

Primenom predloženog modela moguće je naći vrednost prosečne zatezne čvrstoće $\bar{R}$ u proizvoljnom vremenskom momentu *t*, a zatim posredno i vrednost zbirne prekidne sile *F*, pa na osnovu njih odrediti vek eksploatacije užeta.

LITERATURA

[1] M. Zeković, P. Trifunović, N. Đukanović: Rezultati periodičnih ispitivanja čeličnih izvoznih užadi iz rudnika Srbije, Laboratorija za tehnologiju materijala u rudarstvu, RGF Beograd, 1980-2010.

[2] N. Miličić, P. Trifunović, M. Miličić: Procena radnog veka izvoznog užeta na osnovu rezultata periodičnih laboratorijskih ispitivanja, Podzemni radovi 12 (2003), str. 55-60, RGF Beograd.

[3] V. Jevremović, J. Mališić: Statističke metode u meteorologiji i inženjerstvu, Beograd, 2002.

[4] P. Trifunović, N. Miličić, M. Miličić: Prilog metodologiji za ocenu kvaliteta izvoznih užadi u rudarstvu, Podzemni radovi 13 (2004), str. 49-55, RGF Beograd.

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Novica Staletović, Srdja Kovačević**, Nedeljko Tucović***, Miša Kovačević*****

METHODOLOGICAL FRAMEWORK FOR RISK ASSESSMENT IN THE FUNCTION OF MINING EQUIPMENT MAINTENANCE AND MANAGEMENT IMS (QMS, AMS, EMS and OHSAS) IN MINING COMPANIES

Abstract

This paper points out the opportunities and needs for integration the maintenance function with other management systems in accordance with the requirements of ISO 9001, ISO 14001, OHSAS 18001 as well as the new Standard ISO 55001. It defines the flowchart of risk assessment in the procedure of mining equipment maintenance as well as the methodological framework for risk assessment in the procedure of mining equipment maintenance. The proposed risk assessment model defines the criteria for probability of occurrence the hazardous events as the consequences that may arise, as well as the mechanisms for control the assessed risk. This risk assessment model can be also put in the context of integrated risk management.

Keywords: *risk assessment, mining equipment, system of equipment management*

INTRODUCTION

Mining companies and/or specific organizations involved in the maintenance of mining equipment are faced with various risks that may affect the realization of these objectives. Objectives may relate to a number of activities in the mining company, from strategic initiative for all operations, processes and projects and, can be reflected in terms of corporate social responsibility, meeting the requirements of legislation, commercial and financial measures.

Risk assessment involves the application of logical systematic methods for communication and consultation during the maintenance process of mining equipment. Risk assessment is that part of management which provides a structured process that analyzes the hazardous events that may cause the cancellation of mining equipment, and can lead to the incidents, accidents and accidents that are reflected in unplanned deadlock, breakdowns, environmental pollution, occupational injuries, fires and similar.

The objectives of development this methodological procedure of risk assessment for maintenance the mining equipment is to try to find the answers to the following questions:

- What might happen in the process of maintenance the mining equipment and why (identification of hazardous events that can cause failure or unplanned deadlock)?

* *Faculty of Ecology and Environmental Protection Union University-Nikola Tesla, Belgrade*
** *EPS PC Open Pits Kosovo - Obilić, Zetska 15, Belgrade*
*** *AD Jugoinspekt Belgrade, Čika Ljubina 8, Belgrade*
**** *Certification Body YUQS Ltd.; Trg Nikole Pašića V, Belgrade*

- What is the probability of hazardous events that can cause a failure?
- Whether are there factors that can influence on reduction the probability of occurrence of hazardous events?
- Whether are the levels of estimated risk acceptable and whether they require further treatment?

This proposed methodological procedure of risk assessment comply with the general principles of risk assessment so that it can be used in other organizations-facilities for maintenance the machinery and other purposes, and design of integrated management systems in mining companies. The proposed procedure is compatible with the Standards IEC/FDIS 31010:2009 and AS/NZS ISO 31000:2009 [12], [13].

Organizations dealing with maintenance for a long time sought to improve their business, both from the point of view of interior organizatrion and optimization the maintenance systeme and the external costs of supply and pressure. Pressures In recent times, the pressures are more and more and they are reflected in the need for energy savings and increased employee safety and environmental protection. Thus, not surprisingly, is a development of a new standard ISO 55001 *Asset Management Systems - Requirements.* [5]

Standards ISO 9000, 9001 and 9002 have been on the market since 1987, then the standard ISO 14001 since 1996 and BS OHSAS 18001 since 2000. It is a logical continuation of development the quality in the system of equipment maintenance and development the new standard ISO 55001, which is expected in early 2014.

Mining companies with established Integrated Management System (IMS), such as the quality management system (QMS) in accordance with ISO 9001, the equipment management system (AMS) in accordance with ISO 55001, the environmental management system (EMS) in accordance with ISO 14001, management system of occupational health and safety (OHSAS) in accordance with BS OHSAS 18001, can certainly expect that the effectiveness and efficiency of the company business will go upward, and that the company will contribute to the sustainable development both to the company and wider community as a whole.

2 OBJECTIVE AND PURPOSE OF RISK ASSESSMENT IN MINING EQUIPMENT MAINTENANCE

Risk assessment in the procedure maintenance of mining equipment is intended to provide the evidence based on identification and analysis of hazardous events that have occurred in the past or may occur and cause failure; how to treat the assessed risks and how to choose the best option of assessed risk management. Some of the main advantages of performing risk assessment include:

- Understanding the risk and its potential impact on the objectives of organization, which deals with the maintenance of mining equipment;
- Identification the critical points in the processes of mining equipment maintenance;
- Comparison of risk in the alternative technologies or approaches of mining equipment maintenance;
- Communication with assessed risk and uncertainties;
- Assistance in establishing the priority of actions to reduce the level of assessed risk;
- Contribution towards the prevention of incidents, accidents and accidents (emergencies);
- Selection of different forms of risk treatment in order to meet the requirements related to the management of mining equipment maintenance;

Providing the information that will help in assessment whether the risk is acceptable when compared to the pre-defined criteria.

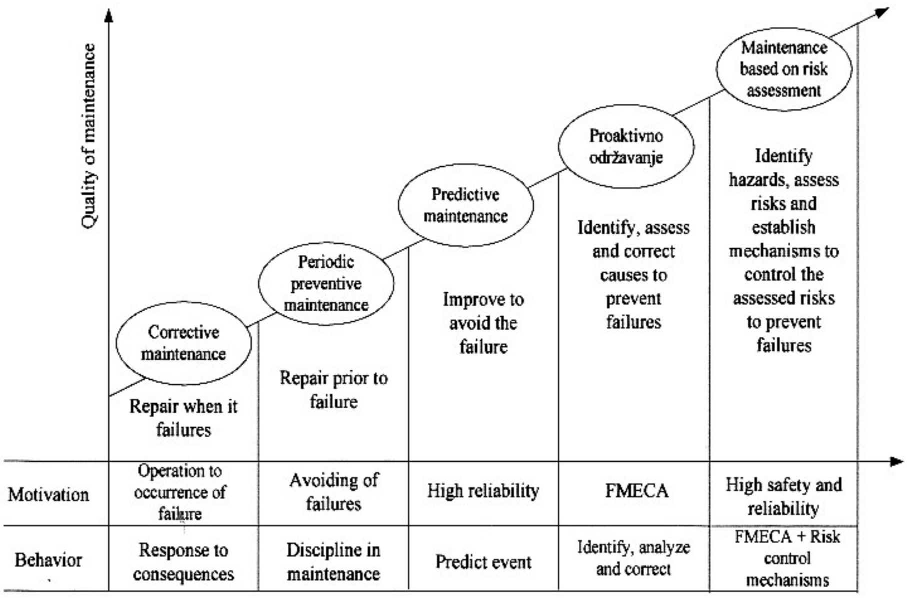


Figure 1 *Development of conceptions for maintenance and increasing the quality [14]*

3 MANAGEMENT OF THE RISK QUALITY BASED ON RISK ASSESSMENT

Equipment management strategy is systemic and coordinated activities by which the organization optimally and continuously improves its assets and equipment, its activities, risks and costs over the lifetime of equipment in order to achieve the defined strategic plan. [5]

The basic advantages from the standpoint of strategic management of equipment with optimal lifetime include:

- Satisfied clients (internal and external) due to the improved performance and control of products or services by certain standards;
- Improved health and safety at work;
- Improved environmental protection:
- Long-term planning and continuous performance;
- Improving the corporate reputation, whose benefits can be the increased share value, higher staff satisfaction and more effective and efficient procurement;
- The ability to demonstrate that demonstrate that sustainable development is actively represented in the mining equipment management.

Maintenance is the set of activities of administrative, organizational, technical and technological nature, aimed to the preservation and improvement the oeprating characteristics or insurance the state of maintened means and in which it has the ability to perform the dedicated function [14].

Maintenance, based on risk management ,is the latest approach in risk assessment of failure the technical systems and consequences that such failure may cause on the operation of system. Introduction of the risk concept allows to model by more realistic the failure of technical systems and assessment the expected consequences. Specifically, the risk quantification allows determination the optimal level of risk.

The idea of maintenance, based on risk assessment, appeared in the late 80s of the last century in the United States. Sometime later, the first document (ASME 1991) was published. As the latest generation of maintenance based on reliability, a methodology was developed that is based on the risk assessment of failure component and the impact that this failure can cause on the operation of system (RBM - *Risk Based Maintenance*). This approach is essentially no different from the RCM approach, except in the fact that the contribution to boosting the reliability level, in this case, is measured by degree of risk reduction.

The advantages of RBI are [15]:

- Determining the potential risks on technical system,
- Possibility of quantifying the benefits of maintenance procedures,
- By finding solutions in the field of maintenance,
- Optimal utilization the existing resources.

The fields of application the management on the basis of risk associated with maintenance activities are:

- Risks during the performance of maintenance activities,
- Risks as an integral part of the methodology of maintenance activities (organization of work, logistic support, motivation, education and training),
- Risk due to a lack of maintenance - (staff reliability and human factors).

Since the failure of some component is essentially statistical process (probability of occurrence), the risk is an adequate size, which can serve as a reference for making decisions on maintenance activities. Risk management, therefore plays an important role in the maintenance of technical systems. If the probability of hazardous event occurrence is very low, then the risk of failure is small. It may be noted that the need for maintenance is quantified by the risk: the higher the risk the higher the need for maintenance.

The National standards for risk management appeared for the first time in Australia and New Zealand in 1995 [13], then in Canada in 1997, and in the UK in 2000. The risk assessment is a comprehensive process of identifying, analyzing and assessment of risk[5]. Risk assessment provides to the decision makers and responsible parties an improved understanding the risks that may affect the achievement of objectives and adequacy and effectiveness of control that is already in force. This provides a basis for decisions about the most and appropriate approach used for the treatment of risk. The output of the risk assessment is input into decision making process in the organization. The following Figure 2 shows the general concept of risk assessment.

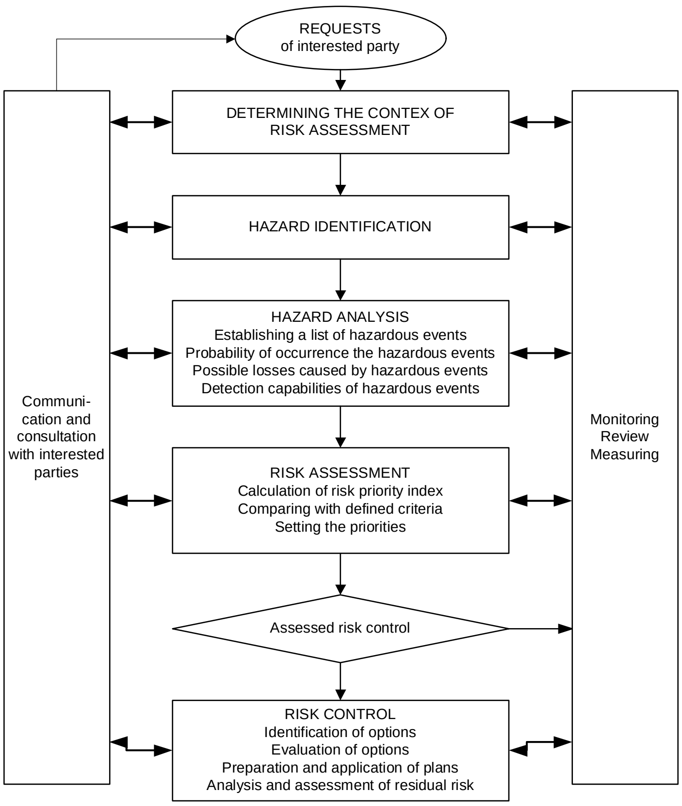


Figure 2 *Process of risk assessment [8] [12]*

Understanding the term "quality" was constantly changed with the passage of time. The term "quality" was primarily related only to the product, then in the late of twentieth century spread to the processes and organization as a whole. The concept of sustainable development was developed along with it.

The term "quality" becomes meaningful only when it is placed in the context of characteristics of products and/or services that can be then specified in terms of standard or level of service. So, the quality is: overall feature and characteristic of products or services that lead to the customer/user satisfaction of service.

Risk management as a support to the achievement of quality objectives involves planning, control and reduction of risk within all aspects of quality. In recent years as a support to this, a large number of standards for risk management are developed such as: IEC/FDIS 31010:2009 and AS/NZS ISO 31000:2009.

The British Institute of Asset Management in cooperation with *the British Standards Instution*, published in 2004 PAS-55, the first publicly available specification for management of assets (equipment) organization. The specification has proved to be very successful, so the companies used it in the field of transport, mining and other forms of production. In 2008, the amendment of Specification (PAS 55: 2008) was made: *The International Standards Organization* (ISO) has adopted PAS 55: 2008 as the basis for development the new series ISO55000. The adoption of Standard is planned at the beginning of 2014.

The new ISO 55001 Standard will define the requirements for certification in a way that is compatible with the series of Standard ISO 9000, ISO 14000, OHSAS 18000, etc.

In addition to compatibility with other management systems, the future standard will be applicable to the organizations of all sizes, from the Small and Medium Enterprises to the multinational organizations that want to establish a management system of equipment (fixed assets), in order to optimally and sustainably manage with their equipment during their life cycle.

Structure of ISO 55001 Standard will be largely similar to the other management systems as to require the existence of equipment management policy, strategies, objectives, plans, determining the representative members from the point of equipment management. Policy of equipment management should be based on the Strategic Plan in accordance with the nature of equipment and other organizational policies. It is necessary to define, in policy, the general framework of risk management in the organization or to comply with applicable legal, regulatory, statutory and other requirements and to clearly state the principles that will be applied as well as the organizational approach to the occupational health and safety, environmental protection and sustainable development.

In defining the plans of equipment management, it is necessary to take into account:

a) the risks associated with equipment which, if they are realized, may have the consequence of accident or emergency situation;
b) key potential delays in operation for equipment management;
c) activities to be taken to the aim of response to an accident and/or emergency and mitigating the consequences;
d) competence and training of staff on equipment maintenance to respond to emergencies;
e) the needs for risk holder that an accident and/or emergency situation can affect or that are required to respond to such situations.

The request of the future ISO 55001 Standard from the viewpoint of risk management is explicit that the organization should establish, implement and maintain the documented processes and/or procedures for identification and assessment the risks associated with equipment management, and to identify and implement the necessary control measures throughout the life cycle of equipment [17].

The methodology of the risk management should:

- be defined in relation to the field of application, nature and time in order to provide to be proactive rather than reactive, and
- ensure the identified, prioritized and documented risk, as well as control application, when it is appropriate.

Identification and assessment of risks in the process of equipment maintenance should take into consideration the possibility of real and potential hazardous events and their consequences, and should cover the risks associated with functional equipment failure, accidental or intentional equipment damage, then the operational risks including control of equipment, human factors and other factors, and activities that affect the performance, working conditions, occupational safety and environmental protection.

4 PROPOSAL OF METHODOLOGICAL FRAMEWORK OF RISK ASSESSMENT IN MINING EQUIPMENT MAINTENANCE

Methodological framework of risk assessment involves defining the criteria for risk assessment, as follows:

- Probability of occurrence the hazardous event that may cause failure of mining equipment;
- Nature and types of consequences that may relate to the process;
- Risk levels;
- Acceptable risk levels;
- Establishing the control mechanisms for assessed risks.

Hazardous events can cause failures and usually are associated with particular factors. By the origin and course of action, the factors can be divided into: external and internal.

External factors are activities of various entities, events or occurrences, and physically are located outside the organization.

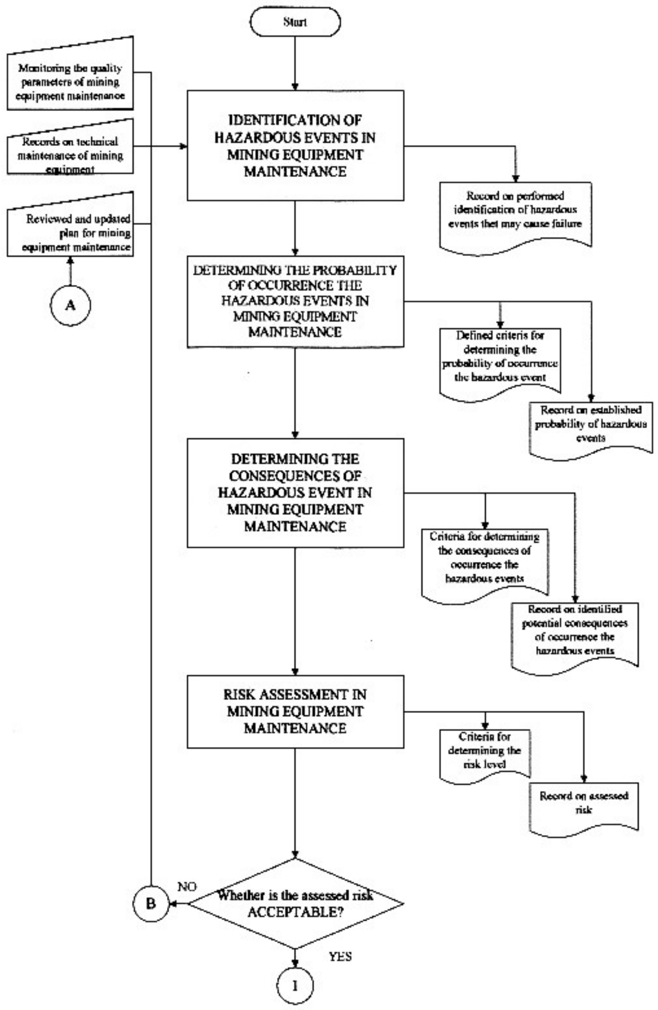
Internal factors are activities, events or occurrences, and physically are located within the organization.

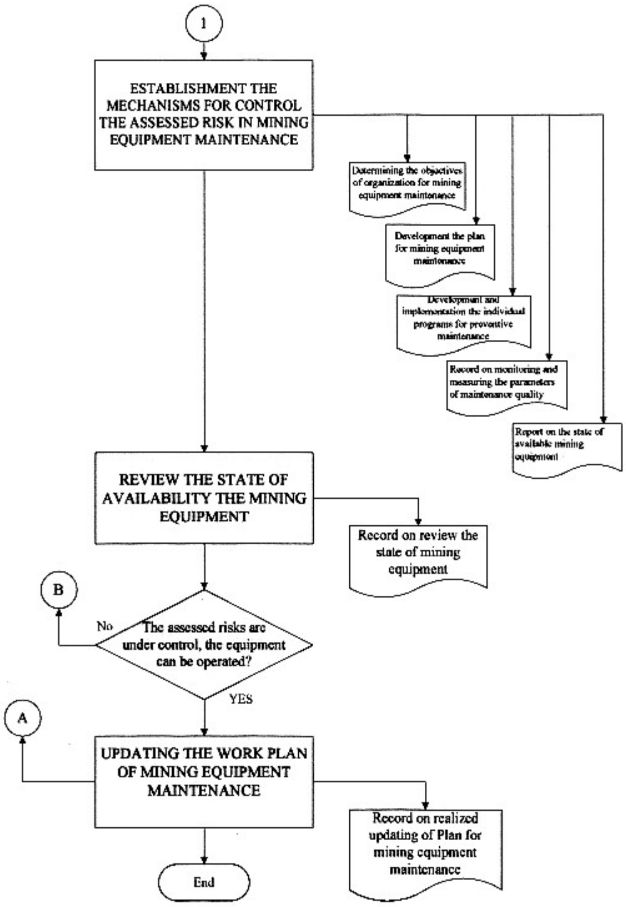
Internal factors are usually:

- History of negative/hazardous events;
- Inconsistency of organization with the legislation;
- The size or dispersion of organization;
- Inadequate way of organizing the operation;
- Insufficient training of staff;
- Existing systems of equipment maintenance.

Possibility of realization the certain hazardous events that may cause a failure is shown by the risk level. The risk level is directly dependent on the frequency of occurrence the hazardous events, sensitivity of the system, and the current system state [10].

4.1 Flowchart of risk assessment and management in the procedure of mining equipment maintenance





4.2 Selection of Method and Criteria for Risk Assessment

Risk assessment includes the probability of occurrence the hazardous events and consequences of realization the hazardous event that may cause a failure [12] and it can be expressed as follows.

R = V x P

Where:

R - risk level;

V - probability that potential hazard will result in potential hazardous event and cause failure;

P - consequences or effect that can put the hazardous event on the value of organization, natural and man-made values and environmental quality.

4.2.1 Assessment the Probability of Hazardous Events

Probability of occurrence the hazardous event that can cause the equipment failure (**V**) is expressed according to the following expression:

V = U # R

U - frequency of occurrence the hazardous event that can cause the equipment failure;

R - sensitivity to the possibility of realization the hazardous event.

Probability, that potential hazard results in hazardous event, is a combination of frequency the event of certain hazard and sensitivity of organization. Probability that a potential hazard results in hazardous event is graded as follows: 1 - very unlikely, 2 - unlikely, 3 - moderately likely, 4 - probably, 5 - very likely.

Table 1 *Criteria for determining the probability of hazardous event occurrence*

	Frequency - U	Sensitivity - R	V = U # R
1	**very rare** occurrence of hazardous event	**very high** no maintenance function	**very unlikely**
2	**occasional** occurrence of hazardous event	**high** only organizational maintenance measures	**unlikely**
3	**frequent** pojava opasnog događaja	**medium** only technical maintenance measures	**moderately likely**
4	**prevailing** occurrence of hazardous event	**low** organizational and technical maintenance measures	**probably**
5	**very often** occurrence of hazardous event	**very low** in the function of system maintenance	**very likely**

Frequency refers to the repetition of certain threat that realization of hazardous even will be realized in the observed period of time Frequency is graded as follows: 1 – very rare, 2 - occasional, 3 - frequent, 4 - prevailing, and 5 - very often

Sensitivity presents the current state of maintenance system for equipment/fixed assets or sensitivity the organization/facility/process on hazard of failure. Sensitivity is graded as follows: 1 - very high vulnerability - no measures of maintenance function, 2 – high vulnerability - only organizational maintenance measures in a function, 3 – mean vulnerability - only technical maintenance measures in a function, 4 - low vulnerability – organizational and technical maintenance measures in a function, 5 - very low vulnerability – the established, certified and many time checked system of equipment management.

Table 2 *Matrix for assessment the probability of failure*

SENSITIVITY		very high	high	medium	low	very low
FREQUENCY		1	2	3	4	5
very rare	1	3	2	1	1	1
occasional	2	4	3	2	2	1
frequent	3	5	4	3	2	2
prevailing	4	5	4	3	3	3
very often	5	5	5	4	3	3

4.2.2 Consequences of Hazardous Event

The consequences of hazardous even **(P)** are expressed according to the expression:

P= Š # K

Š - damage of specific mining machinery where hazardous event can cause consequences;

K - criticality, value or importance the protected value for organization in which the hazardous event can cause consequences.

Consequences present the effect of hazardous events on equipment (main assets) of organization, and they are manifested by the size of damage in relation to the critical importance of protected values.

Consequences are graded as follows: 1 - very light, 2 - light, 3 - medium severe, 4 - severe and 5 - very severe.

Table 3 *Criteria for determining the consequences*

	Damage - Š	Criticality - K	P = Š # K
1	**very small** - to 1,000.00 Euros or very small consequences	**very large** - complete disruption in running the organization	**very light consequences**
2	**small** – from 1,000.00 to 10,000.00 Euros, or small consequences	**large**-shaken functioning of the organization	**light consequences**
3	**medium** - from 10,000.00 to 100,000.00 Euros or serious consequences	**medium** – possible functioning with increased efforts and additional resources	**medium severe consequences**
4	**large** - more than 100,000.00 Euros, or severe and multiple serious consequences	**small** - possible stopping of the working process	**severe consequences**
5	**very large** - more than a million Euros or catastrophic consequences	**very small** - solving on the go by regular activities	**very severe consequences**

Damage is a measure of damage the protected value (equipment/fixed assets) and it can result in various degrees. Damage is graded and expressed as: 1-very small damage, 2-small damage, 3-medium damage, 4-large damage and 5-very large damage.

Criticality is a measure of value or importance of protected value.

Criticality is graded as follows: 1 - very large, 2 - large, 3 - medium, 4 – small and 5 - very small.

Table 4 *Matrix for assessment the consequences*

CRITICALITY / **DAMAGE**		very large	large	medium	small	very small
		1	2	3	4	5
very small	1	3	2	1	1	1
small	2	4	3	2	2	1
medium	3	5	4	3	2	2
large	4	5	4	3	3	3
very large	5	5	5	4	3	3

4.2.3 Defining the Risk Level

The risk level is graded as:

1) Very small (or negligible) risk (R = 1 and 2)
2) Low risk (R = 3, 4 and 5)
3) Moderately increased risk (R = 6, 8 and 9)
4) High risk (R = 10, 12, 15 and 16)
5) Very high risk (R = 20 and 25)

Table 5 *Matrix for risk assessment*

CONSEQUENCES OF PROBABILITIES		**very light**	**light**	**medium severe**	**severe**	**extremely severe**
		1	2	3	4	5
very unlikely	1	1	2	3	4	5
unlikely	2	2	4	6	8	10
moderate likely	3	3	6	9	12	15
likely	4	4	8	12	16	20
very likely	5	5	10	15	20	25

The assessed risks are classified, according to the defined categorization, into:

1) Acceptable Risk (R = 1, 2, 3, 4 and 5)
2) Conditionally Acceptable Risk (R = 6, 8, 9)
3) Unacceptable Risk (R = 10, 12, 15, 16, 20 and 25)

Upon completion the risk assessment process, the approach is aimed to the establishment the control mechanisms of assessed risk. Selection the appropriate option for establishment the mechanisms of risk control involves balancing the costs and efforts in application the option and benefits that can be drawn from it [8].

Large number of options for establishment the mechanisms of risk control can be considered and applied individually or in combination. In deciding, take into account rare, but the risks that can justify the actions of establishment risk control mechanisms that are not justified (permitted) by the strict economic rules [10].

In defining the risk management or considering the changes in the current management, the measures and options of risk reduction must be considered according to the following hierarchy:

a) measures and options for elimination or avoiding the risks;
b) measures and options for mitigation or replacement (substitution) the risks;
c) measures and options for engineering control the feasibility of applied strategies, plans and programs and the analysis of price and benefits;
d) measures and options for defining the procedures and guidelines for equipment maintenance;
e) measures and options for implementation the technical diagnostics.

CONCLUSIONS

Mining companies that want to grow their business must have at all times the relevant information on what equipment/fixed assets are available and in a functional condition. Analysis the condition of equipment/fixed assets needs to devote the sufficient attention because, in this way, the company management has important information that encourage the adoption of appropriate decisions for improvement the system of equipment management as well as overall integrated management system. A very important step in development of equipment maintenance system is the inclusion of top management and personnel responsible for operation and maintenance of equipment.

Defined flowchart and methodological procedure of risk assessment in the process of maintenance the equipment/fixed assets is of great benefit to development the system of equipment management (AMS). Risk assessment and establishment the control mechanisms management is of great benefit in the design of integrated management systems [8]. The proposed model of risk assessment allows properly processing and usage the information on risk in maintenance in decision-making at the relevant levels of organization [8].

Methodology of risk management is proposed and defined in maintenance of mining equipment, that:

- provides to be proactive, not reactive, and
- provides the identification, prioritized and documented risks, as well as implementation of control, when it is appropriate.

Proactive and comprehensive risk assessment, as it is defined in this paper, is an organization that deals with mining equipment maintenance of mining equipment and it can:

- create and approve the policy of assessed risk management;
- inform all interested parties (employers, management, customers, etc/) for the state of availability of its mining equipment;
- define the control mechanisms of assessed risk that matches the performances of organization for mining equipment maintenance;
- ensures compatibility of risk management objectives in mining equipment

maintenance with the objectives and strategy of organization;

- provides compliance with the law and bylaw legislation as well as legal documents of organization pertaining quality management of mining equipment maintenance;
- provides a distribution of needed resources for assessed risk management.

REFERENCES

[1] Asset Management Consulting Limited brochure: Asset Management Excellence (2010)

[2] Australian Emergency Management Committee, 2009: National Emergency Risk Assessment Guidelines, Tasmanian State Emergency Service, Hobart.

[3] Anđelković B., Staletović N., Preventive Engineering in the Field of Fire in Design of Technological Systems, Preventive Engineering, No. 2. Dunav Preving, Belgrade, 1999, pp. 27-31.

[4] BSI: Asset Management-Overview, Principles and Terminology, ISO PC 251/N48

[5] Curović D., Gavrilović M.; Asset Management – Series of Standard ISO 55000; Quality and Excellence, No. 9-10; Belgrade 2012.

[6] European Standard EN 15341 – Maintenance - Key Performance Indicators.

[7] Kovačević S.; Staletović N.; Tucović N.; Methodological Approach to Risk Assessment in a Function of System Management of Occupational Health and Safety in PU OP "Kosovo" Business Policy - Quality, ISSN 0354-2408 - UDC 006 +658.5; First XXI Nos. 10-11, 2011.

[8] Kovačević S., Staletović N., N. Tucović, R. Janković; Quantitative Assessment of Risk Management in the Function of Integrated Systems, 14.DQM, International Conference of Quality Management and Reliability ICDQM – 2011, (ISBN 978-86-86355-05-8, pp.159-165), 29-30 June 2011, Belgrade, Serbia.

[9] Petrović D., Damnjanović Z., Đenadić D., Pantović R., Milić V., Application of Modern Computer Devices and Tools to Reduce Accidents in the Mining Systems, Mining Engineering, Bor, No. 2, pp. 29-40, 2010.

[10] Staletović N, Kovačević S., Kovačević M.; Methodological Approach to Identification of Aspects and Evaluation the Impacts on the Environment for the Project "Exploitation of Magnesite in the Deposit Čavlovac - Masnica"; Mining Engineering, 2012; ISSN 1451-0162.

[11] Staletović N.; Evaluation of OH&S Risks in a Function of Preventive Engineering and Integrated Management Systems (QMS/EMS/OHSAS); Technique - Menadžment, Vol. 59, No. 3, pp. 8-14, 2009.

[12] Standard IEC/FDIS 31010:2009(E) Risk Management - Risk Assessment Techniques

[13] Standards Australia and Standards New Zealand; Standard Risk Management AS/NZS 4360:2009. Sydney and Wellington: Standards Australia and Standards New Zealand.

[14] Papić Lj.; Preventive Management, Research Centre DQM, Čačak, 1998, pp.109.

[14] Papić Lj., Milovanović Z; Maintenance and Reliability of Technical Systems, DQM, Prijevor, 2007.

[16] www.umsgroup.com

[17] www.pragma world.net

[18]http://*en.wikipedia.org/wiki/Asset_management*

[19] http://theiam.org/what-asset-management

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Novica Staletović[*], *Srdja Kovačević*[**], *Nedeljko Tucović*[***] *Miša Kovačević*[****]

METODOLOŠKI OKVIR PROCENE RIZIKA U FUNKCIJI ODRŽAVANJA RUDARSKE OPREME I UPRAVLJANJA IMS (QMS, AMS, EMS i OHSAS) U RUDARSKIM KOMPANIJAMA

Izvod

U ovom radu ukazane su mogućnosti i potrebe integracije funkcije održavanja sa ostalim menadžment sistemima u skladu sa zahtevima ISO 9001, ISO 14001, OHSAS 18001 kao i novog standarda ISO 55001. Definiše se dijagram toka procene rizika u postupku održavanja rudarske opreme kao i metodološki okvir za procenu rizika u postupku održavanja rudarske opreme. Predloženi model procene rizika definiše kriterijume za verovatnoću pojave opasnih događaja kao posledice koje se mogu javiti kao i mehanizme za kontrolu procenjenog rizika. Ovaj model procene rizika se može staviti i u kontekst integrisanog upravljanja rizicima.

Ključne reči: *procena rizika, rudarska oprema, sistem menadžmenta opremom*

1. UVOD

Rudarske kompanije i/ili specifične organizacije koje se bave održavanjem rudarske opreme suočavaju se sa različitim rizicima koji mogu uticati na ostvarivanje zadatih ciljeva. Ciljevi se mogu odnositi na niz aktivnosti u rudarskoj kompaniji, od strateške inicijative za sve operacije, procese i projekte i mogu se ogledati u pogledu društveno odgovornog poslovanja, ispunjenja uslova zakonske regulative, komercijalnih i finansijskih mera.

Procena rizika obuhvata primenu logičkih sistematskih metoda za komunikaciju i konsultaciju tokom procesa održavanja rudarske opreme. Procena rizika je onaj deo upravljanja koji obezbedjuje struktuirani proces, koji analizira opasne događaje koji mogu uzrokovati otkaz rudarske opreme, a može uzrokovati incidente, akcidente i udese koji se ogledaju u neplaniranom zastoju, havariji, zagađenju životne sredine, povredi na radu, požaru i tsl.

Ciljevi razvoja ovog metodološkog postupka procene rizika pri održavanju rudarske opreme je da se pokušaju naći odgovori na sledeća pitanja:

- Šta se može desiti u postupku održavanja rudarske opreme i zašto (identifikacija opasnih događaja koji mogu uzrokovati otkaz ili neplanirani zastoj)?
- Koja je verovatnoća pojave opasnih događaja koji mogu uzrokovati otkaz?
- Da li postoje faktori koji mogu da utiču na smanjenje verovatnoće pojave opasnih događaja?
- Da li su nivoi procenjenog rizika prihvatljivi i da li zahteva dalji tretman?

[*] *Fakultet za ekologiju i zaštitu životne sredine Univerzitet UNION-NIKOLA TESLA Beograd*
[**] *EPS JP Površinski kopovi Kosovo - Obilić, ul. Zetska br. 15 Beograd*
[***] *AD Jugoinspekt Beograd, Čika Ljubina 8, Beograd*
[****] *Sertifikaciono telo YUQS d.o.o; Trg Nikole Pašića V Beograd*

Ovaj predloženi metodološki postupak procene rizika pridržava se opštih principa procene rizika tako da se može koristiti i u drugim organizacijama/postrojenjima za održavanje mašina i za druge svrhe i projektovanjaintegrisanih menadžmen sistema u rudarskim kompanijama. Predloženi postupak je kompatibilan sa standardima IEC/FDIS 31010:2009 i AS/NZS ISO 31000:2009 [12], [13].

Organizacije koje se bave održavanjem u dugom vremenskom periodu su nastojale da unaprede svoje poslovanje, kako iz ugla unutrašnjeg uređenja i optimizacije sistema održavanja tako i od spoljašnjih troškova isporuke i pritisaka. Pritisci su u novije vreme sve veći i ogledaju se u potrebi uštede energije i većoj bezbednosti zaposlenih i zaštite životne sredine. Shodno tome i nije iznenađenjeda se razvija novi standard ISO 55001 *Asset Management Systems – Requirements.* [5]

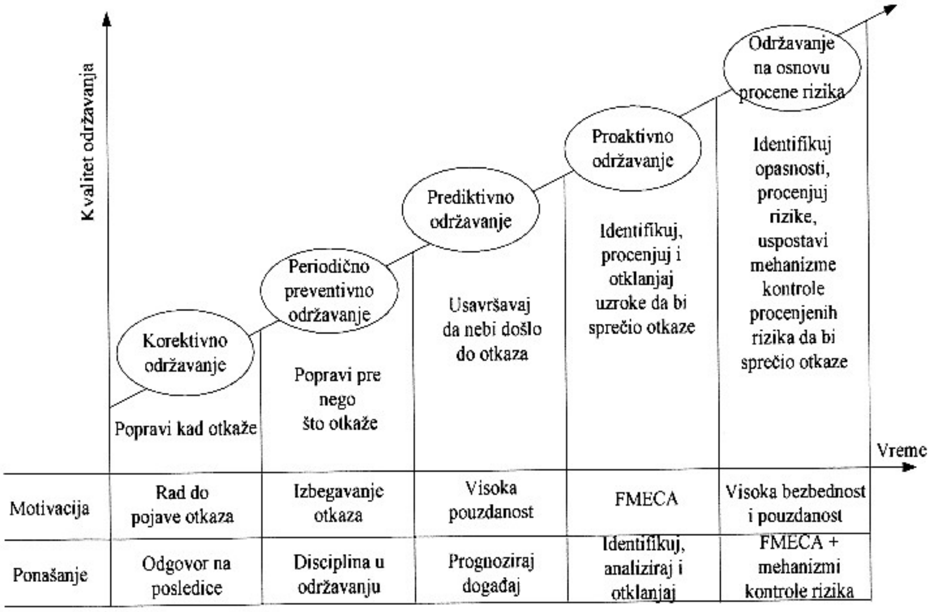
Standardi ISO 9000, 9001 i 9002 su na tržištu od 1987, zatim standard ISO 14001 od 1996 i standard BS OHSAS 18001 od 2000. To je logičan nastavak razvoja kvaliteta u sisremu održavanja opreme i razvoja novog standarda ISO55001, koji se očekuje početkom 2014 godine.

Rudarske kompanije sa uspostavljenim integrisanim menadžment sistemima (IMS) kao što su sistem menadžmenta kvalitetom (QMS) u skladu skladu sa ISO 9001, sistem menadžmenta opremom (AMS) u skladu sa ISO 55001, sistem menadžmenta zaštitom životne sredine (EMS) u skladu sa ISO 14001 i sistem menadžmenta zaštitom zdravlja i bezbednosti na radu (OHSAS) u skladu sa BS OHSAS 18001 sasvim sigurno mogu očekivati da će efektivnost i efikasnost poslovanja kompanije ići uzlaznom linijom, da će kompanija dati svoj doprinos održivom razvoju kako kopanije tako i šire društvene zajednice u celini.

2. CILJ I SVRHA PROCENE RIZIKA PRI ODRŽAVANJU RUDARSKE OPREME

Procena rizika u postupku održavanja rudarske opreme ima svrhu da obezbedi dokaz na bazi identifikacija i analiza opasnih događaja koji su se u ranijem periodu dogodili ili se mogu dogoditi i uzrokovati otkaz, kako tretirati procenjene rizike i kako odabrati najpovoljniju opciju upravljanja procenjenim rizikom. Neke od glavnih prednosti vršenja procena rizika uključuju:

- Razumevanje rizika i njegov potencijalni uticaj na ciljeve organizacije koja se bavi održavanjem rudarske opreme;
- Identifikacija kritičnih tačaka u procesima održavanja rudarske opreme;
- Poređenje rizika u alternativnim tehnologijama ili pristupima održavanja rudarske opreme;
- Komunikacija sa procenjenim rizikom i neizvesnosti;
- Pomoć kod uspostavljanja prioriteta postupanja u cilju smanjenja nivoa procenjenog rizika;
- Doprinos sprečavanju incidenata, akcidenata i udesa (vanrednih situacija);
- Izbor različitih oblika tretmana rizika u cilju ispunjenja zahteva u vezi sa upravljanjem održavanjem rudarske opreme;
- Pružanje informacija koje će pomoći u proceni da li je rizik prihvatljiv kada se uporedi sa unapred definisanim kriterijumima.



Sl. 1. *Razvoj koncepcija održavanja i povećanje kvaliteta [14]*

3. UPRAVLJANJE KVALITETOM ODRŽAVANJA NA BAZI PROCENE RIZIKA

Strategija upravljanja opremom predstavlja sistemske i koordinirane aktivnosti pomoću kojih organizacija optimalno i kontinualno unapređuje svoja sredstva i opremu, svoje aktivnosti, rizike i troškove tokom veka trajanja opreme u cilju postizanja definisanog strateškog plana. [5]

Osnovne prednosti sa stanovišta strateškog upravljanja opremom sa optimalnim vekom trajanja podrazumeva:

- zadovoljne klijente (unutrašnji i eksterni) zbog poboljšanog učinka i kontrole proizvoda ili usluge po određenim standardima;
- poboljšana zaštita zdravlja i bezbednost na radu;
- poboljšana zaštita životne sredine;
- dugoročno planiranje i kontinuirani učinak;
- poboljšanje korporativne reputacije, čije prednosti mogu biti povećana vrednost akcija, veća satisfakcija osoblja i efektivnija i efikasnija nabavka;
- sposobnost da se demonstrira da je održivi razvoj aktivno zastupljen u upravljanju rudarskom opremom.

Održavanje predstavlja skup aktivnosti administrativnog, organizacijskog, tehničkog i tehnološkog karaktera, čiji je cilj očuvanje i poboljšanje radnih karakteristika ili osiguranje stanja održavanog sredstva, a u kojem ono ima sposobnost obavljanja namenske funkcije [14]

Održavanje zasnovano na risk managementu je najnoviji pristup u oceni rizika otkaza tehničkih sistema i posledica koje takav otkaz može da prouzrokuje na funkcionisanje sistema. Uvođenje pojma rizika omogućuje da se na realističniji način modeluje otkaz tehničkih sistema i procene očekivane posledice. Tačnije, kvantifikacija rizika omogućuje određivanje optimalnog nivoa rizika.

Ideja o održavanju na bazi procene rizika pojavila se kasnih 80-tih godina prošlog veka u SAD. Nešto kasnije, publikovan je i prvi dokument (ASME 1991). Kao najnovija generacija održavanja zasnovanog na pouzdanosti razvila se i metodologija koja se bazira na proceni rizika otkaza komponente i uticaja koji taj otkaz može da prouzrokuje na funkcionisanje sistema (RBM - *Risk Based Maintenance*). Ovaj pristup u suštini se ne razlikuje od RCM pristupa, osim u cinjenici da se doprinos povišenju nivoa pouzdanosti u ovom slučaju vrednuje kroz stepen smanjenja rizika.

Prednosti RBI su [15]:

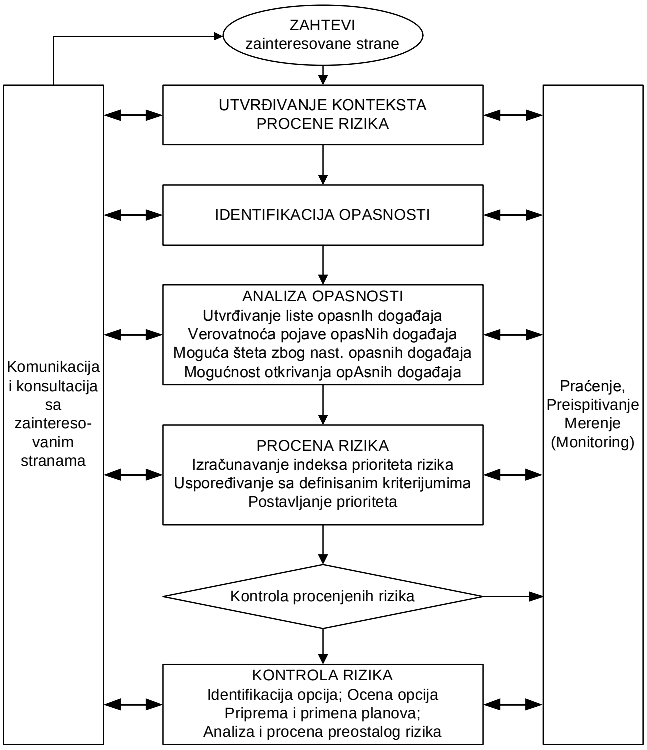
- određivanje potencijalnih rizika na tehničkom sistemu,
- mogućnost kvantifikovanja koristi postupaka održavanja,
- pomoću pronalaženju rešenja u oblasti održavanja,
- optimalno iskorišćenje postojećih resursa.

Oblasti primene upravljanja na bazi rizika u vezi sa aktivnostima održavanja su:

- rizici tokom izvođenja aktivnosti održavanja,
- rizici kao integralni deo metodologije aktivnosti održavanja (organizacija rada, logistička podrška, motivacija, edukacija i trening),
- rizik zbog nedovoljnog održavanja - (pouzdanost osoblja i ljudski faktor).

Pošto je otkaz neke komponente u suštini statistički proces (verovatnoća pojave), rizik je adekvatna veličina koja može da posluži kao orjentir za donošenje odluka o aktivnostima održavanja. Upravljanje rizikom, samim tim ima bitnu ulogu u održavanju tehničkih sistema. Ukoliko je verovatnoća pojave opasnog događaja veoma mala, onda je rizik otkaza mali. Može se primetiti da je potreba za održavanjem kvantifikovana rizikom: što je veći rizik to je veća potreba za održavanjem.

Nacionalni standardi za menadžment rizikom prvi puta su se pojavili u Australiji i Novom Zelandu 1995. godine [13], zatim u Kanadi 1997. godine i u Velikoj Britaniji 2000. godine. Procena rizika je sveobuhvatan proces identifikovanja, analize i procene rizika (ISO TC 223/SC: Upravljanje rizicima – Uputstvo o principima i implementaciji upravljanja rizicima). Procena rizika obezbeđuje donosiocima odluka i odgovornim stranama poboljšano razumevanje rizika koji mogu uticati na ostvarenje ciljeva i adekvatnost i efektivnost kontrole koja je već na snazi. Ovo obezbeđuje osnovu za odluke o većini i odgovarajući pristup koji se koristi za tretman rizika. Izlaz procene rizika je ulaz u procesim odlučivanja u organizaciji. Na sledećoj slici 2., prikazan je opšti koncept procene rizika.



Sl. 2. *Proces procene rizika [8] [12]*

Razumevanje pojma "kvalitet" se sa protekom vremena stalno menjao. Pojam "kvalitet" se najpre odnosio samo na proizvod, da bi se krajem XX veka proširio na procese i organizaciju u celini. Paralelno sa ovim razvijao se i concept održivog razvoja.

Termin "kvalitet" dobija značenje tek kada se stavi u kontekst karakteristika proizvoda i/ili usluga koje se zatim mogu specificirati u smislu standard ili nivoa usluge. Prema tome kvalitet je: sveukupna odlika i karakteristika proizvoda ili usluga koje vode ka – zadovoljenju kupca/korisnika usluge.

Upravljanje rizikom kao podrška ostvarenju ciljeva kvaliteta podrazumeva planiranje, kontrolu i redukciju rizika u okviru svih aspekata kvaliteta. U novije vreme kao podrška tome razvijen je veći broj standard za upravljanje rizikom kao što su: IEC/FDIS 31010:2009 i AS/NZS ISO 31000:2009.

British Institute of Asset management u saradnji sa *British Standards Instution*, objavio je 2004 godine PAS 55 - prvu javno dostupnu specifikaciju za upravljanje osnovnim sredstvima (opremom) organizacije. Specifikacija se pokazala kao veoma uspešna, tako da su je koristila preduzeća iz oblasti saobraćaja, rudarstva i drugih vidova proizvodnje. U toku 2008 godine izvršena je izmena specifikacije (PAS 55: 2008). *The International Standards Organization* (ISO) je prihvatila PAS 55: 2008 kao osnovu za razvoj nove serije ISO 55000. Usvajanje standarda se planira za početak 2014. godine.

Novi standard ISO 55001 definisaće zahteve za sertifikaciju i to na način da bude kompatibilan sa serijama standard ISO 9000, ISO 14000, OHSAS 18000 i tsl.

Pored kompatibilnosti sa drugim menadžment sistemima budući standard će biti primenljiv organizacije svih veličina, od malih i srednjih preduzeća do multinacionalnih organizacija koje žele da uspostave sistem menadžmenta opremom (osnovnim sredstvima), kako bi optimalno i održivo upravljala svojom opremom tokom njihovog životnog ciklusa.

Struktura standard ISO 55001 će u mnogome biti slična drugim menadžment sistemima tako da se zahteva postojanje politike upravljanja opremom, strategije, ciljeva, planova, određivanje predstvanika rukovodstva sa stanovišta upravljanja opremom. Politika menadžmenta opremom treba da bude zasnovana na strateškom planu u skladu sa prirodom opreme i sa drugim organizacionim politikama. U politici je potrebno definisati i opšti okvir menadžmenta rizika u organizaciji odnosno da bude u skladu sa važećim zakonskim, regulatornim, statusnim i drugim zahtevima i da jasno navede principe koji će se primenjivati kao što su organizacioni pristup zaštiti zdravlja i bezbednosti na radu, zaštiti životne sredine i održivom razvoju.

Pri definisanju planova menadžmenta opremom neophodno je uzeti u obzir:

a) rizike vezane za opremu koji ukoliko se ostvare mogu imati posledicu nezgoda ili vanrednu situaciju;
b) potencijalne zastoje u radu ključne za menadžment opremom;
c) aktivnosti koje će se preduzeti u cilju odgovora na nezgodu i/ili vanrednu situaciju i ublažavanje posledica;
d) kompetenciju i obučenost zaposlenih na održavanju opreme da odreaguju na vanredne situacije;
e) potrebe nosioca rizika na koje nezgoda i/ili vanredna situacija može uticati ili koji su obavezni da odreaguju na takve situacije.

Sam zahtev budućeg standarda ISO 55001 sa stanovišta menadžmenta rizikom je eksplicitan da organizacija treba da ustanovi, primeni i održava dokumentovane procese i/ili procedure za identifikaciju i procenu rizika vezanih za menadžment opremom, i za identifikaciju i primenu potrebne mere kontrole tokom životnog ciklusa opreme [17].

Sama metodologija organizacije za menadžment rizika treba da:

- bude definisana u odnosu na područje primene, prirodu i vreme kako bi obezbedila da bude proaktivna, a ne reaktivna, i
- obezbedi identifikaciju, određivanje prioriteta i dokumentovanost rizika, kao i primenu kontrole, kada je to prikladno.

Identifikacija i procena rizika u procesu održavanja opremom treba da uzme u razmatranje mogućnost stvarnih i potencijalnih opasnih događaja i njihovih posledica i treba da pokriva rizike vezane za funkcionalni kvar opreme, nenamerno ili namerno oštećenje opreme, zatim operativne rizike uključujući i kongrolu opreme, ljudske faktore i druge faktore i aktivnosti koje utiču na učinak, uslove rada, bezbednost na radu i zaštitu životne sredine.

4. PREDLOG METODOLOŠKOG OKVIRA PROCENE RIZIKA U ODRŽAVANJU RUDARSKE OPREME

Metodološki okvir procene rizika obuhvata definisanje kriterijuma za procenu rizika i to:

- verovatnoću pojave opasnog događaja koja može uzrokovati otkaz rudarske opreme;
- prirodu i tipove posledica koje se mogu odnositi na proces;
- nivoe rizika;
- prihvatljive nivoe rizika;
- uspostavljanje mehanizama kontrole procenjenih rizika.

Opasni događaji mogu da uzrokuju otkaze i najčešće su povezani sa određenim faktorima. Po mestu i pravcu delovanja, faktori se mogu podeliti na: spoljne i unutrašnje.

<u>Spoljni</u> faktori predstavljaju aktivnosti različitih subjekata, događaja ili pojava, a fizički se nalaze izvan organizacije.

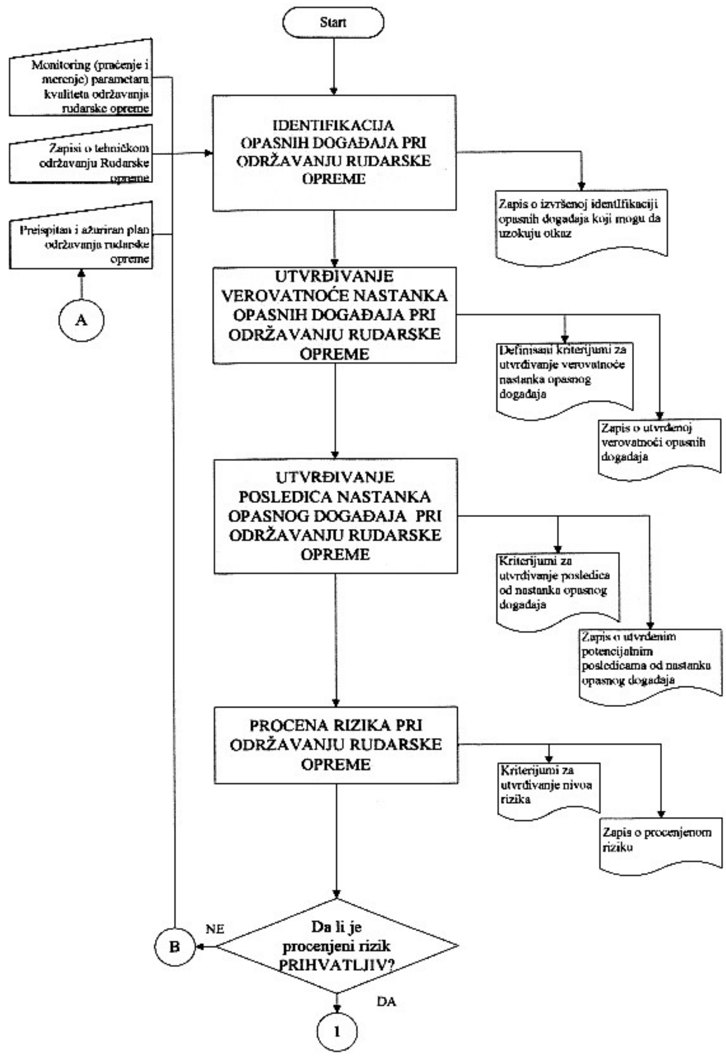
<u>Unutrašnji</u> faktori predstavljaju aktivnosti, događaje ili pojave, a fizički se nalaze unutar organizacije.

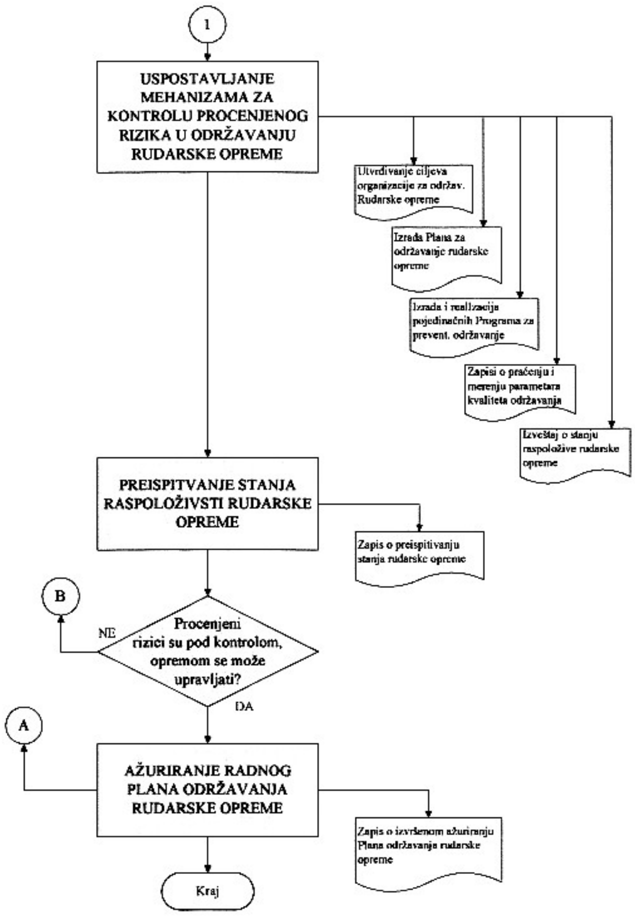
Unutrašnji faktori najčešće su:

- istorija negativnih/opasnih događaja;
- neusklađenost organizacije sa zakonskom regulativom;
- veličina ili razuđenost organizacije;
- neadekvatan način organizacije rada;
- nedovoljna edukovanost zaposlenih;
- postojeći sistemi održavanja opreme.

Mogućnost realizacije pojedinih opasnih događaja koji mogu da uzrokuju otkaz prikazuje se nivoom rizika. Nivo rizika je u direktnoj zavisnosti od učestalosti ponavljanja opasnih događaja, osetljivosti sistema, i postojećeg stanja sistema [10].

4.1. Dijagram toka procene i upravljanja rizikom u postupku održavanja rudarske opreme





4.2. Izbor metode i kriterijuma za procenu rizika

Procena rizika obuhvata verovatnoću pojave opasnih događaja i posledica realizacije opasnog događaja koje mogu da uzrokuju otkaz [12] i može se izraziti na sledeći način.

$$\mathbf{R = V \times P}$$

gde je:

R - nivo rizika;

V - verovatnoća da će potencijalna opasnost rezultirati opasnim događajem i uzrokovati otkaz;

P - posledice ili efekat koji opasni događaj može da ostavi na vrednosti organizacije, prirodne i radom stvorene vrednosti i kvalitet životne sredine.

4.2.1. Procena verovatnoće opasnog događaja

Verovatnoća pojave opasnog događaja koji može da uzrokuje otkaz opreme (**V**) se izražava se prema sledećem izrazu:

$$\mathbf{V = U \# R}$$

U - učestalost ili frekvencija dešavanja (pojavljivanja) opasnog događaja koji može uzrokovati otkaz opreme;

R - osetljivost organizacije na mogućnost realizacije opasanog događaja.

Verovatnoća da potencijalna opasnost rezultira opasnim događajem predstavlja kombinaciju učestalosti dešavanja određenog opasnog događaja i osetljivosti organizacije. Verovatnoća da potencijalna opasnost rezultira opasnim događajem stepenovana je na sledeći način: 1 – vrlo malo verovatno; 2 – malo verovatno; 3 – umereno verovatno; 4 – verovatno; 5 – vrlo verovatno.

Tabela 1. *Kriterijumi za određivanje verovatnoće nastanka opasnog događaja*

	Učestalost - U	Osetljivost - R	V = U # R
1	**vrlo retka** pojava opasnog događaja	**vrlo velika** uopšte nema funkcije održavanja	**vrlo malo verovatno**
2	**povremena** pojava opasnog događaja	**velika** samo organizacione mere održavanja	**malo verovatno**
3	**česta** pojava opasnog događaja	**srednja** samo tehničke mere održavanje	**umereno verovatno**
4	**pretežna** pojava opasnog događaja	**mala** organizacione i tehničke mere održavanja	**verovatno**
5	**veoma česta** pojava opasnog događaja	**vrlo mala** u funkciji sistemsko održavanje	**vrlo verovatno**

Učestalost se odnosi na ponavljanje određene pretnje da će doći do realizacije opasnog događaja u posmatranom vremenskom periodu. Učestalost se stepenuje na sledeći način: 1 - vrlo retko; 2 - povremeno; 3 - često; 4 - pretežno; i 5 - veoma često.

Osetljivost predstavlja postojeće stanje sistema održavanja opreme / osnovnih sredstava, odnosno osetljivost organizacije / postrojenja / procesa na opasnost od otkaza. Osetljivost se stepenuje na sledeći način: 1 - vrlo velika ranjivost - uopšte nema mera funkcije održavanja, 2 - velika ranjivost - u funkciji samo organizacione mere održavanja, 3 - srednja ranjivost – u funkciji samo tehničke mere održavanja, 4 - mala ranjivost - u funkciji organizacione i tehničke mere održavanja i 5 - vrlo mala ranjivost - uspostavljen, sertifikovan i više puta proveren sistem menadžmenta opremom.

Tabela 2. *Matrica za procenu verovatnoće otkaza*

OSETLJIVOST / UČESTALOST		**vrlo velika**	**velika**	**srednja**	**mala**	**vrlo mala**
		1	**2**	**3**	**4**	**5**
vrlo retko	1	3	2	1	1	1
povremeno	2	4	3	2	2	1
često	3	5	4	3	2	2
pretežno	4	5	4	3	3	3
veoma često	5	5	5	4	3	3

4.2.2. Posledice opasnog događaja

Posledice opasnog događaja (**P**) se izražavaju prema izrazu:

P= Š # K

Š - šteta, oštećenje specifične rudarske mehanizacije na kojoj opasan događaj može izazvati posledice;

K - kritičnost, vrednost ili važnost štićene vrednosti za organizaciju u kojoj opasan događaj može izazvati posledice.

Posledice predstavljaju efekat opasnog događaja po opremu (osnovna sredstva) organizacije, a manifestuju se kroz veličinu štete u odnosu na kritičnost važnosti štićene vrednosti.

Posledice su stepenovane na sledeći način: 1 - vrlo lake posledice; 2 - lake posledice; 3 - srednje teške posledice; 4- teške posledice i 5- izrazito teške posledice.

Tabela 3. *Kriterijumi za utvrđivanje posledica*

	Šteta - Š	Kritičnost - K	P = Š # K
1	**vrlo mala** -do 1.000,00 Eura ili vrlo male posledice	**vrlo velika**- potpuni prekid funkcionisanja organizacije	**vrlo lake posledice**
2	**mala** – od 1.000,00 do 10.000,00 Eura, ili male posledice	**velika**- poljuljano funkcionisanje organizacije	**lake posledice**
3	**srednja** – od 10.000,00 do 100.000,00 Eura ili teške posledice	**srednja**- moguće funkcionisanje uz povećane napore i dopunska sredstva	**srednje teške posledice**
4	**velika** – više od 100.000,00 Eura, ili teške i višestruke tešeke posledice	**mala**- moguće zaustavljanje procesa rada	**teške posledice**
5	**vrlo velika** – više od milion Eura, ili katastrofalne posledice	**vrlo mala**- rešavanje u hodu, redovnim aktivnostima	**izrazito teške posledice**

Šteta je mera oštećenja štićene vrednosti (opreme/osnovnih sredstava) i može rezultirati u različitim stepenima. Šteta je stepenovana i izražena kao: 1 - vrlo mala šteta; 2 - mala šteta; 3 - srednja šteta; 4 - velika šteta i 5 - vrlo velika šteta.

Kritičnost je mera vrednosti odnosno važnosti štićene vrednosti.

Kritičnost je stepenovana na sledeći način: 1 - vrlo velika kritičnost; 2 - velika kritičnost; 3 - srednja kritičnost; 4 - mala kritičnost i 5 - vrlo mala kritičnost.

Tabela 4. *Matrica za procenu posledica*

KRITIČNOST / **ŠTETA**		**vrlo velika**	**velika**	**srednja**	**mala**	**vrlo mala**
		1	**2**	**3**	**4**	**5**
vrlo mala	1	3	2	1	1	1
mala	2	4	3	2	2	1
srednja	3	5	4	3	2	2
velika	4	5	4	3	3	3
vrlo velika	5	5	5	4	3	3

4.2.3. Definisanje nivoa rizika

Nivo rizika stepenovan je kao:

1) Vrlo mali (ili zanemarljiv) rizik (R = 1 i 2)
2) Mali rizik (R = 3, 4 i 5)
3) Umereno povećani rizik (R = 6, 8 i 9)
4) Veliki rizik (R = 10, 12, 15 i 16)
5) Izrazito veliki rizik (R = 20 i 25).

Tabela 5. *Matrica za procenu rizika*

POSLEDICE / **VEROVATNOĆA**		vrlo lake	lake	srednje teške	teške	izrazito teške
		1	2	3	4	5
vrlo malo verovatno	1	1	2	3	4	5
malo verovatno	2	2	4	6	8	10
umereno verovatno	3	3	6	9	12	15
verovatno	4	4	8	12	16	20
vrlo verovatno	5	5	10	15	20	25

Procenjeni rizici se prema definisanoj kategorizaciji svrstavaju u:

1) PRIHVATLJIV RIZIK (R = 1, 2, 3, 4 i 5)
2) USLOVNO PRIHVATLJIV RIZIK (R = 6, 8, 9)
3) NEPRIHVATLJIV RIZIK (R = 10, 12, 15, 16, 20 i 25)

Po završetku procesa procene rizika pristupa se uspostavljanju mehanizama kontrole procenjenog rizika. Izbor odgovarajuće opcije za uspostavljanje mehanizama kontrole rizika obuhvata balansiranje troškova i napora u primeni opcije i koristi koja se može iz toga izvući [8].

Veliki broj opcija za uspostavljanje mehanizama kontrole rizika može biti razmatran i primenjen pojedinačno ili u kombinaciji. Kod odlučivanja treba uzeti u obzir retke, ali rizike koji mogu opravdati akcije uspostavljanja mehanizama kontrole rizika koje nisu opravdane (dozvoljene) po strogo ekonomskim pravilima [10].

Pri definisanju upravljanja rizikom, ili razmatranja izmena u postojećem upravljanju, moraju se razmotriti mere i opcije smanjivanje rizika u skladu sa sledećom hijerarhijom:

a) mere i opcije za otklanjanje ili izbegavanje rizika;
b) mere i opcije za ublažavanje ili zamenu (substituciju) rizika;
c) mere i opcije za inženjersku kontrolu izvodljivost primenjenih strategija, planova i programa i analizu odnosa cene i koristi;
d) mere i opcije za definisanje procedura i uputstava za održavanje opreme;
e) mere i opcije za primenu tehničke dijagnostike.

5. ZAKLJUČCI

Rudarske kompanije koje žele da unaprede svoja poslovanja moraju da u svakom momentu raspolažu relevantnim informacijama koja oprema/osnovna sredstva su u raspoloživom i funkcionalnom stanju. Analizi stanja opreme/osnovnih sredstava potrebno je da se posveti dovoljna pažnja jer na taj način menadžment preduzeća raspolaže bitnim informacijama koje podstiču donošenje odgovarajućih odluka za unapređenje sistema menadžmenta opremom kao i celokupnim integrisanim menadžment sistemom. Vrlo važan korak u razvoju sistema održavanja opremom je uključivanje najvišeg rukovodstva i osoblja zaduženog za eksploataciju i održavanje opreme.

Definisani dijagram toka i metodološki postupak procene rizika u postuku održavanje opreme/osnovnih sredstavaje od velike koristi za razvoj sistema menadžmenta opremom (AMS). Procena rizika i uspostavljanje kontrolnih mehanizama upravljanja je od velike koristi i pri projektovanju integrisanih sistema menadžmenta [8]. Predloženi model procene rizika omogućava da se informacije o riziku u održavanju opreme adekvatno procesuiraju i koriste u donošenju odluka na releventnim nivoima organizacije [8].

Predložena je i definisana metodologija menadžment rizika u održavanju rudarske opreme koja:

- obezbedjuje da bude proaktivna, a ne reaktivna i,
- obezbeđuje identifikaciju, određivanje prioriteta i dokumentovanost rizika, kao i primenu kontrole, kada je to prikladno.

Proaktivnom i sveobuhvatnom procenom rizika kako je to definisano ovim radom organizacija koja se bavi održavanjem rudarske opremomože da:

- kreira i odobrava politiku upravljanja procenjenim rizikom;
- obaveštava sve zainteresovane strane (poslodavce, menadžment, korisnike,..) za stanje raspoloživosti svoje rudarske mehanizacije;
- definiše mehanizme kontrole procenjenog rizika koji odgovaraju performansama organizacije za održavanje rudarske mehanizacije;

- osigurava podudarnost ciljeva upravljanja rizikom pri održavanju rudarskih mašina sa ciljevima i strategijom organizacije;
- obezbeđuje usaglašenost sa zakonskom i podzakonskom regulativom kao i sa pravnim aktima organizacije koji se tiču upravljanjakvalitetom održavanja rudarske mehanizacije;
- obezbeđuje raspodelu potrebnih resursa za potrebe upravljanja procenjenim rizikom.

LITERATURA

[1] Asset Management Consulting Limited brochure: Asset Management excellence (2010)

[2] Australian Emergency Management Committee, 2009: National Emergency Risk Assessment Guidelines, Tasmanian State Emergency Service, Hobart.

[3] Anđelković B., Staletović N., Preventivni inženjering u oblasti požara u projektovanju tehnoloških sistema, Preventivni inženjering, br. 2. Dunav Preving, Beograd, 1999, str. 27-31.

[4] BSI: Asset Management-Overview, principles and terminology, ISO PC 251/N48

[5] Curović D., Gavrilović M.; Asset Management – serija standarda ISO 55000; Kvalitet i izvrsnost br. 9-10; Beograd 2012

[6] European standard EN 15341 – Maintenance – Key performance Indicators

[7] Kovačević S.; Staletović N.; Tucović N.; Metodološki pristup procene rizika u funkciji upravljanja sistemom zaštite zdravlja i bezbednosti na radu u JP PK "Kosovo"; Poslovna politika - Kvalitet; ISSN 0354-2408 - UDC 006+658.5; Godina XXI Broj 10 - 11-2011.

[8] Kovačević S., Staletović N., N. Tucović, R. Janković; Quantitative Assessment of Risk Management in the Function of Integrated Systems, 14. DQM Međunarodna konferencija Upravljanje kvalitetom i pouzdanošću ICDQM – 2011, (ISBN 978-86-86355-05-8, pp. 159-165), 29-30. jun 2011. godine. Beograd, Srbija.

[9] Petrović D., Damnjanović Z., Đenadić D., Pantović R., Milić V., Primena modernih računarskih uređaja i alata za smanjenje akcidentnih situacija u rudarskim sistemima Rudarski radovi, Bor, br. 2, str. 29-40, 2010

[10] Staletović N, Kovačević S., Kovačević M.; Metodološki pristup identifikacije aspekata i vrednovanje uticaja na životnu sredinu za projekat »Eksploatacija magnezita u ležištu Čavlovac – Masnica«; Rudarski radovi 2012; ISSN 1451-0162

[11] Staletović N.; Ocena OH&S rizika u funkciji preventivnog inženjeringa i integrisanih sistema menadžmenta (QMS/EMS/OHSAS); Tehnika - Menadžment, vol. 59, br. 3, str. 8-14, 2009.

[12] Standard IEC/FDIS 31010:2009(E) Risk management — Risk assessment techniques

[13] Standards Australia and Standards New Zealand; Standard Risk Management AS/NZS 4360:2009. Sydney and Wellington: Standards Australia and Standards New Zealand.

[14] Papić Lj.; Preventivno održavanje, Istraživački centar DQM, Čačak, 1998, 109 str.

[14] Papić Lj., Milovanović Z; Održavanje i pouzdanost tehničkih sistema, DQM, Prijevor, 2007

[16] www.umsgroup.com

[17] www.pragma world.net

[18] http://*en.wikipedia.org/wiki/ Asset_management*

[19] http://theiam.org/what-asset-management

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Nenad Vušović[*]*, Igor Svrkota*[*]*, Daniel Kržanović*[**]

SPATIAL DATA INFRASTRUCTURE[***]

Abstract

Development of spatial data infrastructure is directly related to development of spatial data collecting technologies, IC technologies and level of social development. Spatial data types provide the basic mechanisms of abstraction for spatial data geometric structure modeling, their attributes, operations and relations. Spatial data infrastructure includes metadata, sets and services of spatial data, network services and technologies, agreements on sharing, access and utilization and mechanisms of coordination and supervision, processes and procedures, established guided or available, depending on the INSPIRE directive.

Keywords: *GIS, geo informatics, spatial data infrastructure (SDI), INSPIRE directive.*

1 INTRODUCTION

Spatial data infrastructure exists since the first spatial data started to be collected and showed at plans and maps. Traces of such activities could be found in the earliest antique times, in Babylon and Egypt. For a long period of time, the analog map was the most efficient way of showing spatial data. The map was a precursor of data bases, information systems and, in a way, a precursor of spatial data infrastructure, too. It enables display of spatial positions, connections and relations of objects and occurrences, as well as display of their qualitative and quantitative changes in time. Development of spatial data infrastructure since then is directly related to development of technologies for spatial data collection, information and communication technologies and level of social development. GIS technology is the main cause of these changes. Spatial information, integrated in different products and software applications, became a product dedicated to wide market. Due to information and communication technologies, conventional presentation of spatial data belongs to the past. Today, spatial data are usually gained, stored, processed, analyzed and presented in digital form through numerous applications. Spatial data enable the basic mechanisms of abstraction for modeling of spatial data geometric structure, their attributes, operations and relations between them.

2 SPATIAL DATA INFRASTRUCTURE

The term "infrastructure" represents the basic frame of system or organization, as well as means (people, structures,

[*] *University of Belgrade, Technical Faculty in Bor*
[**] *Mining and Metallurgy Institute, Bor*
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equipment) needed for the certain activity. However, there is a clear difference between spatial data infrastructure and other infrastructural forms. In this case the term infrastructure is used for promotion the concept of environment support, which enables the access to spatial data using minimum composite of regulations, standards, protocols and other specifications.

The term SDI (spatial data infrastructure) is often used for description the basic composite of technology, politics and institutional agreements, aiming to make easier access to spatial data. Spatial data infrastructure, in organizational and technical terms, provides the significant advantages compared to the standard spatial databases. However, it still has some technical issues, such as sharing, availability and accessibility of spatial data, as well as interoperability. Interoperability is the ability to joint functioning of different systems, techniques or organizations. Software is the best example of interoperability, where many programs can use the same format or protocol.

Spatial database is a collection of spatial data type, operators above them, data lists, strategies for their processing, etc. and they can operate with lots of post – relation data base management systems (DBMS) and program languages such as Java, Visual Basic, etc. It should be mentioned that the spatial data bases are just one of the components, but also a core of spatial data infrastructure.

Spatial data infrastructure is a term that includes much more than simple collection of spatial data or spatial database. There are lots of different data and attributes, well described (metadata) in a sense of revealing, visualization, evaluation (catalogues, web mapping) and other methods, thus providing the access to spatial data. Also, it includes the additional services and applications in order to make using of spatial data easier.

Construction of functional spatial data infrastructure requires the organizational agreements, needed for coordination and administration at the local, national and international level. The infrastructure provides an ideal environment for relation of spatial data and applications, through introduction of minimum suitable standards and politics. Concept of spatial data infrastructure represents realization of vision, aimed by entire geoinformational community. By that vision, the spatial data and tools were supposed to be widely used for management and operations in many different disciplines.

Elementary economic pragmatism and development of information and communication technologies led to development of SDI concept. There are several opinions and definitions that describe SDI. There are some of the definitions of spatial data infrastructure that are given bellow:

- Spatial data infrastructure implies to a group of spatial data, metadata, standards, users and technologies, interactively related, aiming to use the spatial data in a flexible and efficient manner;
- Spatial data infrastructure provides a base for data inquiries, their estimation and application at every social level: government, public sector, private sector and citizenship;
- Spatial data infrastructure represents politics, regulations and human resources needed for collecting, processing, storage, distribution and improvement the spatial data usage.

As the summary of these definitions, spatial data infrastructure is easiest to be defined as a system of spatial data, metadata, producers and tools that are connected aiming to disseminate and use spatial data simply and efficiently at any social level. Synonyms for spatial data infrastructure are geographic- informational strategy, infrastructure of geospatial data and geoinformational infrastructure. Spatial data infrastructure represents a system for collecting the spatial information that describe and display objects, contents, attributes and appearances on the

Earth. Also, it makes them available to wide circle of users. Geoinformational infrastructure, or Infrastructure for Spatial Information in Europe (INSPIRE) is a directive of the European Commission aiming to create the infrastructure for European geodata.

3 CONCEPT OF DEVELOPMENT AND IMPLEMENTATION THE SPATIAL DATA INFRASTRUCTURE

There are different approaches in concepts of SDI development and implementation, but basically, each concept includes a combination of organizational and technical components. Developing countries, as well as countries in transition process, are challenged to improve the spatial data infrastructure and provide the access to information according to the sustainable development. One of the most important tasks at the beginning of such process is creation of the national catalogue of spatial data and metadata. The first step includes institutional agreement on establishing the spatial data infrastructure, as well as preservation the basic series of data. Also, it is necessary to define a type of data that are used in the majority of applications. Commonly used data are reference points, leveler and hydrographic data, addresses, administrative borders, airplane and satellite photos, roads, data on property, etc.

The second step is creation the metadata information system. Metadata help users to find data they are interested in. Development of metadata services has to be followed with rising of awareness about necessity to create the agreement on data access, defining of service prices, licensing, authorization and similar. Internet and development of spatial data access portals bring wide opportunities, both to the users and providers. Along with these steps, it is necessary to harmonize and coordinate spatial data with the corresponding regulations and standards. Technically, the most important components are technologies and applications. Technological improvements completely changed the way of access to spatial data and their use. The final step is to implement the spatial data base and establish national, regional (European) or Global Spatial Data Infrastructure (GSDI).

From the current point of view, development of spatial data infrastructure can be divided into two generations. The first generation was mainly directed to the technical solutions and data as the final product (product oriented), while the second generation was aimed to the users and services (service oriented). The users of spatial data are no longer interested in data access only, but also in services and analyses, which includes combining of different databases and other sources. The first generation of spatial data infrastructure was mainly financed from budgets of the national spatial data institutions. However, such support was usually unilateral and it did not include financing and development of the second generation of SDI (Giff and Coleman, 2003). Further development of the existing spatial data infrastructures requires redefining of mechanisms for restructuring, implementation and maintenance. The existing financing models are no longer adequate and changes are required. Hierarchical concept of spatial data infrastructure, from local to the global level, also requires development of financing strategy for such implementation and its maintenance.

4 ELEMENTS OF SDI

The main elements of spatial data infrastructure are the following:

1. *Spatial data;*
2. *Metadata;*
3. *Standards;*
4. *Clearinghouse (Catalogue) and*
5. *Partnership.*

Successful implementation of specific elements requires creation of suitable environment, with the following properties:

- Standardized contents, parts and procedures;
- Main sources of spatial data and networked users;
- Technical infrastructure adjusted to simple and efficient use.

Figure 1 shows physical implementation of some parts of spatial data infrastructure.

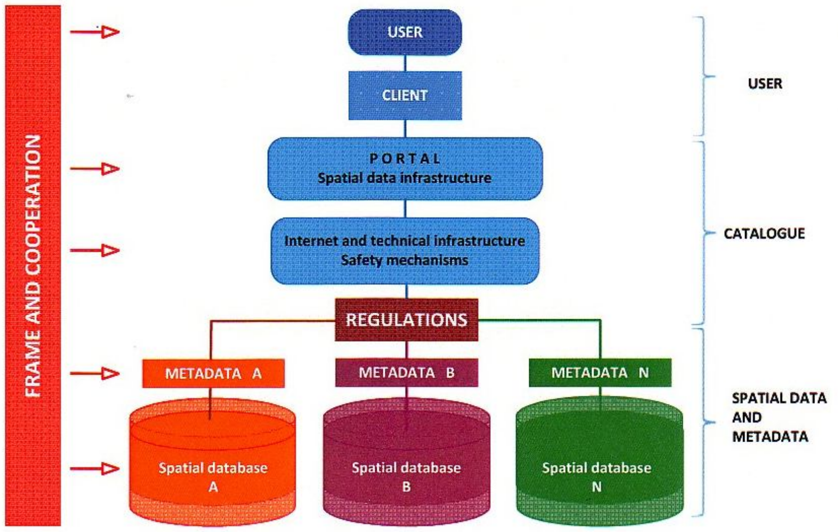

Figure 1 *Physical implementation of SDI*

The basic concept of physical implementation is to create simple and undisturbed spatial data flow from databases to users. Such data flow requires suitable network and other technical infrastructure, established according to corresponding standards. The user, who accesses database through client (web browser), has to be able to search the spatial data, using free metadata as an instrument for evaluation the user convenience.

The important factor in physical implementation is an institutional context, which demands fundamental changes in spatial data management, from their acquisition to the final use (Masser, 2004). These changes include creation of program for capacity building, which enables the efficiency of spatial data infrastructure, along with all subjects included in the process.

In such context, the capacity building is not only development of human potential, but also the organizational improvement and entire social transformation. Arguably, the spatial data infrastructure requires changes in life styles and development of collective consciousness on its potential and development of IT society in general.

4.1 Spatial Data

In the present time of IT revolution, a large amount of data is collected daily through satellite sensors. Acquired data come both from ground surface and bellow surface. The most important component in the process, without whom the infrastructure would not even exist, are the spatial data. Spatial data are all data connected to the spatial component. They describe objects and phenomena of the real word which are spatially referenced (by coordinates, address or administrative area). Spatial data set is a collection of mutually connected spatial data.

Spatial data services are operations executable through computer applications on spatial data stored in the spatial data sets or connected metadata. Spatial object is an abstract image of real phenomenon, related to the specific location or geographic area. The nature of spatial data is multidisciplinary, and the foundation of spatial data infrastructure are topographic and cadastre data. The primary aim of spatial data infrastructure is to enable easy access to spatial data to wide circle of users, such as public and private sectors and companies at the local, national, regional and global level. Inside the infrastructure, spatial data are divided into basic, or framework dataset and others, or thematic dataset. From the start of acquiring, the framework data have multifunctional purpose, while thematic dataset is made of thematic layers. Framework data are composed for various purposes (cadastre, geodetic frameworks, and topographic bases) and they can be combined and upgraded with other data. Thematic data are created for a single use, but they could be also used for other purposes.

Usually, each country establishes its priorities in definition of framework and thematic data. Since spatial data are related to the space, the spatial reference system is very important factor in the process. Distribution, use and comparison of spatial data, gained from different sources, systems or organizations, is possible only if they are in the same reference system, or if the real time conversion is provided. Reference system has to provide the spatial determination of locations with well defined horizontal and vertical datum (Vusovic, 2012).

Establishment of framework of spatial data represents a joint effort that includes all participants of spatial data infrastructure, in order to create widely available source of the basic spatial data. The framework sorts geospatial data by different topics, depending on user requirements, and then creates the environment for their further development and use. Framework of spatial data can be overviewed through three aspects:

1. Spatial data;
2. Procedures and technologies of data creation and utilization;
3. Institutional relations and business practice as a backup to the entire environment.

The purpose of spatial data framework establishment is to reduce data redundancy and improve relations between groups of spatial data. Selection of spatial data type depends on users and their demands and needs. GIS has recognized three main groups of spatial data users, and databases are created according to these groups. The first group is mainly focused to spatial data analysis. This group consists mainly of specialists, scientists and government servants. Their activities are focused to isolated environments and they use specific databases, specially designed for them. Expansion of internet created another group of users. Their utilization of spatial data is limited to applications with the user friendly level. There are many internet pages that provide different services, such as information on shortest destination paths, vehicle monitoring and similar. Increasing the number of PDA and cellular phone users led to creation the new applications for specific purposes, thus forming the third group of users. An example of such application is a cellular phone application that represents user at some distant point. The application downloads data segment required for specific task, operates with data segment at distant location and finally synchronizes amended and processed data with the main database at the end of working day. The important aspect of these applications is that client takes over only the data segment required for processing, operates locally with these data and works off line.

Framework of spatial data includes different types of data, but usually the following data groups: cadastre, traffic, hydrographic, administrative units, geodetic base, heights, geographic denominations and names. Cadastre data should be highlighted, since they are used as the base of spatial data infrastructure and they are considered as the most important in definition the spatial data frameworks in most countries (Cetl, 2005).

4.2 Metadata

Metadata have always been needed to describe the meaning and properties of data, in order to improve understanding, classification, utilization and management of data. Metadata are described as "data on data" in any medium. Generally, metadata are the group of attributes which describe content, quality, availability, access, conditions, location and other relevant information on geodata. They can also be the data which describe properties of some source in digital format. They are useful in the process of overview, transfer and documentation of some content. Also, they are used to speed-up and improve searching in huge amount of data and discover more relevant information. Metadata are helpful in discovering and organization of resources and they enable interoperability using the defined schemes and protocols. With digital identification, the resources gain unique marks that metadata are referenced to. Types of metadata depend on the environment they are used in. They can be applied in relational databases, data storages, database contents, where they can describe any data (photos, videos), in spatial data description, etc. Metadata schemes are structural sets of metadata with a specific purpose, for example to determine a type of a document. There are different metadata schemes. Each metadata scheme has limited number of elements, where each element has the name and meaning. Implementation – in order to make utilization of metadata schemes in context of network resources possible, it is necessary to mark them with a set of signs which enable scheme recognition. Text formats used in this process are XML, SGML, HTML, MIME, etc. This way metadata are embedded into document using tags. This can be created by direct entering of symbols, or by the use of editing programs. Development and application of metadata are huge advances in finding and using information, especially today when internet becomes the main source of infor mation. In digital sense, metadata are structured data which describe, explain, locate, or in any other way enable easier resource management. Metadata provide the answers to "what, who, where, why, when and how" questions about geospatial data.

4.3. Norms and Standards

Norms and standards in the area of spatial data are necessary for anyone who deals with acquisition, creation, distribution and utilization of spatial data, whether individually or related to non-spatial information. Since creating norms is a dynamic process, there are significant number of norms and standards that are in a phase of development or upgrading. Terms "standard" and "norm" are often used as synonyms, although they have different meanings. Terms "standard" and "standardization" are widely accepted in English speaking areas, while other languages prefer term "norm". Norms are de jure, i.e. approved by corresponding organization, while standards are de facto, i.e. the results of application by number of users (for instance, dxf format). Creating norms for spatial information is important for establishing transfer between different users, applications, systems and locations. Norms are created and adjusted aiming to standardize actions and procedures for distribution and maintenance of data. This way unified data flow is provided, from creators to users, which is the main principle of in spatial data infrastructure building. Standardization of spatial data is developed at several levels: national level, regional level (CEN) and international level (ISO – International Organization for Standardization). In Europe, CEN (*Comité Européen de Normalisation*) has jurisdiction for issues of standardization. Norms and standards should define methods, tools and services for data management, acquisition, processing and analysis of data, access to data, display and transfer of data between different users, systems and locations. Standardization includes creation, nomination and implementation of different standards. ISO 19115 Metadata Standard defines a scheme for description the spatial data and services. This standard enables creation of metadata on identification, quality, space and time scheme, reference system and spatial data distribution. It can be used for creation the clearinghouse and full data description for groups and series of data, individual data and data properties.

4.4 Clearinghouse (Catalogue)

Each organization that creates spatial data has to provide their description by metadata and ensure access to all of the details, so that the users would be able to validate usability and beneficiary of data, depending on their needs. The role of clearinghouse is to prepare metadata for different organizations, update them, validate and enable access. Based on such support, the users are able to find and use spatial data in the most efficient way. Spatial data clearinghouse, in the context of spatial data infrastructure, may be defined as the access network, focused on search, access and other related services on spatial data. Clearinghouse enables the following actions:

- Metadata search, in order to find the spatial data;
- Finding links for full data accesses, where it is enabled;
- Uniformed, distributed search through the unified user interface on any server across the globe;
- Free mechanisms for "advertising" of data groups, through the "truth in labeling" principle.

Clearinghouse is a repository with descriptions of resources, i.e. any metadata that describes what is available in the system, for example: OGC services, descriptions of geospatial data groups (ISO 19115), images, scenes, symbol, display rules, etc. So, clearinghouse provides integral overview of group of available resources. Generally, clearinghouse may contain several servers on internet with information about existing data, i.e. metadata. Clearinghouse provides interface for finding geoinformation on web through OGC standards. Clearinghouse architecture is the server – client, where servers contain metadata and services, while clients have the access through web browser. In some way, clearinghouse is the one-stop shop for spatial data (Crompvoets, 2004).

4.5. Cooperation and Partnerships

The establishment of efficient spatial data infrastructure stands on building cooperation and partnerships of institutional agreements and communications. In most of cases, in different concepts of spatial data infrastructures worldwide, the main acknowledgement is that it could not be built by single organization. Only cooperation between various organizations at all levels of national, public and private sector, data users, academic community and everyone who is related to the spatial data, may create environment that, in the long-term period of time, enables establishment, sustainability and management of spatial data infrastructure. The most important elements of cooperation are distribution of responsibility, distribution of costs, distribution of benefits and joint control. Distribution of responsibility implies the individual responsibility of each subject, aiming to establish the effective spatial data infrastructure. Responsibility cannot be strictly directed to an individual subject. Similarly, the costs and benefits also have to be distributed between various subjects, depending on their participation. The important element of this cooperation is the joint control, as an instrument of improvement the relations and communication. Each of these elements is important, regardless on focus of cooperation, whether it is profit or establishment the spatial data infrastructure. Benefits of cooperation are reflected to the entire society, and not only to the subjects involved in process.

CONCLUSION

The world of spatial data is of key importance, not only to itself, but to the entire society. From wider perspective, this sector is just one of many directly depending on development of technology, politics and many other elements usually out of their control. General vision in many countries is to create the virtual environment where spatial information will be available to the users in the quickest and simplest way, at any time and in any place. Accomplishment of spatial data infrastructure is the main support to this vision. The first generations of spatial data infrastructures have arose into the second generation, but they are constantly facing difficulties on their way to match the needs of users. The existing clearinghouses, which are mainly passive mechanisms, are not able to answer these needs.

From the long-term point of view, matching needs of users has to be the most important aim in development of spatial data infrastructure. Groups of data that are not in use are useless. Need for spatial data from users may be observed as the general social need. That is why further development should enable most convenient and suitable access to data, according to the needs of users. There are four key elements in identifying as the most important in future development of spatial data infrastructure:

1. Creation of suitable management strategy;
2. Making data access easier;
3. Building capacities;
4. Increase of interoperability.

These elements should be a base for improvement the existing spatial data infrastructures and lead to creation the second generation of infrastructures, oriented towards users and services.

REFERENCES

[1] Anzlic (1997): Spatial Data Infrastructue for Australia and New Zealand (www.anzlic.org.au/anzdiscu.htm).

[2] Clinton, W. J. (1994): Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastrucutre, Execute Order 12906, Federal Register 59, 17671-17674 (www.cdit.edu.cn/digi/12906.html).

[3] Coleman, J. D. and McLaughlin, J. (1997): Defining Global Geospatial Data Infrastructure (GGDI): Components, Stakeholders and Interfaces, International seminar on Global Geospatial Data Infrastructure, University of North Carolina, October, 1997.

[4] Cetl, V.: The Analysis of Improvements Spatial Data Ionfrastructure, PhD Thesis, University of Zagreb, Faculty of Geodesy (2007), (in Croatian)

[5] DG XIII-E3 (1996): Towards a European Policy Framework for Geographic Information, A Working Document (www2.echo.lu/gi/en/gi2000/gi2000dd.html).

[6] Vušović N., Svrkota I., Vaduvesković Z.: Spatial Reference Systems, Mining Engineering 3 (2012) (http://www.irmbor.co.rs/pdf/rudarski/rudarski3_12.pdf)

[7] Vušović N., Svrkota I., Vaduvesković Z.: Spatial Reference System of Serbia, Mining Engineering 1 (2013) (http://www.irmbor.co.rs/pdf/rudarski/rudarski1_13.pdf)

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Nenad Vušović, Igor Svrkota*, Daniel Kržanović***

INFRASTRUKTURA PROSTORNIH PODATAKA***

Izvod

Razvoj infrastrukture prostornih podataka direkno je povezan sa razvojem tehnologija prikupljanja prostornih podataka, informaciono-komunikacionim tehnologijama i stepenom društvenog razvoja. Prostorni tipovi podataka obezbedjuju osnovne mehanizme apstrakcije za modelovanje geometrijske strukture prostornih podataka, njihove atribute, operacije nad njima i relacije izmedju njih. Infrastruktura prostornih podataka podrazumeva metapodatke, setove i servise prostornih podataka, mrežne servise i tehnologije, sporazume o deljenju, pristupu i upotrebi i mehanizme koordinacije i nadzora, procese i procedure, uspostavljene, vodjene ili stavljene na raspolaganje u skladu sa INSPIRE direktivom.

Ključne reči: *GIS, geoinformatika, infrastruktura prostornih podataka (SDI), INSPIRE direktiva*

1. UVOD

Infrastruktura prostornih podataka postoji od trenutka kada su se prvi prostorni podaci počeli sistematski prikupljati i prikazivati na planovima i kartama. Tragovi tih aktivnosti nalaze se još u najranijim vremenima antike, Babilona i Egipta. Najefikasniji način za prikazivanje prostornih podataka, tokom dugog istorijskog perioda, bila je analogna karta. Karta je bila preteča prvobitne prostorne baze podataka, prvobitnog prostornog informacionog sistema i na neki način preteča infrastrukture prostornih podataka. Karta omogućava prikaz prostornog razmeštaja, povezanosti i uzajamnih odnosa predmeta i pojava, kao i prikaz kvalitativnog i kvantitativnog menja-nja tog stanja kroz vreme. Razvoj infrastrukture prostornih podataka od tih davnih vremena do danas direktno je povezan sa razvojem tehnologija prikupljanja prostornih podataka, informaciono komunikacionim tehnologijama i stepenom društvenog razvoja. Tehnologija GIS-a jeste „glavni krivac“ za nastale promene. Prostorne informacije, integrisane u druge proizvode i softverske aplikacije, postale su proizvod namenjen masovnom tržištu. Zahvaljujući informacionim i komunikacionim tehnologijama konvencionalni način prezentovanja podataka o prostoru pripada prošlosti. Danas se prostorni podaci uglavnom sakupljaju, arhiviraju, obradjuju, analiziraju i prezentuju u digitalnoj formi kroz veliki broj aplikacija. Prostorni tipovi podataka obezbedjuju osnovne mehanizme apstrakcije za modelovanje geometrijske strukture prostornih podataka, njihove atribute, operacije nad njima i relacije izmedju njih.

2. INFRASTRUKTURA PROSTORNIH PODATAKA

Pojam infrastruktura predstavlja osnovni okvir nekog sistema ili organizacije, ali i sredstva (ljudi, objekata, opreme) potrebnih za neku aktivnost. Medjutim, postoji jasno

* *Univerzitet u Beogradu, Tehnički fakultet u Boru*
** *Institut za rudarstvo i metalurgiju, Bor*
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razgraničenje izmedju infrastrukture prostornih podataka i drugih infrastrukturnih formi. Pojam infrastruktura koristi se za promociju koncepta pružanja podrške okoline koja omogućuje pristup prostornim podacima uz korišćenje minimalnog skupa normi, standarda, protokola i drugih specifikacija.

Pojam infrastruktura prostornih podataka (eng. *Spatial Data Infrastructure, SDI*) često se koristi da označi osnovni skup tehnologije, politike i institucionalnih sporazuma, čiji je cilj lakši pristup prostornim podacima. Infrastruktura prostornih podataka u organizacionom i tehničkom smislu, pruža znatne prednosti u odnosu na standardne prostorne baze podataka, ali i kod nje postoje institucionalni i tehnički problemi deljivosti i dostupnosti prostornih podataka i interoperabilnosti. Pod interoperabilnošću se podrazumeva sposobnost za zajednički rad različitih sistema, tehnika ili organizacija. Softver je najbolji primer interoperabilnosti, kada više programa mogu da upotrebnjavaju isti format ili iste protokole.

Prostorna baza podataka (eng. *spatial database*) je kolekcija prostornih tipova podataka, operatora nad njima, popisima podataka, strategija za procesiranje takvih podataka, itd. i mogu da rade sa mnogim post-relacionim DBMS (eng. *Data Base Management System*) kao i sa programskim jezicima kao što su *Java*, *Visual Basic* itd. Treba istaći da su prostorne baze podataka samo jedna od komponenti, ali i jezgro infrastrukture prostornih podataka.

Infrastruktura prostornih podataka jeste pojam koji označava mnogo više od jednostavnog skupa prostornih podataka ili prostorne baze podataka. Ona podrazumeva mnoštvo prostornih podataka i atributa, dovoljno opisanih (metapodataka), u smislu otkrivanja, vizuelizacije, ocene podataka (katalozi, *web* kartiranje) i drugih metoda, koji obezbedjuju pristup prostornim podacima. Takodje, ona obuhvata i dodatne usluge i aplikacije namenjene lakšem korišćenju prostornih podataka.

Izgradnja funkcionalne infrastruktura prostornih podataka podrazumeva organizacione sporazume neophodne za koordinaciju i administriranje na lokalnom, nacionalnom i medjunarodnom nivou. Infrastruktura obezbedjuje idealno okruženje za vezu prostornih podataka i aplikacija kroz primenu minimuma pogodnih standarda i politike. Koncept infrastrukture prostornih podataka predstavlja realizaciju vizije cele geoinformacione zajednice koja je bila da će se prostorni podaci i alati lako i masovno upotrebljavati za upravljanje i rad u velikom broju disciplina.

Elementarni ekonomski pragmatizam i razvoj informaciono-komunikacionih tehnologija vodili su u pravcu koncepta infrastrukture prostornih podataka. Postoji više shvatanja i definicija o tome što je to infrastruktura prostornih podataka. Navešćemo deo literaturno obradjenih definicija i ideja o tome što je to infrastruktura prostornih podataka:

- Infrastruktura prostornih podataka podrazumeva skup prostornih podataka, metapodataka, standarda, korisnika i tehnologije, koji su interaktivno povezani, u funkciji korišćenja prostornih podataka na efikasan i fleksibilan način;
- Infrastruktura prostornih podataka osigurava osnovu za traženje prostornih podataka, njihovu procenu i primenu na svim društvenim nivoima: u državnoj upravi, javnom i privatnom sektoru i gradjanstvu;
- Infrastruktura prostornih podataka označava politiku, norme i ljudske resurse potrebne za prikupljanje, obradu, skladištenje, distribuciju i unapredjenje upotrebe prostornih podataka.

Kroz sažetak navedenih definicija, infrastruktura prostornih podataka se na najjednostavniji način može sagledati kao sistem prostornih podataka, metapodataka, proizvodjača, korisnika i pripadnih alata koji su medjusobno povezani sa ciljem jednostavne i efikasne diseminacije i korišćenja prostornih podataka na svim društvenim nivoima. Sinonimi za infrastrukturu prostornih podataka jesu geografsko-informaciona strategija, infrastruktura geoprostornih podataka i geoinformaciona infrastruktura. Sa jedne strane, ona predstavlja sistem za sakupljanje prostornih informacija koje sporazumno opisuju i prikazuju objekte, sadržaje, atribute i pojave na Zemlji, a sa druge strane, te prostorne informacije čini dostupnim širokom krugu korisnika. Geoinformaciona infrastruktura ili infrastruktura za prostorne informacije u Evropi - INSPIRE (eng. *Infrastructure for Spatial Information in Europe*) je direktiva Evropske komisije sa ciljem da kreira infrastrukturu za geopodatke u Evropi.

3. KONCEPTI RAZVOJA I IMPLEMENTACIJE INFRASTRUKTURE PROSTORNIH PODATAKA

Postoje različiti pristupi u konceptu razvoja i implementacije infrastrukture prostornih podataka, ali u osnovi svaki pristup podrazumeva kombinaciju organizacionih i tehničkih komponenti. Zemlje u razvoju, kao i zemlje u tranziciji, pred izazovom su poboljšanja infrastrukture prostornih podataka i pružanja pristupa informacijama u skladu sa održivim razvojem. Jedna od prvih zadataka u tom procesu je stvaranje nacionalnog kataloga prostornih podataka i metapodataka. Prvi korak podrazumeva institucionalni dogovor o uspostavljanju infrastrukture prostornih podataka, kao i očuvanju osnovnog niza podataka. Takodje, potrebno je definisati koje se to vrste podataka koriste u većini aplikacija. Ovde se obično govori o referentnim tačkama, nivelmanskim i hidrografskim podacima, adresama, administrativnim granicama, avio i satelitskim snimcima, putnoj mreži, podacima o imovini i sl.

Drugi korak odnosi se na izgradnju informacionog sistema za metapodatke. Metapodaci pomažu korisnicima da pronadju podatke koji ih zanimaju. Razvoj servisa metapodataka mora biti praćen podizanjem svesti o potrebi dogovora pristupu podacima, odredjivanju cena usluga, licenciranju, zaštiti autorskih prava i sl. Internet i razvoj portala za pristup prostornim podacima pružaju u tom smislu široke mogućnosti, kako korisnicima tako i provajderima. Paralelno sa ovim koracima, nužni su i uskladjivanje i koordinacija prostornih podataka sa odgovarajućim standardima i normama. U tehničkom smislu, najvažnije komponente su tehnologije i aplikacije. Napredak tehnologije potpuno je promenio put dolaska do prostornih informacija i njihovo korišćenje. Na kraju slede implementacija baze prostornih podataka i uspostavljanje nacionalne, regionalne (evropske) ili globalne infrastrukture prostornih podataka – GSDI (eng. *Global Spatial Data Infrastructure*).

Gledano iz sadašnje perspektive, razvoj infrastrukture prostornih podataka može se podeliti u dve generacije. Prva generacija bila je prvenstveno orijentisana ka tehničkim rešenjima i podacima kao krajnjem proizvodu (eng. *product oriented*), dok je druga generacija orijentisana ka korisniku i uslugama (eng. *service oriented*). Korisnicima prostornih podataka nije više cilj da dodju do podataka već da koriste različite usluge i analize, što uključuje kombinovanje različitih heterogenih baza prostornih podataka i ostalih izvora. Prva generacija infrastruktura prostornih podataka finansirana je uglavnom iz budžeta nacionalnih institucija za prostorne podatke. Medjutim, ova podrška bila je najčešće jednostrane prirode i nije predvidjala finansiranje i razvoj druge generacije infrastrukture prostornih podataka (Giff i Coleman, 2003). Dalji razvoj postojećih infrastruktura prostornih podataka zahteva redefinisanje mehanizama za restrukturiranje, implementaciju i održavanje. Postojeći modeli finansiranja nisu više adekvatni i zahtevaju promene. Hijerarhijski koncept infrastrukture prostornih podataka, od lokalnog do globalnog nivoa, zahteva i razvoj strategije finansiranja takve implementacije i njenog održavanja.

4. ELEMENTI INFRASTRUKTURE PROSTORNIH PODATAKA

Osnovne elemente infrastrukture prostornih podataka čine:

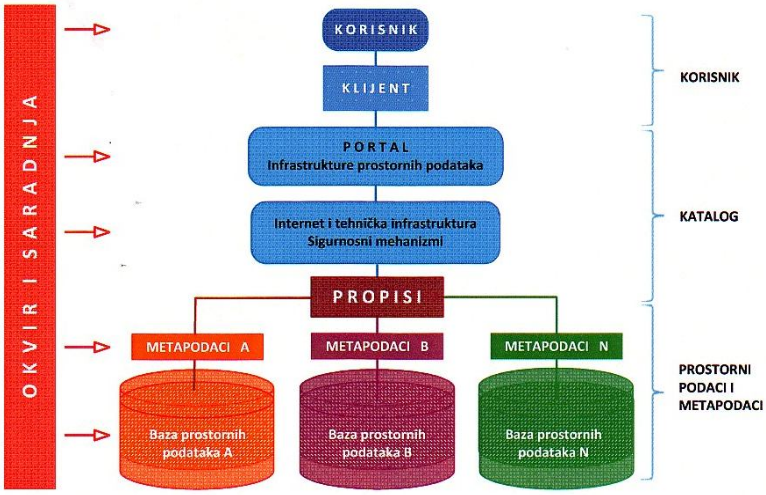
1. **Prostorni podaci** (eng. *Spatial Data*);
2. **Metapodaci** (eng. *Metadata*);
3. **Norme i standardi** (eng. *Standards*);

4. **Katalog** (eng. *Clearinghouse*);
5. **Saradnja** (eng. *Partnerships*).

Uspešna implementacija pojedinih elemenata infrastrukture geoprostornih poda taka podrazumeva stvaranje okruženja u kome su:

- sadržaj, delovi i procedure standardizovani;
- osnovni izvori prostornih podataka i umreženi korisnici;
- tehnička infrastruktura prilagodjena jednostavnoj i efikasnoj upotrebi.

Na slici 1. prikazana je fizička implementacija pojedinih delova infrastrukture prostornih podataka.



Sl. 1. *Fizička implementacija infrastrukture geoprostornih podataka*

Osnovni koncept fizičke implementacije infrastrukture geoprostornih podataka podrazumeva stvaranje jednostavnog i nesmetanog toka prostornih podataka od baza podataka, za njihovu pohranu, do korisnika. Taj tok podrazumeva odgovarajuću mrežnu i ostalu tehničku infrastrukturu uspostavljenu u skladu sa odgovarajućim normama i standardima. Korisniku koji pristupa putem klijenta (*Web* pretraživača) mora biti omogućeno pretraživanje prostornih podataka putem besplatnih metapodataka kao instrumenta ocene pogodnosti za upotrebu.

Važan faktor u fizičkoj implementaciji infrastrukture geoprostornih podataka je i institucionalni kontekst, što podrazumeva potrebu za fundamentalnim promenama u načinu upravljanja prostornim podacima od njihova prikupljanja do upotrebe (Masser 2004). Te promene zahtevaju stvaranje programa izgradnje kapaciteta (eng. *capacity building*), kojim će se osigurati efikasnost infrastrukture geoprostornih podataka kao i svih uključenih subjekata. U tom kontekstu izgradnja kapaciteta ne uključuje samo razvoj ljudskih potencijala, već i organizacionu promenu kao i celokupnu društvenu transformaciju. Nesumljivo, infrastruktura geoprostornih podataka zahteva promenu u načinu življenja i izgradnju kolektivne svesti o njenom potencijalu u razvoju informacijskog društva.

4.1. PROSTORNI PODACI

U današnje vreme informatičke revolucije, velika količina podataka se svakodnevno prikuplja preko satelitskih senzora, kako podacima sa površine Zemlje tako i podacima koji se nalaze ispod površi terena. Najvažnija komponenta bez koje infrastruktura geoprostornih podataka uopšte ne može postojati su prostorni podaci. Prostorni podaci (eng. *spatial data*) su svi podaci povezani sa prostornom komponentom. Opisuju objekte i pojave stvarnog sveta koje su prostorno referencirane (koordinatama, adresom ili administrativnim područjem). Set prostornih podataka podrazumeva kolekciju prostornih podataka koji su medjusobno povezani. Servisi prostornih podataka označavaju operacije koje se mogu obaviti pozivanjem računarske aplikacije nad prostornim podacima koji su sadržani u setovima prostornih podataka ili na povezanim metapodacima. Prostorni objekat je apstraktna predstava stvarnog fenomena, a u vezi sa konkretnom lokacijom ili geografskim područjem. Priroda prostornih podataka je multidisciplinarna, a temelj infrastrukture prostornih podataka čine topografski i katastarski podaci. Primarni cilj infrastrukture prostornih podataka jeste da širokom krugu korisnika olakša pristup prostornim informacijama, u javnom i privatnom sektoru, za upotrebu na nivou preduzeća, zatim na, lokalnom, državnom, nacionalnom, regionalnom i globalnom nivou. U kontekstu infrastruktura prostornih podataka prostorni podaci se dele na osnovne (eng. *framework dataset*) i ostale ili tematske (eng. *thematic dataset*). Od početka prikupljanja osnovni podaci imaju višenamensku upotrebu, dok ostale podatke čine tematski slojevi. Osnovni podaci namenjeni su višenamenskom korišćenju (katastar, geodetska osnova, topografske baze) i mogu se kombinovati i nadogradjivati sa ostalim podacima. Ostali podaci (tematski) su podaci proizvedeni za jednu namenu, ali mogu imati i znatno širu upotrebu. Po pravilu svaka država odredjuje svoje prioritete pri definisanju osnovnih i ostalih podataka. Kako su prostorni podaci vezani uz prostor, vrlo važnu ulogu ima prostorni referentni sistem. Distribucija, upotreba i uporedjivanje prostornih podataka iz različitih heterogenih izvora i sistema, te izmedju različitih organizacija, moguća je samo ako su podaci u istom referentnom sistemu ili ako je omogućena konverzija u isti sistem u realnom vremenu. Referentni sistem mora osigurati odredjivanje lokacija u prostoru uz dobro definisan horizontalni i vertikalni datum (Vušović, 2012).

Uspostavljanje okvira osnovnih podataka (eng. *framework of spatial data*) predstavlja zajednički napor svih učesnika infrastrukture prostornih podataka u stvaranju široko dostupnog izvora osnovnih prostornih podataka. Okvir razvrstava geoprostorne podatke po različitim temama u zavisnosti od potreba korisnika te stvara okruženje za dalji razvoj i njihovo korišćenje. Okvir prostornih podataka može se sagledati kroz tri gledišta:

1. Prostorni podaci;
2. Postupci i tehnologije izrade i korišćenja podataka;
3. Institucionalne veze i praksa poslovanja kao podrška celokupnom okruženju.

Svrha uspostavljanja okvira prostornih podataka je smanjenje redundanse podataka i poboljšanje veza izmedju skupova prostornih podataka. Izbor pojedinih tipova osnovnih podataka svodi se na podatke koje koristi najveći broj organizacija i običnih korisnika i koji imaju najširu upotrebu. GIS je prepoznao tri osnovna skupa korisnika prostornih baza podataka, što je uslovilo pojavu zahteva za specijalizovanim tipovima prostornih baza podataka. Prva vrsta korisnika isključivo je orijentisana ka analizi prostornih podataka. Ove korisnike uglavnom čine specijalisti, naučnici i državni službenici, koji obavaljaju poslove u izolovanom okruženju i koriste specifične prostorne baze podataka namenjene isključivo njima. Razvojem interneta, formirala se druga grupa korisnika prostornih podataka, koji korištenje ovakvih podataka svode na aplikacije koje imaju *user friendly* nivo. Primera ovakvih internet stranica ima mnogo, pa se mogu nabrojati stranice koje pružaju informacije o najkraćim mogućim putanjama na nekoj relaciji, prikaza praćenja vozila itd. Povećanjem broja korisnika mobilnih telefona i PDA uredjaja, ukazala se potreba za kreiranjem novih aplikacija posebne namene što je uslovilo formiranje treće grupe korisnika. Primer ovakve aplikacije može biti aplikacija na mobilnom uredjaju koji predstavlja klijenta na nekom udaljenom mestu. Ovakva aplikacija preuzima segment podataka potrebnih za konkretan zadatak, radi sa takvim segmentom podataka na udaljenoj lokaciji i na kraju vrši sinhronizaciju izmenjenih i obradjenih podataka sa glavnom bazom podataka na kraju radnog dana. Važan aspekt ovih aplikacija je da klijent preuzima samo segment podataka potrebnih za obradu, radi u lokalu sa takvim podacima i to u *off line* režimu.

Okvir prostornih podataka u pojedinim zemljama u najvećoj meri uključuje sledeće skupove podataka: katastar, saobraćaj, hidrografija, administrativne jedinice, geodetska osnova, visine, geografski nazivi i imena. Ovde treba posebno istaći podatke katastra koji su kao podaci krupne razmere temelj infrastrukture geoprostor nih podataka i zauzimaju prvo mesto u definisanju okvira prostornih podataka u gotovo svim zemljama sveta (Cetl, 2005).

4.2. METAPODACI

Metapodaci (eng. *metadata*) su oduvek bili potrebni kako bi opisali značenje i svojstva podataka, sa ciljem boljeg razumevanja, klasifikovanja, upotrebe i upravljanja podacima. Metapodaci predstavljaju „podatke o podacima“ u bilo kojem medijumu. Uopšteno, metapodaci predstavljaju skup atributa koji opisuju sadržaj, kvalitet, dostupnost, pristup, uslove, lokaciju i druge relevantne informacije o geopodacima. To su i podaci koji opisuju karakteristike nekog izvora u digitalnom obliku. Korisni su kod pregledanja, prenosa i dokumentovanja nekog sadržaja. Takodje, koriste se da bi se ubrzalo i poboljšalo pretraživanje velike količine podataka, i otkrilo što više relevantnih informacija. Metapodaci pomažu pri otkrivanju i organizaciji resursa, te omogućavaju interoperabilnost korišćenjem definisanih šema i protokola. Digitalnom identifikacijom resursima se daju jedinstvene oznake na koje se metapodaci referenciraju. Tipovi metapodataka zavise od okruženja u kojem se koriste. Mogu se primenjivati u relacionim bazama podataka, skladištima podataka, u sadržaju baza podataka opisujući bilo kakve datoteke (fotografije, video), pri opisivanju prostornih objekata i dr. Šeme (eng. *scheme*) metapodataka su strukturirani setovi metapodataka s odredjenom svrhom, na primer za odredjivanje tipa nekog dokumenta. Postoje različite šeme metapodataka. Svaka šema metapodataka ima ograničen broj elemenata, gde svaki taj element ima svoje ime i značenje. Implementacija - da bi upotreba šema metapodataka u kontekstu mrežnih resursa bila moguća, potrebno ih je obeležiti setom znakova koji omogućavaju prepoznavanje šeme. Tekstualni formati kojima se to može izvesti su XML, SGML, HTML, MIME i dr. Metapodaci se tako ugradjuju u dokument pomoću „tagova“. To se može napraviti direktnim upisivanjem simbola ili pomoću programa za editovanje. Razvoj i primena metapodataka predstavljaju veliki napredak u pronalaženju i korišćenju informacija, pogotovo u današnje vreme kada Internet polako postaje glavni izvor informacija. U digitalnom smislu metapodaci su strukturirani podaci koji opisuju, objašnjavaju, lociraju ili na neki drugi način omogućavaju lakše upravljanje resursima. Metapodaci daju odgovor na pitanja "*šta, ko, gde, zašto, kada i kako*" za geoprostorne podatke.

4.3. NORME I STANDARDI

Norme (eng. *norms*) i standardi i (eng. s*tandards*) na području prostornih podataka potrebni su svima koji se bave prikupljanjem, izradom, distribucijom i upotrebom prostornih podataka, bilo samostalno ili u sprezi sa nekim informacijama nevezanim uz prostor. Kako je normizacija, s obzirom na razvoj tehnologija dinamičan proces, velik broj normi i standarda vezanih uz prostorne podatke nalazi se u odredjenoj fazi razvoja ili dopune. Pojmovi standard i norma koriste se često kao sinonimi iako imaju različita značenja. Pojam standarda i standardizacije široko je prihvaćen u engleskom govornom području dok se uostalim jezicima koristi pojam norme i normizacije. Norme su *„de jure"* odnosno odobrene od priznate organizacije, a standardi *„de facto"* odnosno rezultat primene velikog broja korisnika (npr. *dxf* format). Normizacija prostornih informacija važna je za uspostavljanje prenosa izmedju različitih korisnika, aplikacija, sistema i lokacija. Izradom i prilagodjavanjem normi potrebnoje normirati postupke i procedure definisanja i opisivanja podataka, metode za njihovo strukturiranje i kodiranje kao i postupke za distribuciju i održavanje podataka. Time se osigurava jednoobrazan tok podataka od proizvodjača do korisnika, što je osnovni princip u stvarenju infrastrukture prostornih podataka. Normizacija prostornih informa cija odvija se na nekoliko nivoa: na nacionalnom nivou, na regionalnom nivou (CEN) i medjunarodnom nivou - ISO (eng. *International Organization for Standardization*). U Europi je za pitanja normizacije nadležan Europski komitet za normizaciju – CEN (fran. *Comité Européen de Normali-sation*). Norme i standardi bi trebali da odrede metode, alate i usluge za upravljanje podacima, prikupljanje, obradu i analizu podataka, pristup podacima te prikaz i prenos takvih podataka izmedju različitih korisnika, sistema i mesta. Standardizacija podrazumeva izradu, donošenje i implementaciju različitih standarda. ISO 19115 Metadata standard definiše šemu za opisivanje prostornih podataka i usluga. Ovaj standard omogućava izradu metapodataka o identifikaciji, kvalitetu, prostornoj i vremenskoj šemi, referentnom sistemu te distribuciji prostornih podataka. Može se upotrebiti za izradu kataloga i punog opisa podataka te za skupove i serije podataka, pojedinačne podatke i svojstva podataka.

4.4. KATALOG

Svaka organizacija koja izradjuje prostorne podatke morala bi dati njihov opis metapodacima i pružiti dovoljno detalja kako bi korisnici mogli odrediti upotrebljivost i korisnost tih podataka zavisno od njihovih potreba. Uloga kataloga je priprema metapodataka različitih organizacija, njihovo pohranjivanje, provera valjanosti i omogućavanje pristupa, kako bi na bazi njih korisnici mogli pronaći i koristiti prostorne podatke na najefikasniji način. Katalog (eng. *clearinghouse*) prostornih podataka u kontekstu infrastrukture prostornih podataka, može se razmatrati kao pristupna mreža koja je fokusirana na pretraživanje prostornih podataka, pristup i ostale povezane servise. Katalog omogućava:

- Pretragu metapodataka u cilju pronalaženja geoprostornih podataka;
- Linkove ka punom pristupu podacima, tamo gde je to omogućeno;
- Uniformnu, distribuiranu pretragu kroz jedinstveni korisnički interfejs prema svim serverima širom sveta;
- Besplatan mehanizam za „reklamiranje“ svojih skupova podataka širom sveta po principu “istinitosti u obeležavanju”.

Katalog je repozitorijum koji sadrži opise resursa, odnosno, bilo koje metapodatke koji opisuju šta je dostupno u sistemu, kao na primer: OGC servisi, opisi geoprostornih skupova podataka (ISO 19115), slike, scene, simboli, pravila za prikaz, itd. Dakle, katalog obezbedjuje integralni pogled na skup dostupnih resursa. Uopšteno, katalog može sadržati više servera na Internetu koji sadrže informacije o postojećim podacima odnosno metapodatke. Katalog obezbedjuje interfejs za pronalaženje geoinformacija na *web*-u kroz OGC standarde. Arhitektura kataloga je server-klijent gde serveri sadrže metapodatke i usluge, a klijenti njima pristupaju putem *web* pretraživača. Na neki način katalog predstavlja *one-stop shop* za prostorne podatke (Crompvoets 2004).

4.5. SARADNJA I PARTNERSTVA

Uspostavljanje efikasne infrastrukture prostornih podataka počiva na izgradnji saradnje i partnerstva (eng. *partnerships*) institucionalnih dogovora i komunikacije. U većini slučajeva i u različitim konceptima infrastrukture prostornih podataka širom sveta, osnovno saznanje je da ona ne može biti izgradjena od strane samo jedne organizacije. Saradnjom izmedju različitih organizacija na svim nivoima državnog, javnog i privatnog sektora, korisnika podataka, akademske zajednice i svih onih koji su svojom delatnošću vezani za prostorne podatke stvara se okruženje u kome je, u dugoročnom periodu omogućeno uspostavljanje, održavanje i upravljanje infrastrukturom prostornih podataka. Najvažniji elementi saradnje su: raspodela odgovornosti, raspodela troškova, raspodela koristi i zajednička kontrola. Raspodela odgovornosti podrazumeva pojedinačnu odgovornost svakog subjekta sa krajnjim ciljem uspostavljanja efektivne infrastrukture prostornih podataka. Odgovornost ne može biti ograničeno usmerena isključivo na pojedinačan subjekat. Slično tome, mora se razmotriti raspodela troškovi i raspodela koristi koji, takodje, moraju biti raspodeljeni izmedju pojedinih subjekata, zavisno od njihove uloge. Važan element u tom medjudelovanju pojedinih subjekata je zajednička kontrola kao instrument poboljšanja medjusobne saradnje i komunikacije. Svaki od navedenih elemenata je po sebi važan nezavisno od toga da li je saradnja usmerena ka ostvarivanju dobiti ili kao podrška uspostavljanju infrastrukture prostornih podataka. Koristi od uspostavljanja saradnje moraju se odraziti na čitavo društvo, a ne samo na uključene subjekte.

ZAKLJUČAK

Svet prostornih podataka od ključne je važnosti kako samom sebi, tako i za društvo u celini. Gledano iz šire perspektive taj sektor samo je jedan od mnogih koji direkno zavisi od razvoja tehnologija, politike i raznih drugih elemenata koji su najčešće izvan njegove kontrole. Opšta vizija u mnogim zemljama je stvaranje virtualnog okruženja u kome će prostorne informacije biti dostupne korisnicima na najbrži i najjednostavniji način u bilo koje vreme i na bilo kome mestu. Ostvarenje infrastrukture prostornih podataka osnovna je podrška toj viziji. Prve generacije infrastruktura prostornih podataka razvijaju se ka drugoj pri čemu su suočene sa stalnim poteškoćama zadovoljavanju potreba korisnika. Postojeći katalozi, koji najvećim delom predstavljaju pasivne mehanizme, ne mogu zadovoljiti te potrebe.

Dugoročno gledano zadovoljavanje potreba korisnika mora biti osnovni cilj u razvoju infrastrukture prostornih podataka. Skupovi podataka koji se ne koriste su beskorisni. Kroz potrebu korisnika za prostornim podacima može se posmatrati opšta potreba društva. Zato dalji razvoj treba da omogući korisnicima podatke saglasno njihovim potrebama na najefikasniji način i na način koji korisnicima najbolje odgovara. U budućem razvoju infrastrukture prostornih podataka mogu se identifikovati četiri ključna elementa koji imaju vitalnu ulogu u tome: 1. kreiranje odgovarajuće upravljačke strategije; 2. olakšavanje pristupa; 3. izgradnja kapaciteta i 4. povećanje interoperabilnosti. Navedeni elementi treba da budu osnova za poboljšanje postojeće infrastrukture prostornih podataka i vode ka stvaranju druge generacije orijentisane ka korisnicima i uslugama.

LITERATURA

[1] Anzlić (1997): Spatial data infrastructure for Australia and New Zealand (www.anzlic.org.au/anzdiscu.htm).

[2] Clinton, W. J. (1994): Coordinating geographic data acquisition and access: The National Spatial Data Infrastructure, Execute Order 12906, Federal Register 59, 17671-17674 (www.cdit.edu.cn/digi/12906.html).

[3] Coleman, J. D. and McLaughlin, J. (1997): Defining Global Geospatial Data Infrastructure (GGDI): Components, Stakeholders and Interfaces, International seminar on Global Geospatial Data Infrastructure, University of North Carolina, October, 1997.

[4] Cetl, V.: Analiza poboljšanja infrastrukture prostornih podataka, doktorska disertacija, Sveučilište u Zagrebu, Geodetski fakultet (2007)

[5] DG XIII-E3 (1996): Towards a European Policy Framework for Geographic Information, A working Document (www2.echo.lu/gi/en/gi2000/gi2000dd.html)

[6] Vušović, N. Svrkota, I, Vaduvesković, Z.: Spatial Reference Systems, Mining Engineering 3 (2012), (http://www.irmbor.co.rs/pdf/rudarski/rudarski3_12.pdf)

[7] Vušović, N. Svrkota, I, Vaduvesković, Z.: Spatial Reference System of Serbia, Mining Engineering 1 (2013) (http://www.irmbor.co.rs/pdf/rudarski/rudarski1_13.pdf)

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Vladimir Jovanović[*], *Vladimir Jovanović*[**], *Marija Jovanović*[***]

FLUE GAS DESULPHURISATION IN SERBIA - TECHNOLOGIES, LEGAL AND ECONOMIC ASPECTS

Abstract

Combustion of coal results in sulfur dioxide (SO_2) emissions which cause detrimental impacts on the environment and human health. Electric power generating units account for the majority of SO_2 emissions in Serbia. Environmental regulations in Serbia require gradual implementation of flue gas treatment technologies for control the emissions of pollutants into the atmosphere. As far as Serbian thermal power plants are concerned, the basic design of systems for flue gas desulphurisation has been developed for two thermal power plants. As wet limestone-based FGD technologies dominate in the world because of high SO_2 removal efficiency, cost effectiveness, and gypsum as the by-product, it is expected that Serbian thermal power plants will use this technology. This paper presents a review of commercially available FGD technologies, as well as legal and economic perspective of the process. U.S. EPA's National Risk Management Research Laboratory has published the Coal Utility Environmental Cost Workbook which providesthe rough-order-of-magnitude budgetary cost estimates as the starting point for the limestone forced oxidation cost model that might be a good starting point for cost estimates for Serbian electric utilities.

Keywords*: flue gas desulfurization, regulations, costs*

INTRODUCTION

Coal provides 40% of the world electricity needs and it has been the fastest-growing global energy source since the beginning of the 21st century. Growth in coal use in the last decade has been driven by economic growth of developing economies. Irrespective of economic benefits of coal for those countries, its environmental impact should not be overlooked. Despite positive efforts to retrofit the old plants and decommission the oldest, the least efficient ones, and build more efficient plants, the current state is far from what is needed.

Combustion of coal results in sulfur dioxide (SO_2) emissions which cause detrimental impacts on the environment -

[*] *Law Faculty of Economics and Justice, University Business Academy, Novi Sad, Geri Karolja 1, e-mail: v.jovanovic@itnms.ac.rs*
[**] *Institute for Technology of Nuclear and Other Mineral Raw Materials, Belgrade, Franchet D'Eperea 86*
[***] *High School of Professional Studies in Accounting and Stock Exchange Business, Belgrade, Imotska 1*

acid deposition in the environment, and human health - aggravation of the existing cardiovascular disease, breathing difficulties, respiratory illness. Electric power generating units account for the majority of SO_2 emissions in Serbia. SO_2 emissions are vary considerably for different Serbian coal mines, e.g. for lignite from Kosovo mines, they are in the range from around 600 do 1200 μg/m^3, for lignite from Kolubara mines of around 1800 do 4000 μg/m^3, and for lignite from Kostolac mines of around 4500 to 8000 μg/m^3, while SO_2 emission limit values for 300 MW plants are 650 μg/m^3 [1]. Data published by the Environmental protection service of the thermal power plant “Nikola Tesla“ show that emissions from that plant exceed emission limit values set by regulations by three to four times [2].

Since the 1970`s, various policy and regulatory measures have created a growing commercial market for clean coal technologies, with the result that their costs have fallen and performance has improved. Undoubtedly, the air quality will continue to improve in the future because of the improved technology.

Environmental regulations, introduced in Serbia in the past decade, require gradual implementation of flue gas treatment technologies for controlling the emissions of pollutants into the atmosphere. As far as Serbian thermal power plants are concerned, the basic design of systems for flue gas desulfurization (FGD) have been developed for the thermal power plants “Nikola Tesla” A and “Kostolac” [3].

This paper presents a review of commercially available FGD technologies, as well as legal and economic perspective of the process of flue gas desulfurization in Serbia.

CLASSIFICATION OF FLUE GAS DESULPHURISATION TECHNOLOGIES

There are various technologies for removal of SO_2 from flue gas produced by thermal power plants, and some of them have tens of thousands of hours of operational experience. This paper considers commercially available FGD technologies with reliable performance and sufficient quality and quantity of data.

Commercially available FGD technologies can be classified as non-regenerative and regenerative, depending on treatment of sorbent after sorption of SO_2. In the non-regenerative technologies, SO_2 is permanently bound by the sorbent, which is utilized as by-product (e.g., gypsum), or disposed of as a waste. In regenerative technologies, during regeneration process, t SO_2 is released from sorbent and may be further processed to provide liquid SO_2, sulfuric acid or elemental sulfur. Both technologies can be further classified as wet or dry. Wet slurry waste or by-product is produced in wet processes, and flue gas leaves the absorber saturated with moisture. In dry processes, dry waste material is produced and flue gas leaving the absorber is not saturated with moisture. The “conventional” classification of FGD processes is shown in Table 1.

Table1 *Classification of FGD processes*

Flue gas desulfurization			
Non-regenerative		Regenerative	
Wet	**Dry**	**Wet**	**Dry**
Limestone forced oxidation	Lime spray drying	Sodium sulfate	Activated carbon
Limestone inhibited oxidation	Duct sorbent injection	Magnesium oxide	
Lime	Furnace sorbent injection	Sodium carbonate	
Magnesium-enhanced lime	Circulating fluidized bed	Amine	
Seawater			

According to the information of the International Energy Agency's Coal Research Center in London, England provided in CoalPower3 Database regenerative FGD processes are used only marginally, while the non-regenerative FGD processes are most frequently applied. In this paper, FGD technologies are grouped into the following three major categories: non-regenerative wet FGD, non-regenerative dry FGD and wet and dry regenerative FGD. This grouping of FGD technologies is consistent with other economic evaluations of FGD [4].

Non-regenerative Technologies

In non-regenerative wet FGD processes, the flue gas reacts with alkaline limestone slurry in a spray tower or tray tower absorber, most often counterflow vertically oriented spray tower. Limestone slurry is prepared in two steps. The first, limestone is crushed into fine powder of desired particle size distribution, and after that it is mixed with water in a slurry preparation tank. Sorbent slurry is then pumped into the absorber reaction tank. In a counterflow tower, the flue gas flows upwards, while limestone slurry is sprayed downwards by an array of spray nozzles. SO_2 is removed in the absorber by sorption and reaction with the slurry. These reactions are completed in a reaction tank, in which finely ground limestone particles dissolve and react with dissolved SO_2.

In order to improve reliability of system, the majority of non-regenerative wet FGD applications require control of oxidation, so limestone forced oxidation process (LSFO) has become the preferred technology worldwide. Limestone inhibited oxidation process is particularly well suited for applications with high sulfur coals (LSIO).

Hydrated calcitic lime slurry in the lime process is more reactive than limestone slurry, but is more expensive. Magnesium-enhanced lime process (MEL) is a variation of the lime process in which lime is magnesium-enhanced (usually 5-8 % magnesium oxide). Magnesium salts are more soluble compared to calcitic sorbents and scrubbing liquor; dolomitic lime is more alkaline (usually 20 % magnesium oxide). Due to the increased alkalinity and solubility, pH value is usually in the range of 6.0

to 7.0. The lime process benefits from the alkalinity of fly ash, too. The efficiency of MEL is higher in much smaller absorbers than limestone scrubbers, which enables a considerable decrease of liquid-to-gas ratio.

In the seawater process, the natural alkalinity of seawater neutralizes SO_2. The seawater chemical process is similar to the LSFO. The seawater is discharged into the ocean after scrubbing, so the evaluations of local conditions and construction materials with increased corrosion resistance are reqired for this process due to high concentrations of chloride.

In dry FGD technologies, SO_2-containing flue gas contacts alkaline sorbent, most often lime, which produces dry waste with properties similar to fly ash. The sorbent can be in an aqueous slurry form or as a dry powder. Absorber vessels for reaction of sorbent with SO_2 are necessary in the lime spray drying and circulating fluidized bed processes, while in duct sorbent injection process and furnace sorbent injection processes, only sorbent delivery equipment is required. In these processes, sorbent recirculation increases their utilization.

Lime Spray Drying (LSD) is rarely used for high sulfur content coals and the sorbent in it is in aqueous slurry form.

In the Duct Sorbent Injection (DSI) process, finely dispersed sorbent, hydrated lime or sodium bicarbonate, contact with the flue gas in the flue gas duct between the air preheater and particulate control device. The amount of hardware is minimized.

In the Furnace Sorbent Injection (FSI), a dry sorbent is injected into the furnace in toptimum temperature region above the flame.

In the Circulating Fluidized Bed (CFB), a dry sorbent, most often $Ca(OH)_2$, contacts with humidified flue gas, which flows upward through a bed of sorbent solids to a particulate control device. Some of its catch is recirculated in order to increase the utilization of sorbent. An additional benefit of this process is continuous abrasion of sorbent particles, which results in the exposure to fresh alkali.

Regenerative FGD Technologies

Regenerative FGD technologies include four wet regenerative processes in which sodium sulfite, magnesium oxide, sodium carbonate, and amine are in contact with flue gas, and one dry regenerable process with the use of activated carbon. These processes are characterized by their product, a concentrated stream of SO_2. Regenerative FGD technology is only marginally used throughout the world. These processes have comparatively high operating labor costs relative to the other FGD processes. Product marketability may be the major problem. As the result, some of the existing regenerable FGD-technology-equipped units have been converted to advanced limestone wet FGD.

Previous Application of Procedures for Flue Gas Desulphurisation

In 1980, approximately 30,000 MWe FGD capacity was installed and this trend was increased at approximate rate of 100,000 MWe per decade [5]. There was no significant increase in regenerable FGD capacity since the early '80s. Since the wet FGD technology has dominated so far, an analysis of wet FGD processes application is interesting. The majority of FGD technology applications worldwide make wet limestone and spray drying processes. In wet FGD technologies, which do not use wet limestone, the lime as more expensive sorbent is used, or they are limited by the availability of sorbent required by the process. Dry FGD technologies, apart from LSD, have not had sufficient commercial experience or offer limited sorbent utilization.

Wet FGD technologies predominate over other technologies because of high SO_2 removal efficiency coupled with cost effectiveness, particularly wet-limestone-based technologies. Gypsum, as byproduct, has increased the attractiveness of wet FGD technologies. Limited utilization of dry FGD technologies resulted from higher reagent cost and limitations regarding by-product disposal.

Forced limestone once through wet process is most widely used wet scrubbing system in the world today, comprising around one third of the wet scrubbing systems. Forced oxidation is preferred process because it reduces the scaling potential within the scrubber, enhances dewatering capability, and produces abyproduct suitable for either landfill or sale as gypsum for agriculture and cement industry. Enhanced dewatering capability additionally reduces the waste disposal area requirement.

LEGAL ASPECT OF FLUE GAS DESULPHURISATION IN SERBIA

Environmental protection legislation, particularly THE Directive 2010/75/EU of the European Parliament and Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) [6] sets stringent operating conditions, technical requirements and emission limit values (ELV) for plants for SO_2 at 200 mg/m^3. Such regulations require a detailed analysis of the coal quality, as well as careful selection of flue gas desulphurisation technology and cost estimation.

One of the main goals of the National Environmental Protection Program of the Republic of Serbia from 2005 to 2014 in the energy sector, is reduction the emission of sulfur oxides from the thermal power plants, such as the Thermal Power Plant "Kostolac B" and Thermal Power Plant "Nikola Tesla A" and "Nikola Tesla B". So far, onlythe electro filters have been installed for removal of particulate matter in these plants, but no measures have been implemented for flue gas desulfurization.

As wet limestone-based FGD technologies dominate in the world because of high SO_2 removal efficiency, cost effectiveness, and gypsum as by-product, it could be expected that the Serbian thermal power plants will use this technology and two companies, Hitachi, Mitsubishi, have presented their technologies for FGD in the wet limestone process with commercial gypsum production at the First Symposium "On Flue Gas Desulphurisation", held in Palić in 2012. [7, 8].

The Ministry of Education, Science and Technological Development of the Republic of Serbia has funded the Project "Development of Technological Processes for Obtaining of Ecological Materials Based on Nonmetallic Minerals" and within it some investigations of lithotamnian limestone from the "Dobrilovići" deposit near Loznica for use in non-regenerative wet process. These investigations proved that this limestone is suitable for flue gas desulphurisation and provides gypsum as by-product of the process with satisfying quality [9].

In the past two decades, the capital costs for SO_2 scrubbers have decreased by over 30% and are reported to be approximately $ 100/kW [10]. Retrofit of scrubbers on the existing units increases the capital cost up to 30% depending on modifications of the existing equipment and conditions under which the units operate, such as flow rate and temperature. Costs also increase with the increase of sulfur content since the same volume of gas must be treated with more reagent. Limestone and lime as reagents are not expensive themselves, but the use of additives or reagent enhancers significantly increases costs. Costs are also affected by waste product disposal costs, by-product saleable prices, as well as by loss of required energy and other fixed and variable costs [5]. Control efficiencies for limestone systems are limited to approximately 90%, while control efficiencies of lime is up to 95%, but it is significantly more costly.

ESTIMATION OF FLUE GAS DESULPHURISATION COSTS

Continuous Emission Measurement often does not provide data of the required accuracy for FGD retrofit design, so the additional data have to be calculated based on coal analysis and the existing boiler data which are individually measured [11]. Coal quality analysis provides essential input data for flue gas desulphurisation plant design – reference coal quality, flue gas analysis at the inlet of the plant, as well as the range of SO_2 concentrations in flue gas [12].

Flue gas desulphurisation process does not involve only system of flue gas and absorber, but also associated systems for sorbent preparation and by-product management. The basic parameters, used for designing of FGD systems, are work parameters of plants (such as its power, specific heat consumption, excess air, flue gas temperature), flue gas characteristics (volume flow, moisture, concentration of chlorides and fluorides, particulate matter and SO_2), allowed content of particulate matter in the emitted flue gas, required by-product quality. Technical and economic analyses of the possibility of application the flue gas desulphurisation processes in the Serbian power plants showed that wet limestone forced oxidation process is the best solution.

The additional elements that should be considered are space around the power plant, investments, the time power plant has to be stopped for during the installation of FGD system, plans for operation of power plant during the year.

Gypsum as by-product of desulphurisation process requires to be disposed at non-hazardous waste disposal landfill where no biodegradable waste is disposed, and the disposal landfill must fulfill the necessary conditions for preventing soil, air and surface water pollution by combination of geological barriers and impermeable layers [13].

CONCLUSION

Coal burning in the electricity generation accounts for the greatest share of sulfur dioxide emissions in Serbia. The environ-mental regulations, which have been adopted in Serbia in the past decade, require gradual introduction of technologies for flue gas treatment, while one of the basic goals of the National Program for Environmental. Protection of the Republic of Serbia 2005-2014 in the energy industry is decreasing the sulfur dioxide emissions from the thermal power plants.

So far, in the thermal power plants, no measures have been taken for flue gas desulphurisation. As limestone based flue gas technologies dominate in the world due to high efficiency, cost-efficiency and gypsum as by-product, it can be expected that the Serbian thermal power plants would use this technology. Technical and economic analyses of the possibility of application the flue gas desulphurisation technologies in the thermal power plants in Serbia have shown that the LSFO technology is the best solution.

The Air Pollution Prevention and Control Division of U.S. EPA's National Risk Management Research Laboratory has published the Coal Utility Environmental Cost Workbook (CUECost) [14]. CUECost provides rough-order-of-magnitude budgetary cost estimates (±30 % accuracy) for between 100 and 2000 MWe net LSFO application based on the user-defined design and economic criteria. CUECost algorithms provide the starting point for the LSFO cost model that might be a good starting point for cost estimates for the Serbian electric utilities.

REFERENCES

[1] Decree on Limit Values of Pollutant Emission into Air, Official Gazette of the Republic of Serbia 71/201 i 6/2011.

[2] http://kgh.kvartetv.com/fajlovi/37.%20kongres/37-38.pdf

[3] Mitrović D, Kostović N, Milovanović Đ, Some specific design aspects of integration flue gas desulfurization plants at existing lignite fired thermal power stations in Serbia, Proceedings of the First symposium "On Flue Gas Desulfurization", Chamber of Commerce and Industry of Serbia, (2012) 12-19.

[4] Keeth RJ, Ireland PA, and Radcliffe PT, Economic Evaluations of 28 FGD Processes, in Proceedings of the 1991 SO_2 Control Symposium Palo Alto CA, Electric Power Research Institute, 1991, 273-2-90.

[5] http://www.iea-coal.org.uk/site/2010/database-section/coal-power?LanguageId=0

[6] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:334:0017:0119:en:PDF.

[7] Okamoto T, Nagayasu T, Tanaka N, Mitsubiši wet flue gas desulfurization technology, Proceedings of the First symposium "On Flue Gas Desulfurization", Chamber of Commerce and Industry of Serbia, (2012) 60-71.

[8] Taguchi Y, Vollmer B, Hitachi flue gas desulfurization technology, Proceedings of the First symposium "On Flue Gas Desulfurization", Chamber of Commerce and Industry of Serbia, (2012), 27-34.

[9] Sekulić Ž, Jovanović V, Kašić V, Lithotamian limestone from the deposit "Dobrilovići" in flue gas desulfurization by wet process, Mining Engineering, 3 (2012) 41-48.

[10] Smith D, Cost of SO2 scrubbers down to $ 100/kW, Power Engineering, 105 (2001) 63-66.

[11] Thomsen R, Dickamp M, FGD design criteria, Proceedings of the First symposium "On Flue Gas Desulfuri-

zation“, Chamber of Commerce and Industry of Serbia, (2012) 20-26.

[12] Stojiljković D, Životić D, Milovanović D, Jovović A, Manić N, Jovanović V, The importance of defining the reference coal characteristics for designing FGD systems, Proceedings of the First symposium “On Flue Gas Desulfurization“, Chamber of Commerce and Industry of Serbia (2012) 2-11.

[13] Vlajić D, Simović I, Kostović N, Stanković M, Disposal sites of TPP Kostolac B3 block flue gas desulfurization gypsum suspension, Proceedings of the First symposium “On Flue Gas Desulfurization“, Chamber of Commerce and Industry of Serbia (2012) 155-162.

[14] http://www.epa.gov/ttncatc1/products.html#cccinfo

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Vladimir Jovanović, Vladimir Jovanović**, Marija Jovanović****

ODSUMPORAVANJE DIMNIH GASOVA U SRBIJI – TEHNOLOŠKI POSTUPCI, PRAVNI I EKONOMSKI ASPEKTI

Izvod

Sagorevanjem uglja emituje se sumpor-dioksid (SO_2), koji štetno utiče na životnu sredinu i zdravlje ljudi. Postrojenja za proizvodnju električne energije emituju najveći deo sumpor-dioksida u Srbiji. Propisi iz oblasti zaštite životne sredine u Srbiji nalažu postepenu implementaciju tehnologija za tretman dimnih gasova, odnosno kontrolu emisija zagađivača u atmosferu. Što se termoelektrana u Srbiji tiče, pripremljeni su idejni projekti za odsumporavanje dimnih gasova za dve termoelektrane. Kako u svetu dominira primena tehnoloških postupaka za odsumporavanje dimnih gasova zasnovanih na mokrim postupcima zbog visoke efikasnosti u otklanjanju SO_2, ekonomske isplativosti i dobijanja gipsa kao nusproizvoda, može se očekivati da će se ovaj postupak primenjivati i u termoelektranama u Srbiji. Ovaj rad predstavlja pregled tehnoloških postupaka za odsumporavanje dimnih gasova, kao i pravne i ekonomske aspekte postupaka. Laboratorija za istraživanje upravljanja rizicima američke Agencije za zaštitu životne sredine objavila je model za izračunavanje troškova zaštite životne sredine kod upotrebe uglja. Ovaj model daje okvirnu procenu troškova koja može služiti kao polazna osnova za procenu troškova odsumporavanja dimnih gasova u termoelektranama u Srbiji.

Ključne reči: *sagorevanje uglja, odsumporavanje dimnih gasova, propisi, troškovi*

UVOD

Sagorevanjem uglja obezbeđuje se 40 % potreba za električnom energijom u svetu, a ugalj predstavlja globalni izvor energije sa najvećim rastom potrošnje od početka ovog veka. Porast potrošnje uglja u poslednjoj deceniji podstaknut je ekonomskim razvojem zemalja u razvoju. Bez obzira na ekonomsku korist od uglja koje te zemlje imaju, ne sme se prevideti njegov uticaj na životnu sredinu. Uprkos naporima da se stara postrojenja tehnološki unaprede i da se najstarija (najmanje efikasna) izbace iz upotrebe, te da se izgrade termoelektrane sa odsumporavanjem dimnih gasova, trenutno stanje u ovoj oblasti je daleko od zadovoljavajućeg.

Sagorevanje uglja dovodi do emisije sumpor-dioksida (SO_2), koji ima štetne posledice po životnu sredinu (acidifikacija životne sredine) i po ljudsko zdravlje

* *Pravni fakultet za privredu i pravosuđe, Univerzitet Privredna akademija, Novi Sad, Geri Karolja 1, e-mail: vladimir.marija.jovanovic@gmail.com*
** *Institut za tehnologiju nuklearnih i drugih mineralnih sirovina, Beograd, Franše D'Eperea 86*
*** *Visoka škola strukovnih studija za računovodstvo i berzansko poslovanje, Beograd, Imotska 1*

(pogoršanje postojećih kardiovaskularnih oboljenja, teškoće sa disanjem, respiratorna oboljenja). Postrojenja za proizvodnju električne energije odgovorna su za najveći deo emisija SO_2 u Srbiji. Koncentracije SO_2 se bitno se razlikuju kod lignita iz pojedinih ugljenih basena. U slučaju lignita Kosovskog basena su od 600 do 1200 $\mu g/m^3$, kod lignita Kolubarskog basena od oko 1800 do 4000 $\mu g/m^3$, kod lignita Kostolačkog basena od 4500 do 8000 $\mu g/m^3$. Granična vrednost emisije SO_2 za ložišta toplotne snage veće od 300 MW iznosi 650 $\mu g/m^3$ [1]. Prema podacima kojima raspolaže Služba za zaštitu životne sredine JP TENT, emisija SO_2 iz Termoelektrane „Nikola Tesla“ je tri do četiri puta veća od GVE koju propisuje naša Uredba (650 $\mu g/m^3$) [2].

Od sedamdesetih godina prošlog veka različite regulatorne mere stvorile su komercijalno tržište za tehnologije čistog sagorevanja uglja koje sve više raste, što za posledicu ima smanjenje troškova postupaka i unapređenje njihovih performansi. Nesumnjivo je da će kvalitet vazduha u budućnosti biti sve bolji zbog primene unapređenih tehnologija.

Propisi u oblasti zaštite životne sredine koji su usvojeni u Srbiji u protekloj deceniji zahtevaju postepeno uvođenje tehnologija za tretman dimnih gasova radi kontrole emisija zagađivača u atmosferu. Što se tiče termoelektrana u Srbiji, izrađeni su idejni projekti za odsumporavanje dimnih gasova (ODG) za termoelektrane „Nikola Tesla“ A i „Kostolac“ [3].

Ovaj rad daje pregled komercijalno dostupnih tehnoloških postupaka za ODG, kao i pravnu i ekonomsku perspektivu problema odsumporavanja dimnih gasova u Srbiji.

KLASIFIKACIJA TEHNOLOŠKIH POSTUPAKA ZA ODSUMPORAVANJE DIMNIH GASOVA

Postoje različiti tehnološki postupci za uklanjanje SO_2 iz dimnih gasova koji proizvode termoelektrane, a neke od njih se primenjuju već više desetiha hiljada časova. Ovaj rad bavi se komercijalno dostupnim tehnološkim postupcima za ODG sa pouzdanim performansama i dovoljnom količinom pouzdanih podataka.

Komercijalno dostupni tehnološki postupci za ODG mogu se klasifikovati na neregenerativne i regenerativne zavisno od tretmana sorbenta nakon sorpcije SO_2. Kod neregenerativnih tehnoloških postupaka, SO_2 se trajno vezuje za sorbent koji se koristi kao nusproizvod (npr. gips), ili predstavlja otpadni materijal. Kod regenerativnih tehnoloških postupaka, tokom postupka se SO_2 izdvaja od sorbenta i može se dalje obrađivati kako bi se dobio tečni SO_2, sumporna kiselina ili elementarni sumpor. Oba tehnološka postupka se mogu dalje klasifikovati na „mokre“ i „suve“ postupke. Vlažan mulj kao otpad ili nusproizvod se dobija mokrim postupkom, a dimni gas izlazi iz apsorbera zasićen vodom. U suvom postupku dobija se suvi otpad, a dimni gas koji izlazi iz apsorbera nije zasićen vodom. „Tradicionalna“ klasifikacija postupaka za ODG prikazana je u Tabeli 1.

Tabela 1. *Klasifikacija tehnoloških postupaka za ODG*

<table>
<tr><th colspan="4">Odsumporavanje dimnih gasova</th></tr>
<tr><th colspan="2">Neregenerativni</th><th colspan="2">Regenerativni</th></tr>
<tr><th>Mokri</th><th>Suvi</th><th>Mokri</th><th>Suvi</th></tr>
<tr><td>Odsumporavanje sa krečnjakom ubrzanom oksidacijom</td><td>Suvi postupak sa raspršivanjem</td><td>Odsumporavanje sa natrijum sulfatom</td><td rowspan="5">Odsum-poravanje sa aktivnim ugljem</td></tr>
<tr><td>Odsumporavanje sa krečnjakom prekinutom oksidacijom</td><td>Ubacivanje sorbenta u dimni kanal</td><td>Odsumporavanje sa magnezijum oksidom</td></tr>
<tr><td>Odsumporavanje sa krečom</td><td>Direktno ubacivanje sorbenta u ložište</td><td>Odsumporavanje sa natrijum karbonatom</td></tr>
<tr><td>Odsumporavanje sa magnezijumom obogaćenim krečom</td><td rowspan="2">Odsumporavanje u fluidizovanom sloju</td><td rowspan="2">Odsumporavanje aminima</td></tr>
<tr><td>Odsumporavanje sa morskom vodom</td></tr>
</table>

Prema informacijama Centra za istraživanje uglja Međunarodne agencije za energiju iz Londona datim u bazi podataka CoalPower3, regenerativni postupci ODG koriste se retko, dok se najčešće koriste neregenerativni postupci za ODG. U ovom radu tehnološki postupci za ODG su grupisani u tri osnovne kategorije: neregenerativni mokrim postpukom, neregenerativni suvim postupkom i regenerativni tehnološki postupci za ODG suvim postupkom. Ovakva podela tehnoloških postupaka za ODG je u skladu sa procenama troškova ODG [4].

Neregenerativni tehnološki postupci

Kod neregenerativnih tehnoloških postupaka za ODG dimni gas reaguje sa alkalnom krečnjačkom suspenzijom u ložištu ili u dimnom kanalu, najčešće u toranjskom suprotno strujnom apsorberu. Krečnjačka suspenzija se priprema u dve faze. Najpre se krečnjak melje u fini prah, nakon čega se meša sa vodom u rezervoaru za pripremu suspenzije. Suspenzija sorbenta se zatim raspršuje u rezervoar za reakciju apsorbera. U toranjskim suprotnostrujnim apsorberima dimni gas se kreće naviše, dok se krečnajčka suspenzija raspršuje naniže pomoću mnoštva mlaznica. SO_2 se uklanja u apsorberu sorpcijom i reakcijom sa suspenzijom. Ove reakcije se dovršavaju u reakcionom bazenu, u kome se fino mlevene čestice krečnjaka rastvaraju da bi reagovale sa rastvorenim SO_2.

Kako bi se unapredila pouzdanost sistema, kod većine mokrih neregenerativnih postupaka za ODG potrebna je kontrola oksidacije, tako da je odsumporavanje sa krečnjačkom ubrzanom oksidacijom postalo tehnološki postupak izbora širom sveta. Odsumporavanje sa krečnjakom prekinutom oksidacijom je naročito pogodno za ugalj sa visokim sadržajem sumpora.

Hidrirana krečna kalcitna suspenzija u krečnom postupku je reaktivnija od krečnjačke suspenzije, ali je tehnološki postupak skuplji. Postupak sa krečom obogaćenim magnezijumom predstavlja varijaciju krečnog postupka u kome se kreč obogaćuje magnezijumom (obično 5-8 procentnim magnezijum okisdom). Magnezijumove soli su rastvorljivije u poređenju sa kalcitnim sorbentima, a tečnost za ispiranje, dolomitski kreč, je alkalnija (obično dvadesetoprocentni magnezijum oksid). Zbog povećane alkalnosti i rastvorljivosti, pH vrednost je obično u rasponu od 6,0 do 7,0. Postupak sa krečom je uspešniji i zbog alkalnosti letećeg pepela. Efikasnost odsumporavanja magnezijumom obogaćenim krečom je veća u znatno manjim apsorberima od krečnjačkih postrojenja za prečišćavanje, što omogućuje značajno smanjenje koeficijenta gas-tečnost.

U postupku sa morskom vodom prirodna alkalnost morske vode neutralizuje SO_2. Hemijski proces sa morskom vodom je sličan krečnjačkom postupku sa ubrzanom oksidacijom. Morska voda se ispušta u okean nakon prečišćavanja, tako da su za ovaj postupak neophodni procena lokalnih uslova i građevinski materijali sa pojačanom otpornošću na koroziju zbog visokih koncentracija hlorida.

U suvim postupcima za ODG dimni gas koji sadrži SO_2 reaguje sa alkalnim sorbentom, najčešće krečom, te u toj reakciji nastaje suvi otpad koji ima karakteristike slične letećem pepelu. Sorbent može biti tečna suspenzija ili suvi prah. Delovi apsorbera u kojima dolazi do reakcije sorbenta sa SO_2 su neophodni u suvom sistemu sa raspršivanjem i sistemu sa cirkulišućim fluidizovanim slojem, dok je kod ubacivanja sorbenta u dimni kanal i direktnog ubacivanja sorbenta u ložište potrebna samo oprema za dopremanje sorbenta. U ovim postupcima recirkulacija sorbenata povećeva njihovo iskorišćenje.

Suvi postupak sa raspršivanjem se retko koristi za ugalj sa visokim sadržajem sumpora, a sorbent u ovom postupku je u tečnom stanju.

U postupku ubacivanja sorbenta u dimni kanal fino raspršeni sorbent, hidrirani kreč ili natrijum hidrogenkarbonat, reaguje sa dimnim gasom u dimnom kanalu između grejača i elektrofiltra. Količina opreme je minimalna.

U postupku direktnog ubacivanja sorbenta u ložište suvi sorbent se ubrizgava u ložište u optimalnoj temperaturnoj regiji iznad plamena.

U postupku sa cirkulišućim fluidizovanim slojem suvi sorbent, najčešće $Ca(OH)_2$, reaguje sa ovlaženim dimnim gasom koji se kreće naviše kroz suve sorbente do elektrofiltara. Deo zahvata se recirkuliše kako bi se povećalo iskorišćenje sorbenta. Dodatna korist ovog postupka je stalna abrazija čestica sorbenta koja dovodi do izlaganja svežim alkalima.

Regenerativni tehnološki postupci odsumporavanja dimnih gasova

U regenerativne tehnološke postupke za ODG spadaju četiri mokra regenerativna postupka u kojima azot suboksid, magnezijum oksid, natrijum karbonat ili amini reaguju sa dimnim gasom, i jedan suvi regenerativni postupak u kome se koristi aktivni ugalj. Proizvod ovih postupaka je tečni SO_2. Regenerativni tehnološki postupci za ODG se koriste neznatno u svetu. Ovi postupci imaju komparativno visoke troškove u odnosu na ostale postupke ODG. Veliki problem ovih postupaka je prodaja nusproizvoda. Posledica toga je da su neka postrojenja koja su koristila regenerativne tehnološke postupke za ODG počela da koriste mokre krečnjačke postupke za ODG.

Dosadašnja primena postupaka za odsumporavanje dimnih gasova

Godine 1980. instalirana su postrojenja za ODG na termoelektrane ukupne snage oko 30.000 MW, a taj trend se nastavio sa oko 100.000 MW svakih deset godina [5]. Nije bilo značajnog povećanja kapaciteta postrojenja za ODG regenerativnim postupcima od početka osamdesetih godina prošlog veka. Kako mokri postupci za ODG do sada dominiraju, zanimljiva je analiza primene mokrih postupaka za ODG. Većina tehnoloških postupaka za ODG koji se primenjuju u svetu su mokri postupci sa krečnjakom i suvi postupak sa raspršivanjem. Kod mokrih tehnoloških postupaka za ODG koje ne koriste krečnjak koristi se kreč kao skuplji sorbent, ili je njihova primena ograničena dostupnošću sorbenta koji postupak zahteva. Suvi tehnološki postupci za ODG osim suvog postupka raspršivanjem nisu se našli u komercijalnoj upotrebi u dovoljnoj meri, ili kod njih postoji problem ograničene upotrebe sorbenta.

Mokri tehnološki postupci za ODG dominiraju nad drugim postupcima usled visoke efikasnosti uklanjanja SO_2 i ekonomske isplativosti, naročito mokri postupci koji se zasnivaju na krečnjaku. Gips kao nusproizvod čini mokre postupke za ODG atraktivnijim. Retka upotreba suvih postupaka za ODG posledica je većih cena reagenasa i ograničenja u pogledu odlaganja nusproizvoda.

Odsumporavanje sa krečnjakom ubrzanom oksidacijom je najrasprostranjeniji postupak u u svetu danas, i ovi sistemi čine oko jedne trećine mokrih sistema za uklanjanje SO_2. Ubrzana oksidacija je postuapk koji se najčešće koristi stoga što smanjuje mogućnost oksidacije postrojenja za ODG, poboljšavanja mogućnost sušenja i daje nusproizvod koji se može koristiti za punjenje zemljišta ili za prodaju kao gips za poljoprivredu ili industriju cementa. Unapređena sposobnost sušenja dodatno smanjuje površinu prostora potrebnog za smeštaj otpada.

PRAVNI ASPEKT ODSUMPORAVANJA DIMNIH GASOVA U SRBIJI

Regulativa koja se odnosi na zaštitu životne sredine, a naročito Direktiva 2010/75/EU Evropskog parlamenta i Saveta od 24. novembra 2010. o industrijskim emisijama (integrisana prevencija i zaštita zagađenja) [6] postavlja stroge uslove, tehničke zahteve i GVE za postrojenja u pogledu emisije SO_2 na 200 mg/m^3. Ovakvi propisi zahtevaju detaljnu analizu kvaliteta uglja, kao i pažljiv odabir tehnološkog postupka za odsumporavanje dimnih gasova i procenu troškova.

Jedan od osnovnih ciljeva Nacionalnog programa za zaštitu životne sredine Republike Srbije za period od 2005-2014. godine u energetskom sektoru je smanjenje emisije sumpornih oksida iz termoelektrana kao što su Termoelektrana “Kostolac B” i Termoelektrana “Nikola Tesla A” i “Nikola Tesla B”. Do sada su u ovim termoelektranama ugrađeni samo elektrofiltri za uklanjanje čestica, ali nisu preduzete nikakve mere u cilju odsumporavanja dimnih gasova.

Kako su tehnološki postupci za ODG zasnovani na krečnjaku u svetu u najširoj upotrebi zbog visoke efikansosti, ekonomske opravdanosti i gipsa kao nusproizvoda, može se očekivati da će termoelektrane u Srbiji koristiti ovaj postupak. Dve kompanije – Mitsubishi i Hitachi predstavile su svoje tehnološke postupke za odsumporavanje dimnih gasova mokrim krečnjačkim posutpkom na Prvom simpozijumu “O odsumporavanju dimnih gasova” održanom na Paliću 2012. [7, 8].

Ministarstvo prosvete, nauke i tehnološkog razvoja Republike Srbije finansiralo je projekat “Razvoj tehnoloških procesa za dobijanje ekoloških materijala zasnovanih na nemetalnim mineralima”, u okviru koga su vršena ispitivanja litotamnijskog krečnjaka iz ležišta “Dobrilovići” u blizini Loznice za upotrebu u neregenerativnim mokrim postupcima. Ova ispitivanja pokazala su da se ovaj krečnjak može koristiti za odsumporavanje dimnih gasova, kao i da se u tom postupku dobija gips zadovoljavajućeg kvaliteta kao nusproizvod [9].

U poslednje tri decenije troškovi postrojenja za uklanjanje SO_2 u svetu su se smanjili za preko 30%, te postoje proračuni da su troškovi odsumporavanja danas oko 100 $/kW [10]. Postavljanje sistema na postojeća postrojenja povećava troškove do 30% zavisno od modifikacija postojeće opreme i uslova pod kojima postrojenja rade, kao što su protok i temperatura. Troškovi takođe rastu sa porastom sadržaja sumpora, budući da se ista količina gasa mora tretirati sa više reagensa. Krečnjak i kreč kao reagensi po sebi nisu skupi, ali upotreba aditiva ili reagenasa značajno povećava troškove. Na troškove utiče i trošak odlaganja otpada, cena nusproizvoda, kao i gubitak energije koja je potrebna za postupak i drugi fiksni i varijabilni troškovi [5]. Efikasnost kontrole emisija kod krečnjačkih sistema je ograničena na oko 90%, dok je kontrola efikasnosti kreča do 95%, ali je značajno skuplja.

PROCENA TROŠKOVA ODSUMPORAVANJA DIMNIH GASOVA

Kontinualno merenje emisije ne daje dovoljno precizne podatke za projektovanje postrojenja za ODG, tako da se dodatne informacije moraju pribaviti na osnovu analize uglja i podataka o postojećem ložištu koji se pojedinačno mere [11]. Analizom uglja dobijaju se ključni podaci za projektovanje postrojenja za odsumporavanje dimnih gasova – referentni kvalitet uglja, analiza dimnih gasova na ulazu u postrojenje, kao i opseg koncentracija SO_2 u dimnim gasovima [12].

Postupak odsumporavanja dimnih gasova ne zahteva samo sistem za dimni gas i apsorber, već i povezane sisteme za pripremu sorbenta i odlaganje nusproizvoda. Osnovni parametri koji se koriste za projektovanje sistema za ODG su radni parametri termoelektrane (kao što je snaga bloka, specifična potrošnja toplote, višak vazduha, temteratura dimnog gasa), karakteristike dimnog gasa (zapreminski protok, vlaga, koncentracija hlorida i fluorida, sadržaj čestica i SO_2, dozvoljeni sadržaj čestica u emitovanom dimnom gasu), zahtevani kvalitet nusproizvoda. Tehnička i ekonomska analiza mogućnosti primene postupka odsumporavanja dimnih gasova u termoelektranama u Srbiji pokazala je da je mokri krečnjački postupak ubrzanom oksidacijom najbolje rešenje.

Dodatni činioci koje treba razmotriti pri proceni troškova odsumporavanja dimnih gasova su prostor oko termoelektrane, investicije, vreme na koje je potrebno zaustaviti termoelektranu tokom instalacije sistema za ODG, plan rada termoelektarne tokom godine.

Gips kao nusproizvod postupka odsumporavanja zahteva deponovanje na bezbednoj deponiji na koju se ne deponuje biorazgradivi otpad, a deponija mora da ispuni neophodne zahteve u cilju sprečavanja zagađenja tla, vazduha i površinskih voda kombinacijom geoloških barijera i neprobojnih slojeva [13].

ZAKLJUČAK

Sagorevanjem uglja u postrojenjima za proizvodnju električne energije emituje se najveći deo sumpor dioksida u Srbiji. Propisi u oblasti zaštite životne sredine usvojeni u Srbiji u protekloj deceniji zahtevaju postepeno uvođenje tehnoloških postupaka za tretman dimnih gasova, a jedan od osnovnih ciljeva Nacionalnog programa za zaštitu životne sredine Republike Srbije za period od 2005-2014. godine u energetskom sektoru je smanjenje emisije sumpornih oksida iz termoelektrana. Do sada u termoelektranama nisu preduzete nikakve mere u cilju odsumporavanja dimnih gasova. Kako tehnološki postupci za ODG zasnovani na krečnjaku dominiraju u svetu zbog visoke efikasnosti, ekonomske opravdanosti i gipsa kao nusproizvoda, može se očekivati da će termoelektrane u Srbiji koristiti ovaj postupak. Tehnička i ekonomska analiza mogućnosti primene postupka odsumporavanja dimnih gasova u termoelektranama u Srbiji pokazale su da je „mokri" krečnjački postupak ubrzanom oksidacijom najbolje rešenje.

Sektor za prevenciju i kontrolu aerozagađenja Nacionalne istraživačke laboratorije za upravljanje rizikom SAD objavio je model za izračunavanje troškova zaštite životne sredine za termoelektrane (Coal Utility Environmental Cost Workbook, CUECost) [14]. Pomoću njega je moguće napraviti grubu kalkulaciju troškova (sa preciznošću od ± 30 %) za termoelektrane snage između 100 i 2000 MW u slučaju primene mokrog krečnjačkog postupka ubrzanom oksidacijom, a koja se zasniva na projektu i ekonomskim kriterijumima po odluci korisnika. CUECost algoritmi predstavljaju polaznu osnovu za izračunavanje troškova odsumporavanja dimnih gasova mokrim krečnjačkim postupkom ubrzanom oksidacijom koji mogu biti dobra polazna osnova i za procenu troškova ODG termoelektrana u Srbiji.

LITERATURA

[1] Uredba o graničnim vrednostima emisija zagađujućih materija u vazduh, Službeni glasnik RS 71/201 i 6/2011.

[2] http://kgh.kvartetv.com/fajlovi/37.%20kongres/37-38.pdf

[3] Mitrović D., Kostović N., Milovanović Đ., Specifičnosti projektovanja postrojenja za odsumporavanje dimnih gasova na postojećim termoelektranama na lignit u Srbiji, Zbornik radova Prvog simpozijuma Odsumporavanje dimnih gasova", Privredna komora Srbije, (2012) 12-19.

[4] Keeth RJ, Ireland PA, and Radcliffe PT, Economic Evaluations of 28 FGD Processes, in Proceedings of the 1991 SO_2 Control Symposium Palo Alto, CA, Electric Power Research Institute, 1991, 273-2-90.

[5] http://www.iea-coal.org.uk/site/2010/database-section/coal-power?LanguageId=0

[6] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:334:0017:0119:en:PDF

[7] Okamoto T., Nagayasu T., Tanaka N., Mitsubiši tehnologija mokrim postupkom odsumporavanja dimnih gasova, Zbornik radova Prvog simpozijuma „Odsumporavanje dimnih gasova", Privredna komora Srbije, Beograd, 2012, 60-71.

[8] Taguchi Y., Vollmer B., Tehnologija firme Hitachi za odsumporavanje dimnih gasova, Zbornik radova Prvog simpozijuma „Odsumporavanje dimnih gasova", Privredna komora Srbije, Beograd, 2012, 27-34.

[9] Sekulić Ž., Jovanović V., Kašić V., Litotamnijski krečnjak ležišta "Dobrilovići" u odsumporavanju dimnih gasova mokrim postupkom, Rudarski radovi, 3 (2012) 41-48.

[10] Smith D., Cost of SO_2 scrubbers down to $ 100/kW, Power Engineering, 105 (2001) 63-66.

[11] Thomsen R., Dickamp M., Kriterijumi za projektovanja postrojenja za odsumporavanje dimnih gasova, Zbornik radova Prvog simpozijuma "Odsumporavanje dimnih gasova", Privredna komora Srbije, (2012) 20-26.

[12] Stojiljković D., Životić D., Milovanović D., Jovović A., Manić N., Jova-

nović V., Značaj definisanja referentnih karakteristika uglja za projektovanje sistema za ODG, Zbornik radova Prvog simpozijuma "Odsumporavanje dimnih gasova", Privredna komora Srbije, (2012) 2-11.

[13] Vlajić D., Simović I., Kostović N., Stanković M., Deponije suspenzije gipsa iz procesa odsumporavanja bloka TE Kostolac B3, Zbornik radova Prvog simpozijuma "Odsumporavanje dimnih gasova", Privredna komora Srbije, (2012) 155-162.

[14] http://www.epa.gov/ttncatc1/products.html#cccinfo

INSTRUCTIONS FOR THE AUTHORS

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Volume and Font size. The work needs to be written on A4 paper (210x297 mm), margins (left, right, upper and bottom) with each 25 mm, in the Microsoft Word later version, font Times New Roman, size 12, with 1.5 line spacing, justified to the left and right margins. It is recommended that the entire manuscript cannot be less than 5 pages and not exceed 10 pages.

Title of Work should be written in capital letters, bold, in Serbian and English. Under the title, the names of authors and institutions where they work are written under the title. The author of work, responsible for correspondence with the editorial staff, must provide his/her e-mail address for contact in a footnote.

Abstract is at the beginning of work and should be up to 200 words, include the aim of the work, the applied methods, the main results and conclusions. The font size is 10, italic.

Key words are listed below abstract. They should be minimum 3 and maximum of 6. The font size is 10, italic.

Basic text. The papers should be written concisely, in understandable style and logical order that, as a rule, including the introductory section with a definition of the aim or problem, a description of the methodology, presentation of the results as well as a discussion of the results with conclusions and implications.

Main titles should be done with the font size 12, bold, all capital letters and aligned with the left margin.

Subtitles are written with the font size 12, bold, aligned to the left margin, large and small letters.

Figure and Tables. Each figure and table must be understandable without reading the text, i.e., must have a serial number, title and legend (explanation of marks, codes, abbreviations, etc.). The text is stated below the figure and above the table. Serial numbers of figures and tables are given in Arabic numbers.

References in the text are referred to in angle brackets, exp. [1, 3]. References are enclosed at the end in the following way:

[1] Willis B. A., Mineral Procesing Technology, Oxford, Pergamon Press, 1979, pg. 35. (for the chapter in a book)

[2] Ernst H., Research Policy, 30 (2001) 143–157. (for the article in a journal)

[3] www: http://www.vanguard.edu/psychology/apa.pdf (for web document)

Specifying the unpublished works is not desirable and, if it is necessary, as much as possible data on the source should be listed.

Acknowledgement is given where appropriate, at the end of the work and should include the name of institution that funded the given results in the work, with the name and number of project, or if the work is derived from the master theses or doctoral dissertation, it should give the name of thesis / dissertation, place, year and faculty where it was defended. Font size is 10, italic.

The paper works are primarily sent by e-mail or in other electronic form.

Editorial address : Journal MINING AND METALLURGY ENGINEERING BOR
Mining and Metallurgy Institute
35 Zeleni bulevar, 19210 Bor
E-mail: nti@irmbor.co.rs; milenko.ljubojev@irmbor.co.rs
Telephone: +381 (0) 30/435-164; +381 (0) 30/454-110

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Slike i tabele. Svaka ilustracija i tabela moraju biti razumljive i bez čitanja teksta, odnosno, moraju imati redni broj, naslov i legendu (objašnjenje oznaka, šifara, skraćenica i sl.). Tekst se navodi ispod slike, a iznad tabele. Redni brojevi slika i tabela se daju arapskim brojevima.

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Adresa uredništva je: Časopis MINING AND METALLURGY ENGINEERING BOR
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Zeleni bulevar 35, 19210 Bor
E-mail: nti@irmbor.co.rs ; milenko.ljubojev@irmbor.co.rs
Telefon: 030/435-164; 030/454-110

Svim autorima se zahvaljujemo na saradnji.

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