Vesna Ljubojev, Vesna Marjanović*, Dragan Milanović*, Suzana Stanković**

MINERALOGICAL CHARACTERISTICS OF SLAG (FROM THE FLOTATION PLANT OF RTB BOR) GRANULATED IN THE LABORATORY CONDITIONS**

Abstract

A sample of slag from the Flotation Bor, RTB Bor, was mineralogical tested after granulation in the laboratory conditions. Minerals contained in the sample of granulated slag are: fayalite and ferrite that form the basis with rarely sprayed fine particles of magnetite, pyrite, chalcopyrite, bornite, copper matte and elemental - native copper [6, 7]. Granulation of slag was conducted in the laboratory conditions on the device specially designed for this purpose.

Keywords: *smelter slag, copper minerals, fayalite, mineralogical testing*

INTRODUCTION

The copper smelter slag is produced as a by-product during the pyrometallurgical copper smelting. The composition and concentration of elements in slag depends on the composition of ore concentrate which is processed and technological processing methods. Slag represents the complex systems of a number of components, which occur at high smelting temperature, such as non-metallic inclusions and newlyformed oxides [1].

Many years metallurgical processing of copper concentrate in the industrial complex of RTB Bor has created a dump slag, which is used as the secondary raw material, as it contains significant amounts of valuable metals. Total amount of slag in the "Depot - Slag 1" amounts to about 9,190,940 tons with the medium content of Cu - 0.715%, Au – 0.282 g/t, Ag - 4.5 g/t and Mo 0.0413% [2].

In the Flotation Plant Bor, the section C was originally designed for flotation of ore, and later adapted for flotation of slag [3].

The process of slag comminution in the plant consists of crushing and grinding.

However, the ore is suitable for comminution from the standpoint of consumption the energy, linings and grinding bodies of slag and to explore the possibility of energy saving and reducing the wear of linings and grinding bodies in the process of grinding; heating of slag was carried out in the laboratory conditions to the melting point and its cooling by a jet of water to form the granules of slag. It would consider the possibility of expulsion the process of comminution in the industrial conditions, and enabled the saving of energy and raw material [4].

SAMPLE AND EXPERIMENTAL METHOD

A sample of smelting slag was taken from the crushing process in the Flotation Plant in Bor [4].

* *Mining and Metallurgy Institute Bor*

** *This work is the result of the Project TR33023 "Development of Technologies for Flotation Processing the Copper Ore and Precious Metals to Achieve Better Technological Results" funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia*

Upon completion the natural drying, sampling was performed according to the standard method of sampling and a repre-

sentative sample was formed that was physically and chemically analyzed. The chemical composition of the sample is given in Table 1.

Table 1 Chemical content of sample and granulated slag [5]

Content (%) compound – chemical element	Sample	Analytical method
Cu	0.33	ASS
Fe ₃ O ₄	3.41	A- Fe ₃ O ₄
CaO	19.60	V
S	0.20	G
Fe	27.92	V
SiO ₂	46.72	G
Al ₂ O ₃	4.52	ICP-AES

The term granulation involves rapidly cooling the liquid-hot slag under the pressurized cold water and obtaining the slag in the form of irregular granules. The quality of granules depends on the chemical composition of slag, slag temperature before spillage, rate of slag spillage, pressure and the amount of cooling water [4].

Previously dried and analyzed slag was subjected to melting in an induction furnace for smelting, power of 100 kWh, in a pot volume V = 10 h, manufacturer ELING - Loznica. During the experiment, 25 kg of slag was melt at the temperature of spillage of T = 1,250°C [8].

Granulation of slag in the laboratory conditions was performed on a specially designed granulator which is mobile and allows rapidly cooling of slag by jets, which are located on the front side of the tank, just behind a roller of granulator, which has one part immersed in cooling water. Below the roller is a carrying basket with a perforated bottom that accepts the resulting granules and that after discharging the total amount of slag from furnace is removed by a crane after draining, left in a basket for granulated slag [4].

Copper and slag are insoluble in each other and due to this they are separated from each other in the furnace precipitator. Copper matte drops are denser than the slag and under the influence of gravity pass through

the slag and form a separate layer at the bottom of the furnace. Less dense layer of slag floats on a layer of copper matte. In the furnace precipitator, blister and slag layers are formed separately in two separate layers. The basic components of slag during melting of copper concentrate are SiO₂, FeO, Fe₂O₃ and MgO, and slag often contains Fe₃O₄, Al₂O₃, Cu₂S, and smaller quantities fine droplets of mechanically affected copper. Copper content in the slag of flame furnace should be from 0.15 to 0.25%. However, due to significant presence of mechanically included copper matte in the slag, and due to the chemical bound copper in the form of copper oxide, copper content in the slag is higher [1].

Compound FeO in slag is most commonly found in the form of fayalite, Fe₂SiO₄, in which an excess of iron oxide can be dissolved, as it is the case in base slag.

MINERALOGICAL TESTING OF GRANULATES SLAG

Determination of mineral composition and structural-textural characteristics of minerals was made on a representative sample [6, 7].

The samples poured into acrylic resin are made of the obtained representative sample of granulated slag. Determination of slag

samples was done on a microscope for transmitted and reflected light, the brand AXIOSKOP 40, with the device for micro-photo. The chemical analysis on Niton was also carried out.

Qualitative mineralogical analysis was carried out under the polarization microscope for reflected light in the air for the purpose of identification the ore and non-ore minerals. Quantitative mineralogical analysis was carried out by the method of parallel sections, with spacing of 1 mm. The distance between the examined fields and sections were moved by hand. Determination of slag samples was done on the microscope for transmitted and reflected light, the brand AXIOSCOPE 40, with the device for microphoto.

Based on the qualitative mineralogical analyses the following mineral composition of slag was determined: solid sulfide melt (Cu-Fe), chalcocite, pyrite, copper, chalcopyrite, bornite, magnetite and gangue minerals. Gangue minerals were presented with a

glass with occurrence a variety of eutectic dendrites (fayalite and others) that were not particularly determined.

Structural characteristics of samples can be divided into:

1. Simple mesogen present the investigated mineral that is easily adhered to one mineral or only gangue-double mesogens.
2. Complex mesogen presents the investigated mineral that is adhered to more minerals and gangues – multiple mesogens.

Macroscopic description of granulated slag

Granulated slag has various coarseness with visible larger pieces. The spheroids of different sizes, smooth surfaces can be observed in a sample of granulated slag, Figure 1, as well as large number of very sharp glassy particles of slag, Figure 2. The sample is dark gray to black.

Figure 1 Spherical grains in granulated slag, binocular, magnification 6.5 x

Figure 2 Grains of granulated slag (sharo edges), binocular, magnification 2.0 x

Microscopic description

Microscopic analysis has showed that the granulated slag is mainly built of fayalite and ferrite that build the basis in which fine particles of magnetite, pyrite, chalcopyrite, chalcocite, bornite, copper matte and elemental (native) copper are rarely sprayed, Figure 3.

Fayalite (iron silicate) is represented in the form of poke crystals, which indicates

the product of smelting - slag. Ferrites (various iron oxides), also indicate the product of ore smelting. They are represented in the form of skeletal crystals (dendrites), Figure 9.

Magnetite occurs predominantly independent, in the form of cube and radial radiating aggregates. It rarely occurs in irregular shapes, Figures 7 and 8.

Pyrite is the most common of all sulfide minerals and occurs in the form of hypidiomorphic grains, mostly independent (free grain).

Since copper minerals occur chalcopyrite, chalcocite and bornite, in Figure 6.

Chalcopyrite occurs in irregular, relatively small, fields, rarely adhered to chalcocite,

while some grains are permeated with chalcocite.

Chalcocite is less frequent in fine grains; it is free or is adhered to chalcopyrite and gangue mineral.

Elemental (native) copper occurs in the form of fine spherical shapes and small veins, Figures 4, 5 and 10.

Microphotos of slag

Figure 3 Copper matte, bornite and chalcopyrite, magnification 500 x II N

Figure 4 Veins of elemental copper in fayalite basis, magnification 500 x II N

Figure 5 Veins of elemental copper, magnification 500 x II N

Figure 6 Chalcopyrite grains in fayalite basis, permeated with chalcocite, magnification 500 x II N

Figure 7 Magnetite in the form of cube, chalcopyrite, magnification 500 x II N

Figure 8 Magnetite in various forms, magnification 500 x II N

Figure 9 Fayalite dendrites, magnification 500 x II N

Figure 10 Veins of elemental copper, magnification 500 x II N

Chemical analysis of samples of granulated slag was done on apparatus NITON XL-L3t-900 from which it can be concluded that iron is the most common of 25.791%. This indicates a large content of

iron minerals, which after thermal oxidation treatment transfer into Fe_2O_3 and Fe_3O_4 . The copper content is 0.156%. The obtained results are shown in Table 2 and Figure 11.

Table 2 Chemical analysis obtained by recording on X-ray NITON XL-3t-90

Compounds – Chemical elements	Cu	S	Fe	Si	Ca	Al	Zn
Content, %	0.156	1.117	25.791	21.639	11.082	2.588	0.121

Figure 11 Chemical analysis obtained by recording on X-ray NITON XL-3t-90

CONCLUSION

Granulated slag from the process of pyrometallurgical smelting of copper is in the form of spherical grains and grains with sharp edges. Slag mainly contains oxide species and several species of sulfide minerals. The main component is the fayalite basis in which copper, chalcopyrite, magnetite and copper matte are permeated. Copper is in the form of copper matte and elemental copper in the form of veins in the fayalite basis. Magnetite is in the form of cube and other various forms.

REFERENCES

- [1] Morales A., Cruells M., Roca A., Bergo R., Treatment of Copper Flash Smelter Dusts for Copper and Zinc Extraction and Arsenic Stabilization, *Hydrometallurgy* 105(2010), p. 148-154.
- [2] Mitrović Z., et al., Main Mining Project for Slag Excavation from Technogenic Deposit "Depot Slag 1", Verification the Technological Process of Concentrate Obtaining and Superelevation of the Flotation Tailing Dump "RTH" in Bor to K +378 for Annual Production of 1,200,000 t Slag; Copper Institute Bor, 2006;
- [3] <http://rtb.rs/rtb-bor-doo/rudnik-bakra-bor/flotacija-bor/>
- [4] Magdalinović S., Milanović D., Čadenović B., Marjanović V., Technological Method of Slag Granulation to Reduce Grain-size at the Inlet into Flotation, *Mining Engineering* 3(2011), p. 101-110;
- [5] Čadenović B., Marjanović V., Ljubojev V., Milanović D., Possibilities of Use the Copper Matte From Smelter Slag in its Direct in its Direct Discharge from Furnace, *Mining Engineering*, 2(2012), p. 143-148;
- [6] Ljubojev V., Petrović J., Krstić S., Mineralogical Characteristics of Smelting Slag in the Technogenic Deposit "Depot 1" (Bor, Serbia). The Geology in digital Age: Proceedings of the Meeting of the Association of European Geological Societies (MAEGS 17), Belgrade (2011), p. 237-240;
- [7] Ljubojev V., Report on Microscope Testing of Granulated Slag, MMI Bor, May, 2013.
- [8] Čadenović B., Drobnjaković B., Milanović D., Magdalinović S., New Laboratory Plant for Granulation Using the Changed Technological Process of Smelter Slag Discharging, *R. radovi* 4(2011), p. 99-104.
- [9] Požega E., Gomidželić L., Copper Smelters with Reveratory and ISASMELT Furnace, *Bakar* 2(2010), p. 25-32.

Vesna Ljubojev*, Vesna Marjanović*, Dragan Milanović*, Suzana Stanković*

MINERALOŠKE OSOBINE ŠLJAKE (IZ POGONA „FLOTACIJE“ RTB BOR) GRANULISANE U LABORATORIJSKIM USLOVIMA**

Izvod

Uzorak šljake iz pogona „Flotacije“ Bor, RTB-a Bor je mineraloški ispitivan posle granulacije u laboratorijskim uslovima. Minerali koji se nalaze u uzorku granulisane šljake su: fajalit i ferit koji čine osnovu, u koju su retko uprsane sitne čestice magnetita, pirita, halkopirita, bornita, bakrenca i elementarnog – samorodnog bakra [6, 7]. Granulisanje šljake je vršeno u laboratorijskim uslovima na uređaju specijalno konstruisanom za tu namenu.

Ključne reči: topionička šljaka, minerali bakra, fajalit, mineraloško ispitivanje

UVOD

U topionicama bakra šljaka nastaje kao nus-proizvod u toku pirometalurškog topljenja bakra. Sastav i koncentracija elemenata u šljaci zavisi od sastava koncentrata rude koja je prerađena i tehnoloških postupaka prerade. Šljaka predstavlja složene sisteme većeg broja komponenata, koji nastaju na visokoj temperaturi topljenja, kao što su nemetalni uključci i novonastali oksidi [1].

U industrijskom kompleksu RTB Bor višegodišnja metalurška prerada koncentrata bakra stvorila je deponiju šljake, a koja se koristiti kao sekundarna sirovina, jer sadrži značajne količine korisnih metala. Ukupne količine šljake u „Depo - šljake 1“ iznose oko 9.190.940 t sa srednjim sadržajem Cu - 0,715%, Au - 0,282 g/t, Ag - 4,5 g/t i Mo 0,0413% [2].

U pogonu „Flotacije Bor“, sekcija C je prvobitno projektovana za flotaciju rude, a

kasnije je prilagođena za flotaciju šljake [3]. Proces usitnjavanja šljake u pogonu se sastoji od drobljenja i mlevenja.

Međutim, ruda je pogodnija za usitnjavanje sa stanovišta potrošnje energije, obloga i meljućih tela od šljake i da bi se istražila mogućnost uštede energije i smanjenje habanja obloga i meljućih tela u procesu usitnjavanja, u laboratorijskim uslovima izvršeno je zagrevanje šljake do tačke topljenja i njeno hlađenje mlazom vode radi formiranja granula šljake. Time bi se razmotrila mogućnost izbacivanja procesa drobljenja u industriskim uslovima, i omogućila ušteda energije i repro materijala [4].

UZORAK I EKSPERIMENTALNA PROCEDURA

Uzorak topioničke šljake uzet je iz procesa drobljenja u pogonu „Flotacije“ u Boru [4].

* Institut za rudarstvo i metalurgiju Bor

** Ovaj rad je proistekao kao rezultat projekta TR33023 „Razvoj tehnologija flotacijske prerade ruda bakra i plemenitih metala radi postizanja boljih tehnoloških rezultata“ finansiranog od strane Ministarstva prosvete, nauke i tehnološkog razvoja Republike Srbije

Po završetku prirodnog sušenja izvršeno je uzorkovanje prema standardnoj metodi i formiran je reprezentativan

uzorak koji je fizički i hemijski analiziran. Hemijski sastav uzorka dat je u tabeli 1.

Tabela 1. Hemijski sastav uzorka i granulisanе šljake [5]

Sadržaj (%) jedinjenja - hemijskog elementa	Uzorak	Analitička metoda
Cu	0,33	ASS
Fe ₃ O ₄	3,41	A- Fe ₃ O ₄
CaO	19,60	V
S	0,20	G
Fe	27,92	V
SiO ₂	46,72	G
Al ₂ O ₃	4,52	ICP-AES

Pod pojmom granulacije podrazumeva se naglo hlađenje tečne usijane šljake pod pritiskom hladne vode i dobijanje šljake u vidu nepravilnih granula. Kvalitet granula zavisi od hemijskog sastava šljake, temperature šljake pre izlivanja, brzine izlivanja šljake, pritiska i količine rashladne vode [4].

Prethodno osušena i analizirana šljaka je podvrgnuta topljenju u indukcionoj peći za topljenje, snage 100 kWh, u loncu zapremine V=10 L, proizvođača ELING - Loznica. Prilikom eksperimenta istopljeno je 25 kg šljake, temperatura pri kojoj je šljaka izlivena je bila T=1.250°C. [8]

Granuliranje šljake u laboratorijskim uslovima je izvršeno na specijalno konstruisanom granulatoru koji je mobilan i omogućava, da se šljaka naglo hladi mlaznicama, koje se nalaze na čeonj prednjoj strani rezervoara, odmah iza valjka granulatora, kome je jedan deo potopljen u rashladnu vodu. Ispod valjka je prihvatni koš sa perforiranim dnom, koji prihvata nastale granule i koji se nakon izlivanja celokupne količine šljake iz peći vadi uz pomoć dizalice i nakon ceđenja, odlaže u korpu za granulisanu šljaku [4].

Bakrenac i šljaka su nerastvorljivi jedan u drugo i zbog toga oni se odvajaju jedno od drugog u pećnom taložniku. Kapljice bakrenca su gušće od šljake i pod uticajem

gravitacije prolaze kroz šljaku i na dnu peći formiraju poseban sloj. Manje gušći sloj šljake pluta na sloju bakrenca. U pećnom taložniku, slojevi blistera i šljake formiraju se odvojeno u dva posebna sloja. Osnovne komponente šljake prilikom topljenja bakarnog koncentrata su SiO₂, FeO, Fe₂O₃ i MgO, a šljaka često sadrži i Fe₃O₄, Al₂O₃, Cu₂S, i u manim količinama sitne kapljice mehanički zahvaćenog bakrenca. Sadržaj bakra u šljaci plamene peći trebao bi da bude od 0,15 do 0,25 %. Međutim, zbog značajnog prisustva mehanički uključenog bakrenca u šljaci i zbog hemijski vezanog bakra u obliku oksida sadržaj bakra u šljaci je veći [1].

Jedinjenje FeO u šljaci se najčešće nalazi u obliku fajalita, Fe₂SiO₄, u kome može biti rastvoren i višak gvožđe-oksida, kao što je slučaj u baznim šlakama.

MINERALOŠKO ISPITIVANJE GRANULISANE ŠLJAKE

Na reprezentativnom uzorku izvršena je determinacija mineralnog sastava i određivanje strukturno-teksturnih karakteristika minerala [6, 7].

Od dobijenog reprezentativnog uzorka granulisanе šljake urađeni su preparati uliveni u akrilnu smolu. Determinacija uzoraka šljake rađena je mikroskopom za propuštenu

i odbijenu svetlost, marke AXIOSKOP 40, sa uređajem za mikrofotografiju. Takođe, urađena je hemijska analiza na Nitonu.

Kvalitativna mineraloška analiza rađena je pod polarizacionim mikroskopom za odbijenu svetlost u vazduhu u cilju identifikacije rudnih i nerudnih minerala. Kvantitativna mineraloška analiza rađena je metodom paralelnih profila, sa rastojanjem od 1 mm. Rastojanje između ispitivanih polja i profila pomerana su ručno. Determinacija uzoraka šljake rađena je mikroskopom za propuštenu i odbijenu svetlost, marke AXIOSKOP 40, sa uređajem za mikrofotografiju.

Na osnovu kvalitativnih mineraloških analiza utvrđen je sledeći mineralni sastav šljake: čvrsti sulfidni rastop (Cu-Fe), halkozin, pirit, bakar, halkopirit, bornit, magnetit i minerali jalovine. Minerali jalovine predstavljani su staklom sa pojavom različitih

eutektičkih dendrita (fajalit i dr.) koji nisu posebno određivani.

Strukturne karakteristike uzoraka možemo podeliti na :

1. Prosti sraslac, predstavlja ispitivani mineral koji je jednostavno srastao sa jednim mineralom ili samo jalovinom - dvojni sraslaci.
2. Složeni sraslac, predstavlja ispitivani mineral koji je srastao sa više minerala i jalovinom višebrojni sraslaci.

Makroskopski opis granulisane šljake:

Granulisana šljaka je različite krupnoće sa vidljivim većim komadima. U uzorku granulisane šljake mogu se zapaziti sferični oblici različite veličine, glatkih površina, slika 1., kao i veliki broj veoma oštih staklastih čestica šljake, slika 2. Uzorak je tamnosive do crne boje.

Sl. 1. Sferična zrna u granulisanoj šljaci, binokular, uvećanje 6,5 x

Sl. 2. Zrna granulisane šljake (oštri ivici), binokular, uvećanje 2,0 x

Mikroskopski opis

Mikroskopskim ispitivanjem utvrđeno je da je granulisana šljaka pretežno izgrađena od fajalita i ferita koji grade osnovu u koju su retko uprskane sitne čestice magnetita, pirita, halkopirita, halkozina, bornita, bakrenca i elementarnog (samorodnog) bakra, slika 3.

Fajalit (silikati gvožđa) su zastupljeni u vidu pritkastih kristalića, što ukazuje na proizvod topljenja rude – šljaka. Feriti (razni

oksidi gvožđa), takođe ukazuju na proizvod topljenja rude. Zastupljeni su u vidu skeletnih kristala (dendrita), slika 9.

Magnetit se javlja pretežno samostalan, u formi kocke i radialno zrakastih agregata. Ređe se javlja u nepravilnim oblicima, slika 7 i 8.

Od svih sulfidnih minerala pirit je najzastupljeniji i javlja se u vidu hipidiomorfih zrna, uglavnom samostalan (slobodna zrna).

Od minerala bakra javljaju se halkopirit, halkozin i bornit, slika 6.

Halkopirit se javlja u nepravilnim, relativno sitnim, poljima, retko srastao sa halkozinom, dok su pojedina zrna prožeta halkozinom.

Mikrofotografije šljake

Sl. 3. Bakrenac, bornit i halkopirit, uvećanje 500 x II N

Sl. 4. Žilice elementarnog bakra u fajalitskoj osnovi, uvećanje 500 x II N

Sl. 5. Žilice elementarnog bakra u bakrencu, uvećanje 500 x II N

Sl. 6. Zrno halkopirita u fajalitskoj osnovi, prožeto halkozinom, uvećanje 500 x II N

Sl. 7. Magnetit u formi kocke, halkopirit, uvećanje 500 x II N

Sl. 8. Magnetit u različitim formama, uvećanje 500 x II N

Sl. 9. Dendriti fajalita,
uvećanje 500 x II N

Sl. 10. Žilice elementarnog bakra,
uvećanje 500 x II N

Hemijska analiza uzoraka granulirane šljake urađena je na aparatu NITON XL-L3t-900 iz koje se može konstatovati da je gvožđe najzastupljenije 25,791%. To ukazuje na veliki sadržaj minerala

gvožđa, koji nakon termičkog tretmana oksidacijom prelaze u Fe_2O_3 i Fe_3O_4 . Sadržaj bakra je 0,156%. Dobijeni rezultati su prikazani na u tabeli 2 i na slici 11.

Tabela 2. Hemijska analiza dobijena snimanjem na rengenu NITON XL-3t-90

Jedinjenja - hemijski elementi	Cu	S	Fe	Si	Ca	Al	Zn
Sadržaj, %	0,156	1,117	25,791	21,639	11,082	2,588	0,121

Sl. 11. Hemijska analiza dobijena snimanjem na rengenu NITON XL-3t-90

ZAKLJUČAK

Granulisana šljaka iz procesa pirometalurškog topljenja bakra je u obliku sferičnih zrna i zrna oštih ivica. Šljaka sadrži uglavnom oksidne vrste i nekoliko sulfidnih vrsta minerala. Glavna komponenta je fajalitska osnova u koju je prožet bakar, halkopirit, magnetit i bakrenac. Bakar se nalazi u obliku bakrenca i elementarnog bakra u obliku žilica u fajalitskoj osnovi. Magnetit se nalazi u formi kocke i drugim različitim formama.

LITERATURA

- [1] Morales A., Cruells M., Roca A., Bergo R., Treatment of Copper Flash Smelter Dusts for Copper and Zinc Extraction and Arsenic Stabilization, Hydrometallurgy 105(2010), p. 148-154.
- [2] Mitrović Z., i dr., Glavni rudarski projekat otkopavanja šljake iz tehnogenog ležišta „Depo Šljake 1”, verifikacija tehnološkog procesa dobijanja koncentrata i nadvišenje flotacijskog jalovišta „RTH” u Boru do K +378 za godišnju proizvodnju od 1.200.000 t šljake; Institut za bakar Bor, 2006.
- [3] <http://rtb.rs/rtb-bor-doo/rudnik-bakra-bor/flotacija-bor/>
- [4] Magdalinović S., Milanović D., Čadenović B., Marjanović V., Tehnološki postupak granuliranja šljake radi sniženja krupnoće na ulazu u flotaciju, Rudarski radovi 3(2011), str. 101-110
- [5] Čadenović B., Marjanović V., Ljubojev V., Milanović D., Mogućnost iskorišćenja bakrenca iz topioničke šljake kod njenog direktnog izlivanja iz peći, R. Radovi, 2(2012), str. 137-142.
- [6] Ljubojev V., Petrović J., Krstić S., Mineralogical characteristics of smelting slag in the technogenic deposit “Depo 1” (Bor, Serbia). The Geology in digital Age: Proceedings of the Meeting of the Association of European Geological Societies (MAEGS 17), Belgrade (2011), p. 237-240.
- [7] Ljubojev V., Izveštaj o mikroskopskom ispitivanju granulirane šljake, IRM Bor, Maj, 2013.
- [8] Čadjenović B. Drobnjaković B., Milanović D., Magdalinović S., Novo laboratorijsko postrojenje za granuliranje izmenjenim tehnološkim postupkom izlivanja topioničke šljake, R. radovi 4(2011) str. 93-98
- [9] Požega E., Gomidželić L., Topionice bakra sa plamenom i ISASMELT peći, Bakar 2(2010), str. 25-32.