University of Belgrade
Technical Faculty in Bor,
Mining and Metallurgy
Institute Bor

54th International October Conference on Mining and Metallurgy

PROCEEDINGS

Editors:
Ljubiša Balanović
Dejan Tanikić

18-21 October 2023, Bor Lake, Serbia

PROCEEDINGS,

54th INTERNATIONAL OCTOBER CONFERNCE

on Mining and Metallurgy

Editors:

Prof. dr Ljubiša Balanović

Prof. dr Dejan Tanikić

University of Belgrade, Technical Faculty in Bor

Technical Editor:

M. Sc. Miljan Marković

University of Belgrade, Technical Faculty in Bor

Publisher: University of Belgrade, Technical Faculty in Bor

For the publisher: Dean Prof. dr Dejan Tanikić

Circulation: 200 copies

CIP - Каталогизација у публикацији Народна библиотека Србије, Београд

622(082)(0.034.2)
669(082)(0.034.2)

INTERNATIONAL October Conference on Mining and Metallurgy (54 ; 2023 ; Borsko jezero)
Proceedings [Elektronski izvor] / 54th International October Conference on Mining and Metallurgy - IOC 2023, 18-21 October 2023, Bor Lake, Serbia ; [organized by] University of Belgrade, Technical Faculty in Bor and Mining and Metallurgy Institute Bor ; editors Ljubiša Balanović, Dejan Tanikić. - Bor : University of Belgrade, Technical Faculty, 2023 (Niš : Grafika Galeb). - 1 USB fleš memorija ; 1 x 1 x 5 cm

Sistemski zahtevi: Nisu navedeni. - Nasl. sa naslovne strane dokumenta. - Tiraž 200. - Preface / Ljubiša Balanović. - Bibliografija uz svaki rad.

ISBN 978-86-6305-140-9

a) Рударство -- Зборници b) Металургија -- Зборници

COBISS.SR-ID 126659849

Bor Lake, Serbia, October 18-21, 2023

Conference is financially supported by
The Ministry of Science, Technological
Development and Inovation
of the Republic of Serbia

SCIENTIFIC COMMITTEE

Prof. Dr Dejan Tanikić *(Serbia) - president*
Prof. Dr Nada Štrbac *(Serbia) - vice-president*
Prof. Dr Radoje Pantović *(Serbia) - vice-president*

Dr Ana Kostov *(Serbia)*
Prof. Dr Adam Grajcar *(Poland)*
Prof. Dr Adina Negrea *(Romania)*
Dr Andrei Rotaru *(Romania)*
Prof. Dr Batrić Pešić *(USA)*
Dr Biserka Trumić *(Serbia)*
Prof. Dr Boštjan Markoli *(Slovenia)*
Dr Branislav Marković *(Serbia)*
Prof. Dr Cornelia Muntean *(Romania)*
Prof. Dr Daniela Grigorova *(Bulgaria)*
Prof. Dr Dejan Ivezić *(Serbia)*
Prof. Dr Desimir Marković *(Serbia)*
Prof. Dr Dimitris Panias *(**Greece**)*
Prof. Dr Dimitriu Sorin *(Romania)*
Prof. Dr Dmitry Vasilyev *(Russia)*
Dr Dragan Komljenović *(Canada)*
Prof. Dr Dragan Manasijević *(Serbia)*
Dr Dragan Milanović *(Serbia)*
Prof. Dr Dragan Milovanović *(Serbia)*
Prof. Dr Dragoslav Gusković *(Serbia)*
Prof. Dr Dušan Oráč *(Slovakia)*
Prof. Dr Duško Minić *(Serbia)*
Prof. Dr Endre Romhanji *(Serbia)*
Prof. Dr Essen Suleimenov *(Kazakhstan)*
Prof. Dr Farzet Bikić *(Bosnia and Herzegovina)*
Prof. Emeritus Fathi Habashi *(Canada)*
Prof. Dr Grozdanka Bogdanović *(Serbia)*
Prof. Dr György Kaptay *(Hungary)*
Prof. Dr Ivan Mihajlović *(Serbia)*
Prof. Dr Iveta Vaskova *(Slovakia)*
Prof. Dr Jakob Lamut *(Slovenia)*
Prof. Dr Jasmin Suljagić *(Bosnia and Herzegovina)*
Dr Jasmina Stevanović *(Serbia)*
Dr Jasna Stajić Trošić *(Serbia)*
Prof. Dr Jovica Sokolović *(Serbia)*
Prof. Dr Jožef Medved *(Slovenia)*
Prof. Dr Kaikun Wang *(China)*
Prof. Dr Karl Heinz Spitzer *(Germany)*
Prof. Emeritus Karlo Raić *(Serbia)*
Prof. Dr Kemal Delijić *(Montenegro)*
Prof. Dr Komnitsas Konstantinos *(Greece)*
Prof. Dr Kostas Matis *(Greece)*
Prof. Dr Krzysztof Fitzner *(Poland)*
Prof. Dr Luis Filipe Malheiros *(Portugal)*
Prof. Dr Milan Antonijevic *(Serbia)*
Prof. Dr Milan Trumić *(Serbia)*
Dr Mile Bugarin *(Serbia)*
Dr Milenko Ljubojev *(Serbia)*
Prof. Dr Milovan Vuković *(Serbia)*
Prof. Dr Mira Cocić *(Serbia)*
Mirjam Jan-Blažić *(Slovenia)*
Prof. Dr Mirjana Rajčić Vujasinović *(Serbia)*
Prof. Dr Mirko Gojić *(*Croatia*)*
Dr Miroslav Sokić *(Serbia)*
Prof. Dr Mirsada Oruč *(Bosnia and Herzegovina)*
Dr Nadežda Talijan *(Serbia)*
Prof. Dr Natalija Dolić *(*Croatia*)*
Prof. Dr Nedeljko Magdalinović *(Serbia)*
Prof. Dr Nenad Radović *(Serbia)*
Prof. Dr Nenad Vušović *(Serbia)*
Prof. Dr Nicanor Cimpoesu *(Romania)*
Prof. Dr Nobuyuki Masuda *(*Japan*)*
Prof. Dr Onuralp Yucel *(*Turkey*)*
Prof. Dr Pavel Broz *(*Czech Republic*)*
Prof. Dr Petr Solozhenkin *(*Russia*)*
Prof. Dr Petrica Vizureanu *(Romania)*
Dr Sun Zhongmei *(**China**)*
Prof. Dr Ridvan Yamanoglu *(*Turkey*)*
Prof. Dr Rodoljub Stanojlović *(Serbia)*
Prof. Dr Rositsa Paunova *(**Bulgaria**)*
Prof. Dr Sead Ćatić *(Bosnia* and *Herzegovina)*
Prof. Dr Sergey Krasikov *(*Russia*)*
Dr Slavomír Hredzák *(*Slovakia*)*
Prof. Dr Snežana Milić *(Serbia)*
Prof. Dr Snežana Šerbula *(Serbia)*
Prof. Dr Srba Mladenović *(Serbia)*
Dr Srećko Stopić *(Germany)*
Prof. Dr Stojan Groudev *(Bulgaria)*
Prof. Dr Sulejman Muhamedagić *(Bosnia and Herzegovina)*
Prof. Dr Svetlana Ivanov *(Serbia)*
Prof. Dr Tatjana Volkov-Husović *(Serbia)*
Prof. Dr Tomaš Havlik *(Slovakia)*
Prof. Dr Velimir Radmilović *(Serbia)*
Prof. Dr Velizar Stanković *(Serbia)*
Prof. Dr Vesna Grekulović *(Serbia)*
Dr Vladan Ćosović *(Serbia)*
Vladan Mihailović *(Serbia)*
Dr Vladan Kašić *(Serbia)*
Prof. Dr Vladimir Krstić *(Canada)*
Prof. Dr Vladislav Kecojević *(USA)*
Dr Walter Valery *(Australia)*
Prof. Dr Xuewei Lv *(China)*
Prof. Dr Yong Du *(China)*
Prof. Dr Žarko Radović *(Montenegro)*
Prof. Dr Zdenka Zovko Brodarac *(Croatia)*
Dr Zoran Stevanović *(Serbia)*
Prof. Dr Željko Kamberović *(Serbia)*

ORGANIZING COMMITTEE

Prof. dr Ljubiša Balanović, Full Professor *(UB TF Bor) - president*
Prof. dr Saša Stojadinović, Full Professor *(UB TF Bor) - vice-president*
Prof. dr Srba Mladenović, Full Professor *(UB TF Bor) - vice-president*
Dr Ana Kostov, Principal Research Fellow *(MMI Bor) - vice-president*

Prof. dr Nada Štrbac, *Full Professor (UB TF Bor)*
Prof. dr Dragan Manasijević, *Full Professor (UB TF Bor)*
Prof. dr Vesna Grekulović, *Full Professor (UB TF Bor)*
Prof. dr Đorđe Nikolić, *Full Professor (UB TF Bor)*
Prof. dr Milan Radovanović, *Full Professor (UB TF Bor)*
Prof. dr Marija Petrović Mihajlović, *Full Professor (UB TF Bor)*
Prof. dr Zoran Štirbanović, *Associate Professor (UB TF Bor)*
Prof. dr Milan Gorgievski, *Associate Professor (UB TF Bor)*
Prof. dr Saša Marjanović, *Associate Professor (UB TF Bor)*
Prof. dr Ivana Marković, *Associate Professor (UB TF Bor)*
Prof. dr Žaklina Tasić, *Associate Professor (UB TF Bor)*
Doc. dr Dejan Petrović, *Assistant Professor (UB TF Bor)*
Doc. dr Anđelka Stojanović, *Assistant Professor (UB TF Bor)*
Doc. dr Uroš Stamenković, *Assistant Professor (UB TF Bor)*
Dr Jasmina Petrović, *Assistant with PhD (UB TF Bor)*
Vladimir Nikolić, *Assistant (UB TF Bor)*
Milica Zdravković, *Assistant (UB TF Bor)*
Miljan Marković, *Assistant (UB TF Bor)*
Milijana Mitrović, *Assistant (UB TF Bor)*
Milan Nedeljković, *Assistant (UB TF Bor)*
Avram Kovačević, *Teaching Assistant (UB TF Bor)*
Sandra Vasković, *English Lecturer (UB TF Bor)*
Oliver Marković, *IT service (UB TF Bor)*
Violeta Aleksić, *Liquidator (UB TF Bor)*

TABLE OF CONTENTS

Plenary Lectures

Invited Lectures

Conference Papers

HYDROMETALLURGICAL TREATMENT OF MINING WASTE FROM BOR - SERBIA IN AIM OF COPPER RECOVERY

Ljiljana Avramović, Zoran Stevanović, Vanja Trifunović, Radmila Marković, Dragana Božić, Daniela Urošević, Silvana Dimitrijević

Mining and Metallurgy Institute Bor, Zeleni bulevar 35, 19210 Bor, Serbia

Abstract

Flotation tailings deposited on the Old Flotation Tailing Dump in Bor contains 0.2-0.4% Cu and represents a significant resource for recovery of copper and other useful components. The results of experimental laboratory tests of the copper recovery process from the flotation tailings using the beaker leaching (BL) and high pressure leaching (HPL) are given in this paper. By the use of beaker leaching, the degree of copper recovery of 70% and iron of 12% at temperature of 60°C, time of 24 hours and concentration of sulfuric acid of 15 g/l was achieved. A high degree of copper recovery of 99% was achieved by the high pressure leaching using water as an leaching reagent at a temperature of 180°C and pressure of 1.5 MPa.

***Keywords**: flotation tailings, beaker leaching, high pressure leaching, copper recovery*

1. INTRODUCTION

Pyrometallurgical process for copper production from sulphide minerals has existed in Bor for many years. During the processing of such type of ore, there is a formation of tailings generated during the flotation processes and containing the metal sulphides and under the effect of atmospheric conditions, the self-leaching process of tailings is developed resulting in a significant degradation the quality of surrounding water and soil [1,2].

It is estimated that more than 2000 ha of the most fertile coastal area of the Bor River, Bela River, and downstream Timok and Danube have been degraded by the flotation tailings. In addition to the physical contamination of the coastal area, the Bor River is constantly contaminated with wastewater generated by a drainage through the flotation tailing dumps and landfills.

This work presents the results of experimental laboratory test of copper recovery from the flotation tailings by the acid leaching process of tailings at the atmospheric pressure (BL) and high pressure leaching with the addition of oxidant (HPL). The highest level of copper leaching of 99% was achieved using the HPL method.

2. EXPERIMENTAL

For the experimental tests of the leaching process: BL and HPL, the flotation tailings from the Old Flotation Tailing Dump in Bor was used with a particle size of 72% -75 μm. The chemical composition of the initial flotation tailings sample is given in Table 1.

Table 1 - Chemical composition of flotation tailings

Element	Cu	Fe	S-total	S-sulphide	Ag	Au	As
Unit	%	%	%	%	g/t	g/t	%
Content	0.29	9.51	10.10	7.32	1.10	0.50	0.013

The BL experiments were carried out in order to investigate the effect of the following parameters: temperature (20-80ºC), sulfuric acid concentration (2-40 g/l H_2SO_4) and process time (2-48 h). The pulp density of 25% and stirring rate of 700 rpm were constant in all experiments. After completion of the leaching process, the filtered leaching solutions were analyzed to determine the leaching degree of Cu and Fe.

The HPL experiments were carried out on the same samples of flotation tailings in the Nitto Koastu autoclave, Japan, with a volume of 2 L of reaction vessel. The effect of sulfuric acid concentration (0-50 g/l), pulp density in the range of 10-40% and temperature (140-180°C) with the oxygen introduction at total pressure of 0.8 to 2.0 MPa was tested. The reaction time in all experiments is 60 minutes and stirring rate is 700 rpm.

The ICP-OES Spectro Vision device was used to analyze the concentration of tested elements.

3. DISCUSSION OF RESULTS

3.1. Beaker Leaching

The leaching degrees of copper and iron, depending on the process temperature, concentration of H_2SO_4 in the leaching solution and leaching time are shown in Figures 1,2 and 3, respectively.

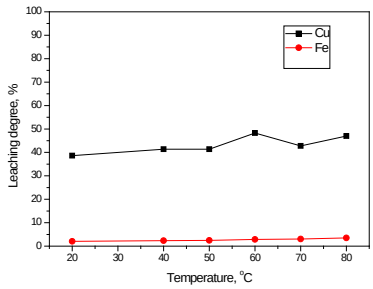

Figure 1 - The temperature effect on a leaching degree of Cu and Fe (τ=2 h, 2g/l H_2SO_4)

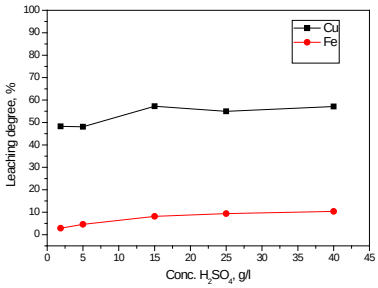

Figure 2 - The concentration effect of H_2SO_4 on a leaching degree of Cu and Fe (τ=2 h, t= 60ºC)

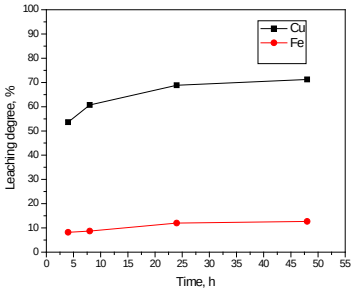

Figure 3 - The time effect on a leaching degree of Cu and Fe (15g/l H_2SO_4, t= 60ºC)

Based on the obtained testing results of the temperature effect (Figure 1), the leaching degree of copper ranges from 38% (20ºC) - 48% (80ºC). Considering that the similar values for the leaching degree of copper were obtained at temperatures of 60°C and 80°C (48% and 47%, respectively), it was decided that the further tests of the flotation tailings leaching process should be carried out at 60°C. With an increase in H_2SO_4 concentration in the leaching solution (Figure 2), an increase in the leaching degree of copper to 15 g/l was observed. Further increase in the concentration of H_2SO_4 to 40 g/l did not have a significant effect on a leaching degree of Cu. Maximum copper leaching degree of 71% was achieved at a leaching time 48 hours, temperature 60ºC and 15g/l H_2SO_4 (Figure 3).

The most influential parameters for the leaching degree of iron is the concentration of H_2SO_4 in leaching solution (Figure 2) and ranges from 2% (2 g/l H_2SO_4) to 10% (40 g/l H_2SO_4). With an increase in the leaching time of 48 h, an increase in the leaching degree of iron at 12.7% was observed (Figure 3).

Having in mind the fact that copper from the leaching solutions is recovered by the solvent extraction processes and electro-winning SX-EW, and that the increased iron concentration has a negative impact on the electrochemical copper extraction, in a selection the optimal parameter BL, the time was adopted of 24 h, temperature 60°C and concentration H_2SO_4 of 15 g/l.

3.2. High Pressure Leaching

The results of a high pressure leaching (HPL) are presented in Table 2.

Table 2 - Experimental conditions and results of the HPL process

Exp. No.	Pulp density (%)	Reagent	P_{total} (MPa)	Temperature (°C)	Time (h)	Stirring rate (rpm)	Leaching degree (%)	
							Cu	Fe
1	10	H_2O	2	180	1	700	95	24
2	20	H_2O	2	180	1	700	98	43
3	30	H_2O	2	180	1	700	92	60
4	40	H_2O	2	180	1	700	94	61
5	10	20 g/l H_2SO_4	2	180	1	700	97	66
6	10	50 g/l H_2SO_4	2	180	1	700	98	95
7	10	H_2O	0.8	180	1	700	21	2,35
8	10	H_2O	1.5	180	1	700	99	49
9	10	H_2O	2	140	1	700	89	40
10	10	H_2O	2	160	1	700	90	37

Water and sulfuric acid were used as a leaching reagent for the HPL process (Table 2). Leaching with water is based on the fact that the high content of pyrite (FeS_2) in the flotation tailings sample can be the source of H_2SO_4 (Equation 1) [3], which leads to a decrease in the pH (from 3.79 to 0.35) and thus increases copper dissolution (chalcopyrite as the main copper minerals).

$$2FeS_2 + 7.5O_2 + H_2O \rightarrow Fe_2(SO4)_3 + H_2SO_4 \quad (1)$$

By leaching with water, the realized degree of copper leaching was 99%, iron 49%, at 180°C, pressure of 2 MPa, pulp density 10%, time 1 h, stirring rate 700 rpm. With an increase in the H_2SO_4 concentration from 20 g/l to 50 g/l, the percentage of copper leaching has been slightly increased from 97% to 98%, while the degree of iron leaching increases from 67% to 95%. From an economic point of view, H_2O has been selected as a copper leaching medium from the flotation tailings.

The effect of total pressure on copper dissolution from the flotation tailings has been tested in the range of 0.8 to 2.0 MPa, with water as a dissolving medium, temperature of 180°C, pulp density of 10% and time of 60 min (Table 2). The degree of copper leaching was 21% and iron 2.35% at pressure of 0.8 MPa (without the introduction of oxygen). It can be concluded that after the initial dissolution of copper, a passive layer of elemental sulfur [4] was formed on chalcopyrite, which had a negative effect on kinetics of copper dissolution. With an increase in the pressure of 0.8 to 2.0 MPa with the oxygen supply, the degree of copper and iron leaching increased to 99%, i.e. 49%, respectively. The present oxygen allows oxidation and prevents the formation of passivation layer (Equation 2) [3,5].

$$S^{\circ} + 1.5O_2 + H_2O \rightarrow H_2SO_4 \quad (2)$$

With a temperature increase of 140 to 160°C, the degree of copper and iron leaching increased from 89 to 99% and from 37 to 49%, respectively. Based on the literature data [5], the chalcopyrite leaching controls the kinetics of chemical reaction on the grain surface with activation energy of about 70-90 kJ/mol. This implies that the leaching degree is highly dependent on temperature. An optimum condition for the next experiments was chosen to be the temperature of 180°C with a copper leaching degree of 99%.

As shown in Table 2, the first degree of copper leaching has not changed much with an increase of pulp density from 10 to 40%, i.e. no effect on the copper leaching degree [6,7]. As an optimal, the pulp density of 40% is chosen, since in this case the copper concentration in leaching solution is four times higher than the copper concentration in 10% pulp, which is a significant parameter for the copper extraction process from leaching solutions.

4. CONCLUSION

On the basis of the results obtained for the BL process of flotation tailings leaching, it can be concluded that the maximum degree of copper recovery is 71% and iron 12%, while in the HPL process, with the application of water as the leaching reagent, a significantly higher degree of copper recovery of 99% and iron recovery of 61% was realized.

A high concentration of iron in the solution after leaching in the HPL process is a serious problem in further copper recovery processes (SX-EW process) as a commercial product. Due to this reason, a consideration should be given to the possibility of introducing an additional phase of iron removal from the pregnant leaching solutions before the SX-EW process.

In order to select the method of copper leaching from the flotation tailings will largely be a decisive economic aspect of the tested BL and HPL processes what will be the subject of future research.

ACKNOWLEDGEMENTS (optional)

The authors are grateful for funding by the Minister of Science, Technological Development and Innovation of the Republic Serbia, the Grant No. 451-03-47/2023-01/ 200052. Also, this work was financially supported by the EU under Interreg – IPA CBC Romania-Serbia Programme and co-financed by the partner states in the Programme. Project Romania Serbia NETwork for assessing and disseminating the impact of copper mining activities on water quality in the cross-border area (RoS-NET2) eMS code RORS - 337. Also, this work was financially supported by the EU under Program 2nd EIT-HEI call: Building Ecosystem Integration Labs at HEI to foster Smart Specialization and Innovation on Sustainable Raw Materials - HEI4S3-RM.

REFERENCES

References should be listed at the end of the paper as they appear in the text. If a publication is referred in the text, use [1] for one reference, or [1,2,3] for more than one. Use the following styles for journals, proceedings and books, respectively:

[1] R. Jonović, Lj. Avramović, Z. Stevanović, M. Jonović, Mining and Metallurgy Engineering Bor 3 (2014) 153-160.
[2] L. L. Godirilwe, K. Haga, B. Altansukh, Y. Takasaki, D. Ishiyama, V. Trifunovic, Lj. Avramovic, R. Jonovic, Z. Stevanovic, A. Shibayama, Metals 11 (9) (2021) 1335.
[3] B. Han, B. Altansukh, K. Haga, Y. Takasaki, A. Shibayama, Z. Stevanovic, R. Jonović, Lj. Avramovic, D. Urosevic, Y. Takasaki, N. Masuda, D. Ishiyama, A. Shibayama, J. Hazard. Mater., vol. 352 (2018), 192-203.
[4] A.A. Baba, K.I. Ayinla, F.A. Adekola, M.K. Ghosh, O.S. Ayanda, R.B. Bale, S.R. Pradhan, Int. J. Min. Eng. Miner. Process. 1.1 (2012) 1–16.
[5] A. Muszer, J. Wodka, T. Chmielewski, S. Matuska, Hydrometallurgy 137 (2013) 1-7.
[6] R. Padilla, P. Pavez, M.C. Ruiz, Hydrometallurgy 91 (2008) 113-120.
[7] Lj. Avramović, R. Jonović, M. Bugarin, A. Shibayama, K. Haga, H. Baisui, R. Marković, M. Jovanović, XI International Symposium on Recycling Technologies and Sustainable Development (2016), 240-247.