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Prof. Dr Snežana Šerbula

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PREFACE

The 31st international conference Ecological Truth & Environmental Research – EcoTER'24 focuses on showing the latest research findings and innovations in the field of ecology, environmental protection and sustainable development. The conference will be held in Sokobanja (Serbia) in hotel Sunce in the period of 18–21 June 2024.

The aim of the conference is to connect the experts in various fields in order to transform attitudes and behaviors in everyday practices, as well as in the industry and economy sector which is essential for achieving the desired changes that our society must undergo.

The 31st international conference Ecological Truth & Environmental Research – EcoTER'24 is organized by the University of Belgrade, Technical Faculty in Bor, and co-organized by the University of Banja Luka, Faculty of Technology; the University of Montenegro, Faculty of Metallurgy and Technology – Podgorica; the University of Zagreb, Faculty of Metallurgy – Sisak; the University of Pristina, Faculty of Technical Sciences – Kosovska Mitrovica and the Society of Young Researchers – Bor.

These Proceedings encompass 119 papers from the authors coming from the universities, research institutes and industries in 15 countries: Brazil, Norway, USA, Spain, Austria, Libya, Italy, Israel, Slovenia, Croatia, Romania, Bulgaria, Montenegro, Bosnia and Herzegovina, North Macedonia, and Serbia. It is a great honor and pleasure to cordially wish a warm welcome to all the participants of the conference.

As a part of this year's conference, the 6th Student Section – EcoTERS'24 will be held. We appreciate the contribution of the students and their mentors who have also participated in the conference and hope that students will continue to explore and to be curious, since education is a never-ending process, and knowledge is continuously growing.

The organization of the EcoTER'24 conference has been financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia.

The support of the Donors and their willingness and ability to cooperate has been of great importance for the success of the EcoTER'24 conference. The organizing committee would like to extend their appreciation and gratitude to the Platinum donors of the conference – Serbia ZiJin Copper doo Bor and HBIS SERBIA, to the Gold donor of the conference – Elixir Group, as well as to the Silver donor of the conference – Serbian Chamber of Engineers.

We would like to express our sincere appreciation to all the authors who have contributed to the Proceedings. We would also like to express our gratitude to the members of the scientific, organizing and honorary committees, reviewers, speakers, chairpersons and all the conference participants for their support of the EcoTER'24. Sincere thanks go to all the people who have contributed to the successful organization of the EcoTER'24.

Prof. Snežana Šerbula,

President of the scientific and organizing committee

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AGITATION LEACHING OF FLOTATION TAILINGS AT THE PILOT PLANT

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Abstract

Flotation waste, which was produced through seventy years of copper ore processing in RTB Bor, Serbia, is deposited in a flotation tailings pond. In total, almost 22.3 Mt could be considered as available for eventual reprocessing and reuse. Chemical analysis had shown that an average concentration of targeted metals in the tailings is: 0.23% Cu, 0.53 g/t Au and 2.83 g/t Ag. Physical characteristics of representative sample of flotation tailings composites include determination of sample density, bulk density and sample pH. Based on the obtained results of the granulometric analysis, it can be concluded that in the sample 66.50% of the particles are smaller than 75 µm in size. The leaching degrees of the analyzed elements, based on the results of chemical analyzes of the solid residue, achieved after leaching of the composite sample of flotation tailings at the pilot plant were recalculated and are: 75.67% Cu, 16.48% Fe, 4.76% Ag and 5.6% Au.

Keywords: leaching, flotation tailings, pilot plant.

INTRODUCTION

In the process of flotation of copper ore, flotation tailings containing metal sulfides are separated and represent a special challenge for the topic of mining waste management. Due to the formation of acid mine waters (AMD) and the exposure of tailings to atmospheric oxygen, bacteria and water, metals from tailings are dispersed into the environment, which directly affects the degradation of the quality of surface and underground water as well as the surrounding soil [1,2].

Due to the increased exploitation of copper ores and the discovery of low-quality deposits, it can be expected that more tailings will be present in the coming years, which could cause more environmental problems and challenges to solve them.

Considering the fact that the recovery of copper from the ore through the flotation process is about 56%, this indicates that the flotation tailings contain valuable copper components. In addition, old flotation tailings sometimes have higher copper content (0.2–0.4% Cu) than low-grade ores (0.2–0.3% Cu). The copper content of old flotation tailings is similar to the world average content of about 0.4% Cu for copper in mined ore. Considering the current price of copper and predictions that demand for copper will increase, flotation tailings and low-grade copper ores represent a potential future source of copper.

Compared to pyrometallurgical processes, hydrometallurgical treatment has greater potential for treating complex low-grade sulphide ores and concentrates, resulting in increased metal recovery and reduced air pollution hazards. In recent years, research and development

of hydrometallurgical processes has intensified as an alternative to pyrometallurgical treatment.

The calculated mean contents of the deposit of man-made mineral raw materials in the area of the Old Flotation Tailings, calculated on the basis of data obtained during the entire research period (1961/62, 2007, 2015/16, 2016/17, and 2017/18), amount to: 0.530 g/t Au ; 2.826 g/t Ag and 0.230% Cu. It should be noted that during the research period, 1961/62 and during 2007, taken samples were not analyzed for gold and silver, but only for Cu [3].

The calculated reserves of the technogenic deposit amount to 22.3 Mt of mineral raw material, with about 12 t of Au, 63 t of Ag and 51,303 t of Cu metal. On the basis of the above, it can be concluded that significant amounts of gold, copper and silver are present in the flotation tailings, and that a significant profit would be achieved by valorizing them. Over the years, experience has taught us that flotation tailings ponds, containing many hazardous components, negatively affect the environment [4–6].

The aim of this paper was to confirm the leaching of Cu as an adequate process for hydrometallurgical extraction of copper from flotation tailings at the pilot plant after the laboratory tests were completed. And also to consider adequate treatment of the solid residue that is formed in the acid leaching process of copper and in which precious metals are concentrated: gold and silver.

The paper contains a systematized review of physical characteristics and granulometric analysis of representative sample of flotation tailings composite which is acid leached at atmospheric pressure on an enlarged scale – at a pilot plant.

MATERIALS AND METHODS

In this paper, composite samples of flotation tailings with the following designations were used for the planned experimental tests of the leaching process of copper, gold and silver from the tailings of the Old Flotation Tailings:

Composite I + III was formed from samples from the part of the tailings that includes the Old French tailings and Field 1 with an estimated total amount of tailings of 14,862,708 t, which represents about 60% of the total amount of tailings. The estimated metal content is: 37,157 t Cu + 6.7 t Au + 20.0 t Ag.

RESULTS AND DISCUSSION

Physical-chemical characterization of the samples

Physical characteristics of representative samples of flotation tailings composites include determination of sample density, bulk density and sample pH. The results of physical characterization of representative samples of flotation tailings composites are shown in Table 1.

Table 1 *Physical characterization of representative composite samples of flotation tailings*

Sample	Density (g/cm^3)	Bulk mass (kg/m^3)	pH
COMPOSITE I+III	2.765	1176.0	2.82

In Table 2 the chemical characterization of representative sample of flotation tailings composites is presented.

Table 2 *Chemical composition of representative sample of flotation tailings composite I + III*

Element	Unit	Content	Analytical method*
Cu_{uk}	%	0.25	AAS
Cu_{ox}	%	0.18	AAS
Fe	%	7.62	ICP-AES
Ca	%	0.78	ICP-AES
K	%	0.54	ICP-AES
Na	%	0.23	ICP-AES
S	%	9.34	ACS
SiO_2	%	52.88	G
Al_2O_3	%	10.76	ICP-AES
Au	ppm	0.45	FA/AAS
Ag	ppm	1.40	FA/AAS
Sr	ppm	648	ICP-AES
As	ppm	122	ICP-AES
Zn	ppm	23.6	ICP-AES

** AAS - Atomic Absorption Spectrophotometer*
ICP-AES - Inductively Coupled Plasma Atomic Emission Spectrometry
ACS - Carbon and Sulfur Analyzer
G - Gravimetry
FA - flame analysis of precious metals (cupellation)

Based on the copper analysis shown in Table 2, it can be stated that the share of oxide copper in relation to total copper for the examined composite samples is as follows:

COMPOSITE I +III: Cu oxide/Cu total = 0.18/0.25 = 0.72 (72%)

Granulometric composition of the sample

The granulometric composition of sample of the flotation tailings composite was determined by the sieving method on laboratory sieves made of fine mesh, wire and perforated metal plate (SRPS ISO 2591-1:992).

Based on the obtained results of the granulometric analysis, it can be concluded that in the sample COMPOSITE I+III, 66.50% of the particles are smaller than 75 μm in size (Table 3).

Table 3 *The granulometric composition of the flotation tailings composite sample COMPOSITE I+III*

d (mm)	m (%)	R (%)	D (%)
-4+2.36	7.60	7.60	100.0
-2.36+1.70	0.20	7.80	92.40
-1.70+0.850	0.40	8.20	92.20
-0.850+0.600	0.40	8.60	91.80
-0.600+0.425	0.30	8.90	91.40
-0.425+0.300	6.70	15.60	91.10
-0.300+0.212	1.10	16.70	84.40
-0.212+0.150	4.40	21.10	83.30
-0.150+0.106	6.30	27.40	78.90
-0.106+0.075	6.10	33.50	72.60
-0,075+0.053	5.50	39.00	66.50
-0.053+0.038	5.50	44.50	61.00
-0.038+0.00	55.50	100.00	55.50

Copper leaching from the sample composite I+III

In a reactor made of poly-propylene, with a volume of 100 L, the leaching experiment of a composite sample of flotation tailings COMPOSIT I+III in an amount of 15 kg was carried out, under optimal conditions previously defined by laboratory tests (particle size: -75 μm, without the addition of oxidants, temperature: ambient, ratio of solid and liquid phase: 1:4, time: 4h, pH of the suspension: pH=1. To correct the pH value from pH 2.9 to pH 1, it was added 600 ml of concentrated H_2SO_4, which represents the consumption of concentrated sulfuric acid of 70 kg per ton of tailings.

Apparatus for performing enlarged experimental testing of the copper agitation leaching process at the pilot plant is shown in Figure 1.

After the leaching process was completed, the suspension was filtered on a plan filter (Figure 1), and the solid residue was washed with water that was mixed with the alkaline solution. The volume of alkaline solution and rinse water was 87 L.

Figure 1 *Leaching and filtering of the composite sample of flotation tailings COMPOSITE I+III at the pilot plant*

The solid residue was dried in a dryer to a constant mass of 12.5 kg, sampled, its physico-chemical characterization was performed (Table 4 and Table 5), and its granulometric composition was determined, the results of which are shown in Table 6.

Table 4 *Results of physical characterization of the solid residue (*T-SFJ-PILOT)

Sample		Unit	Value
T-SFJ-PILOT	Sample mass	kg	13.2
	Moisture	%	0.90
	Bulk mass	kg/m^3	1120
	Density	kg/m^3	2840
	pH	/	2.72

Table 5 *Results of the chemical analysis of the solid residue after copper leaching from the composite sample COMPOSIT I+III*

Element	Cu (%)	Fe (%)	Ag (g/t)	Au (g/t)
Content	0.073	6.15	1.6	0.51

Based on the results of chemical analyzes of the solid residue, the leaching degrees of the analyzed elements achieved after leaching of the composite sample of flotation tailings I+III at the pilot plant were recalculated and are: 75.67% Cu, 16.48% Fe, 4.76% Ag and 5.6 % Au, which is in agreement with the results obtained at the laboratory level. Given that the content of oxide copper in the composite sample of flotation tailings I+III is 72% (based on the data shown in Table 2), we can state that the copper present in the oxide form was completely leached in the sulfuric acid solution without heating, in a time of 4h and at the ratio of solid and liquid phase 1:4.

Table 6 *Granulometric composition of the solid residue after leaching of the composite sample COMPOSIT I+III*

d (mm)	m (%)	R (%)	D (%)
-0.300+0.212	1.00	1.00	100.00
-0.212+0.150	3.00	4.00	99.00
-0.150+0.106	6.00	10.00	96.00
-0.106+0.075	5.50	15.50	90.00
-0.075+0.053	4.50	20.00	84.50
-0.053+0.038	6.00	26.00	80.00
-0.038+0.020	10.50	36.50	74.00
-0.020+0.00	63.50	100.00	63.50

Based on the obtained results of granulometric analysis, it can be concluded that 90% of the sample of solid residue obtained after agitation leaching of the composite sample of flotation tailings COMPOSIT I+III at the pilot plant consists of particles smaller than -75 μm**.**

CONCLUSION

This paper presents the results of copper agitation acid leaching at atmospheric pressure for 4 hours, with a ratio of solid to liquid phase 1:4, and a concentration of sulfuric acid of 1.7% H_2SO_4 at ambient temperature. Leaching was carried out at the pilot plant, during which

15 kg of flotation tailings were leached. The results showed that under these conditions the percentage of Cu leaching was over 75%.

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