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INVESTIGATION OF PRE-CONCENTRATION OF THE LECE ORE USING DENSE MEDIUM GRAVITY CONCENTRATION

Slavko Todić[1], Predrag Lazić[1], Tamara Gavrilović[2]

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Abstract: The pre-concentration of Pb–Zn ores is commonly performed using gravity concentration in a dense medium. The primary objective of this process is to remove coarse-grained gangue from fully crushed ore using a cost-effective method, while keeping the loss of valuable metals within acceptable limits—comparable to or lower than those observed in flotation processes.

Laboratory tests on ore from the Lece deposit indicate that gravity concentration in a dense medium can successfully remove over 60% of coarse-grained gangue from fully crushed ore. From a process applicability standpoint, this represents a promising result. However, the associated losses of valuable metals—particularly gold and silver—are substantial, reaching approximately 50%. Gold is the most valuable component in the Lece ore. Therefore, pre-concentration at the final crushing stage is not considered feasible at industrial scale.

Keywords: Pb–Zn ores, pre-concentration, gravity concentration, dense medium, pre-concentrate, coarse-grained gangue, metal recovery

1 INTRODUCTION

Gravity concentration in a dense medium can be applied as a pre-concentration method for ores, particularly when coarse-grained gangue—representing at least 40% of the total mass—is removed, while ensuring that metal losses in the gangue remain lower than in the primary beneficiation process (Ćalić, 1990).

The applicability of gravity concentration is typically assessed through sink–float (S–F) analysis, in which coarse-grained gangue is separated at different densities under

[1] Faculty of Mining and Geology, University of Belgrade, Djusina 7, 11000 Belgrade, Serbia,
[2] University of Pristina Faculty of Technical Sciences, Kneza Miloša 7, 38220 Kosovska Mitrovica, Serbia

E-mails: slavko.todic@rgf.bg.ac.rs, ORCID: 0009-0001-7941-9255; predrag.lazic@rgf.bg.ac.rs, ORCID: 0000-0002-3953-2202; tamara.gavrilovic@pr.ac.rs, ORCID: 0000-0003-3448-7753

laboratory or pilot-scale conditions. The separated products are chemically analyzed, and a pre-concentration mass balance is prepared (Deušić and Lazić, 2013).

This study presents the results of laboratory-scale testing on fully crushed ore from the Lece deposit, focusing on the potential application of dense-medium pre-concentration. The final decision on implementing pre-concentration in a dense-medium suspension is always based on a comprehensive economic analysis (Dardis, 1985).

Pre-concentration generally yields a more favorable particle size distribution of the pre-concentrate compared to run-of-mine (ROM) ore. This is primarily because hard, coarse-grained gangue is removed prior to grinding, which positively affects energy efficiency during milling (Motovilov et al., 2019). In addition, the removal of hard, coarse-grained gangue frees up flotation plant capacity proportional to the mass of material rejected through pre-concentration, allowing increased mine throughput without significant investment in flotation facilities (Kolacz, 2017).

Besides dense-medium-based pre-concentration, other methods such as X-ray and optical sorting have also been reported (Karami et al., 2019). Nevertheless, gravity concentration remains one of the oldest mineral processing methods, having been used for more than a century (Legault-Seguin et al., 2016).

Gravity concentration in a dense medium is a robust process capable of handling particles of varying sizes (from 300 mm down to 0.5 mm), provided prior liberation of mineral grains has been achieved (Sheng et al., 2019). Continuous advancements in equipment and process design, including the development of a biconical cyclone for separation in suspensions, have demonstrated promising results (Motovilov et al., 2019).

2 MATERIALS AND METHODS

The Lece ore primarily consists of sulfide minerals and quartz, with a relatively limited variety of mineral species. Ore minerals in the open-pit zone of the deposit formed at low temperatures. The main minerals present include sphalerite, galena, pyrite, chalcopyrite, and gold-bearing quartz (Lece Mine, n.d.).

Sphalerite is one of the most widespread and abundant sulfide minerals in the deposit. It rarely occurs in coarse crystals, being mostly fine-grained, and contains cadmium. Sphalerite in the deposit formed in three distinct stages (Lece Mine, n.d.).

Galena, together with sphalerite, represents the most important mineral in the deposit. The majority of galena occurs as fine-grained crystals and mineral aggregates. Galena formed in three stages; the largest portion belongs to the third stage, a smaller amount to the second, and the least to the first. Galena from the second and third stages occurs without segregation, forming crystalline masses and nests; it contains gold and silver, and is thus referred to as gold-bearing galena. Galena replaces older minerals and is most commonly replaced by pyrite. It is fractured and cataclastic. In the oxidation zone, galena is coated with a thin to thick crust of cerussite (Motovilov et al., 2019).

Pyrite is widespread in the deposit, occurring as rounded granular aggregates, indicative of formation from a gel. Chalcopyrite often cements pyrite and partially replaces it. Pyrite grain size varies but is mostly in the range of 4–5 mm. Pyrite contains traces of gold and silver (Motovilov et al., 2019). Due to the presence of gold and silver in pyrite, a pyrite flotation process has been developed, and the flotation plant at the Lece mine currently produces three concentrates: lead concentrate, zinc concentrate, and pyrite concentrate.

Chalcopyrite is the primary copper-bearing mineral and is always present in small amounts in the ore. Gold occurs in the ore as native metal, found within quartz, galena, sphalerite, and pyrite, typically in rounded forms (Kolacz, 2017).

The tested material, weighing 13.73 kg, was obtained from the Lece mine. This sample represents fully crushed ore taken from the conveyor belt feeding the ball mill. After determining the sample mass, it was sieved through a series of five sieves with mesh openings of 40 mm, 30 mm, 15 mm, 10 mm, and 5 mm to determine the particle size distribution of the feed sample.

The objective of this research was to investigate the potential for pre-concentration by immersing the ore sample in a bromoform ($CHBr_3$) solution. Since it is recommended that fine size fractions –3(2.5) +0 mm are not subjected to pre-concentration, wet sieving (washing) of the entire sample was conducted on a 2.5 mm sieve. The –2.5 +0 mm size fraction was not immersed in bromoform but was dried, weighed, and chemically analyzed separately.

The mass of the +2.5 mm size fraction was 10.15 kg, while the –2.5 +0 mm fraction weighed 3.58 kg. Prior to conducting the sink–float analysis on the +2.5 mm size fraction in the dense medium, the density of the dense liquid (bromoform, $CHBr_3$) was measured using a pycnometer, yielding a density of 2.67 g/cm^3. This relatively low density, close to that of quartz gangue, was chosen deliberately to minimize metal losses in the coarse gangue, even though it may lead to a low yield of the ΔL fraction (coarse gangue). Therefore, these results are considered preliminary.

After stratification of the entire +2.5 mm material, the vessels containing the heavy (ΔT) and light (ΔL) fractions were dried in a ventilated oven. Once dried, the masses of the light and heavy fractions were measured. The heavy fraction (ΔT) weighed 1,650 g, and the light fraction (ΔL) weighed 8,500 g.

Subsequently, the samples were processed and prepared for chemical analysis. This preparation included multi-stage comminution (crushing and grinding), homogenization, and sampling of material for chemical analysis (approximately 100 g per sample, with particle size below 100 μm) (Sheng et al., 2019).

3 RESULTS AND DISCUSSION

The experimental results are presented below, together with a detailed analysis and discussion.

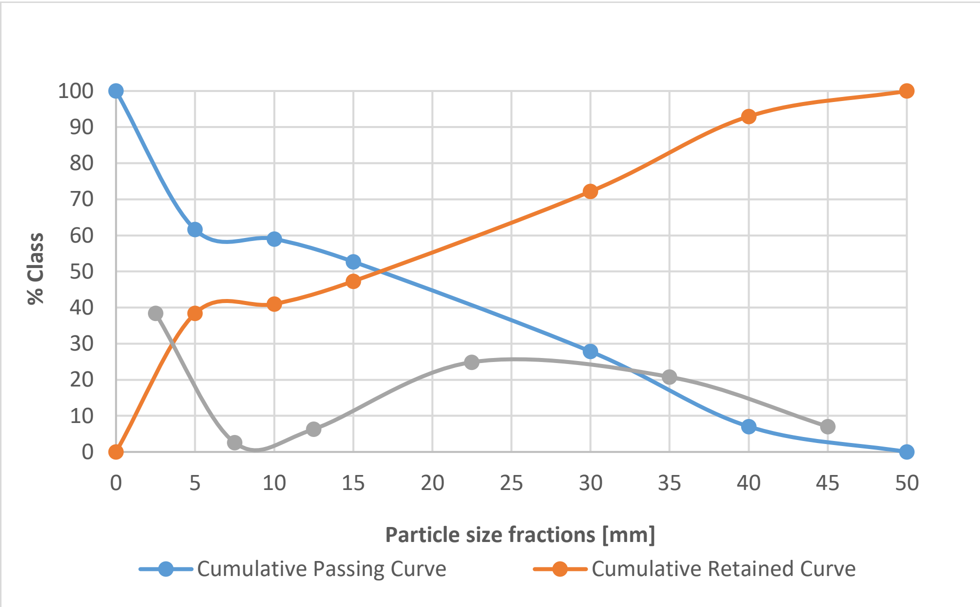

Figure 1 Graphical representation of the particle size distribution of the feed sample

From the particle size distribution diagram (Figure 1), the median particle size (d_{50}) was determined to be 16 mm by intersecting the cumulative oversize and undersize curves with the 50% mass line. The upper limit of the coarse particle size (d_{95}) was read as 44 mm by extending a line from 95% mass on the ordinate to intersect the undersize curve.

The frequency distribution curve represents the mass proportion of each size class, illustrating the relative distribution of particle sizes. In this sample, the most abundant size class by mass is the -5 +0 mm fraction, accounting for 38.38%, whereas the least represented class is the -10 +5 mm fraction, accounting for 2.60%.

Following dry sieving and determination of the particle size distribution, the sample was wet sieved on a 2.5 mm sieve. The undersize fraction (-2.5 +0 mm) was dried, weighed, and submitted for chemical analysis. Sink–float analysis was conducted on the oversize fraction (+2.5 mm), producing two fractions: the heavy fraction (ΔT) and the light fraction/gangue (ΔL). The heavy fraction was then combined with the untreated undersize material (-2.5 +0 mm) to form the pre-concentrate.

The mass balances of the sink–float analysis and the pre-concentration process are presented in Tables 1 and 2.

Table 1 Sink–float analysis balance

Products	M, [kg]	M, [%]	Pb, [%]	Zn, [%]	Au, [g/t]	Ag, [g/t]	I Pb, [%]	I Zn, [%]	`I Au, [%]	I Ag, [%]
Feed	13.73	100.00	0.43	1.03	3.58	6.16	100.00	100.00	100.00	100.00
ΔT	1.65	12.02	0.86	3.35	2.30	8.03	23.86	39.00	7.71	15.68
ΔL(Taili-ngs)	8.5	61.91	0.12	0.28	2.90	3.57	17.15	16.79	50.09	35.91
-2,5 mm	3.58	26.07	0.98	1.75	5.80	11.43	58.99	44.21	42.20	48.42

Based on the mass balance results of the sink–float analysis, it can be concluded that the process was effective in removing coarse-grained gangue, with 61.91% of the feed material separated into the light fraction (gangue). In general, pre-concentration is considered viable when this value exceeds 40%. By combining the heavy fraction with the -2.5 mm size fraction, which was not subjected to gravity concentration, the pre-concentrate was obtained.

The chemical analysis of the pre-concentrate and gangue fractions revealed that the pre-concentrate contained the majority of the valuable metals, while metal losses in the light fraction were minimized. However, significant losses of gold and silver were observed, reflecting the need to carefully consider the economic feasibility of applying dense-medium pre-concentration at the final crushing stage.

The particle size distribution of the pre-concentrate also showed a higher proportion of finer particles compared to the original feed, which is advantageous for subsequent grinding and flotation processes, as it reduces energy consumption and improves the efficiency of downstream operations.

Table 2 Mass and metal balance of preconcentration

Products	M, [kg]	M, [%]	Pb, [%]	Zn, [%]	Au, [g/t]	Ag, [g/t]	I Pb, [%]	I Zn, [%]	I Au, [%]	I Ag, [%]
Feed	13.73	100.00	0.43	1.03	3.58	6.16	100.00	100.00	100.00	100.00
-2,5 [mm] + ΔT	5.23	38.09	0.94	2.25	4.70	10.36	82.85	83.21	49.91	64.09
Tailings	8.50	61.91	0.12	0.28	2.90	3.57	17.15	16.79	50.09	35.91

According to the results of this mass balance, the effectiveness of the pre-concentration test can be assessed from two perspectives. The process successfully removed a substantial portion of coarse-grained gangue (61.91%), which contained 0.12% Pb and 0.28% Zn. The losses of lead and zinc in the tailings were approximately 17%, which is slightly higher compared to the losses observed in flotation tailings. This could potentially be mitigated by applying a lower suspension density during the pre-concentration process.

However, the loss of gold in the coarse-grained tailings—approximately 50%—is considered unacceptable, as is the silver loss of about 36%. These results suggest that a significant portion of gold and silver is associated with quartz, since, at the density used for stratification (2.67 g/cm³), quartz reported to the tailings. From an economic perspective, this outcome could be beneficial because quartz, with a Mohs hardness of 7, is difficult to grind, thereby reducing energy requirements during milling. Nevertheless, the ore exhibits a heterogeneous and complex composition, and gold occurs within quartz minerals in the form of fine filaments. Consequently, the transfer of quartz into the light fraction resulted in substantial losses of gold and silver in the tailings.

4 CONCLUSION

The pre-concentration of ore, when applicable, can offer significant savings in the overall ore processing operation.

Based on the analysis of the obtained pre-concentration mass balances of the crushed ore from the Lece deposit, it can be concluded that the process is applicable in terms of the mass fraction of coarse-grained gangue. Specifically, when more than 40% of the material reports to the light fraction, the pre-concentration process is considered feasible. In this study, the ΔL value reached 61.91%, indicating economic viability from this perspective.

At the stratification density of 2.67 g/cm³, a large portion of quartz reported to the light fraction (tailings), which could provide considerable advantages in subsequent grinding stages. Quartz, with a Mohs hardness of 7, is difficult to grind, so its removal reduces energy consumption, wear on mill liners, and abrasion of grinding media. Furthermore, by removing over 60% of the gangue through pre-concentration, the amount of material requiring grinding—and subsequently flotation—is substantially decreased, allowing for potential increases in plant throughput.

The pre-concentration process would also reduce the volume of fine-grained flotation tailings discharged to the tailings pond, positively affecting environmental management.

However, the main limitation of applying this pre-concentration method is the significant loss of gold and silver to the tailings. As noted, quartz reported to the light fraction, and because the ore has a heterogeneous composition, part of the gold occurs within quartz as fine filaments. Consequently, the gold loss in the tailings is approximately 50%, while silver loss is around 36%.

Considering all these factors, it can be concluded that the pre-concentration process, as applied to the crushed ore from the Lece deposit, is not suitable for practical industrial implementation.

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