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Lead-Zinc Concentrates Quality Improve by Enhancing Slurry Agitation Process

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Abstract: Lead-zinc sulphide ore mined from the Toranica deposit and is processed in the concentrator. The deposit is located in the Osogovo mountain, the northeastern part of the Republic of North Macedonia, near the Bulgarian Macedonian border. The main ore minerals in the lead-zinc ore are represented by galena, sphalerite, chalcopyrite, pyrite, and the non-ore minerals by quartz, carbonates, barite. After crushing and grinding, the ore is beneficiated using a direct selective flotation. It is common knowledge that slurry agitation is important for the flotation efficiency and makes the mineral particles fully mix with the flotation reagent. It was established that with the available conditioning tank agitator in the Toranica lead-zinc concentrator, the necessary slurry agitation is not achieved. This leads to inefficient flotation process and low-quality Pb and Zn concentrates production. During certain periods of the concentrator's operation, a zinc concentrate with an average monthly content of lead impurities is produced, reaching up to 6.08%, while at the same time a lead loss was registered in the final flotation tails. To eliminate the causes leading to deteriorate technological indicators, the lead-zinc ore mineral composition was investigated. Moreover, slurry agitation has been improved by implementing an advanced conditioning tank. High-quality final concentrates production was achieved, and the recovery degree was also increased. This paper is organized divided into four sections. Section 1 gives a brief overview of sulphide lead-zinc ores, their flotation beneficiation, reagents and flowsheets. The second section examines our research and development program to establish the technological possibilities for replacement of an available conditioning tank agitator. In the third section the case study is analyzed, and we propose a new procedure for conditioning tank agitator improvement. Our conclusions are drawn in the final section.

Keywords: Mining engineering, Conditioning tank agitator, Concentrates quality

Introduction

As many authors stated mining industry is witnessing an epochal revolution due to the metals growing demand (copper, iron, aluminum, nickel, gold, lead and zinc), industrial minerals and energy resources (oil, uranium) all over the world and especially in the currently developing economies (Tomova, 2023; Yankova, et. al, 2023). The lead and zinc growing consumption and the global tendency to exhaust deposits containing high-quality lead-zinc ores place increasingly high demands on the efficient lead-zinc ores processing and the full metals recovery. The main lead and zinc source is sulphide lead-zinc ores, which beneficiation by flotation.

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Lead-zinc ores characteristic feature is presence of aggregates associated with sulfides, located among a mass of non-ore minerals or host rocks, which necessitates the fine ore grinding below 74 µm (Barnov et al., 2018; Nayak et al., 2020). Appropriate technological flowsheet selection is of great importance for flotation efficiency, as well as highly selective flotation reagents, which are dependent on several factors such as: mineral and chemical ore composition, physical properties, mineral aggregates size, oxide phases presence, etc. (Nayak et al., 2021; Wei et al., 2021; Zhang et al., 2022; Yang et al., 2022).

In addition to conventional flotation reagents used so far in the concentrators practice, new reagents with improved performance are constantly being developed and synthesized, including biodegradable ones, which are essential for technological circuits (Zhang et al., 2022; Neisiani, Chelgani, 2024). In selective flotation for the separation of galena from sphalerite, xanthates are widely used. However, these reagents are toxic and exhibit some instability in acidic media. The effectiveness of new reagents which, compared to xanthates, have a stronger collection ability and maximum selectivity have been studied (Dong et al., 2021; Wang et al., 2021; Kong et al., 2024).

Lead-zinc sulphide ore mined from the Toranica deposit is processed in the Toranica concentrator nearby Kriva Palanka city. The deposit is in the Osogovo mountain, in the northeastern part of the Republic of North Macedonia, about 24 km from the Kriva Palanka town, near the Bulgarian-Macedonian border. Industrial operation began in 1987 with the production of 41 232 tonnes ore per year, currently reaching around and over 300 000 t (Despodov et al., 2021). According to Serafimovski et al. (2022) the deposit has lead-zinc ore reserves of 4 959101 t and ore resources of 7 640899 t, with Pb+Zn content from 6.33 to 7.40%, Ag 20 g/t. Ore bodies have elongated banded, layered, lens-like shape or irregular morphology. The main ore minerals are represented by sulphides galena, sphalerite, chalcopyrite, pyrite, and non-ore minerals by quartz, carbonates, barite (Serafimovski et al., 2022).

In certain periods of the Toranica concentrator activity, the concentrates produced show deteriorated technological indicators and do not meet the metallurgical processing requirements. This paper describes the results of the research conducted to identify and eliminate the factors, having a negative impact on the flotation efficiency and metals recovery. It was found that the use of current outdated model conditioning tank agitator for reagent addition at the beginning of flotation circuits, contact between reagents and the slurry was not obtained.

Slurry agitation is insufficient, and as a result the subsequent flotation processes efficiency is also reduced. As is well known, proper agitation provides optimal blending due to ensuring a large area of influence. Conditioning tanks prepare the slurry for flotation by ensuring that reagents are effectively mixed. With conditioning tank agitator implementation in the Toranica concentrator the sustainable production of quality concentrates and an increase in metals recovery rate have been achieved.

Materials and Methods

In lead-zinc ore treatment, the main ore minerals were represented by galena and sphalerite, as subordinate by distribution is pyrite and chalcopyrite are observed, and pyrrhotite, pyrite-marcasite pseudomorphs after pyrrhotite, magnetite, hematite, etc. are found in a relatively minor amount. Gangue minerals are represented by quartz, carbonates, barite, micas, skarn minerals from the pyroxene group, garnets, clay minerals, etc.

As illustrated in Figure 1a, the main ore minerals galena and sphalerite usually occur together in common aggregates and are much less often observed in individual form. Corroded grains of pyrite and chalcopyrite are present in the galena in places, and in places of pyrrhotite and pseudomorphoses from pyrite-marcasite after pyrrhotite (Figures 1b, 1c, 1d), as well as quartz and other gangue minerals. Two different varieties of sphalerite are distinguished. The early sphalerite contains emulsion and fine chalcopyrite inclusions, and the later sphalerite is chalcopyrite emulsion-free, homogeneous (Figure 1a, 1c). Pyrite is more abundant than chalcopyrite and is in most cases closely associated with galena. Inclusions of pyrrhotite and pyrite-marcasite pseudomorphs after pyrrhotite are found in places in galena, more rarely in sphalerite (Figures 1c, 1d). The presence of pyrrhotite in the investigated ore due to is magnetic properties will adversely affect the sphalerite flotation properties.

In Toranica concentrator, sulphide lead-zinc ore is being processed by crushing, milling, flotation and concentrate dewatering. Figure 2 presents a detailed mineral processing flowsheet of the concentrator.

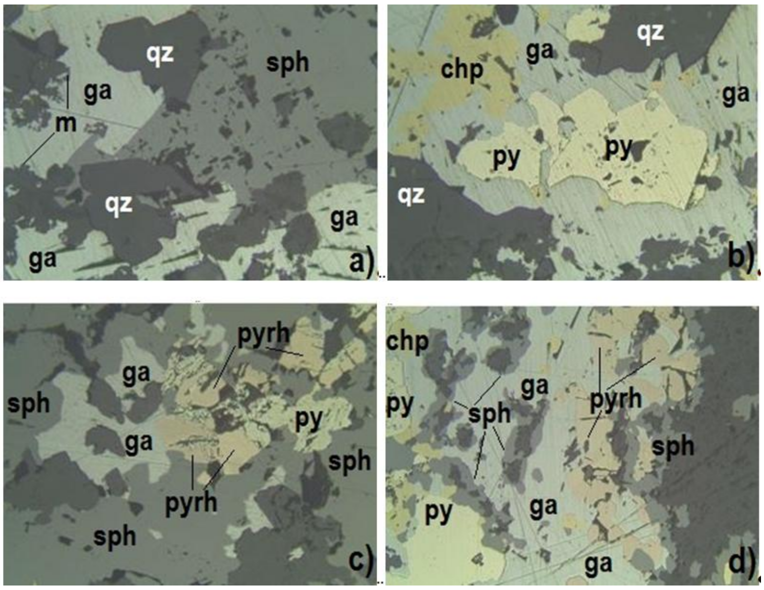

Figure 1. Photomicrographs of lead-zinc ore from the Toranica deposit. a) Sphalerite (sph) and galena (ga), with inclusions of quartz (qz) and flaky aggregates of mica (m); c) Pyrite (py) and chalcopyrite (chp) in galena (ga), corroded by quartz (qz); c) Sphalerite (sph) and galena (ga), with inclusions of pyrrhotite (pyrh) and pyrite (py) pseudomorphosis after pyrrhotite (pyrrh); d) Galena (ga), with inclusions of elongated aggregates of pyrrhotite (pyrh), sphalerite (sph), grains of pyrite (py) and chalcopyrite (chp). Reflected light, N II, length of the observation field 820 µm.

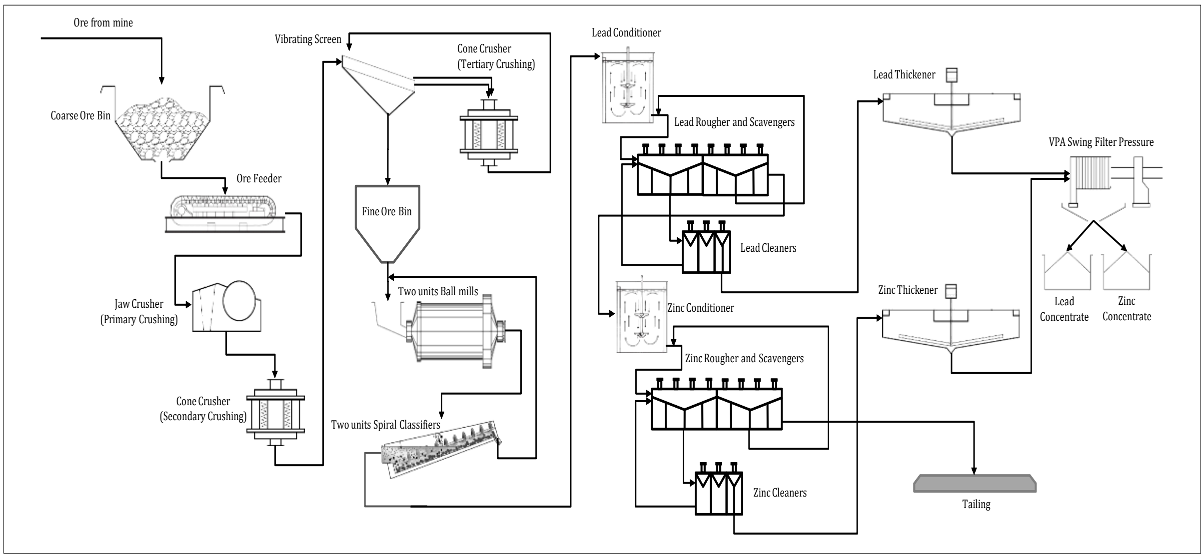

Figure 2. Toranica concentrator mineral processing flowsheet

At the Toranica concentrator, the lead-zinc ore after size reduction, including crushing and grinding are beneficiated using a direct selective flotation flowsheet (Petrov et al., 2024). In this technological flowsheet, galena flotation is initially carried out upon sphalerite depression and after activation of the depressed sphalerite zinc flotation is performed. In the processing industry, direct selective flotation is widely used for lead-zinc sulfide ores beneficiation (Bulatovic, 2007).

Lead and zinc flotation is carried out with mechanical flotation machines which are widely used in non-ferrous, ferrous and precious metals and coal processing. These machines are universal, reliable, have a simple design, facilitating their operation and maintenance. Mechanical flotation machines are highly productive and provide high selectivity and concentrates purity, being considered to be most effective at solid phase content in the slurry up to 30-35%. Slurry agitation, before flotation is important for achieving effective flotation and more complete ore processing metal recovery. With conditioning tank agitator intensive slurry stirring is carried out, in order to evenly distribute the mineral particles and prevent them from settling at the tank bottom. Moreover, uniform distribution of the flotation reagents added is achieved and their reactivity is improved. Slurry agitation contributes to better results in subsequent flotation process, improved metal recovery and reduced production costs.

Research and development program has started to establish the technological possibilities for replacement of an available conditioning tank agitator. The observations we conducted showed that as a result of impossibility of carrying out appropriate agitation, deteriorated technological indicators of the concentrates produced and metals loss in the final waste are established (Table 1 and Figure 3). Table 1 demonstrates that the average monthly lead content in the zinc concentrate during the period July - September 2023 varies from 4.89 to 6.08%, the lead recovery varies from 78.8 to 80.95%, and the lead loss in final tail reaches 0.51%.

Table 1. Average monthly Pb and Zn contents in the ore, concentrates and waste in 2023, before new conditioning tank agitator implementation

2023	Ore		Pb concentrate		Zn concentrate		Tails		Yield (%)		Recovery (%)	
	Grade (%)											
	Pb	Zn	Pb	Zn	Zn	Pb	Pb	Zn	Pb	Zn	Pb	Zn
April	2.25	1.50	69.49	2.42	48.94	3.67	0.39	0.19	2.57	2.57	79.30	83.99
May	2.45	1.43	71.34	2.15	48.75	4.14	0.41	0.16	2.75	2.49	80.01	85.22
June	2.82	1.91	73.46	2.32	49.46	3.42	0.45	0.21	3.11	3.34	80.95	86.19
July	2.83	1.57	71.02	2.03	48.17	5.11	0.49	0.17	3.14	2.79	78.78	85.60
August	3,07	1.46	68.43	2.69	47.54	6.08	0.51	0.18	3.55	2.51	79.28	81.92
September	2.77	1.38	69.61	2.11	48.05	4.89	0.44	0.16	3.22	2.42	80.90	83.98

Figure 3 reports the lead and zinc contents in flotation products, before new conditioning tank agitator implementation in Toranica technological cycle.

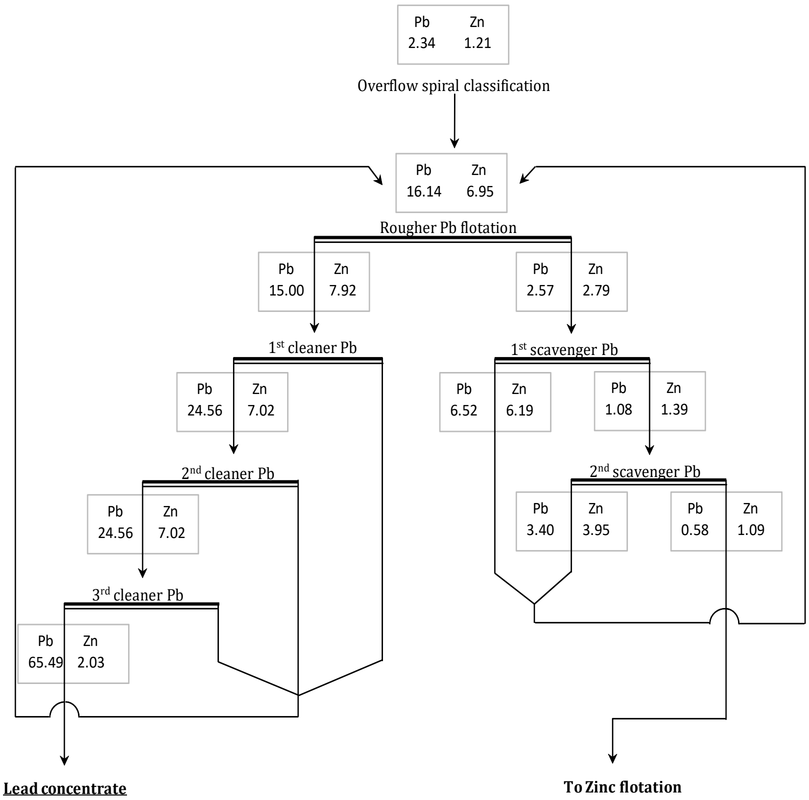

Figure 3. Pb and Zn contents of flotation products in the lead flotation cycle, before new conditioning tank agitator implementation

In order to eliminate the factors adversely affecting the flotation efficiency, quality concentrates production and metals recovery higher degree, studies in depth were carried out to determine the lead-zinc ore mineral composition.

Results and Discussion

Implementation an Advanced Conditioning Tank Agitator

In the literature there are few examples of conditioning tank agitator improvements carried out. In their paper of 2021, Wu et al. noted that regular maintenance shutdowns are required for conditioning tanks to clean sedimentation and scale. The labour cost and production loss during maintenance negatively impact on the economics of the operation (Wu et al., 2021). In (Wu et al., 2021) the authors proposes Swirl Flow technology, developed to improve the reliability of agitation and to maximise conditioning tank agitator online time between maintenance intervals.

In order to improve slurry agitation, an advanced conditioning tank has been put into operation. An air installation from the blower to conditioning tank impeller was affixed. Thus, preventing slurry being precipitation upon impeller. The blades diameter has increased by 100 mm, thus their final diameter reaches 540 mm. The blades angle has been changed by 40, which reaches a value of 370. As a result of the centrifugal force effect from the impeller rotation, the slurry is pushed upwards and does not sedimentation the bottom of the agitator. The power of the electric motor has increased from 15 kW/750 rpm to 18 kW/950 rpm.

As mentioned by Arfken et al. (1984), the Reynolds number is a useful parameter, dimensionless, used to determine if a fluid flow will be steady or turbulent based on the fluid density, flow speed, dynamic viscosity, and a characteristic length associated with the flow. Based on the modified impeller data, comparative Reynolds number values were calculated to determine the fluid flow using the formula:

$$R_e = \frac{\varrho N d^2}{\mu},$$

where: Re – Reynolds number, ϱ – fluid density, g/cm^3, N – rotational speed, rpm, d – impeller diameter, mm, μ - fluid viscosity = 10^{-4}

Before changing the impeller diameter, blades tilt and shaft rotation speed, the Reynolds number is: R_e = $2.17.10^4$, and after changing is: R_e = $3.97.10^4$.
Based on the calculations obtained, it can be assumed that before and after changing the impeller diameter, blades tilt and shaft rotation speed, the fluid flow is highly turbulent, but at the Reynolds number higher value there is a better stirring media that is more suitable for the operation of the conditioning tank agitator.

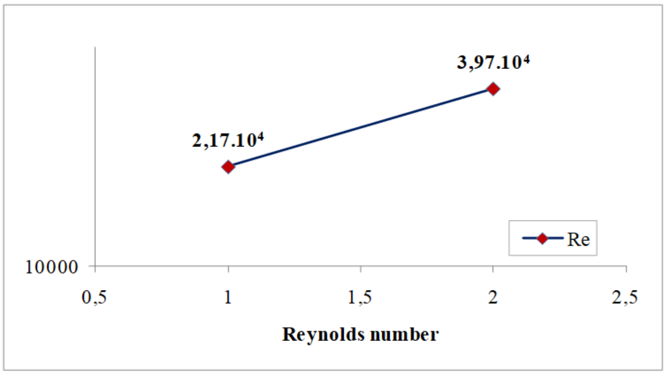

Figure 4. Reynolds number before and after changing the impeller diameter, blades tilt and shaft rotation speed

Table 2. Average monthly Pb and Zn contents in the concentrates and tails after implementation of advanced conditioning tank in the concentrator technological cycle

2023	Ore		Pb concentrate		Zn concentrate		Tails		Yield (%)		Recovery (%)	
	Grade (%)											
	Pb	Zn	Pb	Zn	Zn	Pb	Pb	Zn	Pb	Zn	Pb	Zn
October	2.65	1.41	69.37	2.22	46.42	3.37	0.41	0.17	3.13	2.54	82.14	83.92
November	3.04	1.17	69.95	2.70	49.85	2.96	0.44	0.13	3.68	1.91	84.50	81.22
December	2.92	1.43	69.76	2.73	49.08	2.98	0.39	0.17	3.56	2.40	85.09	82.27

After the changes in the parameters of the conditioning tank agitator, operation in continuous mode was achieved. Better agitation of the flotation reagents added in the slurry is ensured.
The monthly average lead and zinc contents in the concentrates and tails during October - December 2023 are presented in Table 2.

Table 2 demonstrates lead recovery higher degree, which reaches 82.14 – 85.09%. No significant reduction in lead loss was recorded in the final flotation tail. The results of the flotation product sampling show that better selectivity is achieved. Zinc concentrate does not contain lead impurities and fully meets the metallurgical processing requirements (Table 2, Figure 5).

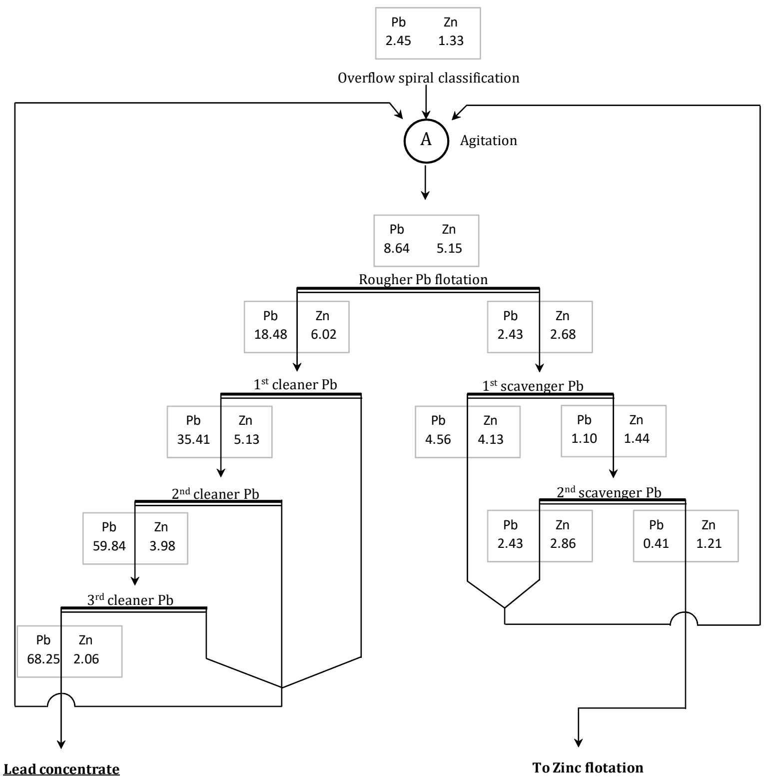

Figure 5. Pb and Zn contents (%) in the flotation products in lead flotation cycle, after advanced conditioning tank implementation

Conditioning tank agitators are crucial components in mineral processing, particularly in the preparation and treatment of slurry before it undergoes flotation (Wu et al., 2015). Wu and co-workers (2015) highlights design improvements for agitated tanks as developed in CSIRO's laboratories, which have solved practical problems in minerals processing operations involving viscous slurries, and this seems to be a reliable approach, because solving problems of rapid tank scaling, sediment build-up and poor mixing of reagent is of great importance. Regular maintenance is essential to ensure optimal performance, prevent wear and tear, and avoid issues like buildup of materials that can affect mixing efficiency. In summary, conditioning tank agitators play a vital role in mineral processing by facilitating the mixing of reagents with mineral slurry, which is key to improving recovery rates and overall process efficiency.

Conclusion

As stated in the Introduction, our main purpose was to identify and eliminate the factors, having a negative impact on the Pb-Zn flotation efficiency and metals recovery. Although more research is needed to identify the lead-zinc sulphide ores beneficiation underlying mechanisms, findings suggest that insufficient slurry agitation leads to the subsequent flotation processes inefficiency. For the efficient flotation it is necessary to strictly observe the optimal regent mode, ensuring a certain contact between the reagents and the mineral particles in the slurry.

The contributions made here have wide applicability. In general, the main achievements, including contributions to the field can be summarised as follows: with implementation an advanced conditioning tank agitator in the concentrator technological circuit has achieved: better slurry agitation with the supplied reagents and produced concentrates selectivity. In our view these results represent an excellent step toward better metals recovery and sustainable quality concentrates production for meeting the metallurgical processing requirements.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

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