Froth flotation study of Pb-Zn ore under different temperature constraints

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Sphalerite flotation represents one of a few sulfide recovery systems that experience significant variations in seasonal performance. The correlation between temperature and plant performance has been observed in several zinc mines across the world, where both too high and too low temperatures impact recovery and grade. In this work, the rougher flotation performance of lead-zinc ores of distinct geological settings was investigated under controlled temperature conditions. A central composite design of the experiment approach was used to investigate the effect of flotation modifiers, namely lime, copper sulfate pentahydrate, and zinc sulfate heptahydrate. Process performance was evaluated by means of bubble size distribution at the top of the froth, concentrate grade, yield, air and water recoveries. Results indicate that temperature variations lead to changes in froth stability, where a more stable froth was observed at colder temperatures and lead to higher yields, air, and water recovery – presumably explaining the lower concentrate grades observed industrially.

1. Introduction

Zinc is one of the most crucial elements for the sustainable development of modern construction, metallurgical and energy sectors among others [1]. It is recognized as one of the fundamental drivers of the green energy transition [2]. The metal was listed as a critical raw material by Canada, Australia, and South Africa in 2021 and 2022 due to its importance in clean technologies and advanced manufacturing [3].

Flotation is the most widely applied technique for processing zinc ores [4]. Zinc metal is never found and mined in pure form from nature, and is generally associated with ores containing lead, copper, and silver. Zinc production predominantly relies on sphalerite ((Zn,Fe)S) extraction from Pb-Zn deposits [5]. Sheridan-Griswold regime achieves Pb recovery by depressing sphalerite and pyrite using cyanide and zinc vitriol. According to the method, subsequent re-activation of sphalerite by copper vitriol at alkali conditions allows to recover zinc to a separate concentrate. This method has been widely applied as one of the most efficient techniques by numerous plants [6]. From the mineralogical point of view, Weiss outlined four main ore factors controlling zinc flotation efficiency: the degree of ore oxidation, the presence of copper minerals in the ore, the content of iron sulfides, and the acidity/basicity of the gangue matrix [7]. In addition to the nature of the ore and the efficiency of the processing method, sphalerite flotation may also be impacted by external factors. In view of climate change and development of deposits at locations with increasingly degrading climate conditions, temperature adds another dimension to the criticality of zinc ores extraction and processing [8]. A review on temperature and climate-induced fluctuations in froth flotation [8] revealed that seasonal changes impact sulfide flotation efficiency through variations in hydrodynamic conditions [9], pulp chemistry, and reagent efficiency [10]. Across the world, the performance of several zinc flotation plants was shown to decline at extreme operating temperatures [8].

Poor flotation performance of sphalerite from polymetallic deposits in winter is explained in the literature by reduced efficiency of depressants and activators [11-13]. Sphalerite losses during summer in some cases were attributed to the decreased collector performance and mineral surface alterations at high temperatures [14]. A brief overview of several zinc mines located in different climate zones may be a useful tool for a better understanding of the temperature impact on flotation at various technological contexts and weather environments.

1.1. Polar mines

The first mine of this category is located above the Arctic Circle in a polar tundra. The area experiences seasonal air temperature fluctuations from -41°C to 16°C [15]. The mined sedimentary exhalative ores are rich in zinc, lead, and silver. The ore is finely disseminated [16] with the most abundant sulfide minerals being sphalerite, pyrite, galena, and marcasite [17]. The plant processing flowsheet consists of 3 stages of flotation: pre-flotation circuit, lead circuit, and zinc circuit [15]. Bulatovic has reported a limited application of lime and cyanide in the plant. Despite flotation being outlined as one of the most challenging mine flowsheet parts among, and despite numerous optimization and expansion projects reported [18], limited data is available on seasonal variations in flotation.

The second mine from the climatic zone was designed to treat volcanogenic massive sulfides to recover copper and zinc [4,19]. It is located in a sub-arctic climate zone characterized by cool summers. Typical reported pulp temperatures at the plant varied from 5°C in winter to around 30°C in summer. The treated ore had complex composition with significant variations in mineralogy. Chalcopyrite and sphalerite are the main valuable minerals, while the main gangue is pyrite in a sedimentary rock [16]. The plant is reported to experience variations in zinc concentration grade between seasons. It was speculated that the possible reasons are efficiency of copper activation, changes in ore oxidation, and miscellaneous effects arising from air and pulp temperature, such as gas dispersion parameters [19].

1.2. Temperate climate mines

The first mine in this category [20] extracts finely disseminated refractory lead-zinc ores with high content of iron sulfides. Massive sulfide zones in the deposit are made up to 90% sulfides, the main sulfide minerals are pyrite, sphalerite, galena, and chalcopyrite [16]. Historically, recovery of sphalerite under similar geo-environmental conditions was reported to be affected by temperature fluctuations, demonstrated by laboratory trials [21].

The second case of the group experiences sharply continental climate conditions with short and hot summers (up to 35°C) and long cold winter (with temperatures reaching -55°C) [22]. More than 80% of the sedimentary exhalative ore from the deposit (SEDEX) is non-sulfide gangue minerals including quartz, siderite, dolomite, and micas. Galena, sphalerite, pyrrhotite and pyrite are the main sulfide minerals [23]. Some laboratory trials [24] with the ore from the deposit have reported galena flotation being affected by the formation of nano-bubbles, while changes for sphalerite recovery were found negligible. The nano-bubble formation on a mineral surface was related to temperature contrasts as a result of mixing heated pulp from milling with cold process waters in winter.

1.3. Tropical mines

The first example mine operates at subtropical semi-arid conditions [25]. The sulfide ore is enriched in copper and zinc [26]. This massive volcanic-hosted sulfide deposit consists of sphalerite, chalcopyrite, galena, pyrite, quartz, chlorite, and some minor sericite and siderite [27]. The plant has reported seasonal problems in zinc recovery related to high pulp temperatures after milling in summer. The recoveries dropped at pulp temperatures above 60°C as a result of collector desorption, and excessive formation of insoluble lead and zinc hydroxides on mineral surfaces [28].

The second example mine is located in arid tropical zone [25] and processes sedimentary exhalative ore rich in carbonaceous gangue [16]. The sulfide minerals are mainly galena, sphalerite, pyrite, and pyrrhotite [29]. For this concentrator, the main seasonal challenge reported was the accelerated collector decomposition at elevated pulp temperatures (above 40°C) leading to poor galena flotation performance [29].

The goal of this paper is to perform an investigation of the historical data from some of the cases described in the introduction, and to experimentally explore the impact of temperature on the efficiency of SEDEX ore flotation in a sequential lead-zinc flotation circuit.

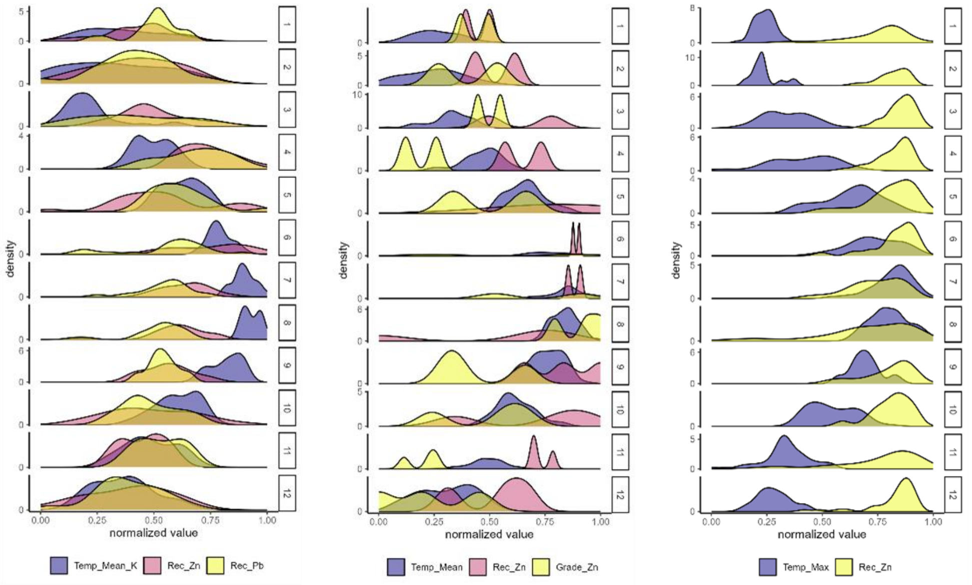
2. Materials and Methods

For the flotation tests, an ore sample from a SEDEX deposit has been used. The samples were nitric acid fusion digested and analyzed by ICP-OES (ICAP-6500DV, Thermo Fisher Scientific). Powder samples were analyzed by X-Ray Diffraction (Bruker D8 Discovery, equipped with Co Kα source, λ= 1.79 Å, Bruker AXS GmbH). The mineralogical composition of the ore was identified as sphalerite, galena, quartz, baryte, and iron sulfides. Rietveld refinement helped to quantify mineral phases using Materials Analysis Using Diffraction (MAUD) software (v. 2992).

The flotation tests were performed in a modified Denver D1 1L flotation cell according to the central composite design of experiment (DOE). In DOE, 3 factors at 5 different levels were tested: temperature (8-42°C), copper vitriol dosage (132-468 g/t), and zinc vitriol dosage (132-468 g/t). Sequential flotation procedure included lead flotation at pH 9 after the conditioning with zinc vitriol, followed by zinc flotation at pH 11 and at varying dosages of copper vitriol. Sodium isopropyl xanthate (20 g/t) and methyl isobutyl carbinol (10 ppm) were used as collector and frother throughout the experiment.

3. Results

Density plots (Figure 1) were built to compare the distributions of zinc recovery, zinc grade, and lead recovery with temperature. For a temperate climate zone, it can be observed that the mine temperature directly correlates with zinc flotation performance. For a tropical mine, during summer months, the Kernel density plot demonstrates longer tails towards lower values, indicating some discrepancies in the flotation process at higher temperatures. For a polar mine, based on the reported data, the temperature did not clearly affect the flotation performance.

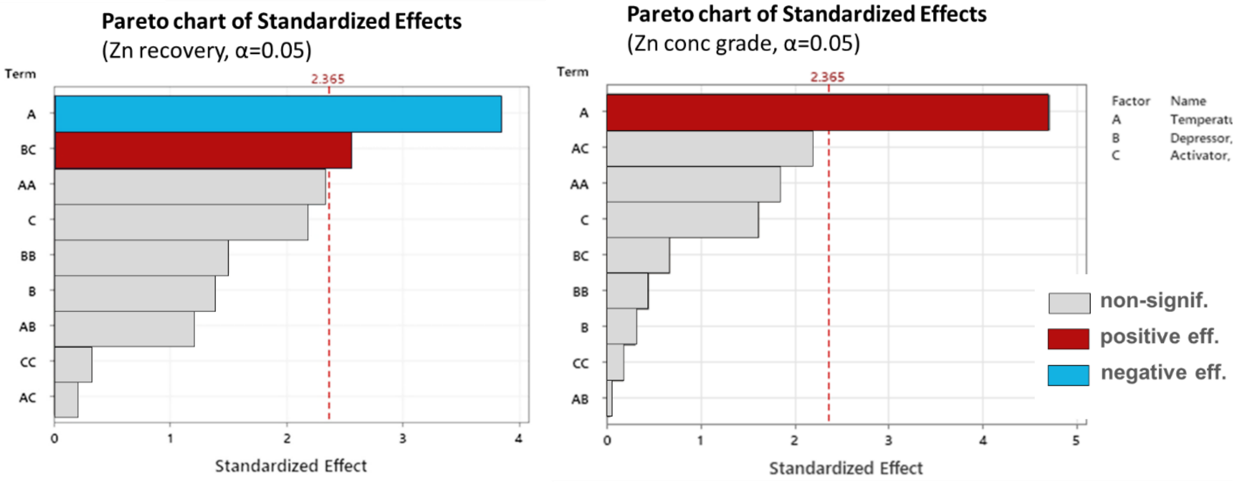


Polar Mine Temperate Climate Mine Tropical Mine

Figure 1. Density plots of monthly distributions of temperature, zinc flotation indicators, and lead flotation indicators

To better understand the observed effects and investigate the cause of fluctuations in flotation, an ore from SEDEX deposit was floated under controlled laboratory conditions at a relatively wide temperature range using modified Sheridan-Griswold approach.

As observed in the pareto charts (Figure 2), among 3 tested factors, temperature was the most significant for both zinc concentrate grade and recovery. Temperature increase had a positive effect on the concentrate grade and negative effect on the recovery (Figure 2).



a **b**

Figure 2. Pareto charts of zinc recovery (a) zinc concentrate grade (b)

For lead circuit performance, when considering 95% confidence interval and the second order equation, the model did not pass F statistical test, indicating low impact of temperature and the used flotation modifiers on galena flotation.

4. Discussions

Higher zinc recoveries observed during laboratory scale flotation tests at lower temperatures could be attributed to increased froth stability and increased entrainment due to a lower forth drainage. Galena flotation performance was not affected by the investigated flotation modifiers as they were intended to modify sphalerite flotation performance. Air recovery and water recoveries were also affected by temperature variations, which ultimately impact the froth stability and transport. The unpronounced seasonal effect in a polar mine could be attributed to a relative low fluctuation in pulp temperature and low utilization of temperature sensitive reagents [30,31]. Additionally, application of cleaner columns reduces entrainment by adjustments in froth wash water. It should be also noted that the tested SEDEX ore is relatively low on iron sulfides, which flotation behavior is sensitive to a pulp temperature [32,33].

5. Conclusions

Flotation performance of a polar mine is seen as relatively robust to seasonal change in an industrial scale, most likely due to the application of flotation columns and low utilization of temperature-sensitive reagents. Application of Sheridan-Griswold regime on a SEDEX ore at different temperatures without cyanide in laboratory scale showed some signs of entrainment and froth stability issues, which increased the yield and sphalerite recovery at lower temperatures.

6. Acknowledgements

The authors are grateful for the financial support from the Natural Sciences and Engineering Research Council of Canada (NSERC), Teck Resources Limited, COREM, SGS Canada Inc. and Flottec (Collaborative Research and Development Grants Program CRDPJ-531957-18). The McGill Engineering Doctoral Award (MEDA) from the Faculty of Engineering at McGill University is acknowledged for providing funding for D. Pashkevich and R. Li. D Pashkevich would also like to acknowledge the Fonds de Recherche du Québec – Nature et technologies (FRQNT) for the award of a doctoral scholarship.

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