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Correlation between the top of froth grade and the operational variables in rougher flotation circuits

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ABSTRACT

Cu grades at the top of the froth (TOF) were compared to the froth depth (h_F) profiles and froth discharge velocity profiles along rougher flotation circuits. Measurements were performed in two self-aspirated flotation banks, one consisting of nine 130 m^3 cells (1-2-2-2-2 arrangement), and the other one of six 250 m^3 cells (1-1-1-1-1-1 arrangement). Two behaviors for the TOF grade were observed: (i) for $h_F \leqslant 10$ cm, a decrease in the TOF grade along the bank was observed because either the decrease in mineral liberation or a potential recovery of slow floating gangue, (ii) for $h_F \geqslant 10$ cm, an increase in the TOF grades with the froth depth was observed, mainly due to an increase in froth selectivity. In addition, an inverse relationship between TOF grades and froth discharge velocities was obtained in most cases. However, in the first rougher cell, both higher froth discharge velocities (7–14 cm/s) and higher TOF grades (20–28%Cu) were observed. The froth in the first cell is typically loaded, which favors the froth stability as well as the concentrate discharge velocity.

The TOF grades of Mo as a function of the operating variables showed the same dependency as those observed with the TOF grade of Cu. This result indicated that Cu and Mo minerals had similar flotation rates in the rougher operation, which was in good agreement with the comparable ranges of Cu and Mo rougher recoveries.

1. Introduction

Flotation processes are used for the selective separation of particles, taking advantage of the differences in the superficial properties of materials. In the flotation processes, fine particles are suspended in a pulp zone, where these particles collide with bubbles of gas (Yianatos, 2007). The hydrophobic particles are selectively attached to bubbles, and then the particle-bubble aggregates are transported to the top of the equipment to form a froth zone (Ata, 2012; Welsby et al., 2010). In the froth zone, the particle-bubble aggregates that overcome the drainage and coalescence processes are carried to the froth surface to be recovered in the concentrate stream.

The recovery of particles to the concentrate stream depends mainly on the chance of reaching the froth surface (Ata, 2008). Some particles constituting the particle-bubble aggregate might be detached from the bubbles, commonly because of a decrease in the bubble surface area in the froth zone (Ata, 2009). The bubble size growth can be caused by several sub-processes, such as liquid drainage, diffusion of gas from small bubbles to large bubbles, the breakup of bubble films and gas coalescence (Ata, 2012; Pugh, 1996; Yianatos et al., 1988). Particle detachment is selective if less hydrophobic particles are firstly detached. Selective particle detachment increases the mineral grade through the froth zone (Yianatos et al., 1988).

Gourram-Badri et al. (1997) studied the separation selectivity as a function of the mineral hydrophobicity (induction time) and liberation during the coalescence processes. The coalescence of mineralized bubbles was caused and non-detached particles were recovered in a Hallimond tube. The experiments showed that the more hydrophilic and locked particles left the bubble surface during the coalescence processes. Yianatos et al. (1988) observed the effect of the froth depth on the Mo grade through the froth zone of an industrial flotation column. Selectivity in the Mo recovery was observed for deep froths, greater than 1 m, with an increase in the Mo grade of 10–15% along the froth zone. Seaman et al. (2004) showed a comparison between the froth surface (touch of froth) and bubble load grades of zinc measured in the cleaner and retreatment circuits at Teck Cominco's Red Dog mine, Alaska. Low differences between the froth surface and bubble load grades were observed in the cleaner circuit. Nevertheless, froth selectivity was identified in the retreatment circuit, where the bubble load

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grade was significantly lower than the froth surface grade, with the exception of the columns and two mechanical cells.

More recently, mineral collection along industrial flotation circuits based on the top-of-froth measurement has been reported (Yianatos et al., 2014). The authors proposed the use of the top-of-froth instead of bubble load measurements for the evaluation of rougher flotation circuits, where rather non-selective froths are typically present. This approach was based on the assumption that, for low–selectivity froths, the mineral that reaches the froth surface (top-of-froth) is similar to the mineral that enters the froth zone by true flotation (bubble load measurement). A slight selectivity has been observed by Yianatos et al. (2014) in the coarse classes because the TOF grades of Cu were slightly greater than the bubble load grades in these classes. Nevertheless, this bias did not significantly influence the overall froth selectivity.

There are several ways to quantify the liberation of particles. For instance, the degree of liberation is defined as the fraction *fully liberated particles of valuable mineral/valuable mineral* (Gaudin, 1939). Bérubé and Marchand (1984) defined the degree of liberation as the mean volumetric grade in valuable minerals within only the mineralized particles. At present, the surface liberation of a valuable mineral can be measured by commercial systems, e.g., QEMSCAN and Mineral Liberation Analysis (MLA) (Lastra, 2007). In these cases, the surface liberation is defined by *total area of valuable minerals/total area of particles*.

In this work, top-of-froth (TOF) grade profiles as a function of the froth depth and the froth discharge velocity profiles are presented. Measurements were performed in two industrial rougher circuits consisting of 130 m^3 and 250 m^3 self-aspirated flotation cells. The circuit arrangements favoured a wide range of froth depths and froth discharge velocities, enabling the evaluation of the froth selectivity (selective particle detachment) as well as the mineral evolution down the rougher circuit.

2. Experimental procedure

A sampling campaign was conducted in an industrial flotation plant (Cu/Mo) that processes 8000 tph of ore from SAG grinding. The rougher flotation circuit consists of eight parallel banks. The rougher circuits A and B were analyzed, both of which have a common raw mineral feed from the secondary grinding. Circuit A consists of six self-aspirated Dorr-Oliver® cells of 250 m^3 arranged in a 1-1-1-1-1-1 configuration (Fig. 1a). The rougher circuit B consists of nine self-aspirated WEMCO® cells of 130 m^3 arranged in a 1-2-2-2-2 configuration (Fig. 1b). The cell pairs in the rougher banks B (i.e., 2–3, 4–5, 6–7, and 8–9) are connected by an open section (communicating vessels). The level control is implemented at the end of each pair of cells. In each flotation cell of Fig. 1, the froth discharge velocity is measured and recorded to the PI (process information) system by Visiofroth cameras (Metso Minerals, 2006).

Five metallurgical samplings for mass balances were performed around the rougher circuits. In addition, radioactive tracer measurements were conducted to determine the solid and liquid flowrate (load) distribution between the rougher circuits (Yianatos et al., 2015). The feed, tail and concentrate were sampled per circuit during surveys of approximately 2–3 h. The samples were assayed for Cu and Mo to estimate the recovery of these elements. The concentrate stream was sampled cell by cell (subject to availability) to obtain the incremental grades of Cu and Mo. The rougher concentrates were sampled as a composite. Each survey consisted of sample cuts every 20–30 min to obtain a composite of approximately 20 L. A total of 5 cuts per survey decreases the standard error of the mean grades according to Lotter and Laplante (2007) and Arrué et al. (2007). The grade data were reconciled to satisfy the total and component mass balances around the circuits. Table 1 summarizes the feed characteristics along with the metallurgical results for Cu and Mo in each rougher circuit. Note the similar ranges of the Cu and Mo recoveries in rougher circuits A and B. In addition, the Mo recoveries achieved comparable results to those obtained for Cu in both flotation circuits. With the exception of Sampling Campaign 3, the concentrate grades were in similar ranges for both circuits. The lower tonnage and higher residence time in Sampling Campaign 3 might lead to a decrease in the concentrate grade.

Top-of-froth measurements (TOF) were conducted along rougher circuits A and B in parallel with metallurgical surveys. Fig. 2 shows the TOF sampler together with the typical sampling location. The sampler (10 cm diameter and 14 cm height) was immersed in the froth up to 0.5 cm from the surface to sample the first layer of the froth. The upper layer of the froth enters the sampler through the sampler perimeter, which was designed with a small curvature to prevent hydraulic entrainment, as shown in Fig. 2(b). Each measurement corresponds to sample cuts approximately every 1 min, with a total of approximately 10 cuts per measurement, obtaining a composite ranging from 100 to 600 g of solid. This procedure reduces the effect of sampling errors and operating variability. The TOF sample makes it possible for particles attached to bubbles as well as particles in the Plateau Borders (first froth layers) to be sampled. The sampling point was located between the froth crowder and the peripheral concentrate launder. This location allows for the minimization of the contamination by entrainment and allows the stagnant zones to be avoided (Yianatos et al., 2014). At industrial scale, an entrainment percentage lower than 10% in the TOF sample has been observed along the rougher banks. Yianatos et al. (2014) did not observe a significant change between the total grades of the bubble load and TOF in low–selectivity froths, which suggests that the TOF sample is representative

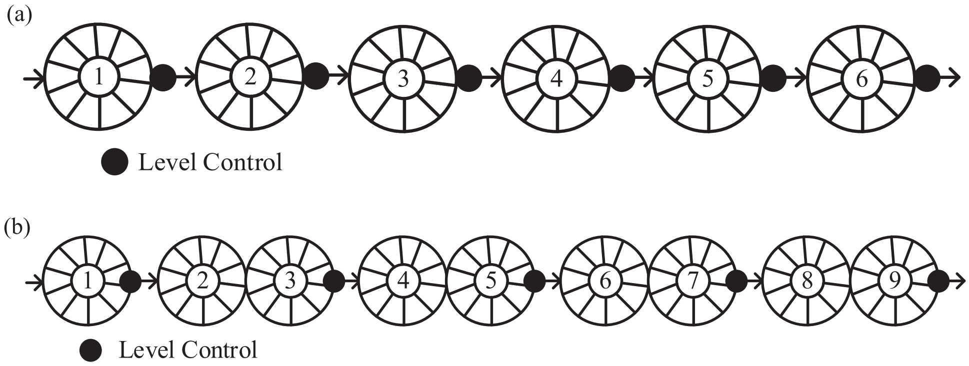

Fig. 1. Rougher flotation circuits along with level control points: (a) circuit A and (b) circuit B.

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