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# Froth liquid transport in a two-dimensional flotation cell

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ABSTRACT

A study of froth liquid transport in flotation cells with very low bubble loading was performed in a two-dimensional flotation cell using a two-phase (air–water) system. The prototype represents a radial section of an industrial flotation cell (130 m$^3$) and was operated at steady state.

The experimental tests consisted of adding a small amount (0.02 mL) of radioactive liquid tracer $I^{131}$ (in a NaI solution) on top of the froth (TOF) or near the bottom of the froth (interface). Eight collimated sensors located along the froth and collection zones allowed the evaluation of liquid transport and drainage in the froth after tracer addition at different distances from the discharge lip.

Longer distances to the overflow discharge lip promote higher water drainage from the froth to the collection zone. For the liquid content near the top of the froth, the liquid drainage increased gradually from almost nil to approximately 50% when the distance to the lip level was increased from 5 to 98 cm. In contrast, the liquid content in the froth near the interface was almost fully drained for distances larger than 15 cm from the discharge lip. This information was complemented by froth surface velocity measurements using the Visiofroth system and showed a good agreement with the liquid transport velocity measured near the discharge lip wall. The increase in the frothcrowder angle (40–50°) also showed a significant effect on the froth liquid transport velocity and similar drainage characteristics.

## 1. Introduction

Froth flotation is a complex process where a pulp flow rate containing a population of particles of different shape, size and composition are contacted with a bubble swarm, consisting of a bubble size distribution, to promote the collision of particles and bubbles and the selective attachment of particles with the formation of particle-bubble aggregates. After aggregate formation, it is required that bubbles be effectively separated from the pulp before entering into the concentrate. For the first purpose, mechanical flotation cells are provided with a collection zone where particles and bubbles are contacted under turbulent conditions generated by a rotor. For the second purpose, a froth zone is created in the upper part of the collection zone, which allows the transport of particle-bubble aggregates from the pulp to the concentrate. The froth zone has two objectives: recovery of particles which enter the froth as particle-bubble aggregates and rejection of particles that reach the froth by non-selective entrainment. These two process stages, collection and separation, are both critical to reach an effective flotation performance. The effect that typical operating variables (gas rate, pulp rate, froth depth, solid percentages and reagent dosages) have on the collection and froth zones is different and, in some cases, opposite. In this sense, the liquid transport in the froth is a key variable because it promotes water recovery and consequently fine particle entrainment. The liquid content in the froth is responsible of fine minerals entrainment. Typically, particles of less than 50 µm starts to be entrained, and particularly recovery of finer particles (5–10 µm) by entrainment increases significantly (Yianatos and Contreras, 2010), which finally decreases the mineral concentrate grade.

Due to the large increase in cells size during the last few decades, froth transport has become more critical because of the larger distances the froth must travel to reach the concentrate. For this reason, new arrangements have been incorporated in mechanical cells to decrease the distance to the discharge lip and to facilitate the froth discharge, such as the frothcrowder and internal radial launders. The study of froth transport in large flotation cells became critical.

Flotation cell design and operation must be properly selected to optimize mineral recovery. In industrial flotation cells, especially in rougher circuits, the mineral recovery by true flotation is very high in the first cells while decreases significantly along the bank (Yianatos et al., 2016). For this reason, entrainment becomes critical in the last

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flotation cells of the row, where the mineral load in the froth is scarce and the impact of particles entrainment is the highest (e.g., 90–95%).

Development of theoretical froth transport models has been fundamental for the knowledge and understanding the motion of each component (liquid, gas and solids) inside the froth. For example, Moys (1984), Murphy et al. (1996) and Neethling and Cilliers (1999, 2003) have shown that bubble motion inside the froth can be well described by the Laplace equation, where the streamlines are derived assuming the gas flow (bubbles) inside the froth is not compressible (small changes in internal pressure) and irrotational (negligible shear stress). Neethling et al. (2003) presented a theoretical relationship for predicting the recovery of liquid from flowing foams and froths. The results have shown good agreement with data obtained in a 2-phase stable foam with mono-dispersed bubbles using a column of circular cross section with a 1.4 cm internal diameter. Unfortunately, validation of these models is difficult at industrial scale, mainly due to the complexity for estimating the parameters involved, which are commonly back-calculated. It should be noted that the conceptual difference between “froth” and “foam” is simply attributed to the number of phases present in the system. In industry, a three-phase system (gas, water and solids particles) is considered a froth, while a structure containing only gas and liquid phases is considered a foam (Pugh, 2016).

On the other hand, Zheng et al. (2004) developed a structural bi-dimensional model of froth transportation in industrial flotation cells, where the froth was divided into three zones: a stagnant zone (located in the back of the cell at a distance larger than L from the discharge lip), a vertical transport zone (of length L) and a horizontal transport zone. It was assumed that the gas leaves the froth only on top of the stagnant zone, while the remaining gas (entering the froth at a distance less than L) is fully reported to the concentrate through the vertical and horizontal zones. Zheng and Knopjes (2004) developed a new model that included the froth velocity profile on the cell surface and residence time distribution of the froth. The model was tested in a 50 $m^3$ cell of a rougher flotation circuit. In this case, the froth stability was found to be an important correction factor for the froth velocity. Zheng et al. (2006) evaluated different experimental and fundamental models on water recovery using a 3-$m^3$ flotation cell. They concluded that all the models fit the experimental data reasonably well. However, fundamental models can be more flexible for predicting purposes, while empirical models commonly require the fitting of parameters for different operating conditions. Li et al. (2014) proposed a model that predicts froth transportation characteristics by including froth rheology as a fundamental parameter. For this model, Li et al. (2016) claimed that understanding the rheology of two phase systems (i.e. aqueous foams) is fundamental for understanding the rheology of three-phase flotation froths.

Experimental results from a rougher flotation cell of 130 $m^3$, such as solid axial profiles in the froth, froth recovery and froth transport times for the three phases (measured by radioactive tracers) were used for developing a froth transport model in terms of operating variables for a three-phase system (Contreras et al., 2013). This model considers a continuous probability function for air releasing on the froth surface and provides a simple and practical understanding of the froth performance in industrial flotation cells of large size.

Previous studies at laboratory scale in a two-dimensional flotation cell with a two-phase system (air-water) have shown the bubble mobility along the foam (froth), air recovery, probability of bubbles recovery and mean residence time as a function of the distance from the lip launder (Leiva et al., 2012; Rojas et al., 2014). Additionally, studies at plant site have shown that entrainment of fine particles occurs mainly near the overflow lip, where the mean residence time of particles is closer to the gas residence time. However, liquid entrainment and mainly floatable solids recovered by attachment (true flotation) showed significantly larger average froth residence times (Yianatos et al., 2008).

The present work addresses the study of liquid transport in the last cells of industrial rougher flotation cells, where the solids content in the froth is very low, e.g. less than 4% in volume, so that the impact of solids on the rheological properties is less significant. To study the froth behavior under these particular conditions, a two-dimensional cell was operated with a two-phase system (air-water), as a first approach for estimating the froth performance. For the experimental testing, the operating characteristics of the prototype cell, such as superficial gas rate (1.5 cm/s), bubble size (1.5–2.5 mm), froth depth (4–6 cm), and froth discharge velocity (4–8 cm/s) were maintained inside the range typically used in three phase flotation froths in industrial cells. Under these conditions, the liquid transport to the concentrate and the fraction of liquid draining back into the collection zone, were evaluated as a function of the distance from the discharge lip wall, as well as for two spatial conditions inside the foam (representing the froth): (a) liquid near the top of the froth and (b) liquid near the interface.

## 2. Experimental part

### 2.1. Two-dimensional flotation cell

The flotation cell, representing a slice of the upper radial section of an industrial flotation cell, which is from the frothcrowder to the discharge lip, was used to evaluate the transport and drainage of liquid while moving in the froth to the concentrate overflow. The two-phase system represents the limiting conditions of very low charged froths (similar to foams), which has been observed in the last cells of industrial flotation banks.

The prototype cell consisted of two plates with an area of 140 cm × 140 cm and a width of 15 cm, as shown in Fig. 1. The selection of the prototype cell size, with 1.4 m froth transport distance to the concentrate overflow and 0.15 m width, was based on the typical distances the froth moves before reaching the discharge lip in large industrial flotation cells. For example, in cells up to 250–300 $m^3$ provided with frothcrowder, the maximum distances the froth travel to reach the internal or external concentrate launders are typically 0.5–1.0 m. The cell included a frothcrowder with a variable angle $\alpha$ in order to evaluate the effect of the angle on the froth discharge velocity. A pressure regulator, a manometer and a mass flowmeter were used to regulate and measure the air flowrate. Bubble generation was provided by 24 porous spargers evenly distributed near the bottom of the cell. The system was also provided with a Visiofroth™ camera (Metso Minerals, 2006), which was installed 40 cm above the top of froth, to measure the froth surface velocity at a distance of 10 cm from the discharge lip. Further details of the cell installation are reported in

**Fig. 1.** Experimental setup.