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An update on the estimation of the froth depth using conductivity measurements

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ABSTRACT

Froth depth is currently measured in industrial flotation columns using a float coupled to an ultrasonic sensor, and less frequently using pressure transducers. The use of the conductivity profile in the upper part of the column has been proposed by some researchers but never used in plants on a regular basis. As compared to traditional ones, this method has the advantage of providing information that could also lead to the evaluation of other internal variables such as the bias rate. In this work, an exhaustive revision of the conductivity-based methods and the most important improvements recently introduced, are presented. Particularly, a novel approach based on a weighted average interpolation is presented, which greatly improves the precision and the smoothness of the estimations.

1. Introduction

Undoubtedly, froth depth (also named pulp level or pulp-froth interface position) is the most used variable (if not the only one) for regulatory process control of industrial flotation columns.

The position of the pulp-froth interface sets the height of the collection zone and therefore, is directly related to the time available for collection of hydrophobic particles on the air bubble surface, the other factor is the tails flow rate. Consequently, it is partially responsible for the valuable mineral recovery. However, large froth depth set-point changes would be necessary to obtain a significant effect on recovery, making its use for recovery optimization purposes rather limited. Instead, the gas flow rate, and through it, the bubble surface area flux available for collection, is preferred.

Nonetheless, pulp-froth interface position is an important control variable since its constancy is a guarantee of stable column operation: a continuously moving interface is certainly undesirable since it implies the risk of feeding the column in the middle of the froth zone or to deepen it so much that a risk of froth collapse may exist.

Pulp-froth interface has been historically monitored using manual floats, pressure transducers (one to three), Metritape®, and more recently floats coupled to an ultrasound device allowing computer control.

A completely different approach, based on measurement of the conductivity profile across the pulp-froth interface was first proposed at McGill University (Moys and Finch, 1988; Uribe-Salas et al., 1991) and later improved at Université Laval (Perez et al., 1993; del Villar et al., 1999). The latest version of this method is very precise, reliable and amenable for process-control purposes, as shown in various applications (Maldonado et al., 2007a,b; Bouchard et al., 2005; Nunez et al., 2006).

Moreover, the availability of such a conductivity profile also allows estimation of the internal downward flow of water (bias rate), a variable otherwise difficult to measure (Perez and del Villar, 1998).

In the following paragraphs, a critical review of some of these methods is made followed by description of the conductivity-based method.

2. Background

A combination of a float and an ultrasonic sensor to measure the froth depth is now commonly used in industrial operations, mainly because of the simplicity of its concept and non-invasive implementation (sensor electronics are not in contact with the pulp). Even though its accuracy is limited by the assumption of uniform pulp and froth density and absence of solids accumulation on the float gauge, its use seems satisfactory to industrial flotation column practitioners.

Pressure gauges have also been used to measure froth depth. Theoretically, a single pressure transducer should suffice for its estimation, as long as the average value of collection-zone and froth-zone specific gravity (ρ_c, ρ_f) are known.

Unfortunately, ρ_c and ρ_f depend on time-varying operating conditions and consequently froth depth values calculated from initial

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pressure-transducer calibration may not represent later operating conditions. The effect of changes in some operating conditions on the calculated froth depth has been discussed by Finch and Dobby (1990), who have concluded that the method is unacceptable, especially for shallow froths and coarse/dense particles.

The use of multiple pressure transducers partially solves this problem since it provides the extra necessary information to estimate the average value of both densities at prevailing operating conditions. The most common practice makes use of three pressure transducers, one located in the uppermost part of the froth zone, and the other two in the collection zone, one close to the interface and the other well below (Fig. 1). Each pressure is related to the height of fluid above the sensor:

$$\begin{aligned} P_1 &= \rho_{f1} g H_1 \\ P_2 &= \rho_{c1} g (H_2 - H_f) + \rho_{f2} g H_f \\ P_3 &= \rho_{c2} g (H_3 - H_f) + \rho_{f2} g H_f \end{aligned} \quad (1)$$

where ρ_{c1} corresponds to the average specific gravity of the gas-pulp mixture between the interface and the intermediate transducer $(P_2), \rho_{c2}$ between the interface and the bottom transducer $(P_3), \rho_{f1}$ between the column lip and the top transducer (P_1), and ρ_{f2} between the column lip and the interface. g is the standard gravity. If one assumes that the collection and froth zone specific gravity are uniform up to or from the interface, i.e., $\rho_{c1} = \rho_{c2} = \rho_c$ and $\rho_{f1} = \rho_{f2} = \rho_f$, the three-equation system can be solved for H_f:

$$H_f = H_1 \cdot \frac{H_3 \cdot (P_3 - P_2) - P_3 \cdot (H_3 - H_2)}{H_1 \cdot (P_3 - P_2) - P_1 \cdot (H_3 - H_2)} \quad (2)$$

This method seems to have given satisfactory results in several installations (Kosick and Dobby, 1990; Huls et al., 1990).

Despite the improvement in froth depth detection introduced by this method (Dirsus, 1999), some problems still remain unsolved. Assuming a uniform specific gravity in each zone, particularly the froth density which is very dependant on the operating conditions, might lead to wrong results as will be shown later. Moreover, the solution of the system of equations requires that the interface be located above the intermediate transducer P_2. If this were not the case, the second transducer equation would become $P_2 = \rho_{f2} g H_2$, which does not allow the calculation of ρ_c (as was the case when H_f was above H_2) but only a second estimate of ρ_c. Therefore, the third equation (only transducer in the collection zone) becomes the single equation available for calculating both ρ_c and H_f, and the method fails. Finch and Dobby (1990) reported a third limitation of the method derived from the assumption that the dynamic component of the pressure is the same in both froth and collection zones.

By using a system of four pressure transducers, two of them multiplexed to provide two pressure readings each, Diaz–Delgado experimentally measured the pressure profile (six points) for various operating conditions (J_g,J_w and J_t) and different froth depth values (del Villar et al., 1995). Using the pressure-height relationship previously presented, the average value of the froth and collection-zone densities were estimated. Important variations within each zone were observed, depending on the prevailing operating conditions. For instance, for two different J_g values (remaining operating conditions being kept constant), the collection-zone density was found to be uniform throughout the distance covered by the lower pressure-transducers, whereas the froth-zone density varied drastically for $J_g = 0.75$ cm/s, while it remained almost uniform for $J_g = 1.25$ cm/s. Under these particular operating conditions, it is clear that the assumption of a constant collection-zone density would not affect the estimation of the froth depth, whereas the assumption of constant froth-zone density would lead to an incorrect estimate. Different operating conditions led to opposite conclusions (ρ_c variable and ρ_f almost constant).

Another problem of the three pressure-transducer method arises from the influence that the pressure tap location could have on the estimation of the froth depth value, as shown in Fig. 2. If the pressure profile **abcd** obtained with the column operating under a froth depth of 85 cm is considered, the solution of the system of Eq. (1) corresponds to the intersection of the straight lines **ab** and **cd** (in this experiment, the actual pressure-transducer locations correspond to **b**, **c** and **d**, respectively).

The method would then report a froth depth estimate of about 60 cm instead of the actual value of 85 cm. This error could be reduced if the froth pressure transducer **b** would have been located closer to the interface (e.g., **b′** or **b″**) with a risk of sensor failure if the interface moves further up, above this transducer's location as previously indicated.

Finally, Fig. 3 compares the froth depth given by the three pressure-transducer method estimates, assuming a constant froth den-

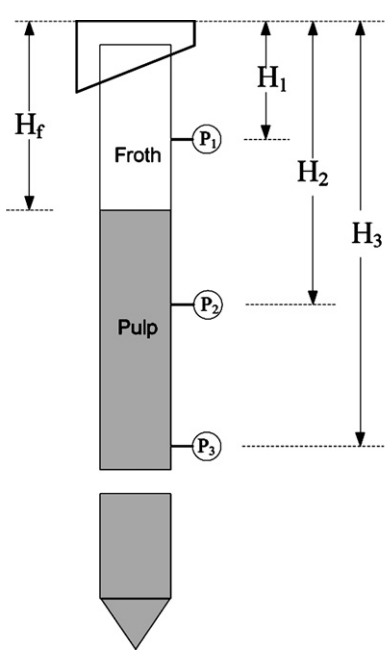

Fig. 1. Froth-depth estimation by three-pressure transducers.

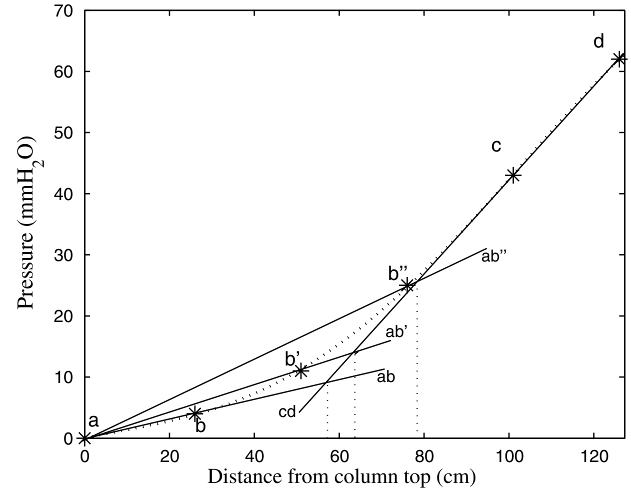

Fig. 2. Estimated froth-depth as a function of pressure-tap's location.