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Recent advances in bias and froth depth control in flotation columns

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Abstract

This paper reviews recent work done at Université Laval in the field of column flotation instrumentation and control. The presented control results rely on froth depth and bias sensors. This work establishes that flotation column control could be substantially improved by using different control methods, such as nonlinear, multivariable, and feedforward control. The emphasis is placed on the way the available information, from sensors and quantitative or even qualitative relationships, may be used to reach the control objectives. Laboratory and pilot-scale results illustrate the discussion.

Keywords: Column flotation; Process control; Process instrumentation; Modelling; Mineral processing

1. Introduction

The metallurgical performance of the column flotation process is determined by the concentrate grade and recovery. Whereas the first one can be continuously monitored using an on-stream analyzer, the second one can only be estimated from a material balance calculation, assuming steady-state. Consequently, automatic control and optimization of flotation columns need to be hierarchically performed using process variables with a strong influence on the metallurgical performance, such as froth depth (H), bias (J_b), gas hold-up (ε_g), or bubble surface area flux (S_b). Local flow rate controllers (regulating the feed, wash-water, tailings, air and reagents flow rates) are at the base of such a control structure where their set-points are the manipulated variables for the higher level of control, i.e. to regulate H, J_b, ε_g and S_b. The ultimate level is given by the optimization of the metallurgical performance according to an economical criterion (e.g. net smelter return) in a cascade scheme using H, J_b, ε_g and S_b set-points as independent variables. This paper reviews recent advances in the field of instrumentation and control of flotation columns using froth depth and bias.

The first part of the paper is dedicated to the description of conductivity-based methods used for the on-line evaluation of bias and froth depth. Different approaches to model the process dynamics for controller tuning purposes are then described and their advantages and drawbacks are analyzed. The third part discusses the various ways the available information may be used to design an effective control strategy. Finally, some laboratory and pilot-scale results are shown to illustrate the achievable column flotation control using the different tools presented in the paper.

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2. On-line evaluation of froth depth and bias

2.1. Background

Froth depth (or pulp–froth interface position) determines the relative importance of the cleaning and collection zones, as shown in Fig. 1. The most common techniques for froth depth measurement have been summarized by Finch and Dobby (1990). Recent developments are reported by Bergh and Yianatos (1993), and Del Villar et al. (1995a,b, 1999). All these methods are based on variations of specific gravity, temperature or conductivity between the two zones to locate the pulp–froth interface position.

Methods using either floats or pressure gauges are commonly used in industrial operations. Even though their accuracy is limited (due to assumptions of uniformity of the pulp and froth density and absence of solids accumulation on the float gauge), they are suited for routine process monitoring.

More recently, techniques using temperature or conductivity profiles measurements along the column upper zone were developed. Aside from being quite accurate, the obtained information can also be used to infer the bias as indicated hereafter. Conductivity probes have been successfully tested by Gomez et al. (1989), Bergh and Yianatos (1993), and Del Villar et al. (1999). Further improvements have included a decrease of the conductivity profile scan time, from one minute (Gomez et al., 1989) to about one second (Del Villar et al., 1999), and the determination of the profile inflection point, associated with the interface position (Del Villar et al., 1999).

The bias is another important variable for the optimization of column flotation due to its high correlation with the concentrate grade for a given reagent dosage and bubble surface area flux. Defined by Finch and Dobby (1990) as "the net downward flow of water through the froth", or by its equivalent "the net difference of water flow between the tailings and feed" (from a mass balance calculation around the collection zone), the bias can be qualitatively interpreted as the fraction of the wash-water flow used for froth cleaning. In practice, the easier-to-measure total wash-water flow rate is more often used for process control. However, the latter does not correlate well with the concentrate grade and recovery since it includes the water fraction short-circuited to the concentrate, which does not contribute to froth cleaning.

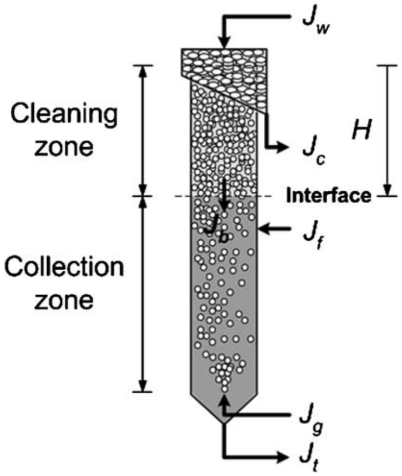

Fig. 1. Flotation column.

Accurate bias measurement, using flow meters and density meters, is difficult to achieve since it assumes steady-state operation. Moreover, Finch and Dobby (1990) have demonstrated that the error propagation resulting from the use of multiple measurement devices leads to high bias relative standard-deviations. These facts justify the development of a more practical method.

Uribe-Salas et al. (1991) have suggested an approach based on a steady-state conductivity balance calculation. The final expression involves the knowledge of the water flow rate in the tailings (J'_t) and concentrate (J'_c) streams, as well as the conductivity of the wash-water (k_w), and the liquid conductivity of the feed (k'_f), tailings (k'_t), and concentrate (k'_c) streams:

$$J_b = J'_t\left(\frac{k'_f - k'_t}{k'_f - k_w}\right) - J'_c\left(\frac{k'_c - k_w}{k'_f - k_w}\right) \quad (1)$$

Although this method is relatively accurate, it is limited to steady-state laboratory-scale trials on two-phase (water and air) systems for on-line applications. When used on a three-phase (minerals, water and air) system, the various conductivities must be measured off-line. Moreover, measuring the concentrate water flow rate J'_c is difficult as a result of its high air content.

Moys and Finch (1988) have reported a relationship between the bias and the temperature profile along the column. An equivalent relationship between the bias and conductivity profile was introduced by Xu et al. (1989) and later detailed by Uribe-Salas et al. (1991). Pérez and Del Villar (1996) have proposed the use of a neural network model approach to obtain a mathematical representation of the relationship between bias and the conductivity profile. The method is discussed in this paper.

2.2. Froth depth measurement

The pulp–froth interface position is inferred from the conductivity profile along the upper part of the column, using a semi-analytical method developed by Grégoire (1997). The conductivity profile sensor is composed of eleven 10-cm spaced stainless electrode rings fitted