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Geometallurgical modelling of the Collahuasi flotation circuit

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ABSTRACT

The flotation rate constant was modelled as a function of air dispersion properties and the complete feed particle size distribution by using the collision–attachment–detachment approach and introducing a parameter (Φ) which represents the inherent floatability of the ore. It was found that this parameter Φ is characteristic of the geometallurgical unit and does not depend on the main operating conditions. The parameter Φ is dimensionless and can be estimated either from laboratory testwork or directly from an industrial kinetics survey and can be used to predict industrial operation, provided that the other components of the model are evaluated under actual operation conditions. An empirical expression for the maximum achievable recovery – infinite time recovery – is also presented. The complete model, including flotation rate constant and infinite time recovery, was tested showing good correlation at both laboratory and industrial scale. At industrial scale the model was able to predict metallurgical results in a time frame of several weeks at Compañia Minera Doña Inés de Collahuasi SCM, showing an average relative error of less than 2%.

1. Introduction

Compañía Minera Doña Inés de Collahuasi SCM initiated the development of a new geometallurgical model to characterize its Rosario deposit in terms of its comminution circuit capacity (Alruiz et al., 2009) and flotation performance. The flotation component of the model is now described in detail.

The flotation process is affected, among other factors, by the dispersion of bubbles and particles. The dispersion of gas into bubbles – gas dispersion – has a key impact on the flotation performance, as described in the literature (Schwartz and Alexander, 2006). Gas dispersion in the collection zone can be characterized by several variables, namely, the superficial gas velocity (J_g), the gas holdup (ε_g), the Sauter mean bubble size (d_b), and the bubble surface area flux ($S_b = 6J_g/d_b$) (Nesset et al., 2006). The latter being perhaps the most important gas dispersion property since it represents the flux of available bubble surface for flotation (Gorain et al., 1997, 1998).

Scaling-up laboratory results to industrial scale is a fundamental problem both for designing new operations and for the optimization of existing ones. The similitude approach is usually applied, where similarities between laboratory and industrial conditions are established by using a series of dimensionless parameters such as the Power number, Flux number, and Reynolds number. Another commonly used approach refers to the use of purely empirical correlations (Vallebuona et al., 2003) where regression techniques and statistical analysis of experimental data from laboratory tests are used. Other authors have modelled the flotation rate parameter as a function of operational parameters such as agitation level (rpm), gas flow rate and particle size (Gorain et al., 1997, 1998, 1999; Kracht et al., 2005).

In the current approach, the flotation rate constant for two Collahuasi's geometallurgical units (UGM, from the Spanish "*Unidad GeoMetalurgica*") are modelled as a function of the gas dispersion properties and the flotation feed particle size distribution, along with operational and equipment parameters. The approach has the advantage of allowing the simulation of flotation performance at different scales. The model introduces a dimensionless parameter (Φ), characteristic of the ore type, that can be used to scale-up results from the laboratory to industrial scale.

2. Flotation kinetics modelling in conventional cells

Several authors have modelled flotation as a first order process (Kelsall, 1961; Arbiter and Harris, 1962; Mao and Yoon, 1997), characterized by a flotation rate constant k:

$$\frac{dN_p}{dt} = -kN_p \quad (1)$$

where N_p is the corresponds to the particle concentration in the machine.

Eq. (1) may be written as follows (Sherrell, 2004):

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$$\frac{dN_p}{dt} = -kN_p = -Z_{pb}P_A(1 - P_D)R_f \tag{2}$$

where Z_{pb} is the collision frequency between particles (index p) and bubbles (index b), P_A is the probability of attachment, P_D the probability of detachment and R_f, the froth recovery, which, in the case of low froth depth, tends towards 1 (Gorain et al., 1998). For the purpose of this article, the froth recovery will be assumed to be unity.

From Eq. (2), the flotation rate constant can be written as:

$$k = \frac{Z_{pb}}{N_p}P_A(1 - P_D)R_f \tag{3}$$

2.1. Attachment and detachment probability

For flotation modelling, the attachment and detachment processes can be estimated using Eqs. (4) and (5) (Yoon and Lutrell, 1989).

The attachment probability can be estimated as follows:

$$P_A = \text{sen}^2\left[2 \cdot \arctan\left(\exp\left(\frac{-(45 + 8 \cdot \text{Re}_b \cdot t_i \cdot U_b)}{15 \cdot d_b \cdot (\frac{d_b}{d_p} + 1)}\right)\right)\right] \tag{4}$$

where Re_b is the bubble Reynolds number.

The detachment probability, P_D, is given by:

$$P_D = \left(\frac{d_p}{d_{p,\max}}\right)^{1,5} \tag{5}$$

where $d_{p,\max}$ is the maximum floatable particle size fed into the machine, which for this article will be defined as P_{95}, i.e., the particle size under which 95% of the particles can be found.

Eqs. (4) and (5) are empirical formulae, valid for single particle size and do not reflect the behaviour of complete particle size distribution. Therefore, in order to calculate the flotation probabilities described above, two expressions representing weighted average flotation probabilities are introduced:

$$P_A = \sum_{i=1}^{n} P_A^i \cdot f_i, \quad P_D = \sum_{i=1}^{n} P_S^i \cdot f_i \tag{6}$$

where f_i represents the retained fraction in the particle size distribution, and n is the number of fractions in the particle size distribution. This weighted average flotation probabilities allows estimating the effect of the feed particle size distribution on flotation kinetics.

2.2. Bubble size estimation

The bubble size can be estimated using Eq. (7), which is an adaptation (Vallebuona et al., 2003) of Gorain's expression (Gorain et al., 1999):

$$d_b = \frac{6}{a \cdot N_s^b \cdot J_g^{c-1} \cdot \text{As}^d \cdot P_{80}^e} \tag{7}$$

where N_s is the peripheral impeller velocity in (m/s); J_g is the superficial gas velocity (cm/s) and As is the impeller aspect ratio.

Data from survey campaigns with direct measurements of J_g and d_b are necessary to estimate the specific values for the parameters a, b, c, d and e (Gorain et al., 1999; Vallebuona et al., 2003). Although Eq. (7) does not consider frother concentration as a parameter, it works well in cases where the frother dosage is close or beyond the critical coalescence concentration, which is a common practice at industrial scale (Laskowski, 2003).

The model presented in this article considers the Sauter mean bubble size as a single bubble diameter representing the complete bubble size distribution. Further development of this model to include the complete bubble size distribution is under way and will be presented in a future article.

2.3. Collision frequency in turbulent flow

According to Abrahamson's model (Abrahamson, 1975) for turbulent flow, Z_{pb} may be written as follows:

$$Z_{pb} = 2^{2/3}\pi^{1/2}N_pN_b\left(\frac{d_p + d_b}{2}\right)^2\sqrt{\bar{U}_p^2 + \bar{U}_b^2} \tag{8}$$

where N_p is the particle concentration expressed as number density and N_b is the number density of bubbles. $\bar{U}_p$ is the particle velocity (Liepe and Moeckel, 1976) and $\bar{U}_b$ is the bubble velocity (Lee and Erickson, 1987), which can be expressed as follows:

$$\sqrt{\bar{U}_p^2} = 0.4\frac{\xi^{4/9}d_p^{7/9}}{\nu^{1/3}}\left(\frac{\rho_s - \rho_l}{\rho_l}\right)^{2/3} \tag{9}$$

$$\bar{U}_b^2 = C_o(\xi d_b)^{2/3} \tag{10}$$

C_o is given by Batchelor (1951) as 2 and ξ corresponds to the energy dissipation rate.

The number density of bubbles (N_b) can be written as a function of gas holdup (ε_g) and bubble size (d_b):

$$N_b = \frac{3\varepsilon_g}{4\pi d_b^3} \tag{11}$$

The gas holdup, on the other hand, can be estimated from the S_b as follows (Finch et al., 2000):

$$\varepsilon_g = \frac{S_b}{5.5} \tag{12}$$

Since none of the expressions used in the model accounts for the inherent floatability of the ore, a dimensionless parameter Φ is included. Therefore, the kinetic rate constant, for turbulent flow conditions, can be expressed as follows:

$$k = \Phi\frac{3\varepsilon_g}{(2\pi)^{1/2}d_p^3}\left(\frac{d_p + d_b}{2}\right)^2\sqrt{\bar{U}_p^2 + \bar{U}_b^2}P_A(1 - P_D)R_f \tag{13}$$

For simplicity, Eq. (13) may be written as:

$$k = \Phi \cdot F \tag{14}$$

where F corresponds to:

$$F = \frac{3\varepsilon_g}{(2\pi)^{1/2}d_p^3}\left(\frac{d_p + d_b}{2}\right)^2\sqrt{\bar{U}_p^2 + \bar{U}_b^2}P_A(1 - P_D)R_f \tag{15}$$

Note that F, as expressed in Eq. (15), has units of 1/s and has to be converted to 1/min in order to be used in Eq. (14).

The parameter Φ should not be confused with the parameter P in the $k - S_b$ model proposed by Gorain et al. (1998). In that model, P accounts for the floatability of the ore, and implicitly for everything that S_b does not account for, i.e., probability of attachment, detachment and collision frequency. In the current model, since all those variables are explicitly included in F, the parameter Φ accounts only for the inherent floatability of the ore.

2.4. Scaling-up from laboratory to industrial scale

F takes different values depending on the operating variables, which may differ between laboratory and industrial scale. Therefore, the expression depends on parameters such as impeller size and aspect ratio, together with gas dispersion properties (bubble size and gas holdup). On the other hand, Φ accounts for the inherent floatability of the particles in the collection zone, which means it is unique for a given geometallurgical unit and can be deter-