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Technical note

Boundary conditions for gas rate and bubble size at the pulp–froth interface in flotation equipment

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Abstract

This paper describes the effective boundary conditions for the gas dispersion parameters of bubble size, superficial gas velocity and bubble surface area flux, in mechanical and column flotation cells. Using a number of previously derived correlations, with appropriate simplifying assumptions, and experimental data reported from plant practices, the boundary conditions were identified. Thus, it was shown that these constraints typically allow for a mean bubble diameter range of $d_b = 1–1.5$ mm and superficial gas rate of $J_g = 1–2$ cm/s, in order to maximize the bubble surface area flux, $S_b = 50–100\ s^{-1}$. Under these conditions there is no carrying capacity limitation, while keeping a distinctive pulp–froth interface.

Keywords: Froth flotation; Flotation bubbles; Flotation machines; Carrying capacity

1. Introduction

Despite the use of different equipment designs and operating conditions, there are two key conditions, which must be considered in all flotation equipments, in order to be a commercially effective separator. One is the formation of a distinctive pulp–froth interface and the second is the provision of the bubble surface area flux for mineral carrying capacity at the pulp–froth interface level. Otherwise, the loss of interface or the maximum carrying capacity will limit the mineral separation.

1.1. Loss of interface

At moderate mean bubble sizes (i.e., mean bubble diameter lower than 1–1.5 mm) a critical relationship exists between the superficial gas and the liquid rates, J_g and J_L, and the mean bubble diameter d_b, which determines the loss of the interface, sometimes called "flooding" condition. This boundary condition has been derived from first principles for the air–water system (Pal and Masliyah, 1990; Xu et al., 1991; Langberg and Jameson, 1992).

The other critical constraint appears at mean bubble diameter larger than 1–1.5 mm, while operating at higher superficial gas rates ($J_g = 2.5–3$ cm/s), when larger bubbles are generated producing a break-through of large bubbles across the pulp–froth interface, also called "boiling" condition (Dahlke et al., 2005). This condition generates a general disturbance at the interface level, also increasing the mineral entrainment and bubble coalescence throughout the froth.

Mean bubble diameter of less than 0.5–0.8 mm are rarely present at the interface level in industrial cells unless a very low superficial air rate was provided (less than 1 cm/s), which also limits the carrying capacity. It has been observed that small bubbles can be either lost into the tailings flow or captured by coalescence with larger ones, near the pulp–froth interface. Thus, a commercial operation typically shows a mean bubble diameter around 1 mm, or larger, at the pulp–froth interface level.

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1.2. Maximum carrying capacity

The maximum carrying capacity, required for mineral transport on the bubble surface, determines the minimum bubble surface area flux for each operation. Thus, there exists a close compromise between the mean bubble size and the superficial gas rate, in order to generate the bubble surface area flux to accomplish the mass transport requirement across the interface.

Xu et al. (1987) discussed the effect of gas rate and bubble size on the carrying capacity at the pulp–froth interface level, for flotation columns. They found that the maximum bubble surface area flux decreased on decreasing the bubble size in order to maintain a distinctive interface. Carrying capacity relationships have been more recently reviewed by Patwardhan and Honaker (2000), King (2001) and Gallegos-Acevedo et al. (2006). Also, Pérez et al. (2002) observed the overloading problem in flotation columns, which also illustrates the limited carrying capacity at pulp–solids content larger than 25% of solids (w/w).

The previous conditions (loss of interface and maximum carrying capacity) are valid for any industrial flotation operation, both in mechanical cells and pneumatic cells or columns, and are independent of the bubble generation and dispersion mechanism.

2. Boundary conditions at the pulp–froth interface

Fig. 1 shows the theoretical boundaries of superficial gas rate versus bubble size for industrial flotation operation (Yianatos, 2003). The corresponding range of bubble surface area flux S_b is also shown in dashed lines.

From Fig. 1, it can be seen that for mean bubble diameter smaller than 1.5 mm, the upper boundary corresponds to the maximum theoretical gas flowrate which can be delivered in order to build a distinctive interface before entering the “flooding” zone with loss of interface.

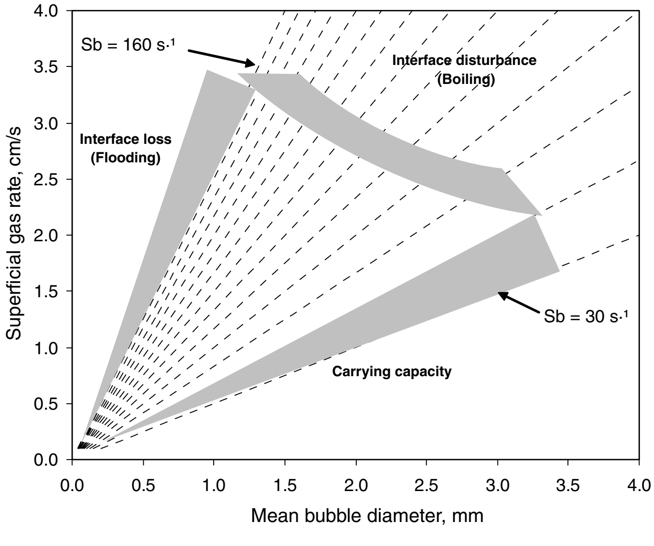

Fig. 1. Zone of distinctive pulp–froth interface and non-limited carrying capacity.

A wide review of industrial flotation data reported in the literature showed that the typical range of mean bubble diameter observed in mechanical cells and columns was $d_b = 1$–1.5 mm, while the superficial gas rate was $J_g = 1$–1.6 cm/s in mechanical cells and $J_g = 1.5$–2.2 cm/s in pneumatic columns (Burguess, 1997; Vera et al., 1999; Yianatos et al., 1999, 2001; Power and Franzidis, 2000; Deglon et al., 2000; Chen et al., 2001; Schwarz and Alexander, 2006; Finch et al., 2006; Nesset et al., 2006).

Grau and Heiskanen (2003) using a laboratory flotation cell (50 L), operating in batch with gas–liquid, found a narrow interval of bubble surface area flux ($S_b = 27$–$36\ s^{-1}$) with a rather low upper limit. Also, they noticed that mean bubble surface area flux calculated from average values, at poor air dispersion, appears to overestimate the bubble surface area flux. Grau et al. (2005) measured the critical coalescence concentration of frothers versus bubble size, using standard flotation frothers in aqueous solutions, and they found a minimum Sauter bubble diameter in the range of 1–2 mm, which is similar to that observed in industrial flotation cells. Recently, an empirical approach has been developed to determine the operating range of flotation cells from gas holdup versus gas rate measurement (Dahlke et al., 2005). The study was developed in industrial flotation mechanical cells equal to or smaller than 50 m^3, where a maximum superficial gas rate of $J_g = 2.5$ cm/s was observed. This result was in good agreement with theoretical predictions on the limits of superficial gas rate, considering a normal range of mean bubble diameter around 1–2 mm.

For a high gas rate, $J_g > 2.5$ cm/s, the mean bubble size increases, the gas holdup becomes unstable and the flow regime is characterized by larger bubbles rising rapidly which creates a significant disturbance at the pulp–froth interface. This boundary condition represents the upper limit sometimes indicated by “boiling” (break-through of large bubbles across the interface). For example, in an industrial flotation column a high superficial air rate ($J_g = 3$ cm/s) was measured (Yianatos et al., 1999). Under this condition, it was observed that the mineral grade axial profiles increased continuously across the pulp–froth interface, showing that the interface was not clearly distinguished because of the disturbance created by the high air rate.

For superficial gas rates smaller than 2.5 cm/s, the lower boundary corresponds to the minimum bubble surface area flux, $S_b = 35$–$45\ s^{-1}$, observed in mechanical cells (Power and Franzidis, 2000; Deglon et al., 2000; Gorain et al., 1997). Below this minimum the system becomes constrained either by carrying capacity limitation (larger d_b) at the pulp–froth interface level or by a limited froth removal, at a low gas flowrate.

Fig. 2 shows the bubble surface area flux S_b, versus mean bubble diameter at different superficial gas rates, $J_g = 0.5$–4 cm/s. Here the superficial liquid rate lines