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An experimental study of the recovery of hydrophilic silica fines in column flotation

D. Martínez-Carrillo, A. Uribe-Salas *

CINVESTAV-IPN Unidad Saltillo, Carr. Saltillo-Monterrey km 13, 25900 Ramos Arizpe, Coahuila, Mexico

Abstract

This paper presents results of tests performed to investigate the effect of gas rate (1.2–2.5 cm/s), hydrophilic fines content (5–20% w/w silica) and froth depth (10–30 cm) on fines recovery in a laboratory-scale flotation column operating without wash-water addition and absence of floatable particles. A model was developed based on the entrainment coefficients presented by [Trahar, W.J., 1981. A rational interpretation of the role of particle size in flotation. International Journal of Mineral Processing 8, 289–327], which describes the mass contribution of the different size classes to the solids recovered in the concentrate. The entrainment model of [Zheng, X., Johnson, N.W., Franzidis, J.P., 2006. Modelling of entrainment in industrial flotation cells: water recovery and degree of entrainment. Minerals Engineering 19, 1191–1203] was also tested. The results show both models described well the dependence of the mass flow rate of hydrophilic solids in the concentrate.

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1. Introduction

Flotation is widely used in the mineral processing industry with the aim of concentrating valuable minerals to obtain high grade concentrates with the lesser amount of contaminating gangue. This separation process is based on the surface properties of the minerals to be separated: one should have hydrophobic properties while the other(s) should be hydrophilic. These properties may have natural origin or may be generated by the use of chemicals (e.g., collector). During the flotation process, particles of the desired mineral (which are commonly hydrophobic) attach to the rising air bubbles formed in the bottom of the cell where air is injected through spargers, and are recovered in the concentrate launder (e.g., true flotation), while the particles of the gangue mineral (variably hydrophilic)

remain in the pulp and are removed from the cell through the tailings line.

Exploitation of ore deposits of minerals which gradually decrease their content of metal values and increase their complexity, has compelled the mining industry to search for solutions to this problem, by increasing the liberation of the mineral species of interest, that is, by substantially reducing the size of the particles obtained during grinding (Johnson, 2005). It is accepted that the degree of liberation of mineral is one of the factors that affects both recovery and concentrate grade.

Grinding and regrinding of ores to increase the degree of liberation of the mineral give rise to an increased amount of fines both of the valuable and gangue minerals. Flotation recovery of fine particles of valuable minerals is marginal due to their low collision–adhesion probability to the gas bubbles. One of the available methods to increase the recovery of fine particles is the floc-flotation process (Lopez-Valdivieso et al., 2005). One of the main problems faces during flotation is the recovery of hydrophilic fines in

* Corresponding author. Tel.: +52 844 438 9644; fax: +52 844 438 9610.
E-mail address: alejando.uribe@cinvestav.edu.mx (A. Uribe-Salas).

the concentrate due to both mechanical and hydraulic entrainment (Ata et al., 2003; Tao et al., 2000), which dilutes the valuable mineral decreasing the concentrate grade of the end product.

Particle transportation to the concentrate may be caused by the following mechanisms:

– Recovery of mineral by true flotation, which is a selective mechanism.
– Recovery of particles by mechanical entrainment, non-selective mechanism (both valuable mineral and gangue particles are trapped between particles adhered to air bubbles in the froth zone).
– Recovery of fine particles by hydraulic dragging (hydrophilic fine particles suspended in the water).

True flotation is the recovery mechanism of valuable minerals of major importance to flotation, which account for most of the particles actually recovered in the concentrate (Savassi et al., 1998). Nevertheless, the efficiency of the separation of the completely liberated particles of the valuable mineral and the gangue particles dispersed in the pulp depends on the degree of entrainment (Zheng et al., 2006).

2. Hydrophilic particles recovery

Dragging of fine hydrophilic particles to the concentrate, that is, the degree of entrainment, has been addressed by different researchers from several perspectives, but with a unique objective: to quantify the mass of hydrophilic particles that reaches the concentrate as a function of water recovery (fraction of water of the feed that is recovered in the concentrate). Trahar (1981) reported that the stream of water that reaches the concentrate affects particle recovery depending on the actual particle size, and based on experimental data developed correlations for silica and sulfide minerals that express the entrainment in terms of the average particle size for narrowed size fractions. The entrainment is defined as the ratio between solids recovery (of particles of certain size average) and water recovery. The correlations are valid for conditions encountered in mechanically stirred cells, shallow froths and no washwater addition, for both laboratory and bench scale. Solids content, frother concentration and presence and absence of hydrophobic-floating particles, were taken into account by the author. Table 1 summarizes some of the findings of Trahar (1981).

Table 1 presents the recovery of fine quartz particles as a function of water recovery (whose ratio will be termed in this paper entrainment coefficient) for the different size fractions of a particle size distribution, represented by an average diameter.

Kirjavainen (1992) presented an empirical model to describe hydrophilic particles entrainment in terms of the probability of the particles to reach the concentrate (P) and expressed as a function of the mass of particles (m) and water recovery rate (w, kg/s/m^2) (Eq. (1) with a, b and c being constants)

$$P = \frac{w^a}{w^a + bm^c} \tag{1}$$

If the feed is fine and the mass (m) of particles is very small the probability of entrainment (P) should approach unity. In such a case the recovery of solids should be equal to the recovery of water or, in other words, the solids recovery to water recovery ratio should be equal to one. This model fitted well the data for different solids content (5–40%) of quartz and phlogopite. Corrections to account for the effect of slurry density and particle shape were also considered by the author.

Other authors (Tao et al., 2000) have suggested that the degree of entrainment (equivalent to the entrainment reported by Trahar) is defined by a linear correlation between the solids recovery and water recovery, as follows:

$$R_a = F_a + e_a R_w \tag{2}$$

where R_a is the recovery of hydrophilic solids; F_a is the recovery of gangue accompanying the floating mineral (e.g., not liberated); e_a is the slope of the regression line between R_a, the solids recovery, and R_w, the water recovery. For a fully liberated mineral F_a is zero, and e_a is equivalent to the entrainment defined by Trahar:

$$R_a = e_a R_w \tag{3}$$

Recently, Zheng et al. (2006) have proposed a model to estimate the recovery of hydrophilic solids by the following equation:

$$R_{ENT,i} = CF_i \cdot ENT_i \cdot R_w \tag{4}$$

where $R_{ENT,i}$ is the recovery of solids of ith size class, R_w is the water recovery and CF_i and ENT_i are the classification function and the degree of entrainment, respectively, of the ith size class, which are defined by

$$CF_i = \frac{\frac{a_{ij}^p \cdot m_i^p \cdot X^p}{100 - X^p}}{\frac{a_{ij}^t \cdot m_i^t \cdot X^t}{100 - X^t}} \quad \text{and} \quad ENT_i = \frac{\frac{a_{ij}^c \cdot m_i^c \cdot X^c}{100 - X^c}}{\frac{a_{ij}^p \cdot m_i^p \cdot X^p}{100 - X^p}} \tag{5}$$

where a_{ij} is the chemical assay of the ith size class of mineral species j, m_i is the mass fraction of the ith size class

Table 1
Role of particle size of silica fines on solids recovery and entrainment (Trahar, 1981)

Average particle size, μm (d_i)	Size fraction (μm)	Ratio of hydrophilic fines recovery and water recovery (R_{si}/R_w)
3.5	+0/−7	0.72
9	+7/−11	0.59
14	+11/−17	0.45
20	+17/−23	0.35
29	+23/−35	0.18
40	+35/−45	0.04

The size fraction for each average particle size, as suggested by the present authors, is also reported.