

REVIEW PAPER

FLUID FLOW AND KINETIC MODELLING IN FLOTATION RELATED PROCESSES Columns and Mechanically Agitated Cells—A Review

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Abstract: In this paper, fluid flow and kinetic models related to minerals flotation process are presented and the advantages and limitations of using this type of models are discussed. The modelling of such processes was firstly developed assuming perfect mixing for the whole system as a black box. Then, a more realistic approach was developed recognizing the interaction between two zones, the particle–bubble collection zone and the froth transport zone.

From a hydrodynamic point of view, experimental data showed that single large mechanical flotation cells can deviate significantly from perfect mixing, while the mixing conditions in a flotation bank of mechanical cells (three to nine cells in series) can be well described as a series of continuous perfectly mixed reactors. From plant experience, it was observed that performance of large industrial pneumatic flotation columns, originally regarded as a counter-current operation, also operate closer to a single perfectly mixed reactor.

Advances in the field of modelling and design of flotation cells and columns, have been achieved because the fluid flow regime, the mass transport conditions at the pulp/froth interface and the froth transport mechanisms are better known and understood. Key parameters such as the *bubble surface area flux*, related to the bubble generation and the rate of particle collection, *bubble loading* related to the mass transport across the pulp-froth interface and *froth recovery*, which is mainly related to the gas residence time in the froth, are relevant for a deeper understanding of this type of equipment.

Keywords: modelling; froth flotation; flotation machines; residence time distribution.

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INTRODUCTION

Flotation is a widely used process within minerals processing industry in the last century, as well as being used for water and waste water treatment, and more recently for de-inking of recycled paper and electrolyte cleaning (oil separation) among other less conventional applications.

In the case of water and waste water treatment the aim of the process is to remove very fine particles of few microns, in very low concentrations, which are collected by small bubbles of 50–100 μm . In mineral processing, however, particles from few microns to several hundred of microns, in 10–40% solid suspensions, are selectively collected by bubbles of 0.5–2 mm. This makes a difference in terms of the type of flotation used, i.e., dissolved air

flotation DAF for the water treatment and dispersed air flotation for minerals separation. Studies on DAF modelling are rather scarce and mainly related to hydrodynamics (i.e., Kwon *et al.*, 2006). Recently, Emmanouil *et al.* (2006) presented the basis for a three phase modelling of an industrial scale DAF tank, using flotation kinetic concepts.

In the last decade, flotation equipment related to mineral processing industry has shown a dramatic increase in size, reaching values of 250 m³ in unitary mechanical flotation cells (Weber *et al.*, 2005) and more than 250 m³ in pneumatic columns (De Aquino *et al.*, 1998). The general feeling, however, is that despite the great advances observed in terms of process knowledge, the mechanisms and principles as well as the design and scale-up of industrial flotation

cells, are still not fully understood. Thus, the scope of this paper is mainly addressed to mineral processing flotation applications, particularly columns and mechanical cells.

From a unit operation point of view, flotation is a solid–solid separation, where fine solid particles, suspended in water, contact an air bubble swarm, in a well-mixed air–pulp dispersion. Particles are classified as floatable if they adhere to the bubbles and are transported up to a froth layer. Flotation separation is based on different mineral surface properties. Hydrophobic particles can attach to air bubbles, while hydrophilic particles do not. In this form hydrophobic particles can be selectively separated by levitation against gravity in the aqueous medium. Thus, it can be seen that flotation is a multi-component, multiphase and heterogeneous separation process.

From a conceptual point of view flotation can be observed as a sequence of two operations, 'reaction' and 'separation' (Finch, 1995), as it is shown in Figure 1.

The reactor is fed with the slurry containing the solids to be separated. Chemical reagents (collector, frother, depressant, and so on.) are added to induce differences in particle surface properties in order to promote the selective aggregation of particles with air bubbles. Energy is required to keep the solids in suspension, typical particle size around 50–150 microns, and to disperse the air into fine bubbles, typically of 1–2 mm. The specific power used at present in large size industrial flotation cells is about 1 kW m^{-3} .

The probability of collection and transfer of a mineral particle from the pulp to the froth can be described as a product of probabilities of occurrence of several sub-processes (Ek, 1992). However, for practical purposes it is very difficult to quantify most of these probabilities. Alternatively, the collection process has been represented similar to a chemical reaction. In this approach the 'reactants' are hydrophobic mineral particles that collide with and adhere to air bubbles. The reaction 'product' is a particle-bubble aggregate that is less dense than the medium and moves upwards against gravity while hydrophilic particles are reported down to the tails.

A necessary condition for mineral separation in a flotation process is the existence of a froth zone with a distinctive pulp–froth interface. Conditions for the co-existence of the froth and fluid (pulp) phases in a flotation column has been theoretically derived from hydrodynamics for two phase systems (air–water), i.e., Pal and Masliyah (1990), Xu *et al.* (1991a), Langberg and Jameson (1992). The critical boundary conditions for industrial flotation equipment in terms of bubble size and superficial gas rate, regarding the loss of the pulp–froth interface, froth stability and limiting carrying capacity has been reported by Yianatos and Henríquez (2007). Thus, it was found that for typical superficial gas rates, $J_G = 1\text{--}2 \text{ cm s}^{-1}$, the optimal range of bubble diameter

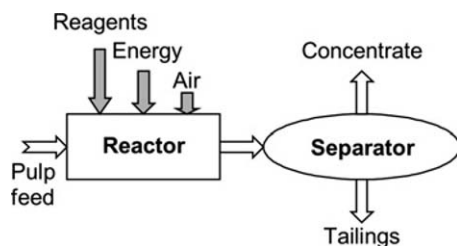


Figure 1. Conceptual flotation design.

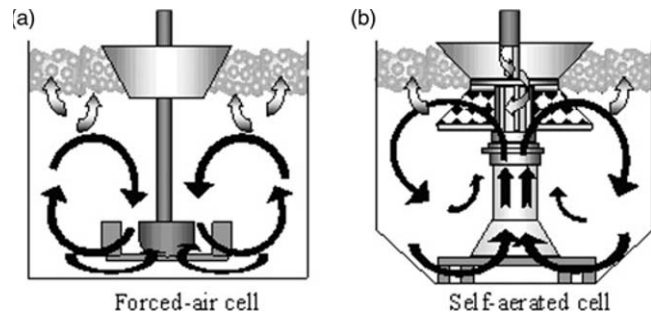


Figure 2. Mechanical flotation cells.

at the pulp/froth interface level was $d_B = 1.0\text{--}1.5 \text{ mm}$, in order to maximize the bubble surface area flux, $S_B = 50\text{--}100 \text{ s}^{-1}$. Otherwise several constraints, i.e., loss of pulp/froth interface (flooding) or greater disturbance at the interface level (boiling), limit the flotation process (Finch *et al.*, 2007).

Mechanically Agitated Cells

Figure 2(a) shows the schematic view of the forced-air cell, with the rotor located near the bottom, and Figure 2(b) shows the self-aerated cell, with the rotor located near the top. In both designs, pulp circulation through the rotor is required to enhance the particle collection performance. Recently, a mid-rotor cell has been developed where the rotor is located at the center of the cell (Lelinski *et al.*, 2005). Also, froth crowders and internal radial launders have been incorporated in order to enhance the froth transport.

Pneumatic Cells

Pneumatic flotation columns are devices of simple construction in which a gas is distributed at the bottom and rises up in the form of a dispersed phase of bubbles in a continuous fluid phase which also contains suspended fine particles.

Counter-current column

Figure 3(a) shows a scheme of the classical flotation column design, considering counter-current contact between

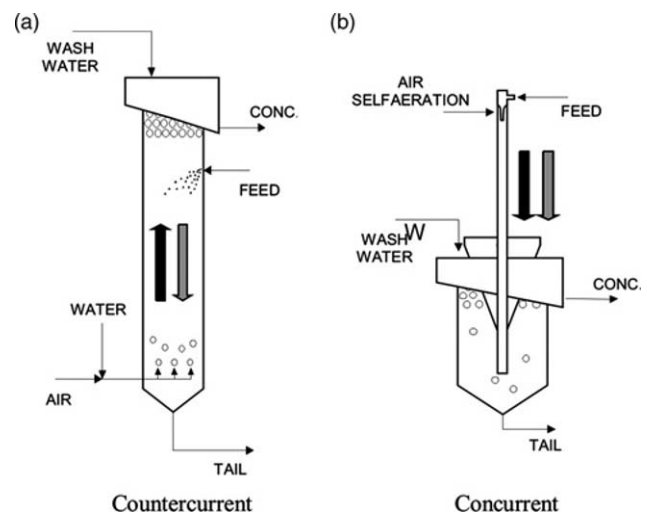


Figure 3. Counter-current and co-current pneumatic flotation.

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