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Improving flotation energy efficiency by optimizing cell hydrodynamics

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ABSTRACT

Flotation is not a particularly energy intensive process. Therefore, flotation optimization has traditionally been focused on grade and recovery performance improvements. However, with the growing need for energy efficiency and the dramatic increase in flotation cell size in recent years it is worth considering how well energy is utilised within flotation cells. In conventional flotation cells a certain amount of energy is required to meet the basic requirements for flotation (air dispersion, solids suspension and particle-bubble collision). This paper investigates how that energy is dissipated in the flotation cell to determine the most efficient use of the imparted energy. The distribution of turbulence and its effect on flotation kinetics are investigated in a mechanical 3 m^3 flotation cell for a range of hydrodynamic conditions. The effect of the different conditions are evaluated considering the Power Number (N_P); a dimensionless number that is a useful hydrodynamic indicator as it represents the ratio of energy added to the flotation cell dissipated as shear to that used to generate bulk flow. Results show that flotation rate in the collection zone and the fraction of the cell with higher turbulence increases as more of the power drawn by the impeller is dissipated as shear in the impeller-stator region (higher Power Number). This should promote higher collision rates and more efficient use of the energy imparted in the flotation cell.

1. Introduction

Comminution of ore is the most energy intensive stage of mineral production and therefore improvements in comminution efficiency can result in significant energy savings (Duffy et al., 2015; Ballantyne and Powell, 2014). In contrast, for froth flotation, which is not energy intensive, optimization has traditionally focused on recovery and final product grade. Examining the energy requirements for mechanically agitated flotation machines, there is a minimum power requirement that is necessary to fulfil the basic flotation requirements of air dispersion, solids suspension and particle-bubble collision (Fallenius, 1987; Jameson, 1992). In order for flotation cells to perform effectively, these requirements have to be met and thus optimal use of energy is critical to the process.

The distribution of the energy dissipation rate within a flotation cell determines both the capture of ultrafine particles (high shear) and the detachment of coarse particles (low shear) (Jameson, 2013). Hence flotation recovery might be maximized by optimizing the proportion of the regions with high and low shear.

The distribution of turbulence and its effect on flotation kinetics were investigated in a 3 m^3 mechanical flotation cell for a range of hydrodynamic conditions. Results from an extensive test work conducted at a copper concentrator in Australia using Metso's RCS 3 m^3 flotation cell are presented. For each set of operating conditions, detailed measurements of cell hydrodynamic characteristics were carried out along with collection of metallurgical samples of feed, concentrate and tailings.

1.1. Energy consumption in flotation

In recent years, the size of mechanical flotation cells has increased dramatically, with cells as large as 600 m^3 now available. Flotation plants using modern large cells consume a significant amount of energy. Murphy (2013) reports that the installed power of a rougher bank of six 300 m^3 flotation cells is equivalent to a small grinding mill (1800 kW).

Hydrodynamic analysis, geometric proportionally and computational fluid dynamics (CFD) have traditionally been used for the design and scale-up of mechanical flotation machines (Nelson et al., 2002; Lelinski et al., 2005). Energy consumption is a key parameter in all of these approaches. Specific power, the power used per unit volume of a flotation cell (kW/m^3), is commonly used to define the energy consumption of mechanical flotation cells and has been used as a scale-up criteria (Harris, 1975). It has also been correlated with flotation kinetics (Schubert, 1989).

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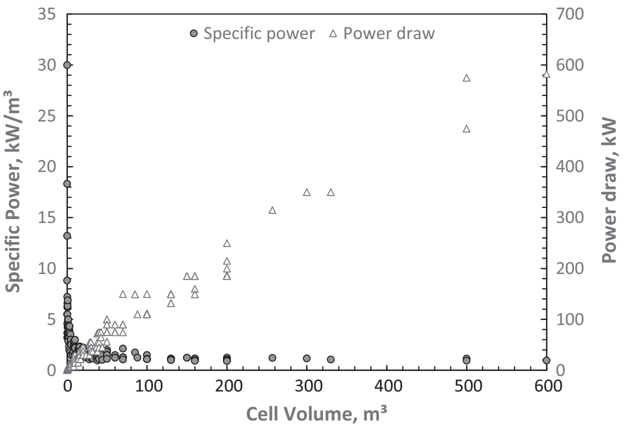

Fig. 1. Power draw and specific power as a function of cell volume (adapted from different flotation cell manufacturer's brochures and from data made available by Power et al., 2000; Nelson and Lelinski, 2000; Gorain et al., 2007).

The installed power per cell (i.e. power draw) increases almost linearly with increase in cell volume (Fig. 1). On the other hand, the specific power (kW/m^3) decreases dramatically as cell volume increases from 0.02 m^3 to about 20 m^3 reaching a minimum of around 1 kW/m^3 for cell volumes greater than 100 m^3.

1.2. Energy dissipation within a flotation cell and its role in flotation performance

Three distinct zones can be identified within a flotation cell: the turbulent, quiescent and froth zones. In the turbulent zone, the rotating action of the impeller provides the energy necessary to keep particles in suspension, enables the generation of small bubbles, and maintains the hydrodynamic conditions needed for efficient bubble-particle interaction. The quiescent zone is less energy intensive than the turbulent zone, and provides conditions for detaching entrained or entrapped gangue particles from created aggregates. This zone also helps maintain a quiescent pulp-froth interface, which stabilizes the froth phase. The froth phase is the upper cleaning zone of the process.

It is clear that along with gas dispersion characteristics, the energy dissipated by the impeller is process-determining in flotation. Its effect on flotation kinetics has been widely studied (Schubert and Bischofberger, 1978; Jameson and Ahmed, 1983; Deglon et al., 1999; Pyke et al., 2003; Newell and Grano, 2006).

Energy dissipation in mechanical flotation cells can be quantified by impeller speed or power input (Ahmed and Jameson, 1985; Deglon et al., 2000; Schubert, 1985, 2008). It can also be determined by measuring, at laboratory scale (and at low concentration of solids), turbulence parameters such as turbulent fluctuating velocities and energy spectra (Jordan and Spears, 1990; Pyke et al., 2002, 2003; Duan et al., 2003).

The distribution of turbulence is extremely difficult to measure throughout the three phase system in a flotation cell, hence the lack of published data. Techniques for turbulence measurement available to date have been applied only to air-water systems (Boyer et al., 2002) and cannot be used in the aggressive and abrasive solids-air-water system found in flotation. The presence of air and solids results in a damping of the turbulence and a reduction in energy dissipation (Schubert, 1999); therefore, it is important to be able to characterise hydrodynamics in three-phase systems.

A novel piezoelectric sensor has recently been developed and used to indicate the distribution of turbulence inside a flotation cell operating with slurry (Tabosa, 2012; Tabosa et al., 2012, 2014). The sensor deflects backwards and forwards in the pulp as a consequence of velocity fluctuation in the turbulent flow. This produces a voltage versus frequency signal, the average of which can be used to characterise the local degree of turbulence. The piezoelectric sensor has been well validated, with measurements being linearly correlated with the fluctuation in the force of the fluid (Meng et al., 2013).

Alternatively, an empirical evaluation of the proportion of the power drawn, P, by an impeller that is transferred into bulk material flow or dissipated in the region of the impeller-stator can be made by using the equation proposed by Hemrajani and Tatterson (2004):

$$P = N_P \rho N^3 D^5 = (\mathcal{K} N^2 D^2) \cdot (N_q \rho N D^3) \qquad (1)$$

where the total kinetic energy $\mathcal{K}$ is proportional to N^{2}D^2 whilst flow rate N_q is proportional to ρND^3, the impeller is represented by N, the impeller rotational speed, and D, impeller diameter, and ρ is the pulp density.

The power number, N$_P$, seems therefore to be a good measure of the proportion of the power drawn by the impeller that is transferred for bulk material flow and dissipated in the impeller-stator vicinity:

$$N_P = \frac{P}{\rho N^3 D^5} = (\mathcal{K} N^2 D^2) \cdot (N_q \rho N D^3) \qquad (2)$$

In the literature on the hydrodynamics of rotor-stator mixers for non-Newtonian fluids, a well-mixed region around the impeller surrounded by stagnant fluid is defined as cavern or pseudo-cavern phenomena. The volume of these caverns was shown to be proportional to the ratio of the stress imparted by the impeller blades into the fluid to the yield stress of the fluid (Doucet et al., 2005; Arratia et al., 2004; Elson et al., 1986).

Doucet et al. (2005) characterised the hydrodynamics of a rotor-stator mixer in terms of power draw and flow patterns and have shown that the evolution of cavern size and shape scale with power number and Reynolds number. By means of a dimensionless power number versus Reynolds number curve, they correlated the shape and magnitude of the pseudo-caverns in the vicinity of the rotor-stator as shown in Fig. 2. The power number and Reynolds number relationship shows that at low Reynolds number (higher N$_P$) the cavern is limited to the vicinity of the rotor-stator only. As Reynolds number increases, N$_P$ becomes lower and constant, the cavern reaches the tank walls and starts to expand vertically in the vessel – a fully turbulent regime is then reached throughout the vessel.

This suggests that at higher power number, more energy is dissipated in the rotor-stator vicinity (cavern formation); while more energy seems to be transferred for bulk material flow as the tank

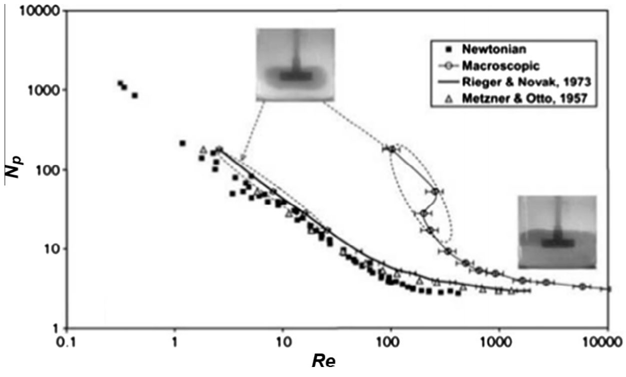

Fig. 2. Location of pseudo-cavern phenomena on power curves for different conditions using Xanthan at 0.2 wt% in a rotor-stator mixer, where N$_P$ is the Power number and Re is the Reynolds number (after Doucet et al., 2005).

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