Available online at www.sciencedirect.com
ScienceDirect
Int. J. Miner. Process. 81 (2007) 224–236
INTERNATIONAL JOURNAL OF MINERAL PROCESSING
www.elsevier.com/locate/ijminpro

Hydrodynamics and scale up in Rushton turbine flotation cells: Part 1 — Cell hydrodynamics

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Received 22 September 2005; received in revised form 30 June 2006; accepted 30 June 2006
Available online 14 August 2006

Abstract

The effect of operating parameters on the hydrodynamics of three geometrically similar Rushton turbine flotation cells with volumes of 2.25, 10 and 50 dm^3 was determined. The operating parameters investigated were superficial gas velocity (J_g), impeller rotational speed (N), and frother (methyl isobutyl carbinol, MIBC) concentration.

Mean energy dissipation values measured using Laser Doppler Velocimetry (LDV) and a torque turntable method were in good agreement. As the cell volume was increased, the mean energy dissipation was proportional to N^3D, rather than N^3D^2 as may be expected based on dimensional analysis. Possible reasons for this difference are discussed. Aeration resulted in a slight increase in mean energy dissipation.

Bubble diameters were measured using a University of Cape Town bubble size analyzer to determine the frother concentration at which a constant bubble diameter was achieved for all operating conditions and cell volumes. The critical frother concentration was 20 ppm MIBC.

The mean bubble velocity was estimated by determining the time required to achieve steady state gas holdup in the top part of the cell after commencing gas sparging. For a constant mean bubble diameter, the bubble velocity increased with increasing superficial gas velocity. As the energy dissipation was increased for a given superficial gas velocity, the bubble velocity decreased linearly until a critical energy dissipation was reached. Above this value, bubble velocity decreased only slightly. As the cell volume increased, the bubble velocity, at the same superficial gas velocity and energy dissipation, also increased.

Keywords: Flotation; Hydrodynamics; Scale-up; Energy dissipation; Bubble size; Bubble velocity

1. Introduction

The collection efficiency with which particles are removed from a flotation pulp (E_{coll}) can be represented as the product of the efficiencies of three sequential sub-processes: viz. — collision (E_c), attachment (E_a) and detachment or stability (E_s) (Derjaguin and Dukhin, 1961). This can be expressed as:

$$E_{coll} = E_c \cdot E_a \cdot E_s \quad (1)$$

The rate of removal of particles by bubbles in a flotation cell is given (Jameson et al., 1977; Duan et al., 2003) by:

$$\frac{dN_p}{dt} = kN_p = -Z_{pb}E_{coll} \quad (2)$$

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0301-7516/$ - see front matter
doi:10.1016/j.minpro.2006.06.007

Thus, the flotation rate constant, k, is proportional to Z_{pb}, the collision frequency per unit volume between particles and bubbles of diameter d_p and d_b respectively, and the collection efficiency. Expressions for the collision frequency and the parameters that make up the collection efficiency have been combined to form a fundamental model of the flotation process (Pyke et al., 2002, 2003; Duan et al., 2003) and can be used to delineate the expected effects of the various hydrodynamic factors which may influence the flotation process.

If solid/liquid interfacial effects are held constant by maintaining constant particle hydrophobicity, flotation behaviour is governed by cell hydrodynamics. The parameters of importance are energy dissipation, bubble diameter and bubble velocity. In practice, the hydrodynamic conditions are determined by the physical operating parameters of impeller rotational speed and superficial gas velocity, as well as frother type and concentration. It is also expected that when the cell volume is increased in scale-up, the operating conditions will need to be varied if the same cell hydrodynamics are to be maintained.

This is the first in a series of papers exploring the relationship between the volume of three geometrically similar Rushton turbine flotation cells, the hydrodynamics within the cells, and the flotation response of a system using particles of constant particle size distribution and contact angle. An overall aim of the study is to determine a set of scale-up criteria to achieve the same size-by-size flotation rate constants in cells of different volume. This particular paper examines the relationship between cell volume, operating parameters and measured hydrodynamic values.

While laboratory and plant flotation rates are usually different (Arbiter et al., 1976), Harris (1973) has suggested that different machine sizes can provide substantially similar flotation performance when the operating variables are appropriately adjusted. Gorain et al. (1997) have shown that it is possible to scale up from a 60 dm^3 cell to a 100 m^3 cell on the basis of bubble surface area flux. However, the use of bubble surface area flux as the sole scale-up criterion does not take into account the effect of turbulence on the flotation process. Gorain et al. (1997) believe that the effect of turbulence is relatively small when comparing most industrial size cells, but may be significant when scaling up from laboratory size cells to industrial cells. The current study is therefore targeted at understanding scale-up from 2.25 dm^3 to 50 dm^3 cells, which is a useful range when considering laboratory cells.

The Rushton turbine cell was chosen to provide a link between the single bubble experiments that had been used to formulate and validate the flotation model (Dai et al., 2000) and those involving bubble swarms and agitation. Rushton turbine cells have been used by Jameson and Ahmed (1983), Deglon (2002), Pyke et al. (2002, 2003), Duan et al. (2003) and Sherrell (2004).

The Rushton turbine has been the subject of a number of detailed investigations (Van't Riet et al., 1976; Costes and Couderc, 1988; Wu and Patterson, 1989; Stoots and Calabrese, 1995; Schafer et al., 1997; Lee and Yianneskis, 1998) so the hydrodynamics, and in particular the distribution of turbulence and energy dissipation, when the cell is filled with liquid only are well established. An important feature of the flow field is a trailing vortex pair that exists behind each stirrer blade (Van't Riet and Smith, 1975; Van der Molen and van Maanen, 1978; Ducoste et al., 1997; Yianneskis et al., 1987).

However, flotation is not a single-phase process, so the effect of the gas and solid phases must also be considered. Turbulent energy dissipation is increased by the presence of gas in the tank (Nesse et al., 1979; Nonaka et al., 1982). The presence of solids causes energy dissipation to be damped (Nesse et al., 1979). This damping effect increases with increasing solids content, and is greater for fine particles.

When a gas is introduced into an agitated body of liquid via a sparger, the bubble size distribution is determined by three phenomena: formation, coalescence and breakup. The presence of small amounts of surface active agents can lead to significant reductions in mean bubble size (Aston et al., 1983; Tucker et al., 1994; Sweet et al., 1997; Aldrich and Feng, 2000; Cho and Laskowski, 2002). This reduction occurs at concentrations at which there is very little change in static surface tension, and is attributed to the ability of the frother to prevent bubble coalescence (Cho and Laskowski, 2002).

Parthasarathy et al. (1991) found that when small bubbles were formed at a porous frit, the bubble diameter remained constant with increasing impeller rotational speed. In the current work, bubbles are produced by forcing air through a porous stainless steel frit with a mean pore diameter of 13 μm. Parthasarathy et al. (1991) used a similar frit and found that the Sauter mean bubble diameter was independent of impeller rotational speed.

In the flotation and scale-up work to follow, which is reported in Part 2 of this series (Newell and Grano, in press), it was decided to maintain a constant mean bubble diameter throughout. This would eliminate a significant variable in the flotation process, and simplify scale-up. In order to do this, the critical coalescence concentration for the frother used (MIBC) had to be determined, and the constancy of bubble diameter for small diameter bubbles and non-coalescing conditions