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Effect of slurry rheology on gas dispersion in a pilot-scale mechanical flotation cell

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ABSTRACT

This paper investigates the effect of slurry rheology on gas dispersion in a 100 l pilot-scale Batequip mechanical flotation cell. The study is conducted using Kaolin, Bindura nickel and Platreef slurries. All three ores display typical non-Newtonian rheological behaviour. The slurry yield stress and viscosity increase exponentially with solids concentration. Bubble size and gas hold-up vary from 0.60 to 1.10 mm and 2% to 15%, respectively. At low/moderate solids concentrations, bubble size and gas holdup display characteristic trends, as noted in numerous literature studies. At high solids concentrations, both bubble size and gas holdup decrease significantly, which is an unexpected finding. This is attributed to the formation of a ‘cavern’ of slurry around the impeller, due to the very high slurry yield stresses. This ‘cavern’ results in the generation of small bubbles in the impeller zone, but poor dispersion of these bubbles throughout the cell, resulting in low gas hold-ups.

1. Introduction

Froth flotation is a separation method used for the beneficiation of a considerable portion of the world’s mineral ores. The majority of flotation occurs in mechanical flotation cells, where effective gas dispersion is a primary requirement for particle–bubble contacting. Mining operations, such as lead–zinc and platinum, are increasingly having to grind ores to ever finer particle sizes in order to liberate the valuable minerals. Ultrafine grinding technologies, such as Isamills, are able to produce particles with a P_{80} as fine as 10 μm (Pease et al., 2006). In addition, operations tend to run flotation circuits at fairly high solids concentrations in order to maximise residence time, accommodate higher tonnages and limit water consumption. Mineral slurries containing fine particles at higher solids concentrations exhibit non-Newtonian rheological behaviour (Muster and Prestidge, 1995; Shi and Napier-Munn, 1996; Prestidge, 1997; Blakey and James, 2003; He et al., 2006; Duarte and Grano, 2007; Alejo and Barrientos, 2009; Das et al., 2011). This behaviour is exacerbated when processing ores containing minerals known to adversely affect rheology, such as certain phyllosilicates (Ndlovu et al., 2010). For these reasons, it is anticipated that slurry rheology will increasingly affect the performance of mechanical flotation cells, as it impacts significantly on cell hydrodynamics.

Cell hydrodynamics refers to fluid flow in the flotation cell and is largely driven by the action of the impeller. Slurry leaves the impeller/stator system in predominantly radial jets which carry kinetic energy, in the form of fluid flow, into the bulk cell where they ultimately decay into turbulence and circulate back to the impeller. Hydrodynamics is governed by vessel characteristics, such as size and shape; impeller properties, such as geometry and rotational speed; and slurry properties, such as density and rheology. Slurries with high densities result in proportionately higher power inputs. Very little research has been conducted on the effect of rheology on flotation cell hydrodynamics. Most research in this area has been in the general chemical engineering field, studying non-Newtonian fluids in stirred tanks (Moore et al., 1995; Fangary et al., 2000; Wilkens et al., 2005; Arratia et al., 2006). However, in the area of flotation, Schubert (1999) found that slurries containing fine particles tended to cause turbulence damping, presumably through an increase in the slurry viscosity. More recently, Bakker et al. (2009, 2010) found that slurries characterised by rheologies with a high yield stress may result in the formation of a yielded ‘cavern’ of slurry around the impeller, with slurry in the bulk cell remaining unyielded, and therefore stagnant.

Gas dispersion refers to the generation of small bubbles in the impeller/stator region and their dispersion throughout the flotation cell by bulk fluid flow. Gas dispersion is largely controlled by cell hydrodynamics and defines the efficiency of the flotation process once the chemistry has been established (Gomez et al., 2003). Gas dispersion is typically characterised by the measurement of bubble size, gas hold-up, superficial gas velocity and bubble surface area flux. Gas dispersion in mechanical flotation cells has been studied extensively (Gorain et al., 1995a,b; Deglon et al., 2000; Finch et al., 2000; Grau and Heiskanen, 2003, 2005; Nesset et al., 2006; Schwarz and Alexander, 2006). However, the

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effect of rheology on gas dispersion in flotation cells has received little attention. Some research has been conducted on the effect of solids concentration on gas dispersion. Here, the bubble size has been found to increase at higher solids concentrations (Tucker et al., 1994; Grau and Heiskanen, 2005).

The objective of this paper is to investigate the effect of slurry rheology on gas dispersion in a mechanical flotation cell. The study is conducted using Kaolin, Bindura nickel and Platreef slurries in a pilot-scale mechanical flotation cell, as used by Van der Westhuizen and Deglon (2007, 2008) and Bakker et al. (2009, 2010).

2. Experimental

2.1. Mechanical flotation cell

The study was conducted on a 100 l pilot-scale Batequip mechanical flotation cell with tank diameter ($T = 0.54$ m) and liquid depth ($Z = 0.80$, $T = 0.44$ m). The cell was agitated by a six-bladed Bateman impeller with ($D = 0.15$ m, $W = 0.10$ m) and impeller clearance ($C_b = 0.15$, $T = 0.083$ m). The impeller clearance resulted in radial circulation patterns back to the eye of the impeller above and below the impeller i.e. a double-figure-of-eight circulation pattern. Impeller speed was adjusted using a variable speed drive and measured by an electromagnetic sensor. Power draw was measured using a three-phase Wattmeter. Air flow rate was adjusted using a needle valve and measured by an air rotameter. A schematic of the flotation cell is shown in Fig. 1.

2.2. Slurry rheology

Tests were carried out using Kaolin, Bindura nickel and Platreef ores. Ores were obtained from the Serina Kaolin mine (Cape Town), Trojan nickel deposit (Harare) and northern limb Bushveld Complex (Mokopane), respectively. These ores were chosen as they are known to cause slurries that exhibit non-Newtonian rheological properties, due to the presence of phyllosilicate minerals (Kaolin – kaolinite; Bindura nickel – serpentine, talc; Platreef – talc). Representative samples of each ore were prepared by milling, followed by blending and splitting in a rotary splitter. Particle size was determined using a Malvern Particle Size Analyzer. Mean particle sizes (d_{50}) were 5 μm for Kaolin, 20 μm for Bindura nickel and 9 μm for Platreef. Ore specific gravities were 2.60 for Kaolin, 3.00 for Bindura nickel and 3.02 for Platreef.

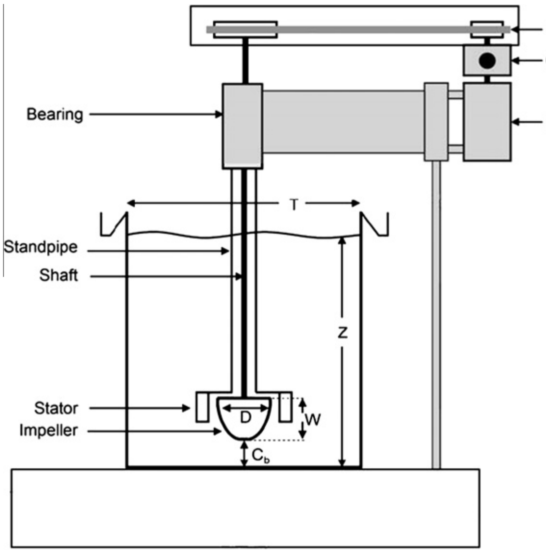

Fig. 1. Pilot-scale flotation cell.

Rheological measurements were carried out using a MCR 300 rheometer with a cup and bob geometry. Shear rates of between 0.1 and 1000 s^{-1} were used. This straddles the shear rate range of between 100 and 800 s^{-1} in the mechanical flotation cell, estimated using the equations of Sanchez Perez et al. (2006). Synthetic plant water was used in all tests in order to simulate industrial conditions (Wiese et al., 2010). The rheological behaviour of the slurry was manipulated by varying the solids concentration for each ore type. Kaolin was varied from 15% to 40% while both Bindura nickel and Platreef were varied from 20% to 60%. The slurry yield stress and viscosity were determined by fitting the Bingham rheology model to the rheogram data, as used by Ndlovu et al. (2010).

2.3. Gas dispersion

Tests were carried out at impeller speeds of between 300 and 650 RPM. This resulted in a range of power intensities (P/V) of approximately 0.50–8.50 kW/m^3, depending on the ore type and solids concentration. This straddles and exceeds the range of power intensities found in industrial mechanical flotation cells (Deglon, 2005). Air flow rate was kept constant at 206 l/min, resulting in a superficial gas velocity ($J_g = 1.5$ cm/s). Frother dosage (MIBC) was maintained at 20 ppm (liquid basis) in order to limit bubble coalescence. Bubble size (mean, d_{10}) was measured photographically using the Anglo Platinum Bubble Size Analyser (Naik and van Drunick, 2007). Measurements were taken at a point approximately 10 cm below the pulp and equidistant between the impeller tip and cell wall. Gas hold-up (global) was measured by recording the change in height of the aerated and unaerated pulp. This simple, yet reliable method of global gas hold-up measurement proved robust. Repeatability was determined from replicates measurements of bubble size and gas holdup for the entire data set. The average standard error for bubble size and gas hold-up were 0.02 mm and 0.45%, respectively.

3. Results and discussion

3.1. Slurry rheology

Fig. 2 shows the effect of solids concentration on the yield stress for the three ores. There is a clear exponential relationship with solids concentration, as observed in numerous studies in the literature e.g. sulphide slurries (Muster and Prestidge, 1995); alumina and zirconia suspensions (Pradip and Malghan, 1998); quartz par-

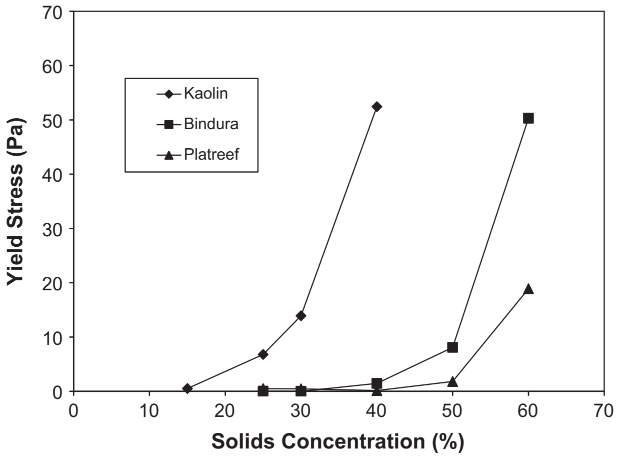

Fig. 2. Graph of yield stress (Pa) versus solids concentration (%).