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Critical contact angle for coarse sphalerite flotation in a fluidised-bed separator vs. a mechanically agitated cell

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ABSTRACT

This work investigates the critical contact angle for the flotation of coarse (850–1180 μm, 425–850 μm and 250–425 μm) sphalerite particles in an aerated fluidised-bed separator (HydroFloat) in comparison to a mechanically agitated flotation cell (Denver flotation cell). In this study, the surface chemistry (contact angles) of the sphalerite particles was controlled by varying collector (sodium isopropyl xanthate) addition rate and/or purging the slurry with either nitrogen (N_2) or oxygen (O_2) before flotation. The flotation performance varied in response to the change in contact angle in both the aerated fluidised-bed separator and the mechanically agitated cell. A critical contact angle threshold, below which flotation was not possible, was determined for each particle size fraction and flotation machine. The results indicate that the critical contact angle required to float coarse sphalerite particles in a mechanically agitated cell was higher than that in the fluidised-bed separator, and increased as the particle size increased. At the same particle size and similar contact angles, the recoveries obtained by the aerated fluidised-bed separator in most cases were significantly higher than those obtained with the mechanically agitated flotation cell.

1. Introduction

To float coarse particles effectively and efficiently, they must possess a high contact angle in a quiescent hydrodynamic environment. The optimum condition for coarse particle flotation is an environment where the agitation within the cell is just enough to keep particles in suspension (Barbery, 1984). Currently, conventional flotation cells fail to meet this criterion because they rely on rotating impellers to generate bubbles while simultaneously keeping particles and bubbles in suspension. The high degree of turbulence in the cells favours the detachment of particles from bubbles. To overcome this inherent limitation of mechanically agitated flotation cells, and provide favourable conditions for coarse particle flotation, fluidised-bed flotation was developed. Fluidised-bed cells operate under more favourable hydrodynamic conditions, allowing for improved particle-bubble collision and attachment which increases the upper limits of coarse particle recovery (Mankosa et al., 2003; Kohmuench et al., 2001). A schematic representation of a fluidised-bed flotation separator is shown in Fig. 1. The theory of operation of the device has been explained elsewhere (Kohmuench et al., 2013).

Overall, particle size plays a major role in flotation. However, the contact angle of particles is even more critical. For every particle size, there exists a critical contact angle below which flotation does not occur (Blake and Ralston, 1985; Crawford and Ralston, 1988). The critical contact angle increases as the particle size increases (Gontijo et al., 2007; Chipfunhu et al., 2011; Awatey et al., 2013a), or decreases as particle size decreases (Miettinen et al., 2010). Generally speaking, flotation becomes more difficult as the critical contact angle increases assuming all other variables are equal.

The current work is aimed at determining whether the critical contact angle for flotation of coarse particles is significantly reduced, in a low turbulent environment such as that found in a fluidised-bed flotation device. This was accomplished by comparing the results obtained with the fluidised-bed separator to those obtained with a Denver flotation cell. The contact angle was measured by condensing nano-size water droplets on the surfaces of the conditioned sphalerite particles using an Environmental Scanning Electron Microscope (ESEM), and measuring the angle of contact between the particles and the droplets.

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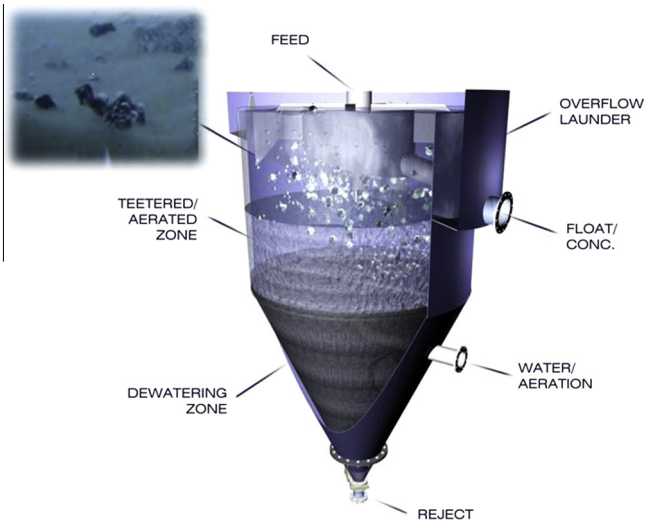

Fig. 1. Schematic representation of the HydroFloat fluidised-bed separator used in this study (Kohmuench et al., 2013).

2. Experimental

2.1. Materials

A high grade sphalerite (ZnS) ore was used for the experiments. The chemical and mineralogical assays of the feed material have been reported previously (Awatey et al., 2013c). Lumps of the sphalerite ore were crushed with laboratory gyratory and roll crushers and dry screened through a 1180 μm and a 250 μm top and bottom size sieves. The oversize of the 1180 μm sieve was crushed again in the roll crusher until all the ore passed through the 1180 μm sieve. The crushed ore (+250–1180 μm) was then split into statistically equivalent samples, each weighing 500 g. The size distribution of the sample is shown previously in Awatey et al. (2013c). Particles finer than 250 μm were not included to maintain the top-to-bottom size ratio at approximately 5:1, which is required to maintain an efficient separation when using fluidised beds for the concentration of minerals. After crushing, most of the sphalerite particles in the ore appeared fully liberated when observed under both an optical and Scanning Electron Microscope (SEM). A minority of the sphalerite was locked in composites with gangue, as shown in Figs. 2 and 3.

2.2. Reagents

Sodium isopropyl xanthate (SIPX) and polypropylene glycol (PPG425) were used as the collector and frother, respectively, in the flotation experiments. Demineralised water ($T = 20\,^{\circ}C$ and pH = 5.7) was used in all the tests. Lime was used as the pH modifier. Nitrogen (N_2) and oxygen (O_2) gases were used in separate cases to purge the flotation feed pulp. Ethylenediaminetetraacetic acid (EDTA) solution (10^{-4} M) was used in some cases to clean the feed particles before flotation. Copper sulphate ($CuSO_4$) was used for sphalerite activation.

2.3. Conditioning

A measured mass (500 g) of the flotation feed was pulped at 35% solids into a 1.5 l Denver flotation cell, which was used for conditioning and to prepare the feed. The pulp was purged with either nitrogen (N_2) or oxygen (O_2) gas while stirring at 800 rpm. Nitrogen was added to reduce the amount of oxidation products that may have formed on the surface of the sphalerite particles during storage. Similarly, oxygen was added to oxidise the sphalerite particles in an effort to change their surface chemistry and manipulate the contact angle. The pH was continuously monitored and maintained at 10 ± 0.04. $CuSO_4$ solution at different concentrations as shown in Table 1 were then added to the pulp and stirred for 5 min, after which the xanthate collector was introduced and the stirring was continued for an additional 2 min. The frother was not added at this stage of conditioning in the case of the fluidised-bed separator; rather it was added by injection into the stream of aerated fluidisation water. In the case of the Denver cell flotation, the frother was added 1 min prior to concentrate collection. The different conditioning regimes employed in this study are shown in Table 1. At the end of each conditioning period, a predetermined amount of the conditioned pulp was extracted and prepared for bubble-particle detachment force and contact angle measurements.

2.4. Flotation

2.4.1. Fluidised-bed flotation

Quartz particles of the same size fractions and similar size distribution (850–1180 μm, 425–850 μm and 250–425 μm) were used to build the fluidised-bed background. These quartz particles simulate the non-float particles that, in practice, autogenously generate the fluidized bed. The fluidisation water and air flow rates were adjusted to avoid channelling within the cell. It is important to avoid the creation of air/water channels in the bed since this creates unwanted turbulence within the cell, which can be detrimental to flotation recovery. The HydroFloat separator is not operated with a discernible froth layer; therefore the addition rate of frother (1 g/t) was just sufficient to create fine bubbles as air was introduced. The optimum operating parameters as determined by Awatey et al. (2013c) were employed in the current work. The conditioned flotation feed was fed to a vibrating over-head feeder which slowly discharged the feed material through a feed funnel into the top of the cell. The concentrate collected at the end of a 10 min flotation period was dried and sieved into the appropriate size fractions and prepared for chemical assay.

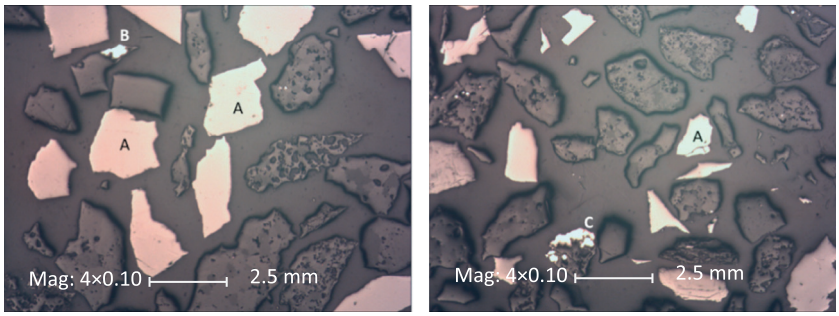

Fig. 2. Optical microscope images showing free (A) and locked (B and C) sphalerite particles in the ore.