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Dynamic froth stability of copper flotation tailings

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ABSTRACT

In this work, dynamic froth stability is used for the first time to investigate the flotation behaviour of copper tailings. Reprocessing of material from tailings dams is not only environmentally desirable, but also increasingly economically feasible as head grades can be high compared to new deposits. Flotation tailings, however, usually contain a large proportion of fine (10–50 μm) and ultra fine (< 10μm) material and the effect of these particle sizes on froth stability is not yet fully understood.

For this study, samples were obtained from the overflow and underflow streams of the primary hydrocyclone at a concentrator that reprocesses copper flotation tailings. These samples were combined in different ratios to assess the dynamic froth stabilities at a wide range of particle size distributions and superficial gas velocities. The findings have shown that the effect of particle size on dynamic froth stability can be more complex than previously thought, with a local maximum in dynamic froth stability found at each air rate. Moreover, batch tests suggest that a local maximum in stability can be linked to improvements in flotation performance. Thus this work demonstrates that the dynamic froth stability can be used to find an optimum particle size distribution required to enhance flotation. This also has important implications for the reprocessing of copper tailings as it could inform the selection of the cut size for the hydrocyclones.

1. Introduction

One of the key challenges currently facing the mining industry is the decreasing head grades whilst the global demand for metals is ever increasing. It is therefore becoming more important for the industry to look to other potential sources to meet the demand. One such source is tailings dams. Historically, processing efficiency was much lower than it is today, resulting in tailings being higher grade (Falagán et al., 2017). For example, over the 20th century the copper grade of tailings has fallen from 0.75% to 0.14% (Gordon, 2002). In some cases historic tailings dams can therefore be higher grade than current deposits. Reprocessing this material is beneficial to industry for several reasons. Firstly, there are lower costs involved compared to a new mine as the ore has already been mined and milled. Secondly, tailings dams present a significant environmental problem, so reprocessing can help to reduce environmental contamination (Chen et al., 2014). However, there is no blanket approach to reprocessing tailings as there will be different requirements associated to each individual dam (Edraki et al., 2014). Another problem is that the majority of material held in tailings dams is fine grained, < 50 μm.

1.1. Fine particle flotation

There are several challenges in the flotation of fine particles, generally those less than 50 μm in size. Firstly, the probability of bubble particle attachment occurring is low (Miettinen et al., 2010). Secondly, they are more easily entrained due to the low particle diameter to Plateau border size ratio (Trahar, 1981) and thirdly, they can require higher quantities of reagents in order to increase the contact angle caused by a higher specific surface area (Chipfunhu et al., 2011).

Whilst there has been a significant body of work in fine particle flotation, it is not yet fully understood whether fine particles stabilise or destabilise the froth. Johansson and Pugh (1992) studied the effects of different contact angles and different particle sizes of quartz on the dynamic froth stability in a laboratory scale, stirred flotation column. For the finest particle size investigated, 26–44 μm, it was found that particles stabilised the froth when they were moderately hydrophobic (Contact Angle ≈50–65°), however at lower contact angles they had little effect on the stability and at higher contact angles they destabilised the froth. Tao et al. (2000) showed that a small increment in the solids concentration of very fine coal particles (10 μm), also in a laboratory scale flotation column, lead to a large decrease in water recovery and this suggested that the fine particles had a destabilising

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effect on the froth.

Ahmed and Jameson (1985) suggested that a potential way to achieve the flotation of fine and coarse particles is to split the feed and use different operating conditions to treat each size. However, this requires a more complex flowsheet and so it is also important to understand if there are techniques for treating different sizes together. The interaction between fine particles and coarse particles of pure silica has been studied by Vieira and Peres (2007) and Rahman et al. (2012). The work by Vieira and Peres (2007) investigated the effects that changing the amount of fine material (38–74 μm) in the feed had on the flotation recovery of different particle sizes using a Denver cell. The results showed that there is an intermediate amount of fines required in the feed to optimise the solids recovery of all particle sizes investigated. They suggested that this can be attributed to an improvement in froth stability. Rahman et al. (2012) also studied the effects of changing feed size (with d80s ranging from 80 to 240 μm) on solids recovery in a laboratory scale flotation column. They found that an increase in the amount of fine material (i.e. a decrease in d80) resulted in increased recoveries. Contrary to Vieira and Peres (2007),Rahman et al. (2012) did not observe that an intermediate amount of fines in the feed produced the best results.

Work by Leistner et al. (2017) investigated the effect that the size of gangue material, quartz, had on the recovery of ultrafine (< 10 μm) and fine (10–50 μm) particles of the target mineral, magnetite. These experiments were conducted in a mechanical laboratory scale flotation cell. The results indicated that using fine quartz increases magnetite recovery for both size fractions whilst using ultrafine quartz particles has the opposite effect. This indicates that the recovery of ultrafine valuable particles can be improved in the presence of coarser gangue particles.

Froth stability is not only dependent on particle size or hydrophobicity, as already discussed, but the superficial gas velocity also plays an important role. Recently, Norori-McCormac et al. (2017) used a novel laboratory scale mechanical flotation cell to investigate the effects of superficial gas velocity and particle size on froth stability, measured using air recovery. They found that at high air rates a relatively fine feed, d80 of 89.6 μm, resulted in higher froth stabilities, yet at lower air rates it was an intermediate feed size that yielded the higher froth stabilities. This suggests that the relationship is more complex than previously thought.

1.2. Dynamic froth stability

The Bikerman test was developed to investigate the foam stability of dynamic systems using a flotation column (Bikerman, 1948). In this test gas is bubbled through a porous membrane into liquid in the column, allowing a foam layer to form at the top. This foam will rise until it reaches a steady state where the volume of gas entering the system, as bubbles, is equal to the volume of gas escaping when the bubbles burst (Bikerman, 1948). Many studies have shown that the height of the column of foam is proportional to the rate of flow of gas in the system and Bikerman (1948) defines the rate of proportionality as the dynamic foam stability (Σ):

$$\Sigma = \frac{V_f}{Q} = \frac{H}{J_g}, \qquad (1)$$

where V_f is the volume of the foam, Q is the volumetric flow rate of the gas, H is the foam height of the system at steady state and J_g is the superficial gas velocity. This rate of proportionality does not only apply to foams but also to froths and can also be described as the average lifetime of a bubble in the froth (Bikerman, 1973).

There have been several studies looking at the effects of particle size and superficial gas velocity on froth stability. Ip et al. (1999) investigated the relationship between froth stability and particle size, using a silica, water, air system. Although the results showed a general decrease in stability with an increase in mean particle size, this was not a smooth change; between a size of 60 μm and 90 μm there was little variation in froth stability. Barbian et al. (2003) used a modified Denver cell with a Platinum Group Metal (PGM) ore and observed that the dynamic froth stability factor decreased with an increase in superficial gas velocities. However, the superficial gas velocities in their work ranged between 0.13 cm s^{-1} and 0.66 cm s^{-1} and were therefore low compared to industrial flotation cells. Aktas et al. (2008) used a similar cell, again with a PGM ore, and observed the same relationship between dynamic froth stability and superficial gas velocity, again investigating the effects at low superficial gas velocities, between 0.26 cm s^{-1} and 0.53 cm s^{-1}. In addition to varying the gas velocity (Aktas et al., 2008) also varied the particle size and found that as the particle size increased the dynamic froth stability decreased, however, only four different sizes were used and these were coarse (d90 of 118 μm to 306 μm) and so the study doesn't give information about a broad range of both fine and coarse particles. More recently, Liang et al. (2015) investigated the effects of coal particles of different sizes on the froth stability again using a modified stability column. Four different size fractions were used here, namely −74 μm, −125 + 74 μm, −250 + 125 μm and −500 + 250 μm. Whilst these sizes consider a wider overall distribution than other studies, each of the size ranges tested was quite broad. These experiments were also run at low gas velocities of 0.2 cm s^{-1}. McFadzean et al. (2016a) studied the effects of particle size on dynamic froth stability for three different ores: a synthetic silica and pyrite ore, a PGM ore, and an Itabirite ore. The results for all three ores showed a smooth decreasing power law relationship when increasing the average feed particle size. Whilst the particle size of the synthetic ore ranges from around 16 μm to 210 μm the other two ores had smaller size ranges, between 29 μm and 71 μm. These experiments were run at a superficial gas velocity of 0.98 cm s^{-1}.

Barbian et al. (2005) developed a froth stability column to be used at industrial scale, allowing froth stability to be correlated to flotation performance. The results, from a copper sulphide ore, showed that the highest dynamic froth stability resulted in the highest copper grade but lowest recovery. McFadzean et al. (2016b) also showed a link between dynamic froth stability and flotation performance in their work. Their study investigated the effects of different frother blends on the froth stability of a PGM ore with an agitated laboratory scale column. The results showed that a higher froth stability resulted in higher recovery, but that there was little correlation with grade. The results from these two studies are contradictory suggesting that the relationship between froth stability and flotation performance is more complicated.

Whilst there have been various studies investigating the dynamic froth stability and the link to particle size, different gas velocities and flotation performance, there has been no attempt to link all three aspects. This work fills this gap by determining the dynamic froth stability of copper flotation tailings, considering different particle size distributions and at a range of superficial gas velocities. In addition, batch flotation tests were performed for selected conditions to obtain a preliminary assessment of flotation performance. The range of particle sizes investigated here are wider than have previously been studied and the superficial gas velocities are higher, and closer to those encountered in industrial flotation cells.

2. Methodology and equipment

2.1. Case study: tailings reprocessing plant

A processing plant in Chile has been reprocessing copper flotation tailings from two historic and one fresh tailings dams since 1992. The grade ranges from 0.12% Cu for the fresh tailings to 0.27% Cu for the historic tailings. The feed from these tailings dams to the plant contains a high proportion of fines, approximately 50%, by mass, of the material passing 10 μm. Once the tailings feed has been transported to the plant it passes through the primary hydrocyclone for the different particle