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Effect of froth rheology on froth and flotation performance

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ABSTRACT

It has been suspected for some time that froth rheology has an impact on froth and flotation performance but little experimental work has been performed to investigate these effects. In this paper, the effect of froth rheology on froth and flotation performance was investigated by performing flotation tests in a 20 L continuous flotation cell using a synthetic ore which was a mixture of pure chalcopyrite and silica. Froth rheology was measured during these tests along with key flotation performance indicators: froth height above the lip, air recovery and silica recovery. It was found that froth rheology was positively correlated to froth height above the lip. Air recovery was also correlated to froth rheology; at low froth viscosity, air recovery increased upon increasing consistency index (a measure of the viscosity of a fluid) while the opposite was found at high froth viscosity. A similar correlation between froth viscosity and silica recovery was also observed.

Measurements of froth rheology were also performed in industrial scale flotation cells processing a platinum ore. The investigated industrial scale froth exhibited similar rheological characteristics to that observed in the laboratory work. Both of the froths have a shear-thinning nature with minor yield stress. Froth height above the lip was also found to be positively correlated with froth viscosity, which supports the conclusions drawn from the laboratory work.

1. Introduction

Froth flotation consists of pulp and froth phases. The function of the froth phase is to enhance the overall selectivity and recovery of the flotation process. The froth achieves these by reducing the recovery of entrained material to the concentrate stream, while preferentially retaining the attached material. This increases the concentrate grade whilst limiting as far as possible the reduction in recovery of valuables. The importance of the cleaning and recovering actions of the froth in flotation has been well recognised (Feteris et al., 1987; Moys, 1978; Schuhmann, 1942; Subrahmanyam and Forssberg, 1988; Yianatos et al., 1988).

The froth efficiency which can be represented by the selectivity and recovery of the process is influenced by froth retention time. A greater froth retention time results in a greater probability of drainage of the water and entrained solids back from the froth phase to the pulp phase through the Plateau borders and vertices within the froth (Wang et al., 2016a). Froth recovery, the fraction of valuable mineral entering the froth phase attached to air bubbles that reports to the concentrate (Finch and Dobby, 1990), is the most commonly used measure of how effectively the froth recovers the valuable mineral. Previous work (Gorain et al., 1998; Mathe et al., 2000) has indicated that froth recovery decreases exponentially with an increase in froth retention time. A higher froth retention time results in an increased probability of froth collapse as well as valuable particle drop-back due to detachment and drainage. However, it is difficult to measure froth recovery (Franzidis and Harris, 2010; Runge et al., 2010). Air recovery, the volume fraction of air that is added to the cell which survives and reports to the concentrate, has been used as a measure of froth stability (Hadler et al., 2010; Leiva et al., 2012; Neethling and Cilliers, 2008; Shean et al., 2017). It has been reported that both higher grade and recovery are obtained at the peak air recovery (Hadler and Cilliers, 2009; Hadler et al., 2010; Shean et al., 2017). The valuable minerals are transported from the pulp-froth interface to the launder by attachment to air bubbles in the froth phase. The more air is recovered to the launder, the more valuable minerals are recovered to be concentrate. Hence, froth recovery is likely to be positively correlated with air recovery.

It is expected that froth rheology can influence froth and flotation performance through its effect on froth retention time. A more viscous froth resists motion towards the lip, increasing the time the froth remains in the flotation cell. Very little work has been performed to investigate the effect of froth rheology on froth and flotation performance other than the work of Shi and Zheng (2003) who showed that froth rheology had a strong correlation with concentrate grade in an Outokumpu 3-m^3 tank cell operated at the Mt Isa Mines (MIM) Copper Concentrator.

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Table 1
The conditions in the CCRD flotation tests (Li et al., 2016a).

Test	Froth height (cm)	Superficial gas velocity ($cm\ s^{-1}$)	Impeller speed (rpm)	Chalcopyrite particle size P80 (μm)	Copper grade (%)
1	7	1.4	900	80	1.0
2	6	1.0	750	50	1.4
3	6	1.8	1050	50	1.4
4	8	1.8	750	50	1.4
5	6	1.0	750	110	0.6
6	6	1.8	750	50	0.6
7	6	1.0	1050	50	0.6
8	6	1.8	1050	110	0.6
9	7	1.4	900	80	1.0
10	7	1.4	900	80	1.0
11	8	1.8	750	110	0.6
12	7	1.4	900	80	1.0
13	8	1.0	1050	110	0.6
14	8	1.8	1050	110	1.4
15	8	1.0	750	110	1.4
16	6	1.8	750	110	1.4
17	8	1.8	1050	50	0.6
18	7	1.4	900	80	1.0
19	7	1.4	900	80	1.0
20	8	1.0	750	50	0.6
21	8	1.0	1050	50	1.4
22	6	1.0	1050	110	1.4
23	7	1.4	900	140	1.0
24	5	1.4	900	80	1.0
25	7	0.6	900	80	1.0
26	7	1.4	900	80	1.0
27	7	1.4	1200	80	1.0
28	7	1.4	900	80	1.8
29	7	1.4	600	80	1.0
30	7	2.2	900	80	1.0
31	9	1.4	900	80	1.0
32	7	1.4	900	80	0.2
33	7	1.4	900	20	1.0

In previous work published by the authors, the effect of froth properties on froth rheology was investigated using the results of a Central Composite Rotatable Design (CCRD) test program (Li et al., 2016a; Li et al., 2016b). This program consisted of 33 flotation tests performed in a 20 litre flotation rig continuously fed by a synthetically created mixture of silica and chalcopyrite. Tests were performed at a range of different operating conditions while froth rheology, metallurgical samples and various froth parameters were measured. The natural extension of this work, is to use this information to also investigate the effect of froth rheology on the froth and flotation performance, the results of which are presented in this paper.

At the end of this paper, a preliminary industrial study of froth rheology conducted in a platinum ore is described. The industrial result was used to validate some findings observed in the laboratory test work.

2. Experimental

Table 1 shows the details of the 33 flotation tests that will be analysed in this paper. They involve varying both cell operational parameters (e.g. froth height, superficial gas velocity and impeller speed) as well as the feed properties with the objective of changing the properties of the flotation froth and thus its rheology. They were performed according to a CCRD experimental design which involves testing each variable at five different levels, as described in detail by Napier-Munn (2014). There are seven repeat tests at a central condition (i.e. Test 1, 9, 10, 12, 18, 19, and 26) and it has been shown that the froth rheology data produced from these tests was reasonably repeatable (Li et al., 2016a; Li et al., 2016b).

The 33 flotation tests were performed in a bottom driven 20 L flotation cell with cross sectional dimensions of 30 by 30 cm. The flotation feed was a mixture of pure chalcopyrite and silica. The chalcopyrite was purchased from Geo Discoveries as bulk rock. The silica was purchased from Sibelco Australia as fine particles (P80 = 73 μm). Before each flotation test, a measured quantity of the chalcopyrite was ground to the targeted particle size distribution, mixed with silica to achieve the desired feed grade, and diluted with Brisbane tap water in a conditioning tank. The volume of water added was that required to achieve 40 wt% solids in the feed to all the tests. Sodium ethyl xanthate (2.0 g/t) and Dowfroth 250 (14.7 ppm) were used as the collector and the frother, respectively.

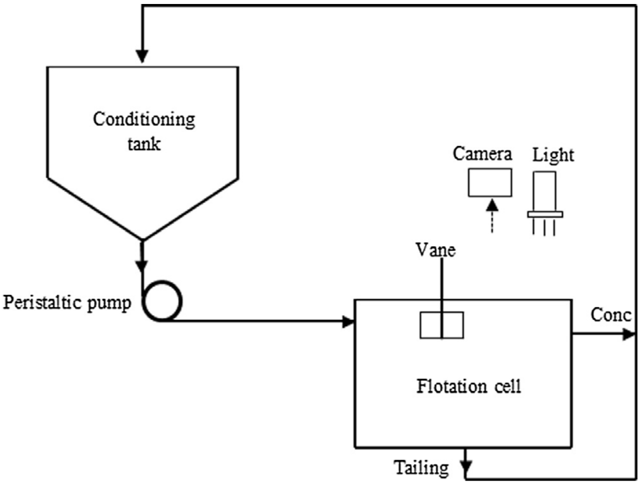

Fig. 1. A pictorial diagram of the experimental set up (Li et al., 2016a).

The flotation tests were operated continuously in a closed circuit by recycling the concentrate and tailing. A pictorial diagram of the experimental set-up is shown in Fig.1. More details of the experiments may be found in previously published work (Li et al., 2016a).

After operating the system a sufficient period to achieve process stabilisation, froth rheology was measured, froth vision was recorded and metallurgical samples (feed, concentrate and tailing) were collected for assay (copper and silica). A ruler was then placed at the middle of the cell lip to measure the froth height above the lip as it discharged into the launder.

The froth rheology measurement was conducted using a 6-blade vane (22 mm in diameter and 16 mm height) attached to an air-bearing rheometer (Anton Paar DSR301). A tube (74 mm in diameter and 150 mm height) was used to encircle the vane to eliminate the effect of the horizontal froth flow on the rheology measurement as previously discussed by the authors (Li et al., 2015). The vane was positioned in the middle of the cell with its upper edge immersed 2 cm into the froth. During the froth rheology measurement, the torque values were measured by increasing the vane speed from 1 rpm to 15 rpm in equal increments. A total of 5 torque values were measured in each test with a 5 s interval between each measurement. Each series of torque measurements were replicated five times for each test. The vane was only immersed in the froth for the period of the rheology measurements and then moved away to not impede the flotation froth movement. The measured raw data were torque value versus vane speed. The method to convert the raw data to the standard rheological terms (i.e. shear stress versus shear rate) has been developed and presented previously by the authors (Li et al., 2015).

A digital video camera (Sony ACC-FV50B) was mounted above the flotation cell to record froth movement and the videos were analysed by a modified SmartFroth machine vision algorithm (Morar, 2010) to determine the froth discharge velocity at the cell launder lip. A single light source was mounted above the froth surface as this results in a single bright light on each bubble – a requirement of the froth analysis algorithm used in the analysis software. The froth velocity was used to calculate air recovery, which will be introduced in Section 4. There was also an attempt to calculate bubble burst rate, the volume of bursting