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Gas dispersion properties of collector/frother blends

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ABSTRACT

The addition of frothers in the flotation process has a significant effect on the hydrodynamic properties of the pulp phase as well as the stability of the froth phase. Some flotation collectors have been reported to have similar hydrodynamic effects, but there are few published quantitative studies. In this paper, the pure forms of the main families of sulfhydryl collectors from thiophosphates, xanthates and xanthate derivatives are tested. The aim was to determine the hydrodynamic properties of each reagent and to examine frother-collector interactions in terms of hydrodynamics. Experiments were carried out in a two phase air-water system using a 3 in. diameter column. Gas holdup (ε_g) and foam height (Hf) were measured to construct hydrodynamic characterization curves. The collectors tested have varied hydrodynamic activity with the xanthogen subgroup of collectors showing different degrees of hydrodynamic activity depending on their structure. In general, sulfhydryl collectors used in salt formulations showed very little hydrodynamic activity, while the oily collectors showed varied hydrodynamic effects from frother-type behavior to defoaming. In all frother-collector blends tested, a variable degree of foam stability loss was observed with this effect more pronounced in blends of weak frother and collector. A slight increase in ε_g was measured for almost all of the collector-frother blends.

1. Introduction

Flotation performance is typically controlled by the addition of chemical reagents such as collectors and frothers. A frother has two main functions: generate and preserve small bubbles in the pulp phase; and provide stability to the froth phase. Three mechanisms of particle recovery into the froth have been proposed: by particle-bubble attachment; by water entrainment; and by entrapment between attached particles (Wills and Finch, 2016). Understanding frother hydrodynamic characteristics has become essential as the selection of an optimum frother is dependent on the needs of a given flotation circuit. Different methods exist to characterize frother strength, based on parameters such as gas holdup (ε_g), Sauter mean bubble diameter (D_{32}) and water carrying rate (Cho and Laskowski, 2002; Azgomi et al., 2007; Moyo et al., 2007). These parameters are strongly influenced by frother type. A strong frother is characterized as having a significantly higher water carrying rate, smaller bubble size and a high gas holdup, but increased frother strength also results in less selective mineral recovery (Azgomi et al., 2007; Melo and Laskowski, 2006; Moyo et al., 2007).

Cappuccitti and Finch (2008) proposed a characterization process termed the "hydrodynamic characterization curve" which correlates foam height as a function of gas holdup, *i.e.* H_f *vs.* ε_g. In this paper, the two-phase liquid-air system is referred to as "foam", with "froth" reserved for the three-phase solid-liquid-air system typical of industrial flotation systems. The relationship between gas holdup (which provides an indication of the bubble size and rise velocity in the pulp phase), and foam height (which reflects foam stability), defines the "hydrodynamic characterization" curve of a frother. The utility of this characterization method can be understood in terms of the rate constant relationship proposed by Gorain et al. (1998), where the rate constant depends on three factors: ore floatability, bubble surface area flux and froth recovery. Thus hydrodynamic characterization curves of gas holdup versus foam height provide indications of the bubble surface area flux and froth recovery, respectively.

Relative hydrodynamic strengths can be determined from the curves produced for multiple frother concentrations. A hydrodynamically strong frother will have a sharp increase in foam height as concentration increases within a relatively small range of gas holdup (a steeper hydrodynamic curve), whereas a hydrodynamically weaker frother will have a gradual increase in foam height as concentration increases over a broader range of gas holdup.

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The shape of the curve therefore gives an indication of the relative strength of a frother.

The main function of a collector is to selectively adsorb on a mineral surface, altering its hydrophobicity such that bubble-particle aggregation can take place for minerals which are not readily floatable in the absence of absence of collector addition. A number of recent studies investigating the influence of collectors on flotation hydrodynamics have shown that amine and many oxhydryl collectors exhibit frother-like properties (Espinosa-Gomez et al., 1988; Laskowski, 1993; El-Shall et al., 2000; Atrafi et al., 2012; Ravichandran et al., 2013; Corona-Arroyo et al., 2015). Atrafi et al. (2012) quantified the frother-like properties of sodium oleate (a common anionic fatty acid collector) and determined it to be a very weak frother over the pH range 6.2–10 with a critical coalescence concentration (CCC) in excess of 70 ppm. The CCC is an indication of bubble size reduction, readers unfamiliar with this concept should consult Cho and Laskowski (2001) and Zhang et al. (2012). Corona-Arroyo et al. (2015) determined the CCC of dodecylamine (DDA), a cationic surfactant, to be 6.2 ppm in a column with a down-comer (pH 7), slightly stronger than MIBC. They also analyzed the hydrodynamics of frother-collector mixtures, and reported a synergistic effect on bubble size with small additions of DDA in the presence of frother.

This work characterizes the foaming properties of the main families of sulfhydryl collectors, by measuring gas holdup and foam heights to establish their hydrodynamic strength profiles. The collectors are compared to frothers of known strength. Mixtures of selected collectors with common weak and strong frothers are then analyzed to determine possible synergetic effects.

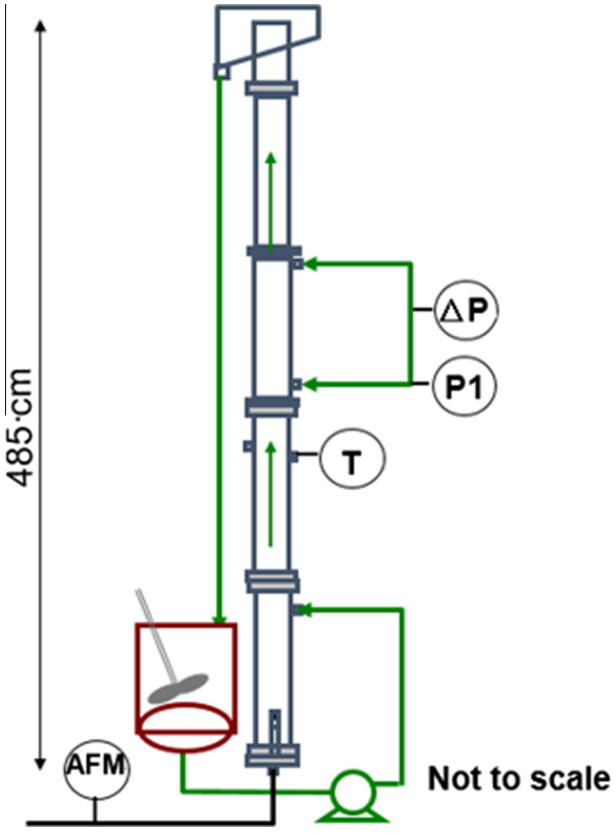

Fig. 1. Schematic diagram of the flotation column.

2. Experimental

2.1. Apparatus

Fig. 1 shows the 3 in. (76.2 mm) diameter laboratory flotation column used to measure hydrodynamic properties in this work. Bubbles were generated with a stainless steel porous sparger installed at the base of the column. Gas holdup (ε_g) was measured using the differential pressure method with a Bailey PTSDDD differential pressure transducer installed at the middle of the flotation column. Calculated ε_g data were determined from the average pressure value over the first 10 min of measurement from the start of air injection.

Gas superficial flowrates (J_g) of 1.0 cm/s and 1.75 cm/s (corrected to standard conditions) were selected to represent low and high flowrate conditions normally found in a flotation cell. Along with a pressure sensor, a temperature sensor was installed on the column wall for the air flowrate correction.

Foam height was measured using a ruler taped to the upper section of the flotation column. The foam height was measured exactly 3 min after the gas holdup reached equilibrium. This time was selected in order to ensure that the foam height had reached equilibrium and to minimize variations between tests. All solutions were mixed with 25 L of Montreal tap water at ambient temperature (20–22 °C) and were manually stirred for a minimum of 5 min for highly soluble collectors and a minimum of 10 min for less soluble collectors. For insoluble collectors, the collectors were first dispersed in a 1 L beaker, stirred using a magnetic stirrer for a minimum of 30 min, and then dispersed into the feed tank. For frother-collector blends, collector concentration was kept constant while hydrodynamic measurements were made across a range of frother concentrations. Frother and collector were first mixed in a 500 mL beaker then dispersed in the solution tank for further conditioning. All tests were conducted in batch and repeated to give a total of five measurements under each condition to ensure reproducible results.

The apparatus was thoroughly cleaned after each experimental run as most of the collectors used are known to form sticky precipitates. The top section of the column was dismantled and scrubbed of any residual precipitate as required.

2.2. Reagents

Methyl isobutyl carbinol (MIBC) and Flottec F150 (a polypropylene glycol) were selected to represent a weak and strong frother, respectively. The collectors were commercial grade provided by Flottec. They were modified to contain the lowest possible levels of solvents such that the results best represented the collector chemistry and not that of the solvents typically present in the commercial products. Table 1 lists the collectors selected from each of the main chemical families. The collectors represent chemistries from the xanthate derivative and thiophosphate family of products. Several dithiophosphate collectors of various hydrocarbon chain lengths, Flottec 2020, 2034, 2041 and 2054, were selected to determine the effect of carbon chain length on the hydrodynamic strength of this type of collector. Xanthates, dithiocarbamates, mercaptobenzothiazole, and thiophosphates are soluble aqueous salts while the xanthate derivatives and kerosene are insoluble oily collectors.

It is appreciated that many of the collectors investigated have very strong affinities for the minerals they are typically used to float (*e.g.*, base metal sulphides) and would therefore be expected to adsorb onto the mineral surfaces during the course of a typical flotation process. The results discussed here can be interpreted as representing the behavior of the residual collector (*i.e.*, the fraction

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