

Effect of frothers and dodecylamine on bubble size and gas holdup in a downflow column



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ABSTRACT

Bubble size and gas holdup were characterized in a two phase gas–water system in a laboratory downflow column. The effect of the cationic surfactant dodecyl amine (MW 185, HLB 10.7) and the frothers MIBC (MW 102, HLB 6.05) and polyglycol F507 (MW 425, HLB 8.63) on the bubble size and gas holdup were investigated. In addition, the effect of blends of MIBC–dodecyl amine (DDA) and F507–DDA on these parameters was assessed. The bubble Critical Coalescence Concentration (CCC) followed the order MIBC > DDA > F507. When blending the frothers with DDA at a concentration below its CCC, the frother CCC decreased and bubbles of finer size were obtained below and above the frother CCC. Static surface tension measurements of aqueous solutions with frothers and DDA as well as with frothers–DDA blends show coadsorption of DDA at the air/aqueous solution interface. The surface tension of aqueous solutions prepared with the blends decreased with the addition of DDA and varied linearly with the frother concentration within the concentration range studied. The gas holdup in the downflow column was determined by the bubble size and decreased with the bubble size. It is shown that frother–DDA blends gave the lowest gas holdup in the downflow column. This work is relevant for the reverse flotation of quartz from iron ores using amine collectors in cells with downflow systems.

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1. Introduction

Bubble columns are widely used as gas–liquid contactor to carry out various types of gas–liquid chemical reactions and mass transfer operations such as stripping, adsorption and mineral flotation. The efficiency of these columns is highly dependent on the dispersion of the gas in the liquid (Mandal et al., 2005). In particular, mineral flotation is a material transport process where minerals are selectively separated using air bubbles (Wills and Napier-Munn, 2006). This process is largely determined by the bubble size and the gas holdup in the flotation cell. Since the conception of the process, various types of flotation cells have been developed to improve the efficiency of particle collection. For the sake of discussion we classify them as follows: (a) mechanical flotation cells, (b) long counter-current flotation columns, (c) short co-current columns and (d) miscellaneous cells. The Jameson cell (short co-current column) has been found to be very effective for both the dispersion of gas in water and bubble–mineral contacting (Evans et al., 1995). A main component in this cell is a downflow

system wherein small bubbles are formed in a high-shear region surrounding a plunging jet, leading to a high interfacial area per unit volume of gas.

Extensive research has been carried out on the effect of frothers on bubble size and gas holdup in flotation cells (Cho and Laskowski, 2002; Laskowski, 2003; Azgomi et al., 2007; Elmahdy and Finch, 2013; Leiva et al., 2010). This research has been mostly focused on upflow systems such as mechanical flotation cells with a rotor–stator mechanism to generate the bubbles and flotation column cells where bubbles are produced by spargers or perforated plates. The effect of frothers on bubble size and gas holdup in flotation cells with a downflow system like the Jameson cell has been scarcely studied. In this system, air and pulp are brought together into a vertical pipe (downcomer), into which the pulp is injected through a nozzle creating a high speed jet. Air is dispersed into the pulp jet, which enters the downcomer in such conditions that it is broken up into microbubbles. These bubbles are carried downward by the pulp, co-currently with mineral particles, but the pulp velocity is sufficiently slow that allows the bubbles to rise against the flow, creating a mixture of high gas content in the downcomer. In the mixing region, particle–bubble collision is very favorable and rapid collection of hydrophobic particles occurs. The bubbly

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mixture discharges into a large diameter chamber (riser) where bubbles with attached hydrophobic particles separate from the pulp. Recently Araya et al. (2014) characterized the effect of MIBC on the gas dispersion in a two phase gas–water system using a Jameson pilot unit. They found a strong correlation between the bubble size and the air-to-liquid ratio, also between the bulk density of the aerated solution in the riser and the vacuum inside the downcomer.

Bubble size and gas holdup in a flotation cell are largely affected by surfactants, which are adsorbed at the gas/aqueous solution interface (Leja, 1982). In flotation, surfactants called frothers are used to disperse injected air into fine bubbles and to stabilize the flotation froth. The frothers are amphiphatic molecules containing non-polar and polar parts. The non-polar part is a hydrocarbon chain and the polar part can be only the hydroxyl (OH) group as in aliphatic alcohol type frothers or OH group bonded to alkoxy ($\text{O}-\text{C}_n\text{H}_{n+1}$) groups as in polyglycol type frothers. Adsorption of frothers at the gas/aqueous solution interface is such that the polar group is oriented toward the aqueous solution phase and the non-polar group towards the air phase. Frothers dramatically affect the bubble size and prevent bubble coalescence once their concentration is above of what is known as critical coalescence concentration, CCC (Cho and Laskowski, 2002; Laskowski, 2003; Grau et al., 2005). Frothers also have a direct role in the breakup of the air stream through a mechanism still obscure (Grau and Laskowski, 2006; Finch et al., 2008). Finch et al. (2008) have proposed that the breakup may arise from local stress or tearing action around the frother molecule adsorbed at the gas/aqueous solution interface.

The effect of frother blends on foaming, bubble stability and bubble size has been scarcely studied. Laskowski et al. (2003) reported that blends prepared with a very small addition of strong frothers (polyglycol) to a selective frother like MIBC behave similarly to the powerful power. There is a decrease of the bubble size below and above the CCC of MIBC. The same behavior was found by Tan et al. (2005). Elmahdy and Finch (2013) reported that this decrease in bubble size occurs only below the CCC of the MIBC. Above the CCC of the MIBC, they reported an increase in the bubble size when the powerful frother is added at concentrations below its CCC.

This work aimed at studying the effect of the cationic surfactant dodecyl amine [DDA, $\text{CH}_3(\text{CH}_2)_{11}\text{NH}_2$] and frothers of two distinct hydrophile-lipophile balance (HLB), molecular structure and molecular weight (MW) on the bubble size and gas holdup in a downflow system. The effect of blends of frother with DDA was also investigated. The frothers studied were those widely used in ore flotation, namely the aliphatic alcohol type frother MIBC [$(\text{CH}_3)_2\text{CH}_2\text{COHCH}_3$], and a polyglycol-type frother [$\text{C}_n\text{H}_{2n-1}(\text{OC}_3\text{H}_6)_m\text{OH}$]. This work is relevant to the reverse flotation of quartz (SiO_2) with amines in concentration of iron ores in flotation cells with downflow systems like the Jameson Cell.

2. Experimental

The MIBC used in this work was from Cytec-Mexico. This company also supplied the polyglycol type frother, Orepreg F507. Analytical grade DDA from Aldrich was used. The MW of DDA, MIBC and F507 are 185, 102 and 425, respectively. The HLB of MIBC and F-507 are 6.05 and 8.625, respectively. Using a value of 9.4 for N (tertiary amine) group and Davies scale (Davies, 1957), the HLB value for dodecylamine is calculated as 10.7. However, the HLB group number of a charged group is not strictly constant and also depends on the electrical charge. According to Ho (1998) the group number for ammonium cation is 20.0. The bubble size measurements in this work were carried out in water at pH 7;

at this pH amine is ionized. Thus, assuming the HLB group number for this group to be 20 the calculated HLB value for dodecylamine is 21.3. This HLB value holds as long as the amine is ionized, which for DDA is true below pH 10. Nesset et al. (2012) showed that CCC values nicely correlate when plotted versus HLB/MW. These values are: 0.06 for MIBC, 0.02 for F-507 and 0.115 for DDA.

Fig. 1 shows a schematic diagram of the experimental set-up used in this work. The main components are: (1) a riser of constant water level, (2) a vertically positioned plexiglass column (downcomer) with its base extending 25 cm below the surface of the constant water level riser, (3) a storage tank for the underflow and overflow water of the riser, (4) a peristaltic pump to feed water to the downcomer, (5) a sampling pipe for collection of the bubbly water coming out of the downcomer, and (6) a viewing system for collecting images of bubbles.

The downcomer consisted of a plexiglass tube of 13 mm inner diameter and 600 mm length. The top of the downcomer was sealed from the atmosphere allowing air and water to pass into the column through inlets at the top. The downcomer discharged into the riser of 100 mm inner diameter and 1L total volume. Tap water with DDA, frother or frother-DDA blends were pumped into the downcomer through a conical-type nozzle of 1 mm inner diameter. The nozzle was fixed at the top of the downcomer so that the water stream was directed along the vertical axis of the downcomer and plunged into a constant water level riser. A calibrated peristaltic pump was used to control the water flow fed to the downcomer. A water superficial velocity (J_a) of 11 cm/s was used in all tests. This water stream is fed to the downcomer as a high velocity jet that passes through a headspace at the top of the column and entrains gas as it plunges into the liquid.

Air was fed at the top of the downcomer at a fixed flow rate of $100 \text{ cm}^3/\text{min}$, which was measured by a calibrated rotameter. This air flow corresponded to an air superficial velocity of (J_g) of 1.32 cm/s. In this work, J_g and J_a are referred to the volumetric air flow rate and volumetric water flow rate per unit cross section of the downcomer, respectively (Majumder et al., 2005). J_g was maintained constant in all the tests.

In the downcomer three zones have been distinguished (Atkinson et al., 2003): (1) a free jet zone, which contains the water jet and air, (2) a mixing zone, which is a region of high shear, recirculation and energy dissipation; it is in the zone that the gas entrained by the water jet is broken into fine bubbles before being transported downward by the water, and (3) a pipe flow zone, which is below the mixing zone. Bubbles are formed in the mixing zone from the entrained gas entering at the plunge point of the

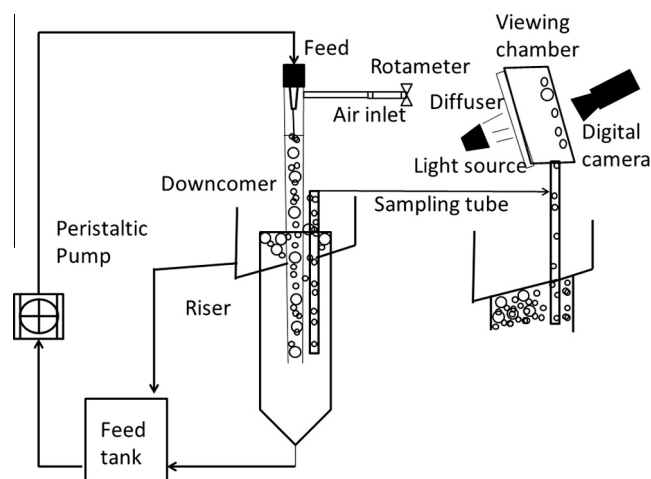


Fig. 1. Schematic diagram of downflow column system for the measurement of gas holdup and bubble size.

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