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Influence of particles on the formation of bubbles from a submerged capillary

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ABSTRACT

This paper will explore the possibility of using colloidal particles as a bubble stabilising agent in froth flotation. Nearly monodisperse 300 nm silica particles were subjected to surface modification through an esterification reaction using a long chain alcohol to create an advancing contact angle of 73.5 °. To study the influence of particles on the growth and departure of a single bubble, experiments were performed with a capillary tube submerged in the hydrophobised silica suspension. A high-speed camera was used to capture the bubbling phenomena in real time. The acquired videos were then analysed to extract the parameters such as bubble size, departure frequency, and growth time through an image-processing software. Experiments were also carried out with MIBC (methyl isobutyl carbinol) and a polyglycol type surfactant (poly(propylene glycol)), PPG) for comparison. The results showed that an increase in the particle concentration resulted in a decrease in mean bubble size produced at the tip of capillary. The same trend was also observed with both frothers.

1. Introduction

Capture rate of hydrophobic particles is strongly dependent on the size of bubbles present in a flotation vessel. It is desirable to produce bubbles as small as practicable to increase the efficiency of the process. Surfactants called frothers are commonly used in this process for the generation of small bubbles (Finch et al., 2008). Another role of frothers in flotation is to form a stable froth so that hydrophobic particles that are picked up in the cell and brought to the froth can be transferred to the lip level safely (Ata, 2012). Although most frothers are excellent at producing small bubbles, their ability to form the stable froth required by an efficient operation is limited. The stability of froth depends strongly on the particle content and the physical and chemical properties of solid particles (Binks and Horozov, 2006; Dippenaar, 1982).

In practice, the stability of froth is largely dictated by the content of floatable particles present in the feed, which can be significantly low, especially in the feed streams to rougher or scavenger stages. One way to improve the stability of froth is to use colloidal particles. Sub-micron particles have been found to be excellent bubble stabilisers over surfactants (Binks, 2002; Hunter et al., 2008), and they may have potential as a froth stabiliser in the flotation process as well. Hydrophobic particles with sub-micron dimensions have relatively high interfacial detachment energies. That is, they strongly adsorb at the air–liquid interface and lead to formation of very stable bubbles and froths (Binks, 2002; Hunter et al., 2008). The present study will explore the possibility of introducing colloidal particles into the flotation process as stabilising agents. To properly understand how the presence of colloidal particles affects the stability and formation of bubbles, the phenomenon of bubbles produced at the tip of an orifice submerged in a liquid pool is investigated.

2. Experimental

2.1. Materials

The surfactants employed in the experimental program were poly(propylene glycol) (PPG, Sigma–Aldrich, ⩾99%) and methyl isobutyl carbinol (MIBC, Sigma–Aldrich, 98%,). For experiments involving particles, we used silica particles in the range of 299–310 nm (FUSO Chemicals, Japan). The particles were hydrophobised through an esterification reaction with 1-Octanol following the technique developed by Hunter (2008). The resulting advancing and receding contact angles were 73.5 ° and 67.5 °, respectively. The contact angle was measured on silica wafer using a

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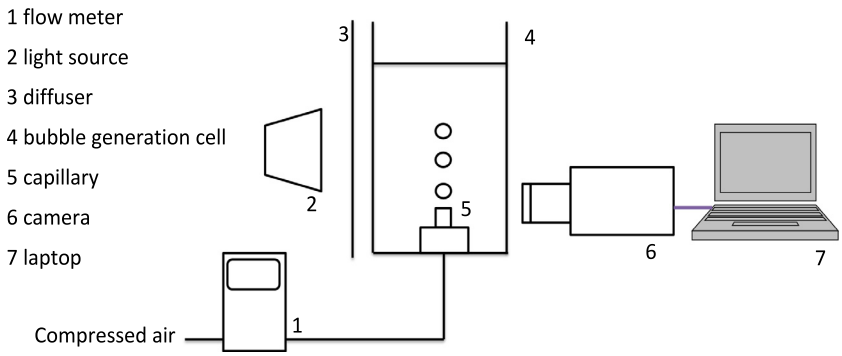

Fig. 1. Experimental arrangement used in the study.

sessile drop technique (Hunter, 2008). The concentration range investigated for both surfactants was 10 ppm, 30 ppm, 50 ppm, and 100 ppm and for the silica particles, it was 0.01 wt%, 0.02 wt%, and 0.03 wt%. Both the surfactant and particle solutions were carefully prepared immediately before each experiment using deionised purified water using the Milli-Q system (Millipore Corporation, Bedford, MA).

2.2. Experimental set-up and procedure

Experiments were carried out in a clear Perspex cell with dimensions of 20 cm (l) × 25 cm (w) × 20 cm (h). The generation of bubbles was facilitated by a constant supply of compressed air through a glass capillary attached vertically to the bottom of the cell. The capillary's outside and inside diameters were 6.38 mm and 0.4 mm, respectively. The air-flow rate to the capillary was manipulated using a mass flow controller (National Instrument, USA), enabling high precision control of the gas flow. The top of the container was covered with a clear sheet to minimise possible contamination. Fig. 1 presents a schematic set-up used in measurements of bubble departure size and dynamic behaviour. A high-speed camera (Photron, USA) equipped with a 16–160 mm lens and ring for magnification was used to monitor and record the bubble's motion. All images were recorded at a frame rate of 1000 fps with the camera set at a resolution of 1024 × 1024 pixels. A spotlight was used to provide light for the videos. A tracing paper was attached at the back of the cell to serve as a diffuser. Fig. 1 shows the experimental arrangement used in the study.

The recorded videos were reviewed, and images were processed offline using in-house software (Photron Fastcam Viewer Application) that comes with the camera. The bubbles' detaching images were saved and processed using ImageJ (National Institutes of Health, NIH). The capillary tube was also photographed and used as a reference length. Bubble equivalent diameter was calculated using the following equation (Quinn and Finch, 2012):

$$d_e = \sqrt[3]{(2a)^2 \times (2b)} \quad (1)$$

where a and b are the major and minor semi-axis measurements, respectively. A two-second video was taken at each experimental condition. For each video, a range of 28–30 bubble departing images were saved at a lower flow rate (10 ml/min), and 47–57 images were saved at a higher flow rate (20 ml/min). This is equivalent to bubble formation at approximately every 60 ms and 35 ms, respectively. All the experiments were replicated at least twice.

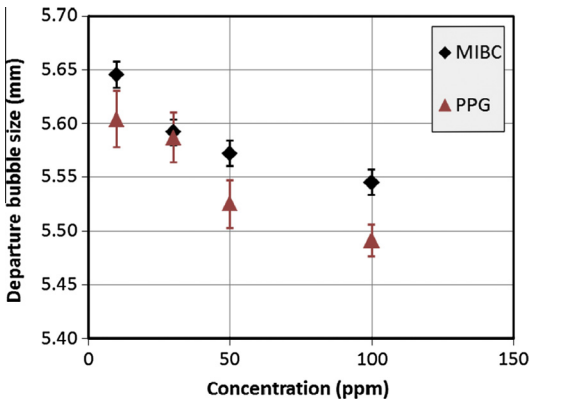

Fig. 2. Variation of departure bubble size with concentration of MIBC and PPG. The error bars are the standard deviations (n = 3).

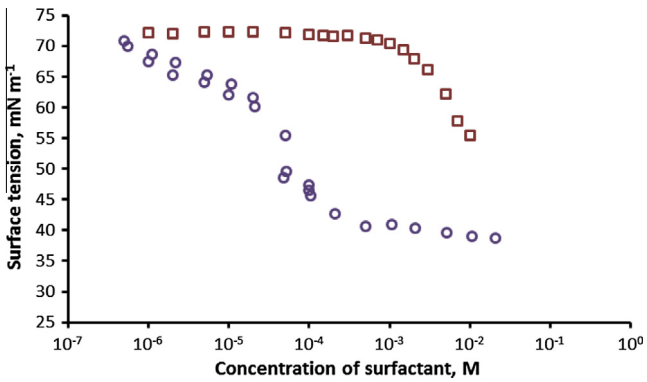

Fig. 3. Equilibrium surface tension vs concentration of PPG (○) and MIBC (□) (Bournival et al., 2014).

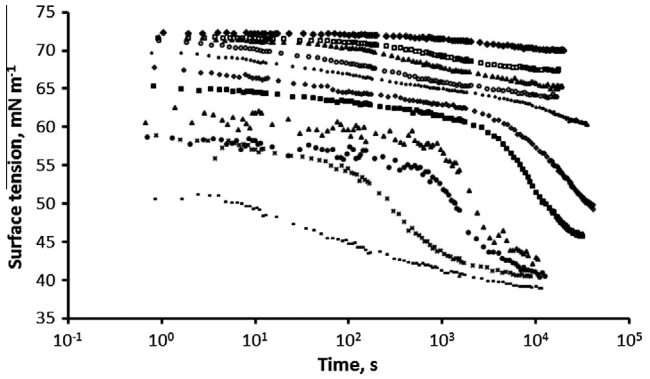

Fig. 4. Dynamic surface tension of PPG solutions at concentrations of (♦) 5.5×10^{-7} M, (□) 2.2×10^{-6} M, (▲) 5.3×10^{-6} M, (○) 1.1×10^{-5} M, (+) 2.1×10^{-5} M, (◇) 5.2×10^{-5} M, (■) 1.0×10^{-4} M, (△) 2.1×10^{-4} M, (●) 5.0×10^{-4} M, (×) 2.1×10^{-3} M, and (-) 1.1×10^{-2} M (Bournival et al., 2014).