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Breakup and re-formation of bubble clusters in a flotation cell

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ABSTRACT

This study is concerned with the behavior of bubble clusters in a well-controlled turbulent flow. We used a specially designed cell where the bubble aggregates could be formed and exposed to breakage by a rotating impeller. The effects of impeller speed and the concentration of collector on cluster behavior were studied. It was found that the size of the clusters increases with the concentration of collector used. We also found that although the clusters could easily be destroyed under the action of impeller, they could reform, especially at lower impeller speeds. It was observed that the size of the bubbles arriving into the impeller region in the absence of particles before breakage was considerably higher than the size of the clusters formed at the same impeller speed. It appears that both cluster breakage and re-formation take place simultaneously, and the extent of formation and regrowth is mainly determined by the hydrophobicity of the particles and the impeller speed.

1. Introduction

Froth flotation is widely applied for the upgrading of base metals such as zinc, copper, and lead and in the processing of coal as well as phosphate and oxide minerals. The process is based on the collection of hydrophobic particles by bubbles introduced into the vigorously agitated suspension. The small air bubbles rise through the suspension, capturing particles as they ascend to the surface. In all previous work on flotation, it has been assumed that the basic mechanism was by the collision of single particles with individual bubbles. All flotation models therefore have been built on this concept. Recently, however Ata and Jameson (2005) observed that bubbles became attached to other bubbles by the action of bridging particles, where more than one bubble was attached to a single particle in a laboratory mechanical flotation cell. The authors found a strong association between the size of the clusters and the concentration of the collector, with the highest collector concentration providing the largest clusters in the cell. Although bubble clusters have been observed previously (Gaudin, 1932; Klassen and Mokrousov, 1963), no attention accorded to this phenomenon. Cluster formation can be harnessed to improve the flotation of coarse particles, because of their enhanced buoyancy relative to single bubbles. While we have been able to create clusters in a mechanical cell, we have seen that they are relatively fragile, and can be disrupted by too high a level of turbulence in the cell (Chen et al., 2015; see also Chen et al., 2010). We have also found that the bubble clusters exhibited good self-reforming properties, completely or partly reforming under right hydrodynamic conditions. This note presents our recent observation on the phenomenon of cluster re-formation, after break-up.

2. Experimental

A detailed description of the experimental arrangement is given elsewhere (Chen et al., 2015), and only a brief explanation will be provided here. The experimental set up consists of two vessels (see Fig. 1). Bubble clusters are formed in the lower vessel and rise into the shear zone in the upper vessel. The rising clusters are guided into the vessel through a conical neck. Water containing collector (dodecylamine Aldrich, Analytical grade) enters through a detachable porous frit in the base of the unit to provide a uniform flow distribution, which is necessary for the fluidization of the particles. Small air bubbles are introduced through the fluidized bed of silica particles, whose size is in the range of 106–250 μm (Unimin, Australia). The clusters are formed by the collision of bubbles with hydrophobic particles in the fluidized bed. They rise into the upper vessel which is essentially a standard mixing cell equipped with four baffles and a standard Rushton impeller driven by a variable speed motor (Lightning, USA). The impeller is 50 mm in diameter and 10 mm in height. The impeller speeds and corresponding power consumptions and energy dissipation rate per unit mass of fluid are shown in Table 1.

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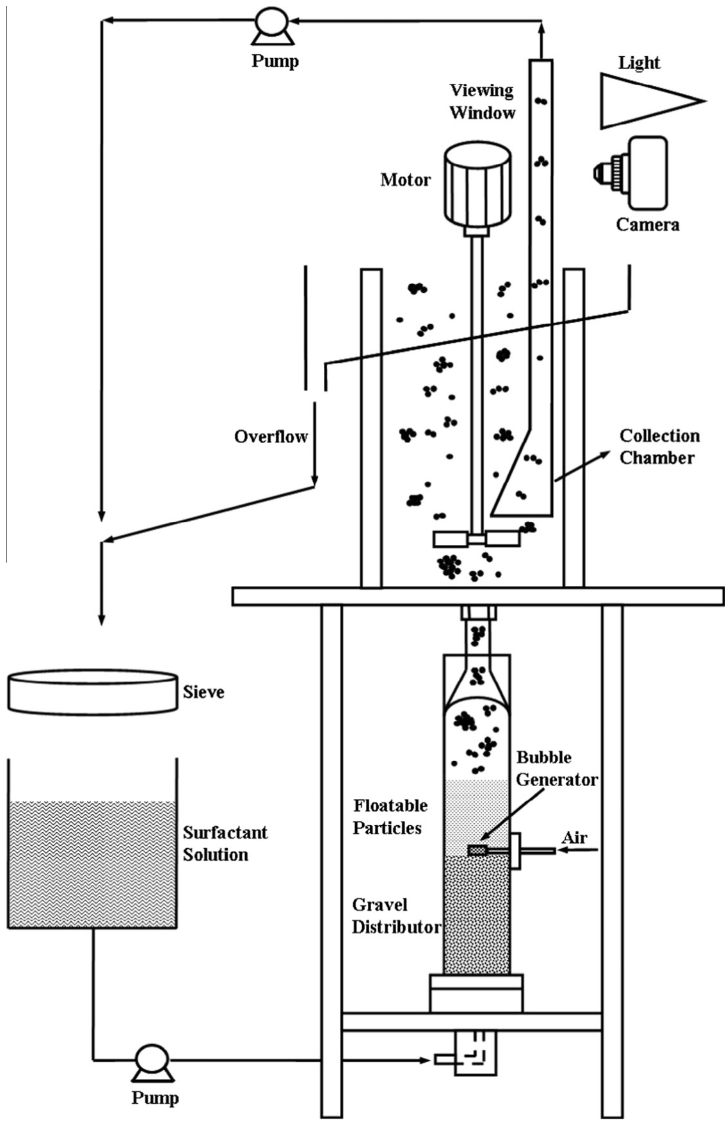

Fig. 1. Schematic of equipment for formation and observation of clusters.

Table 1
The impeller speed and corresponding power consumption and energy dissipation rate. The power consumption is given by $P = P_o \rho_l N^3 D^5$, where P_o is the power number (5.5 for Rushton impeller), ρ_l is the density of the liquid (kg m^{-3}), N is the impeller speed (rps) and D is the diameter of the impeller (=0.05 m). The mean energy dissipation rate is given by $\varepsilon = P/(\rho_l V)$, where V is the volume of the tank (=0.006 m^3).

Impeller speed (rpm)	Power consumption (W)	Energy dissipation rate (W kg^{-1})
800	4.07	0.68
1400	21.83	3.64
1800	46.41	7.73

We used a viewing cell made of two Plexiglass acrylic sheets 300 mm high by 50 mm wide to determine the size of the clusters in the cell. The gap between the sheets was set at 10 mm. One end of the viewing cell was connected to a peristaltic pump and the other end was immersed in the cell at 10 mm above the Rushton impeller (Fig. 1). Bubbles entered the viewing chamber immediately after breakage. The open end is slightly larger than the main body, with a dimension of 40 × 50 mm to allow more clusters to enter the viewing window. Liquid containing clusters and bubbles in the impeller zone was sucked through the viewing cell via the pump at a speed of 0.05 m/s. At this suction speed, the interaction between clusters was not observed in the viewing cell. The clusters in the viewing cell are recorded by a CCD camera (PixeLINK, Canada) at a rate of 1 image/s. The images were downloaded to a computer and analyzed by Optimas imaging software (Media Cyberbetics, USA). Only focused objects with no overlapping were sized. The size of bubbles in the absence of hydrophobic particles was measured in the same way at impeller speeds of 0 and 1800 rpm using a Digital camera (Nikon D100) to provide better visualization of the bubbles. The equivalent diameters of clusters and bubbles were obtained from the imaging software. Approximately 200 bubbles and clusters were counted for each run.

3. Results and discussion

Images of bubbles taken in the absence of particles and bubble clusters were captured at various impeller speeds and DDA concentrations, as shown in Fig. 2. It is observed that the bubbles at zero impeller speed are larger than those at a high impeller speed of 1800 rpm, whose diameter is the smallest among all the images in Fig. 2, although it is noted that the bubble size at 1400 rpm and