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Behaviour of bubble clusters in a turbulent flotation cell

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ABSTRACT

The rate of capture of particles decreases as the particle size increases in froth flotation. It has been postulated that the upper size range of particles that can be recovered in conventional machines could be extended by the use of bubble clusters [1].

This study is concerned with the behaviour of bubble clusters in turbulent flotation cell. The breakup and re-formation of clusters and the effect of bubble size and impeller speed on the behaviour of clusters have been investigated. The apparatus used was essentially a laboratory flotation cell, agitated by a Rushton turbine. The cell was modified to allow pre-formed clusters to rise out of a fluidized bed and into the path of the rotating impeller. The events were captured using a digital camera, and the images were analysed to give the sizes of the bubbles and clusters.

In the first part of the investigation, a collector was used but no frother. Under these conditions, the bubble diameter was effectively controlled by the collector concentration, and it varied considerably. It was found that the sizes of clusters decrease with increasing shear rate at low impeller speeds, and at higher speeds the clusters are broken up into bubbles and particles.

In the second part, frother was used at a concentration above the critical coalescence concentration, to control the bubble size, which remained essentially constant at this concentration. The bubbles were too small to be broken by the action of the impeller, so they always remained at the same size. In this case it was found that when the impeller speed was increased, two stages of formation were observed, the fragmentation and equilibrium stages. In the fragmentation stage, at low impeller speeds, the clusters were loose and filamentous, and as the energy input increases, they rupture and re-form. In the second stage, above a critical impeller speed, dense clusters formed whose size was relatively insensitive to the energy input.

1. Introduction

Froth flotation is one of the most important methods for separation of ore in mineral industry. The method relies on the differences in chemical and physical properties of the valuable minerals and unwanted gangue minerals. The target mineral is treated with a reagent that renders the surface of particles hydrophobic. In contact with air bubbles these hydrophobic particles attach to the bubbles and float to the surface where they are separated from the liquid. Not all the hydrophobic particles can be collected and transported to the concentrate. For a given system there is generally a size range that can be recovered. For base metals, this corresponds to 10–120 μm [13] whilst for coal, particles up to 500 μm can be floated due to its lower density. There are several reasons for declining flotation efficiency above a certain size range. Particle detachment due to stress on the bubble–particle couplet in the turbulent environment [10]; insufficient bubble buoyancy to lift the particles out of the liquid [1]; and difficulty in transferring particles from the liquid phase to the froth [6] are a few obstacles for efficient coarse particle recovery.

Although the reasons for poor recovery of coarse particles have been known for some time, it appears that little has been done to try to overcome the limitations of current flotation practice. Bazin and Proulx [11] used a counter-current column cell to float phosphate ore up to 630 μm in diameter. The column was run so that no froth layer was formed, and there was always an upward flow of liquid to assist the levitation of the particles. It was found that the recoveries in the column were always larger than those in a conventional flotation cell under the same conditions. Soto and Barbery [2] proposed a reagent distribution strategy to improve the recovery of coarse particles, based on the fact that fine particles require less hydrophobicity to be floated. Instead of adding more than 70% collector in the feed to the flotation cell, the flotation tests on a Cu–Pb–Zn ore were conducted by adding 50% or less collector at the top of the bank, with further amounts being added down the bank. It was noticed that the recovery of coarse particles was improved with equivalent or less collector usage.

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The approach taken by South African researchers [12,14–16] to overcome problems related to poor coarse particle flotation was to use the froth phase as a separation medium. The work was based on the assumption that coarse particles with high hydrophobicity would rupture the froth film and therefore penetrate the froth layer under gravity and report to underflow as concentrate, whilst particles with relatively low hydrophobicity would attach to bubbles and remain in the froth. The method has applications for highly naturally hydrophobic minerals such as diamonds. The use of the froth phase as a separation medium was previously investigated by Russian researchers [8].

However, none of these approaches provides significant improvement in recovery of coarse particles. More recently it has been found that the recovery of coarse particles might be improved through the use of multiple bubbles or bubble clusters to lift the particles out of the flotation cell [1]. During experiments on the flotation of silica particles in a laboratory flotation cell, these authors observed that when the contact angle was increased by increasing the concentration of collector, bubbles became attached to other bubbles by the action of bridging particles, where more than one bubble was attached to a single particle. The practical implications for coarse particle flotation are self-evident. If a particle is too large to be lifted by a single bubble, the attachment of one or more additional bubbles may well increase its buoyancy above the level necessary to raise it in the flotation cell. Thus, the presence of such structure in flotation cell may help the flotation of coarser and heavier particles making it possible to extend the upper particle size. However, little is known about the effect of the turbulent shear in the flotation cell, as reflected in the power input or the impeller rotational speed, on the structure of the clusters, or even if clusters can form in existing equipment. In the present paper the behaviour of bubble clusters was studied at impeller speeds where solely turbulent flow applies, in purpose of understanding the entire behaviour of clusters from formation to breakup at highly turbulent conditions.

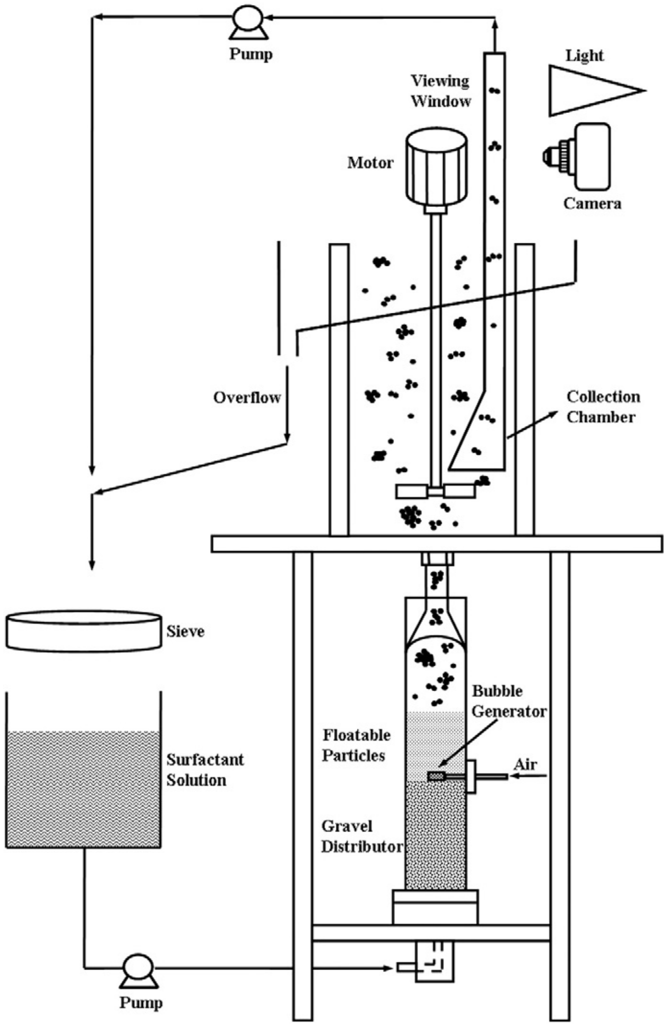

Fig. 1. Schematic of equipment for formation and observation of clusters.

2. Experimental

2.1. Materials

Silica particles (Unimin Australia Ltd, Melbourne, Australia) with diameters in the range 106 to 250 μm were used in the experiments. This size range was chosen because it includes particles that are easily floated (at the lower end of the range) together with particles that are relatively difficult to float in conventional flotation cells (at the upper end of the range). The intention was to investigate the hypothesis that the presence of the finer particles would assist in the formation of clusters that would increase the recovery of the larger particles. Before use, the particles were soaked in concentrated HCl solution and then rinsed in tap water until no change in pH could be detected. Gravel particles with a diameter of 1.7–2.0 mm were used in the base of the bed to aid the water to distribute evenly in the fluidized bed and to reduce the minimum liquid velocity that was required to fluidize the particles. Dodecylamine (Aldrich, Analytical grade) solution with various concentrations was used as surfactant and methyl isobutyl carbinol (MIBC, Merck Schuchardt OHG, 97%) as a frother. The pH of the solutions was adjusted with either NaOH (Univar, Analytical grade) or HCl (Univar, 32%) to 9.

2.2. Apparatus

A schematic arrangement of the equipment is shown in Fig. 1. The equipment consists of two parts: the lower part is responsible for the generation of bubble clusters, whilst the top part is similar to a mechanical flotation cell and is used for observation of clusters. The lower part is a cylindrical column to hold the fluidized bed. It is made of perspex with diameter of 50 mm and height 350 mm. Gravel particles on the bottom were used to distribute the fluidizing water, which was controlled by a variable speed water pump. A porous glass frit was used as the bubble generator. The frit was embedded into the particle bed as shown in Fig. 1. The air flow rate is measured by a rotameter. A cylindrical neck with a diameter of 20 mm connects the two parts. The neck for the entrance of clusters is 64 mm from the front wall and 46 mm from the side wall. The top part is a rectangular mechanical flotation cell with dimensions of 150 × 150 × 270 mm, which is also made of transparent perspex, so the bubble clusters could be visually observed through the walls. Four vertical baffles with dimensions of 15 × 270 mm are mounted in the centre of each wall of the vessel. A Rushton impeller with a diameter of 50 mm and a height of 10 mm is located in the central axis of the cell. The clearance of the impeller is 50 mm. A sieve with an opening size of 45 μm was used to collect particles and separate them from the surfactant solution. The location where the clusters enter into the vessel is shown in Fig. 2.

A visual technique was used to determine the size of clusters. At impeller speeds lower than 400 rpm, the clusters were viewed directly through the wall of the vessel. However, at higher impeller speed (>400 rpm), it was practically impossible to observe the individual bubble clusters in the impeller zone since significant numbers of particles and bubbles were suspended in the cell. A viewing window was built to overcome this problem. A sketch of the viewing cell is shown in Fig. 3. The viewing cell is made of two transparent acrylic sheets (300 mm high × 50 mm wide) positioned 10 mm apart with one end connected to a peristaltic pump and the lower end immersed in the cell at 10 mm above the impeller. The position of the viewing cell allows bubbles to enter the viewing chamber immediately after breakage,