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Experiments on the detachment of particles from bubbles in a turbulent vortex

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ABSTRACT

In this paper we present a new method for studying the detachment of particles from bubbles in a rotating turbulent eddy. The eddy is formed in a wall cavity in a two-dimensional water tunnel with transparent walls. When water flows through the tunnel, a vortical flow field develops in the cavity. The properties of the eddy can be modulated by changing the free-stream velocity of the water in the tunnel. Bubbles are pre-loaded with one or more particles in a fluidized bed flotation device located beneath the vortex cavity. Loaded bubbles are released one at a time into the cavity, and the motion of the bubble-particle aggregate is studied using a high-speed video camera. The diameters of the particles and the bubbles, and the number of particles initially attached to the bubble, can be varied.

The trajectories taken by the bubbles are quite complicated. In some cases, the bubble moves to the centre of the eddy, and particles rotate around its axis. If the rotational speed is sufficient, particles may detach due to centrifugal force. However, other modes were observed, including inertial detachment due to rapid changes in direction of the surface of the bubble, because of changes in trajectory of the bubble as a whole, or because of pulsations and oscillations of the bubble surface. Clusters of bubbles held together by particles were seen to form and reform.

In the traditional explanation for the detachment of particles in flotation cells, it is assumed that particles detach from bubbles rotating in an eddy due to centrifugal force (Schulze, 1977) [1]. Although the conditions assumed in Schulze's theory may exist, it is only one of a range of phenomena that can lead to the detachment of particles from bubbles in a turbulent vortex. The interactions between bubbles and particles is stochastic in nature, and it is impossible to model precisely the series of events that take place when a particle and a bubble make contact with each other and move through the liquid. There can be no simple model for the recovery of hydrophobic particles in flotation machines.

1. Introduction

The recovery of particles by flotation methods is dependent on the particle size. The recovery in existing flotation machines reaches a peak for particle size, typically in the range of 20 to 100 μm. This size range varies as a function of the particle's properties (type and composites). For coarser particles, the recovery drops very quickly [2,3]. If the upper size limit can be increased for flotation, dramatic savings in the grinding energy can be achieved.

Coarse particle flotation is challenging due to the detachment of particles from bubbles, which leads to the observed low recoveries. In a traditional mechanical flotation cell, the impeller is operated at a high rotational speed to suspend the particles, break up the air input into small bubbles and provide the turbulent intensity required to bring the particles and bubble into contact. The influence of hydrodynamics on the detachment of particles from bubbles has been theoretically described. Klassen and Mokrousov [4] explored the various factors contributing to the detachment of particles from bubbles in a flotation process. They analysed the destructive forces acting on the particle bubble aggregates, which can come from: the rise of a mineralized bubble; the action of a liquid stream; the slide of a particle along a bubble; changes in the motion of a bubble; the impact and attrition of particles in the pulp against a mineralized bubble surface; the impact of a bubble with an obstacle; and the oscillation of the bubble's surface. Woodburn, King and Colborn [5] considered the detachment of particles from accelerating bubbles. Schulze [1,6] hypothesised that a bubble-particle aggregate would move into the centre of a rotating eddy in a flotation cell, and the attached particle would be subject to a centrifugal force as it moves around the axis of rotation. When the centrifugal (detaching) force is higher than the capillary (attaching) force, the particle is detached. In an alternative approach, Hui [7] studied the

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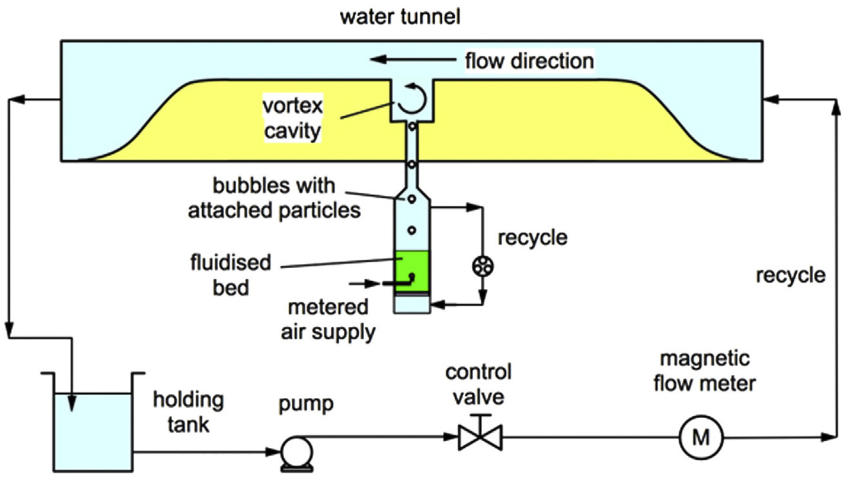

Fig. 1. Diagrammatic sketch of the vortex generation apparatus.

detachment of particles from an oscillating bubble. It is noted that these studies are purely theoretical and hypothetical, and need experimental results to prove their validity.

Experimentally, it is difficult to capture the process of the detachment of particles from bubbles, as the positions of bubble–particle aggregates change with time. Researchers have simulated the detachment for particles using different techniques. The centrifugal method was used to study the detachment of particles due to centrifugal force [8,9]. Particles were attached to an air-liquid interface in a glass cell placed in a laboratory centrifuge. The particles were subject to centrifugal forces of different magnitudes by varying the rotational speed of the centrifuge. The acoustic vibration method was used to study the detachment of particles from oscillating bubbles [10]. The frequency and amplitude of the oscillations was controlled by a loudspeaker. These experiments simulated a single perspective of the flotation environment, i.e., the detachment of particles from bubbles, where bubbles can rotate with an eddy or oscillate in the turbulent field. Nevertheless, the hydrodynamics in a flotation cell are much more complex, and particles can detach from bubbles in many different ways. Omelka et al. [11,12], studied the detachment of particles from bubbles in a turbulent flow generated by grids with different steady flow velocities. It was observed that the detachment of particles was not due to the centrifugal force, but from bubble break-up caused by strong shear. For the first time, Goel and Jameson [13] studied the detachment of particles from bubbles in a mechanical stirred tank. Bubbles were generated in the fluidized bed and attached to particles in the process of rising. The

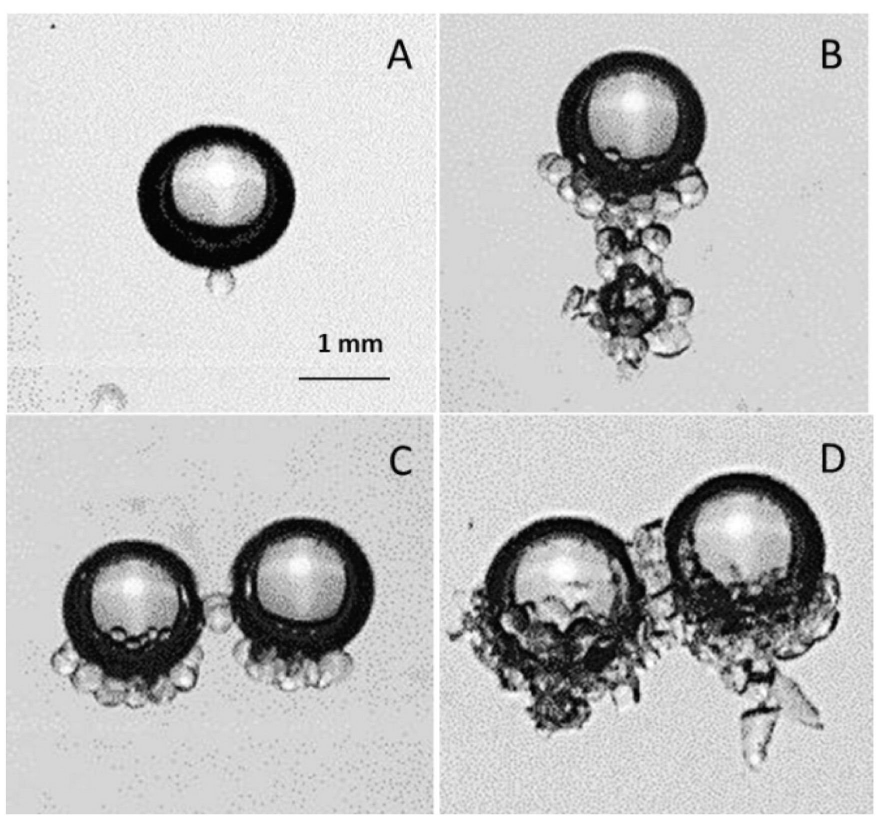

Fig. 2. Some examples of bubble-particle aggregates formed in the fluidized bed. The number of attached particles increased with the concentration of the hydrophobic particles in the fluidized bed.