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Investigation of condition-induced bubble size and distribution in electroflotation using a high-speed camera

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ABSTRACT

In the flotation process, bubble is a key factor in studying bubble-particle interaction and fine particle flotation. Knowledge on size distribution of bubbles in a flotation system is highly important. In this study, bubble distributions in different reagent concentrations, electrolyte concentrations, cathode apertures, and current densities in electroflotation are determined using a high-speed camera. Average bubble sizes under different conditions are calculated using Image-Pro® Plus (Media Cybernetics®, MD, USA) and SigmaScan® Pro (Systat Software, CA, USA) software. Results indicate that the average sizes of bubbles, which were generated through 38, 50, 74, 150, 250, 420, and 1000 μm cathode apertures, are 20.2, 29.5, 44.6, 59.2, 68.7, 78.5, and 88.8 μm, respectively. The optimal current density in electroflotation is 20 A/m^2. Reagent and electrolyte concentrations, current density, and cathode aperture are important factors in controlling bubble size and nucleation. These factors also contribute to the control of fine-particle flotation.

1. Introduction

Since 1970s, numerous studies have focused on the flotation of fine mineral particles [1–4]. The recovery rates of particles with diameters ranging from 1 to 10 μm increase with decreasing bubble size, primarily because of the increased collision efficiency between particles and bubbles [5]. Thus, the fine particle recovery is generally enhanced by using fine bubbles [6].

Fine bubbles generated by electroflotation enhance flotation response of fine minerals such as chalcopyrite, quartz, sphalerite, kaolinite, silica, and cassiterite [7–12]. The size of bubbles produced by electroflotation is affected by several factors, such as the type of electrode material, curvature of the electrode surface, current density, pH, etc. [12]. Studies investigating the effects of current density on bubble size have reported conflicting results. For example, Mansour reported a general increase in hydrogen bubble diameter with increasing current density as a result of bubble coalescence at higher current densities [13]. However, Venczel and Ketkar reported an opposite effect. Burns found no clear trend for bubble diameter as a function of current density within the range of 40–210 A/m^2 [14–16]. By contrast, Lumanauw concluded that mean bubble size increases with current density for smooth-surface electrodes, whereas the opposite trend is observed for rough-surface electrodes [17].

In the published studies on fluidization, considerable effort has been dedicated to measuring and characterizing bubbles as well as to developing a variety of correlations for predicting bubble size and velocity [18–21]. The majority of these correlations for bubble size and velocity are entirely empirical or semi-empirical. A theoretical relationship is initially developed based on a proposed bubble growth mechanism and experimental data are subsequently used to find the fitting parameters. Characterization of bubble phase behavior using only one parameter, such as bubble size, cannot provide the details of bubble evolution during flotation. Studies on bubble positions and equivalent diameters can provide a clearer insight into the phenomena that occur in bubble-particle fluidized beds [22,23].

In this study, a high-speed imaging system is used to obtain direct quantitative measurements of bubble (produced via electrolysis in an aqueous solution) motion. Bubble distributions in different reagent concentrations, electrolyte concentrations, cathode apertures, current densities are determined.

2. Materials and methods

2.1. Materials

Salicyl hydroxamic acid (SHA, 99% purity) was purchased from Shanghai Jingchun Reagent Limited Company (Shanghai, China) and used as a collector. Other chemicals (Na_2SO_4, H_2SO_4, NaOH,

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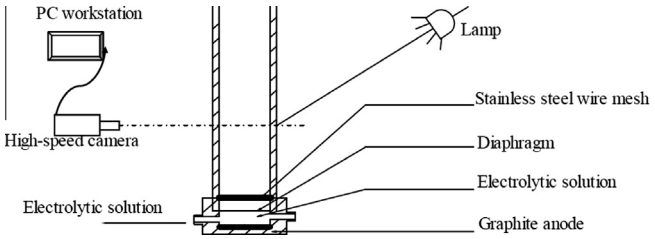

Fig. 1. Sketch of the experimental setup.

etc.) used in the test were also analytically pure. All experiments were performed using only distilled water.

2.2. Methods

Fig. 1 shows the experimental device used in this study. A single-bubble electroflotation tube (a modified Hallimond tube) with a square side face was fabricated with plexiglas for observing bubble sizes and distributions. Graphite flakes were used as electrolytic anode. O_2 bubbles produced by the anode were separated using a polytetrafluoroethylene diaphragm and exported from the latex tube connected above the anode. A stainless steel mesh was used as electrolytic cathode to produce fine H_2 bubbles, which could carry fine particles to float on the surface. The chamber was completely filled with Na_2SO_4 solution.

A high-speed camera with 75 mm lens and F4.5, 2000 f/s shutter speed was used to capture bubble images. A 1000 W halogen light provided highly even illumination by shining on a refraction screen located behind the tank.

2.3. Data processing

Pixel resolution was calibrated by imaging a ruler located in the plane of the rising bubbles. Two software packages, namely, Image-Pro® Plus (Media Cybernetics®, MD, USA) and SigmaScan® Pro (Systat Software, CA, USA) were used for processing images of bubble distribution and analyzing bubble size. The final result was an average of 12 randomly chosen images captured by the high-speed camera.

3. Results and discussion

3.1. Bubble distributions in different SHA concentrations

The characteristics of the bubbles in the flotation system, including bubble size, bubble distribution, surface property, and bridging among bubbles, are affected by reagent concentration, as shown in Fig. 2. When SHA concentration was 10 mg/L, bubbles were large and dispersed. Bubbles also clustered because of the almost nonexistent adhesion among them. Meanwhile, bubble size in 20 mg/L SHA decreased, and adhesion between two bubbles was occasionally observed. When SHA concentration increased to 30 or 40 mg/L, bubble size slightly decreased, and bubble clusters formed by the bridging between two or three bubbles increased clearly. These bubble clusters were more conducive for capturing fine-grained particles, thus increasing their flotation recoveries. The electroflotation result obtained by Qin, which shows that recovery significantly improves when SHA concentration increased from 0 to 40 mg/L, is consistent with our results [10]. In addition, Grau hypothesized that foaming agent concentration has a more significant effect on bubble size than the bubble-generating system [24]. He proved that reagents absorbed on bubble surfaces prevent bubbles from merging, and that bubble size decreases with increasing foaming agent concentration.

3.2. Bubble distributions in different Na_2SO_4 concentrations

The relationship between distribution ratio and bubble size indicates that electrolyte (Na_2SO_4) concentration also affects bubble size distribution (as noted in Fig. 3). In particular, Na_2SO_4 concentration has a significant effect on intermediate-sized bubbles but has less effect on the distribution ratio of smaller or larger bubbles. When Na_2SO_4 concentration increased from 1% to 5%, the size

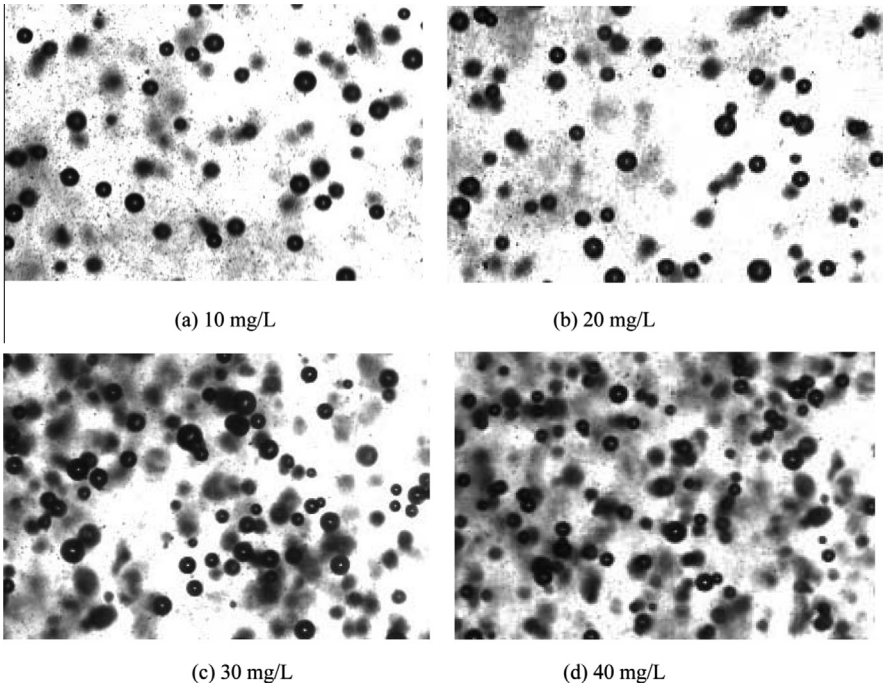

Fig. 2. Bubble distributions in different SHA concentrations (cathode aperture: 74 μm; current density: 20 A/m^2; electrolyte: 1% Na_2SO_4; and electrolytic time: 2 min).