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Nano-microbubble flotation of fine and ultrafine chalcopyrite particles

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ABSTRACT

As is well known to mineral processing scientists and engineers, fine and ultrafine particles are difficult to float mainly due to the low bubble-particle collision efficiencies. Though many efforts have been made to improve flotation performance of fine and ultrafine particles, there is still much more to be done. In this paper, the effects of nano-microbubbles (nanobubbles and microbubbles) on the flotation of fine (−38 + 14.36 μm) and ultrafine (−14.36 + 5 μm) chalcopyrite particles were investigated in a laboratory scale Denver flotation cell. Nano-microbubbles were generated using a specially-designed nano-microbubble generator based on the cavitation phenomenon in Venturi tubes. In order to better understand the mechanisms of nano-microbubble enhanced froth flotation of fine and ultrafine chalcopyrite particles, the nano-microbubble size distribution, stability and the effect of frother concentration on nano-bubble size were also studied by a laser diffraction method. Comparative flotation tests were performed in the presence and absence of nano-microbubbles to evaluate their impact on the fine and ultrafine chalcopyrite particle flotation recovery. According to the results, the mean size of nano-microbubbles increased over time, and decreased with increase of frother concentration. The laboratory-scale flotation test results indicated that flotation recovery of chalcopyrite fine and ultrafine particles increased by approximately 16–21% in the presence of nano-microbubbles, depending on operating conditions of the process. The presence of nano-microbubbles increased the recovery of ultrafine particles (−14.36 + 5 μm) more than that of fine particles (−38 + 14.36 μm). Another major advantage is that the use of nano-microbubbles reduced the collector and frother consumptions by up to 75% and 50%, respectively.

1. Introduction

Froth flotation process separates solid particles based on the differences in physical and surface chemistry properties. It is the most efficient and cost effective for particles within a narrow size range, nominally from 10 to 100 μm for the minerals [1–2]. The lower and upper particle size limits are due to the low probability of collision and high probability of detachment, respectively [3–4]. Nanobubbles, which refer to tiny bubbles mostly finer than a few hundred nanometers, can extend the lower and upper particle size limits for effective flotation of coal, phosphate, and iron ore, etc. [5–16].

In this study, nano-microbubbles were employed to increase the flotation recovery of fine and ultrafine chalcopyrite particles. A two-step attachment model is suggested in this method: first, the nano-microbubbles were selectively attached to the surface of hydrophobized particles. No attempt was made in this step to float the particles (no flotation). At the second step, the conventional-sized bubbles (0.6–2 mm) generated in Denver flotation cell attach on the surface of particles frosted by nano-microbubbles. Thus, bubble/bubble/particle attachment occurs in this method instead of bubble/particle attachment. The significance of this process is that nano-microbubbles, formed on the surface of particles facilitate the attachment of conventional-sized bubbles and subsequently increase the flotation rate of particles.

2. Scientific discussion

Froth flotation of the fine and ultrafine mineral particles has been considered as one of the major technical challenges in the field of mineral processing. The fundamental reason for low flotation rate of the fine particles is primarily due to their low collision efficiency with the conventional flotation bubbles of a given size and velocity [17]. Several flotation technologies have been developed, which aim to increase of the bubble-particle collision efficiency, either by decreasing the bubble size or by increasing the apparent particle size.

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Table 1
Chalcopyrite particle size distribution.

Fraction size (μm)	*W* (g)	Weight (%)	Cumulative over screen (%)	Cumulative under screen (%)
−38 + 28	11.8	13.1	13.1	86.9
−28 + 19.78	16.9	18.8	31.9	68.1
−19.78 + 14.36	20.6	22.9	54.8	45.2
−14.36 + 10.24	12.9	14.3	69.1	30.9
−10.24 + 5	27.8	30.9	100.0	
Total	90.0	100.0		

There are lots of experimental evidences, indicating that bubble-particle collision efficiency and flotation rate increases with decrease of bubble size [18–22]. Unfortunately, the use of small bubbles involves some disadvantages. Low rising velocity of small bubbles that carry attached particles results in a low flotation rate, emphasizing the significance of a substantial residence time in flotation circuits. Another disadvantage is that the lifting force of small bubbles may be too low to ensure process selectivity. Furthermore, it has been observed that microbubbles cause high water recovery, which increases the entrainment of gangue minerals [23–24].

Former studies have shown that flotation recovery of coal and phosphate particles outside the optimum size range and/or of poor floatability can be enhanced by nanobubbles [11]. Nanobubbles can nucleate on ultrafine particles without the need for collision, which is often the rate-determining step in froth flotation for ultrafine particles [25]. In addition, particles are less likely to detach from tiny bubbles due to their lower ascending velocity and centrifugal force associated with the detachment step, reducing the probability of detachment. Few studies have been conducted concerning the use of nano-microbubbles along with large sized bubbles in the flotation of minerals.

In this paper, the fast and reliable technique of laser diffraction was used to measure the size distribution of nano-microbubbles. This method is classified as non-destructive and non-intrusive, and relies on the fact that laser diffraction angle is inversely proportional to particle or bubble size [26]. A typical system consists of a He–Ne laser and suitable detectors to measure the light scattering pattern, and a PC for signal processing and results monitoring. Laser diffraction-based size distribution can be assessed in seconds, and a complete analysis is run in less than 1 min [26]. Laser diffraction results are calculated as the volume-equivalent spherical diameter (ESD).

The objective of this study was to develop an innovative cavitation nano-microbubble flotation process for enhanced recovery of fine and ultrafine chalcopyrite particles. This study was first aimed to determine the size distribution and evaluating the stability of the generated nano-microbubbles. The accurate and reliable technique of laser diffraction was used in the first step. The second purpose of the study was assessing the role of nano-microbubbles on recovery of chalcopyrite in presence of conventional sized bubbles. In this context, comparative flotation experiments were conducted in the absence and presence of nano-microbubbles.

3. Experimental

3.1. Materials

A high purity chalcopyrite sample (purity over 96%) taken from Mazraeh copper mine in Iran was used for flotation tests. The particle size distribution of the chalcopyrite sample was measured by a cyclosizer instrument (Weir Warman Ltd., model M12, UK). Table 1 shows the size distribution of the sample. D_{100} and D_{50} values of chalcopyrite particles were 38 and 15.8 μm, respectively.

Potassium Amyl Xanthate (KAX) from Cheminova was used as the collector, and Methyl Isobutyl Carbinol (MIBC, MW = 102.18 g/mol) from Sigma–Aldrich as frother. Hydrochloric acid (HCl) and sodium hydroxide (NaOH), both obtained from Merck, were used to adjust the pH of the pulp. Double distilled water with a resistivity of 18.2 MΩ prepared by water distillation instrument (SDL12l, OES Co., USA) was used for preparation of all solutions and pulps.

3.2. Generation and size distribution of nano-microbubbles

Fig. 1 schematically shows the nano-microbubbles generation system which was designed based on hydrodynamic cavitation

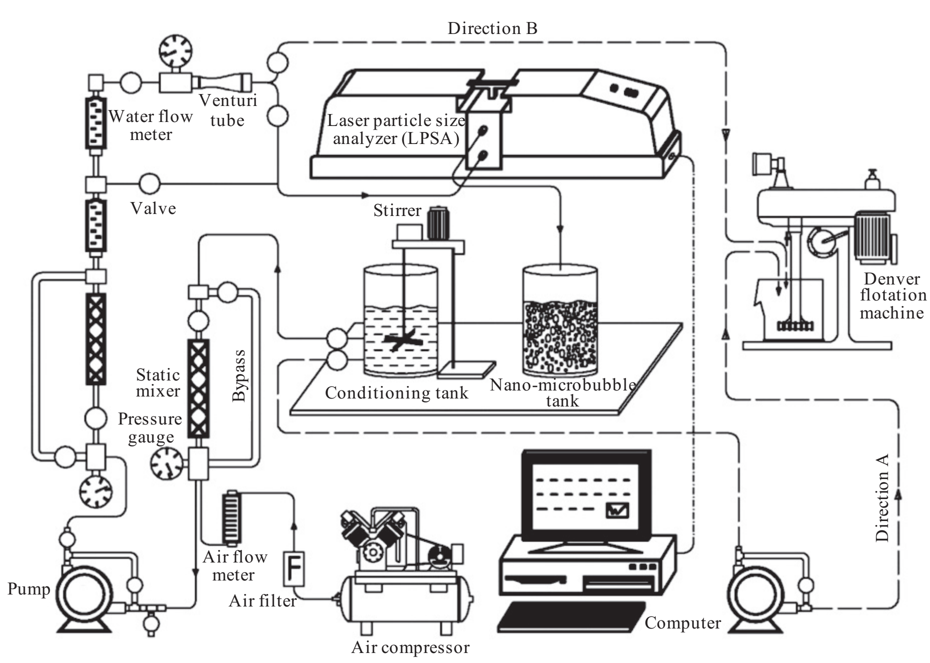

Fig. 1. Schematic diagram of nano-microbubbles generation system and Laser Particle Size Analyzer.