

Observation of fine particle aggregating behavior induced by high intensity conditioning using high speed CCD

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Abstract: The aggregating behavior between bubbles and particles induced by high intensity conditioning (HIC) was studied using high speed CCD technique. Bubble size measurement was conducted, and the attachment behavior between bubbles and particles in HIC cell and flotation cell were observed. The results show that in HIC cell, high intensity conditioning creates an advantage environment for the formation of small size bubble due to hydrodynamic cavitations, and these fine bubbles have high probability of bubble-particle collision, which will enhance fine particle flotation. The bubble-particle attachment experiments indicate that in high intensity conditioning cell, a lot of fine bubbles are produced in situ on the surface of fine particles, and most of fine particles are aggregated under the bridging action of fine bubbles. The observation of bubble-particle interaction in flotation cell illustrates that aggregates created by HIC can be loaded more easily by big air bubble in flotation cell than those created by normal conditioning.

Key words: fine particle flotation; high intensity conditioning; particle aggregation; bubble size measurement

1 Introduction

Flotation is a dominant separation technique employed by the mineral industry, especially in metal recovery. However, this technology only well responds to mineral particle in a narrow size range, out of which flotation efficiency falls substantially. In this century, the ore resources become more and more low-grade and fine due to the industrial scale exploitation. However, particles finer than approximately 10 μm are in general not effectively separated by traditional froth flotation due to their low inertia and high surface energy. Therefore, fine particle flotation is now considered the central part of flotation research. Substantial advances, which have been reviewed by some authors[1–6], have been made for fine particle flotation from both theoretical and technological point of view. High intensity conditioning, for example, has found some success for fine particle flotation in some laboratory tests[7–9].

The effect of conditioning on flotation efficiency has been noticed for many years. In the middle 1970s, WARREN[10] found that increasing the shear rate of the pulp could improve the efficiency of ultra fine

particle flotation. He attributed this improvement to the formation of aggregates taking place within a short agitation range. And this concept of aggregation has been extended by RUBIO[11], and BULATOVIC et al[12], using high intensity conditioning(HIC) method to form aggregates. They found that HIC with the addition of collector, frother and suitable modifiers significantly improved both the recovery and selectivity of ultra fine sulphide minerals. They explained this result by WARREN's shear flocculation theory.

Till now, a lot of studies[8, 13] have been taken for HIC assistant flotation; however, most of them are focused on the relation between input energy and flotation efficiency. Few experiments were reported to describe how the aggregate formed under HIC does. The mechanism of HIC is still not clear. In this study, our aim is to discuss the principle and process of aggregate formation derived by HIC using a high speed CCD technology.

2 Experimental

2.1 Bubble size measurement setup

We created a new experiment setup with image processing system, which can be used to measure the

bubble characteristics such as bubble size distribution and bubble-loading pattern in HIC cell.

The experimental apparatus is presented in Fig.1, which consists of four major parts: conditioning and flotation system, sampling system, and image capturing and processing system. The conditioning system and flotation system used in this study were a high-speed agitation machine and a Denver flotation machine, respectively. The sampling system was made up of a visualization cell and water pump. The image capturing and processing system comprised four components: light and light source, high speed CCD, PC workstation and related software.

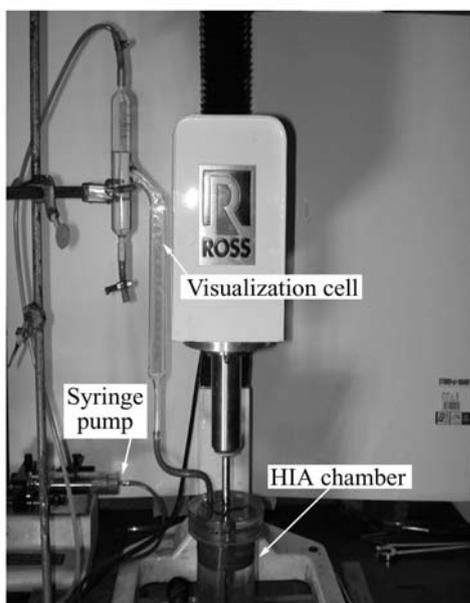
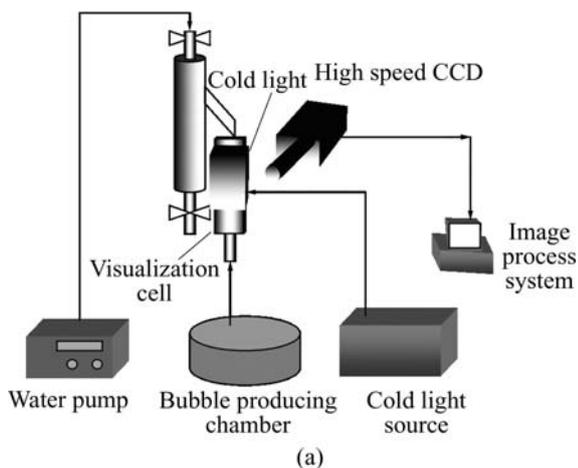


Fig.1 Schematic of bubble size measurement setup: (a) Measurement setup; (b) Sampling setup

2.2 Samples

We used sphalerite as the example mineral, which was provided by Matagami Corp. The sample was crushed in turn by jaw crusher, cone crusher and disk crusher to a size <0.5 mm 80%. The major metallic elements component of the sample are listed in Table 1,

which was got from an absorption spectrophotometer analysis.

Table 1 Metallic element component of sample(mass fraction, %)

Cu	Pb	Zn	Fe
1.11	0.08	37.55	18.55

Before agitation, the sample was ground with an agitation mill to a size of <7.9 μm .

2.3 Bubble size observation

Before experimenting, the chamber must be completely filled with water by pump while turning the sampling tube upward. Then shut up the water and plug the sampling tube into the agitation pulp, which has been pre-agitated with addition of isopropyl xanthate and other modifier. At this time, the water in visualization chamber will keep in quiescence due to the outside air pressure.

During flotation or agitation, the bubbles would come into the sampling tube, and then rise upward due to buoyancy. When the bubbles passed through the visualization area, their motion was captured by the high speed CCD and then was transferred to PC workstation.

2.4 Image analysis and processing

A CPL high-speed camera with a 75 mm lens at F5.6, 1 000 f/s shutter speed was used to image bubbles. Bubbles were back illuminated by a 1 000 W halogen light shining on a refraction screens located behind the tank that provided very even illumination. Bubble images were directly captured to computer memory and analyzed. Pixel resolution was calibrated by imaging a ruler located in the plane of the rising bubbles. The bubble size analysis was fulfilled by commercially developed software Sigma scan. The ultimate result was an average of 12 randomly chosen images captured by high speed CCD.

3 Result and discussion

3.1 Bubble size distribution in HIC cell and flotation cell

Bubble size plays an important role in fine particle flotation. Some research showed that the low flotation recovery of fine particles is mainly caused by the low probability of bubble-particle collision, which is conversely proportional to bubble size[14]. In other words, using small size bubbles can increase the probability of collision and then increase the flotation efficiency of fine particle. Therefore, to know the bubble size in HIC cell and flotation cell is necessary.

Figs.2 and 3 show the bubble images captured by high speed CCD in HIC cell and flotation cell,

respectively. These two experiments were taken in gas-saturated water. The bubble size distributions, got from Figs.2 and 3, are shown in Fig.4. From these results, we can know that the bubble size in HIC cell is about 0.4 mm, which is smaller than the bubble size in flotation cell, 0.7 mm.

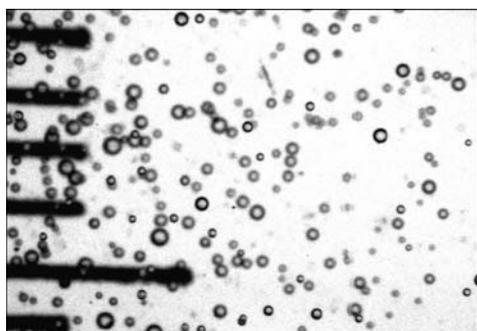


Fig.2 Snapshot of bubble in HIC cell

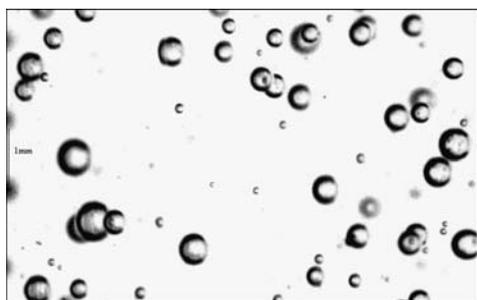


Fig.3 Snapshot of bubble in flotation cell

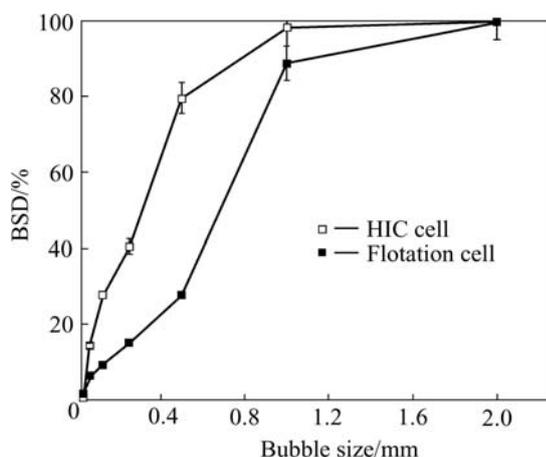


Fig.4 Bubble size distribution in HIC cell and flotation cell

That is to say, in HIC cell, high intensity conditioning creates an advantage environment for the formation of small size bubble. These phenomena can be explained by hydrodynamic cavitations theory.

Hydrodynamic cavitations are the formation of cavitations bubbles and cavities within a liquid stream resulting from a localized pressure drop in the liquid flow. Various experiments on the initiation of cavitations have been carried out[15 – 17]. These experiments showed that hydrodynamic cavitations

normally occur whenever the pressure at a point in a liquid is momentarily reduced below its vapor pressure. This momentarily reduction in local pressure can be got, for example, by adding a high intensity agitation to increase flow velocity and overcome the attractive forces between water molecules. Therefore, hydrodynamic cavity is one of the reasons that HIC can produce small size bubbles.

In fact, there are a lot of technologies in mineral flotation which employ high speed pulp flow to improve the fine particle flotation efficiency such as pneumatic cell flotation[18] and Jameson cell flotation[19], in which the feed speed ranges from 6 to 10 m/s in the slurry injection nozzle. These technologies are similar to HIC in principle to some extent.

3.2 Bubble-particle interaction in HIC cell

The snapshots of bubble-particle attachment in HIC cell is presented in Fig.5. This experiment was conducted in water-gas-solid three-phase system. These images show that most of fine particles are conglutinated on the surface of fine gas bubble to form a solid crust due to the high-speed agitation. Because this crust is hydrophobic, it is easy to combine together to form a cluster or chain, which is marked in Fig.5.

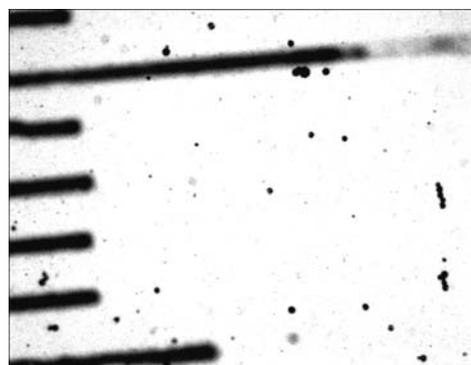


Fig.5 Snapshot of bubble-particle attachment in HIC cell

The single bubble size distribution of these bubbles in three-phase system is shown in Fig.6. It can be seen that the bubble size is about 0.1 mm, which is far smaller than the bubble size in two-phase system, 0.4 mm, in HIC cell. This means that the existence of hydrophobic particles can strengthen the hydrodynamic cavity. This phenomenon has been studied in our previous works, which showed that these particles could act as gas nuclei, which make hydrodynamic cavitations easily[20–23].

3.3 Bubble-particle interaction in flotation cell

From the above experiments, we can know that high intensity agitation can produce tinny bubbles,

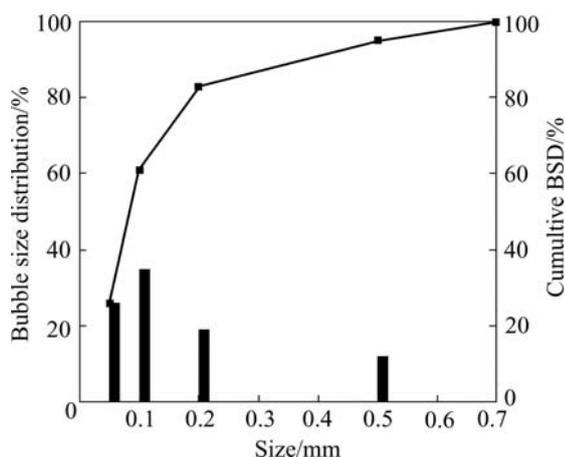


Fig.6 Bubble size distribution of three-phase pulp in HIC cell

which facilitate the aggregation of hydrophobic mineral particles.

Figs.7 and 8 present the typical images of particle-attachment taken in a running flotation cell after a normal conditioning and a high intensity conditioning, respectively. In the case of normal conditioning, the small aggregates are observed to be loaded by some individually bubbles or small size bubble clusters, as shown in Fig.7. In the case of HIC, the large aggregates are seen to attach to and be surrounded by several air bubbles, as shown in Fig.8. Big air bubbles in flotation cell can load easily aggregates created by HIC. This is

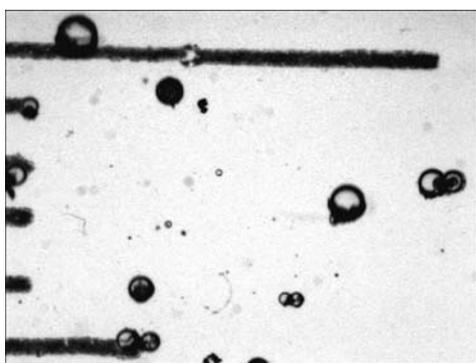


Fig.7 Snapshot of bubble-particle attachment in flotation cell after normal conditioning

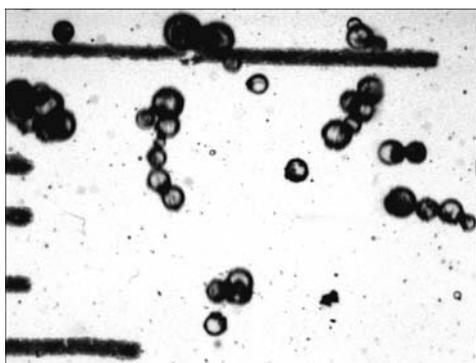


Fig.8 Snapshot of bubble-particle attachment in flotation cell after high intensity conditioning

in good agreement with other work related to HIC assistant flotation.

3.4 Possible mechanism of HIC

The present work has clearly demonstrated that HIC has a distinctly good effect on aggregation of hydrophobic fine particles, which is a basic step for successful separation of fine particles. The probable mechanism can be explained as follows.

Firstly, the tiny bubbles formed in HIC cell, or more preferably in situ on hydrophobic particles, by hydrodynamic cavitations, may cause flocculation by a bubble-bridging mechanism, resulting in an increase in the apparent particle size (Fig.9(a)), thus increasing the collision probability with the bubbles in the flotation cell. Secondly, particles frosted with tiny bubbles may combine together to form a cluster which is favorable to attachment to flotation-sized bubbles, following the two-stage attachment mechanism (Fig.9(b)) proposed by DZIENSIEWICZ and PRYOR[24], and KLASSEN and MOKROUSOV[25]. This mechanism has been discussed in our previous work related to gas nuclei.

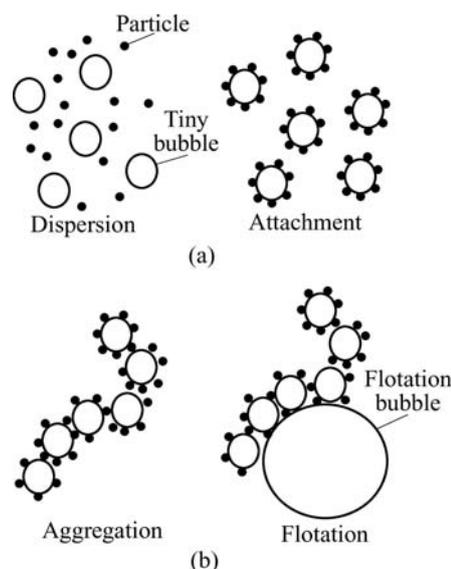


Fig.9 Schematic mechanism of aggregating process caused by HIC

4 Conclusions

1) In HIC cell, high intensity conditioning creates an advantageous environment for the formation of small size bubble due to hydrodynamic cavitations, and these fine bubbles have high probability of bubble-particle collision.

2) The bubble-particle attachment experiment lay out that in high intensity conditioning cell, a lot of fine bubbles are produced in situ on the surface of fine particles, and most of fine particles are aggregated under the bridging action of fine bubbles.

3) Observation of bubble-particle interaction in flotation cell shows that aggregates created by HIC can be loaded more easily by big air bubble in flotation cell than aggregates created by normal conditioning.

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