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A study on bubble formation and its relation with the performance of apatite flotation

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ABSTRACT

The flotation performance is associated with the probability of bubble–particle collision and the aggregate stability. Currently, one of the major challenges of the mining industry is the flotation of fine particles and the generation of medium-sized bubbles (100–1000 μm) can be a good alternative to increase the recovery of these particles. Therefore, new strategies to determine and control bubble sizes, to achieve the desired diameters are very important. This study aimed to characterize and control the bubble size distribution and to consider its relation with the flotation performance. Two different methods (offline and online) were used to measure the bubble size distribution. The results showed that the addition of surfactant was a good alternative to generate bubbles with high percentages of medium-sized bubbles (80–90%) and high air hold-up values (10–12%), simultaneously. Kinetic test showed a direct relation between the bubble size distribution and the P_2O_5 content.

1. Introduction

Phosphorus is mainly used as a core component in nitrogen–phosphorus–potassium fertilizers, but it is also used in animal feed supplements, food preservatives, cosmetics, fungicides, insecticides, detergents, ceramics, water treatment, and in the metallurgical and pharmaceutical industries [1–4].

Phosphate minerals found in phosphate rocks are the main global sources of phosphorus. Phosphate rocks contain varying percentages of P_2O_5 in a calcium matrix [5] in association with a wide assortment of accessory minerals, mainly fluorides, carbonates, clays, quartz, silicates, and metal oxides. Composition varies from one deposit to another [6,7].

The progressive depletion of ore deposits under exploitation, allied to the growing demand for food in the world, makes it imperative to use phosphate deposits rationally [8]. Froth flotation is widely used in mineral processing technologies to separate finely ground valuable minerals from a mixture of gangue minerals initially present in the pulp [9]. Inefficiencies in flotation translate into an enormous loss of revenue and an unnecessary waste of these reserves [10]. Among the flotation devices, column flotation has received considerable attention and its use has become widespread because of its significant advantages over the conventional flotation cell [6].

In the flotation process, solid particles suspended in water come into contact with air bubbles. This process is based on different physicochemical surface properties of minerals. Reagents are added for selective chemical modification of specific mineral surfaces to produce floatability (hydrophobicity) or non-floatability (hydrophilicity). The contact and adherence of hydrophobic mineral particles to air bubbles are a key step in this process [11]. Thus, the major sub-processes of this separation process are the bubble–particle collision, the adhesion of mineral particles to air bubbles, and the detachment [12,13].

Due to this progressive depletion of ore deposits, excessive grinding has been performed in the ore processing to increase the release of phosphorus [14]. During this process a large amount of fines is generated. However, the particle size is a critical parameter for the flotation efficiency [15]. Thus, optimizing the flotation performance of fine particles has been the focus of mineral industries [16].

The efficiency of bubble–particle collision is directly related to the size of mineral particles, and also with the air bubble size. Therefore, understanding the bubble–particle interaction and the forms to enhance it is extremely important to carry out improvements in mineral flotation [17,18]. Thus, bubble size distribution (BSD) plays a major role in the flotation performance [19].

Flotation of fine particles is still a problem for mineral industries, mainly due to the low mass and high surface area. Low mass can be detrimental to flotation due to: low particle momentum with tendency to follow water flow; particle entrainment in

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Nomenclature

PVM	Particle Vision and Measurement
FBRM	Focused Beam Reflectance Measurement
BSD	bubble size distribution
DAF	dissolved air flotation
CCD	central composite design
D_{32}	Sauter mean diameter
ε_o	air hold-up
PMSB	percentage of medium sized bubbles
CCC	critical coalescence concentration

concentrates; mechanically entrapped gangue particles being floated and low probability of collision with bubbles [13]. On the other hand, high surface area directly leads to: high dissolution rate in water; non-selective adsorption of reagents; high pulp viscosity; tendency to be more affected by water chemistry and ions in solution and undesirable surface coating of the valuable particles by fine gangue particles [13]. Thus, the recent development and improvement in the flotation of fine particles have presented processes based on the increase in the probability of collision between bubbles and mineral particles and processes based on more favorable bubble–particle contact [19]. Large bubbles (larger than 1000 μm) can be inefficient in encountering collision and attachment occurrences of fine particles and air bubbles. These coarse bubbles give rise to shear force by hydrodynamics so that the adhesion efficiency between particles and bubbles decrease. Hence, one possible alternative is to reduce the bubble size [13]. The use of very small bubbles (smaller than 100 μm) as in the dissolved gas methodology (DAF) increases the collision probability. However, it severely limits the feed flow rate of the process because of the low velocity of small rising bubbles [20]. Therefore, very fine bubbles (microbubbles) have low carrying capacity, so leading to a reduction in the separation efficiency [21]. Thus, medium-sized bubbles with higher "lifting power" values as compared with microbubbles, and with higher adhesion efficiency between particles and bubbles than coarse bubbles, may be a good solution to achieve a better performance for flotation of fine particles [13].

The bubble size can be controlled by varying the air flow rate and adding surfactants [22]. Surfactants in the flotation process are mainly used to increase the probability of bubble–particle collision by means of producing small bubbles and provide foam stabilization [23]. The addition of surfactants reduces bubble coalescence and pushes bubbles in the slurry zone toward the foam phase, due to the increase in the residence time of the air bubbles. Consequently, the probability of bubble–particle collision increases [12].

Several techniques to determine the bubble size in two-phase systems (air–water) and three-phase systems (air–water–ore) have been developed in recent years [24], but most of them are restricted to the former (air–water), due to the difficulty in obtaining precise data on bubble size in the presence of ore [12,25–30].

Considering that to achieve better flotation performances, the bubble size distribution needs to present a specific range of values and the process needs to be well understood, this research aimed to study the characterization and the control of bubble size and their relationship with the flotation performance. Measurements were obtained in a flotation column and bubbles were generated using a Venturi tube.

2. Materials and methods

Flotation tests were carried out in an acrylic batch flotation column divided into three sections: a 4-cm-diameter, 150-cm-long cylindrical section; a 9.5-cm-high frusto-conical section; and a third cylindrical section with 12 cm long and 10 cm diameter (Fig. 1). The pulp was fed into the top of the column. Air and wash water flow rates were measured using flow meters. The water used in the tests had a pH value of 6.0, turbidity of 0.88 NTU and an electrical conductivity of 61.2 μS/cm.

This experimental apparatus was designed to produce bubbles of different sizes. The bubbles have been produced by a Venturi device coupled to the cylindrical section at the distance of 12 cm from the bottom.

2.1. Methodology to measure the bubble size

2.1.1. Offline method

The offline technique used to measure air bubbles in the air–water system was based on the methodology reported by Santana et al. [13]. Bubbles were measured in a system consisted of a bubble capture cell, a microscope, and a high-resolution digital camera, as shown in Fig. 2. The measurement cell was coupled with a sampling tube, which was attached to the column. Thus, the bubbles were captured from the column at a flow rate adjusted in preliminary tests, in which there was no coalescence or breakage of bubbles. The measurement cell was attached to a microscope with a digital camera and an image analysis software (Ciberlink power). The stereomicroscope used was Nikon brand, model SZM1000. It was used a halogen lamp that accompanied the microscope for lighting. The high-speed camera which was attached to the microscope was MotionScope 2000S brand style.

2.1.2. Online method

Bubbles generated in both systems – the air–water system and the three-phase system (water–air–ore) – were measured in real time. This technique consisted of using two probes (Provided by Mettler Toledo): one for shooting bubbles (PVM – Particle Vision and Measurement – Model ParticleView V19) and one for measuring the bubble size distribution (FBRM® – Focused Beam Reflectance Measurement – Model G400). These probes were adapted in the experimental apparatus at an angle of approximately 45° (Fig. 3). The FBRM probe emitted laser light to optical modules and this light was carefully focused on the probe display whose external surface was in contact with the particles (bubbles in this case). Then, when the laser light crossed a particle, a pulse referring to this time was computed. Finally, each pulse duration was multiplied by the laser scanning speed and the result is the chord length of the particle measured. As this method was online, data was sent to the computer and processed in real time while bubbles were measured and shot.

2.2. Methodology to measure the air hold-up

The technique used to obtain the air hold-up was the same developed by Finch and Dobby [30]. In this technique, the air hold-up was obtained by the pressure difference between two points in the bubble column [31].