Minerals Engineering 85 (2016) 49–54

Contents lists available at ScienceDirect

Minerals Engineering

journal homepage: www.elsevier.com/locate/mineng

Bubble loading measurement in a continuous flotation column

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ARTICLE INFO

Article history:
Received 10 March 2015
Revised 11 June 2015
Accepted 13 August 2015
Available online 30 October 2015

Keywords:
Bubble loading
Flotation column
Axial mixing
Uniform size bubbles
Needle sparger

ABSTRACT

Bubble loading is a macroscopic measure which includes the micro sub-processes of true flotation. In this paper, new instrument for measuring the bubble loading in flotation column with the ability to generate the uniform size bubbles is introduced. This ability (generation of uniform size bubbles with mean diameter of 2 mm and standard deviation of 0.3 mm) make it possible to study the effect of bubble size on bubble loading. Laden bubbles sampling system consists of riser with diameter of 20 mm and height of 720 mm made of glass and collection chamber with diameter of 54 mm and height of 150 mm made of transparent Perspex installed directly on top of the riser. Applying the flotation column with low mixing (vessel dispersion number of 0.32 and axial mixing coefficient of 0.003 m^2/s) and direct entry of bubbles from the riser to collection chamber caused the experiments to be reproducible by nearly 15 g (5% of total feed) of solid samples loaded by bubbles. Measured bubble loading was validated by comparing the recovery obtained based on bubble loading data and the recovery calculated from macroscopic mass flow rates of concentrate and feed. Results showed discrepancies less than 3%, confirming the reliability of bubble loading measurements by the developed instrument.

1. Introduction

In collection zone of flotation, a compromise between gravity and buoyancy forces related to bubble–particle aggregates leads to the flotation of particles. Formation of such aggregate is a function of collision, attachment and detachment probabilities between particles and bubbles (Nguyen and Evans, 2004).

The measurement of the overall bubble loading covers all these sub-processes (Seaman et al., 2004). Application of the bubble loading to study the collection zone removes the effects of froth zone and entertainment, as the bubble loading presents just the true flotation, i.e. the particles that are transferred to froth zone by attachment to bubbles and not by entrainment (Runge et al., 2010). Hence, bubble loading measurement is well suited for investigation and optimization studies on the collection zone recovery by determining the transfer rate of particles from collection zone to froth zone (Bhondayi and Moys, 2011).

As an early study, a single bubble methodology was applied to measure the bubble loading (King, 2001). Some of researchers used the microcell flotation to study the ore floatability parameters that in these researches, sampling the bubble–particles aggregate were possible (Bradshaw and Connor, 1996; Hernandez-Aguilar et al., 2005). Falutsu and Dobby (1992) used a pipe (riser) passing downwards under the froth phase with counter-current addition of water to prevent the rise of suspended solids in order to determine the transfer rate of attached particles across the pulp–froth interface. This device used to study the froth drop back and collection zone recovery. Majority of instruments for bubble loading measurement after Falutsu and Dobby, involve two main parts of riser and collection chamber (Bhondayi and Moys, 2011). Dyer (1995) built up the first bubble loading measurement device based on positive displacement, where "the air released by the bubbles displaces the water from the device causing it to travel down the riser at water bias velocity equal to the superficial gas velocity". Another bubble loading measuring instruments developed based on positive displacement (Moys et al., 2010; Seaman et al., 2004). These devices developed to study the froth characterization specially to study the froth recovery.

As mentioned above previous works on bubble loading deal with froth recovery and entrainment, so bubble loading was measured in Hollimond tube or mechanical cells. But these instruments work in batch operation and mechanical cells work in turbulent regime due to the high extent of mixing.

This research tries to introduce new instrument for measuring the bubble loading in flotation column in steady state conditions. Bubble generator (sparger) has the ability to generate uniform size bubbles that make it possible to study the effect of bubble–particle size ratio on bubble loading. All the experiments are run in continuous steady state conditions and the bubble loading measurement results have been validated by macroscopic mass recovery.

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http://dx.doi.org/10.1016/j.mineng.2015.08.010
0892-6875/© 2015 Published by Elsevier Ltd.

2. Research methodology

2.1. Flotation column

Flotation column used in this research has to work in laminar regime with the least mixing and also it should be small in size and accessible. Designing such a column was performed based on relations between flotation hydrodynamic and column geometry. Axial dispersion and Drift flux models were used in this approach (Hemmati Chegeni et al., 2015).

Residence time distribution (RTD) curve was obtained by impulse injection of KCl solution and measurement of conductivity. According to RTD curve, vessel dispersion number (N_d) and axial mixing coefficient (E) was obtained as 0.32 and 0.003 m^2/s respectively, confirming the low mixing of the column.

2.2. Design and construction of suitable sparger

The sparger has to generate the different mono size bubbles in every test. The designed sparger has been shown in Fig. 1. To generate the mono size bubbles, both porous and orifice spargers were investigated. Figs. 2 and 3 show that Porous plates don't generate mono size bubbles with small standard deviation without/with frother.

But orifice sparger can produce uniform size bubbles; however, the smallest orifice which was technically available to the authors (diameter of 0.5 mm) generated bubbles bigger than 3.5 mm. The predicting model has been offered for bubble diameter generated by orifice (Hernandez-Aguilar et al., 2006):

$$D_b = \sqrt[3]{\frac{6D\gamma}{g\Delta\rho}} \tag{1}$$

where D_b is bubble diameter (m), D is the orifice diameter (m), γ is the water surface tension (N/m), g is the gravitational acceleration (9.81 m/s^2) and $\Delta\rho$ is the effective density between water and gas phase (kg/m^3).

Needle like an orifice can prepare smaller uniform bubbles. Needles have been used in bubble column reactors (Juliá et al., 2007; Mena et al., 2011). Experiments show that needles with inner diameter of 0.8 mm in air flow rate 400 cm^3/min (6.5 mL/s) generate bubbles with mean diameter about 5.5 mm (Juliá et al., 2007). Therefore, in order to reduce the size of bubbles and produce uniform distribution, needles with inner diameter of 0.3 mm were put in a rubber plate used as bubble generator. 30 stainless steel needles were used with equilateral radial pattern with distance of 2 mm between two consecutive needles. Needle's length was 18 mm. All needles were manufactured identically (Fig. 1b). Tests showed that the needles exhibited very similar pressure drops and bubbling behavior.

The bubble size distribution (BSD) was analyzed by image processing techniques. Images were taken by microscopic camera (Dino-Lite Digital Microscope AM-7013M) with the magnification

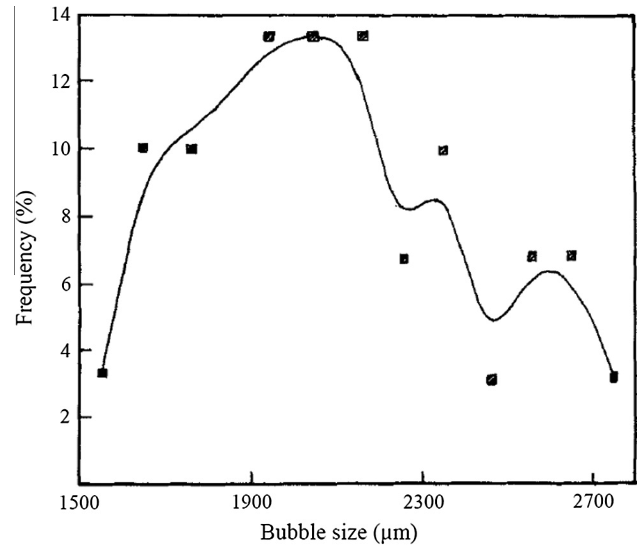

Fig. 2. BSD generated by porous plate without frother (Biswal et al., 1994).

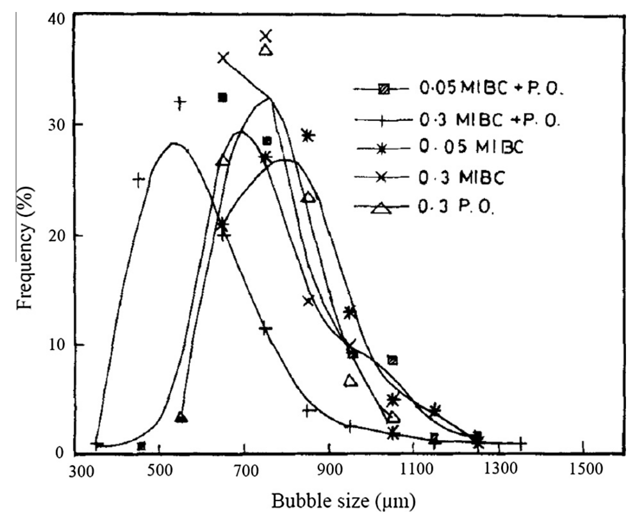

Fig. 3. BSD generated by porous plate with frother (Biswal et al., 1994).

of *200 using a bubble sampler constructed based on HUT bubble analyzer (Grau and Heiskanen, 2003).

2.3. Design and construction of laden bubbles sampler

Designing the riser is to determine the diameter and height. Riser diameter determines the mass of solids that are collected during the tests, moreover affects directly the axial mixing intensity that specify the flow regime in the riser (Bhondayi and Moys, 2011). The effect of riser diameter on axial mixing and entrainment has been studied. Results showed that risers with

Fig. 1. (a) Sparger with the ability of changing orifice and porous plates, (b) plate of needles to generate uniform size of small bubbles.