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Gas holdup estimation in flotation machines using image techniques and superficial gas velocity

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ABSTRACT

This paper presents an indirect method for determining the local gas holdup in the collection zone of flotation machines. The method includes a linear model to describe the gas holdup as a function of the superficial gas velocity and the percent area, defined as the 2D area fraction occupied by bubbles in binary images. Such images were recorded using a bubble viewer. More than 250 images of bubbles were processed to obtain suitable percent area estimations. The ability of the model to describe local gas holdup was tested at laboratory and industrial scale. The latter included self-aerated and forced-air mechanical cells from 8.5 m^3 to 300 m^3 and industrial columns from 42 m^3 to 160 m^3. The model was able to estimate the gas holdup ranging from 2.5% to 15% in laboratory and from 6.0% to 21.0% in industrial machines. As a result, a database of industrial gas holdup is presented, which includes 8 copper concentrators. The proposed methodology is a promising tool for gas dispersion characterization using a unique measurement system.

1. Introduction

Flotation continues to be one of the most important methods for mineral concentration due to its reliability to process ores with low grades as well as heterogeneous mineralogy and liberation. Gas dispersion indicates how the gas is distributed within a flotation machine and it is typically characterized by means of four main parameters: bubble size (d_B), gas holdup (ε_G), superficial gas velocity (J_G) and bubble surface area flux ($S_B = 6\ J_G/d_B$). Gas holdup is defined as the volume fraction of gas in the gas-solid-liquid dispersion, commonly expressed as percentage. Finch and Dobby (1990) reported that gas holdup mainly depends on bubble size, gas and fluid flow rate, mixing patterns and physical properties of the pulp, such as density and viscosity.

Finch et al. (2000) found a linear correlation between bubble surface area flux and the gas holdup for a wide range of cell types and operating regimes. As a result, they suggested that gas holdup might be used for flotation performance evaluation. Massinaei et al. (2009) reported a rather linear relationship between the gas holdup and the collection rate constant of industrial and pilot flotation columns. More recently, Vazirizadeh et al. (2015) showed that the flotation of coarse particles (mixture of talc and quartz, +106/−150 μm) was mainly determined by the gas holdup in a pilot flotation column. In addition, Vazirizadeh et al. (2014) reported that gas holdup exhibits a linear relationship with water recovery as well as an increasing trend with the carrying capacity at laboratory scale.

The presence of gas in the collection zone leads the effective pulp residence time to be shorter than the nominal value (Harbort and Alexander, 2006; del Villar et al., 1992). Therefore, excessive gas holdup in the collection zone might yield to effective pulp residence time decreasing, which negatively affects the mineral recovery.

Gas dispersion characterization enhances the understanding of its relationship with the metallurgical performance and allows control strategies to be developed in industrial flotation machines. Thus, the evaluation of gas dispersion in flotation equipment by bubble size, superficial gas velocity and gas holdup measurements is necessary to detect opportunities for improvement in industrial machines.

1.1. Gas holdup measurement – review of methods

The typical methods for local gas holdup measurements at laboratory and industrial scale are based on: (i) pressure difference (Yianatos et al., 1995; Finch and Dobby, 1990) (ii) capturing, *i.e.* extracting a volume of aerated pulp and determining the

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remaining volume after de-aeration (Sanwani et al., 2006; Yianatos et al., 2001; Deglon et al., 2000; Gorain et al., 1995) and (iii) electrical conductivity (Sanwani et al., 2006; Gomez et al., 2003; Gomez and Finch, 2002).

Gas holdup measurements based on pressure difference have accuracy constraints mainly related to the unknown pulp density, the assumption of negligible bubble-particle density and the error propagation in the ε_G estimation (Amelunxen and Rothman, 2009; Pérez-Garibay and del Villar, 1999). Despite its fairly simple operation, the capturing method might present accuracy problems in the turbulent zones of the flotation machines (Gorain et al., 1995). On the other hand, the sensor based on conductivity has proven to be accurate, but the syphon cell may be prone to plug with particles or bubbles. Industrial testing in flotation systems demonstrated this sensor is capable to operate without plugging during about two weeks (Gomez et al., 2003; Gomez and Finch, 2002). However, longer term measurements have not been reported.

Other methodologies have been proposed in literature for gas holdup estimation in flotation machines. For instance, Yianatos et al. (2010) reported gas holdup estimations in industrial flotation cells by means of the radioactive tracer technique. This technique provides accurate information about gas dispersion, however, it demands high preparation time, personnel and high costs. Other non-invasive technique is based on electrical resistance tomography (ERT), which have been reported by Kourunen et al. (2011). The main advantage of this methodology is that allows the 3D gas holdup distribution to be estimated. Nevertheless, industrial use of this technique is not straightforward, mainly because the process conditions change continuously. This methodology is a promising tool that is still under development.

In this paper, a model for determining the local gas holdup as a function of the percent area occupied by bubbles in binary images and the superficial gas velocity is presented. The percent area was defined as the quotient between the black pixels (bubble representation) divided by the total pixels in the binary images recorded by means of a bubble viewer (Vinnett and Alvarez-Silva, 2015). This procedure will allow the most important gas dispersion variables (bubble size, gas holdup, superficial gas velocity and bubble surface area flux) to be estimated with a unique experimental procedure at industrial scale.

2. Experimental procedure and data analysis

2.1. Laboratory measurements

The gas holdup as a function of superficial gas velocity and image analysis (images recorded by a bubble viewer) was studied at laboratory scale, using a two-dimensional cell that represents a slice of the upper radial section of an industrial flotation cell (Leiva et al., 2012). Forced-air was fed from the bottom to 24 porous spargers. The froth discharge was kept approximately constant by recirculation from the feed tank and the frothcrowder angle was set in 45°, as shown in Fig. 1.

The McGill bubble size analyser (MBSA) along with a Canon GL2 digital camera were used for the image acquisition. The MBSA consists of a sampler tube and a bubble vision chamber. The chamber has an angled window yielding an approximately single plane of bubbles. The rising bubbles are registered by the video camera and the gas accumulates at the top of the chamber. A halogen lamp was employed as an illumination source to obtain close to uniform background for the images. The installation at laboratory scale is depicted in Fig. 1.

The MBSA was adapted to determine the local superficial gas velocity, which was obtained from the water volume displacement over time together with the cross-sectional area of the sampling pipe (bubble input). The estimated local superficial gas velocities were in good agreement with the nominal values obtained with the available instrumentation. Nominal superficial gas velocities were determined as the ratio between the volumetric air flow rate and the cross sectional area of the cell. Volumetric flow rate was measured by a rotameter–manometer system.

The gas holdup was firstly obtained by pressure difference as reported by Finch and Dobby (1990). The pressure measurements were carried out by two transmitters (pressure sensors), which were installed as shown in Fig. 1. These sensors were connected

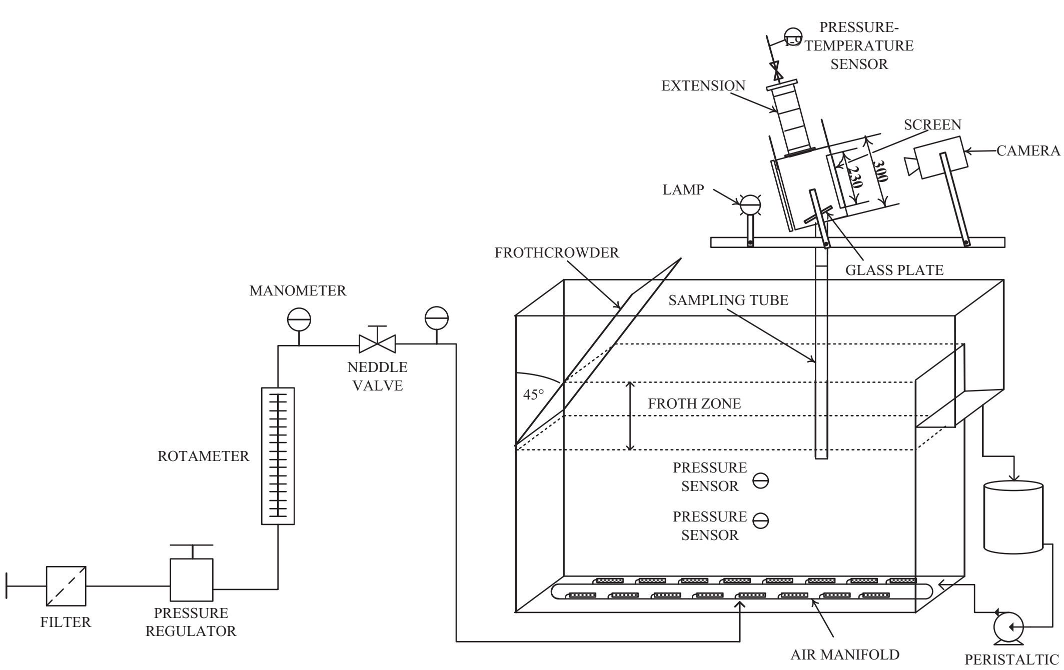

Fig. 1. Laboratory installation for gas holdup measurements and image acquisition (Leiva et al., 2012).

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