Minerals Engineering 74 (2015) 156–162

Contents lists available at ScienceDirect

Minerals Engineering

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

Influence of liberation on bubble–particle attachment time in flotation

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ARTICLE INFO

Article history:
Received 18 January 2014
Revised 3 August 2014
Accepted 11 August 2014
Available online 16 September 2014

Keywords:
Froth flotation
Attachment time
Mineral liberation
Empirical correlation

ABSTRACT

Flotation is controlled by the bubble–particle attachment mechanism which depends on the particle surface properties i.e., the particle composition, the surface liberation of valuable minerals and collector adsorption. This paper focuses on using the bubble–particle attachment method to understand the factors affecting attachment time. The attachment time measurements were performed with sized concentrates obtained by flotation of a copper sulphide ore (Northparkes Mine, Australia) in a mechanically agitated batch flotation cell. Quantitative mineral liberation analysis was used to determine the mineralogy of flotation concentrates. The results showed that the higher the amount of highly and moderately liberated copper minerals in flotation concentrates, the lower the attachment time. By using attachment time and collector dosage, we defined a non-linear empirical correlation to estimate Cu grade. The proposed empirical correlation has shown a satisfactory agreement between the calculated and the experimental Cu grade. These results showed that attachment time measurements are related to the Cu grade. This relationship may be used in the future to develop a practical method (without assays) to monitor changing grade for a specified system (flotation plant). It also may be possible to infer potential grade if mineralogy samples are available, but not enough samples are available for conventional flotation tests. However this requires a significant amount of further work.

1. Introduction

The key mechanism for successful flotation is bubble–particle attachment which is mainly investigated by contact angle measurements (Leja, 1982; Nguyen and Schulze, 2004). However, these measurements cannot always predict the flotation response with Halimond tube (Ye et al., 1989). Namely, even though the minerals are floatable, the contact angle of the minerals can be very small. For that reason, an alternative measure for predicting the susceptibility of mineral to float is bubble–particle attachment time, which is defined as the time required for an attachment of particles to an air bubble when they are in close proximity (Albijanic et al., 2010b). Bubble–particle attachment time involves the three stages: the draining of liquid film between a bubble and a particle, rupture of liquid film and the formation of a three phase contact between air bubble, mineral and liquid (Nguyen et al., 1997).

The measurement and the prediction of bubble–particle attachment time are very important since the information could potentially be used in the future optimisation, modelling and simulation of flotation circuits. However, the prediction of bubble–particle attachment time of real ore particles is very difficult since the surface chemistry of bubbles and real composite particles cannot be described from first principles and hence, the real value lies in ascertaining whether it is possible to establish an empirical model that links bubble–particle attachment time with flotation data. However, the literature does not provide an empirical model describing the relationship between bubble–particle attachment time and flotation data. For that reason, the main objective in this work is to investigate possible relationships between the bubble–particle attachment time and the degree of liberation of a copper-sulphide ore as well as to develop an empirical model which can successfully predict bubble–particle attachment time for an industrial system.

2. Previous work

Numerous researchers have used a device developed by Glembotsky (1953) to measure bubble–particle attachment time, and have shown that flotation recovery is inversely proportional to bubble–particle attachment time (Ye et al., 1989; Yoon and Yordan, 1991; Albijanic et al., 2010a). The Glembotsky device is based on keeping a bubble in contact with an upper surface of

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http://dx.doi.org/10.1016/j.mineng.2014.08.004
0892-6875/

particle bed at different controlled contact times, from which the attachment time is determined at a pre-selected percentage (e.g., 100%) of particle attachment.

Although the Glembotsky device has been typically used to determine attachment time, other techniques might be also used such as the wetting film stability measurements (Letocart et al., 1999) as well as using models to back calculate bubble–particle attachment time (Danoucaras et al., 2013; Min and Nguyen, 2013).

Various researchers have used mainly pure minerals such as quartz (Yoon and Yordan, 1991; Gu et al., 2003; Albijanic et al., 2010a; Subasinghe and Albijanic, 2014; Albijanic et al., 2014) or coal (Ye et al., 1989) to confirm that bubble–particle attachment time is sensitive enough to show changes in physical properties of minerals (particle size and shape), solution chemistry (pH, dissolved ions and surfactant concentration), bubble size and temperature of solution. A comprehensive review of these findings is recently summarized by Albijanic et al. (2010b).

Apart from determining attachment time of pure minerals, attachment time has been also measured in the case of real composite particles (Albijanic et al., 2011, 2012). The most relevant conclusion of these studies is that attachment time is strongly affected by surface exposure of valuable minerals, grade of valuable mineral and collector dosage. For particles with high grade of valuable metal, a dramatic reduction of attachment time was obtained with a small increase of collector dosage. However, in the case of particles with lower mineral grade, attachment time was not influenced by collector addition.

Regarding the prediction of attachment time of real ore particles from the flotation data, Danoucaras et al. (2013) used the P9 flotation model (Savassi, 1998) which shows the relationship between flotation mineral recovery and the following variables: floatability, entrainment, froth and water recovery, the bubble surface area flux and residence time. In the P9 flotation model, the relationship between floatability and the attachment time is described using fundamental models for particle collection by bubble (Dobby and Finch, 1987). By processing the measurements obtained by Vianna (2004) for galena size-liberation classes, Danoucaras et al. (2013) calculated the attachment time. Albijanic et al. (2012) demonstrated that for high grade particles (22.2–40.4%) measured attachment time is close to the value obtained by Danoucaras et al. (2013) while for lower grade particles (<12.3%) the measured attachment time was up to 100 times higher than the attachment time calculated by Danoucaras et al. (2013). In other words, the prediction of bubble–particle attachment time from flotation data using first principles remains a challenge.

3. Materials and methods

3.1. Ore sample

The low grade copper–gold sulphide ore (1% Cu) was obtained from Northparkes mine (New South Wales, Australia). Major valuable minerals, found in this ore, are chalcopyrite (1.1%) and bornite (1.6%), while non-valuable minerals are mainly different type of silicates such as plagioclase (31.8%), quartz (14.7%), orthoclase (12.0%) and muscovite (11.4%). It should be noted that non-valuable sulphide mineral is pyrite (0.2%).

3.2. Flotation experiments

The feed ore was prepared to a P_{80} of 90 microns by wet milling at 60% w/w solids in a laboratory rod mill. The ground sample was transferred to a 5 L bottom driven batch flotation cell, and the required amount of tap water was added to the system (~25% w/w solid ratio). The measured pH of the flotation pulp was between 8.4 and 8.8. Brisbane tap water was used in the flotation experiments.

The impeller speed was set at 800 rpm. Flotation experiments were performed as a function of collector dosage of sodium isobutyl xanthate (SIBX) supplied by Senmin Pty Ltd., South Africa. Additionally, 30 g/t of the Aerofloat 208 promoter (Cytec, USA) were added to the system. After 3 min of conditioning, 14 mg/L of the Interfroth 6880 alcohol based frother (Chemical & Mining Services Pty Ltd, Australia) was added to the flotation pulp. It should be noted that all flotation chemicals were used as supplied. After 2 min of mixing flotation pulp, 15 L/min of air was introduced through diffusers placed at the bottom of the flotation cell, and the flotation took place. An automatic scraper was used to collect the froth into two launders every 8 s. The concentrates were collected after 0.5 min, 4 min and 10 min and were wet screened to obtain the sized fraction (53–106 μm) for the bubble–particle attachment measurements. It is important to note that attachment time depends on particle size (Yoon and Yordan, 1991; Gu et al., 2003). However, it was not possible to use the narrower sized fraction for bubble–particle attachment measurements because the amount of collected fraction (53–106 μm) was less than 1 g. Additionally, the selected size fraction is in the range of optimum floatability (Muganda et al., 2012) and thus was considered suitable for the bubble–particle attachment measurements.

3.3. Bubble–particle attachment measurements

The bubble–particle attachment measurements were conducted with the Induction timer from the University of Alberta, Canada (Gu et al., 2003) as shown in Fig. 1. The sample and a supernatant solution were transferred to a small cell under the bubble holder. The solution pH was 8.5–8.8. A small bubble (1.5 mm in diameter) was generated with a microsyringe, and the distance between a bubble and an upper surface of particle bed was adjusted to be constant in all experiments. The bubble was kept in contact with the upper surface of particle bed for the controlled contact time (10–3000 ms). Then the CCD camera was used to visually observe whether particles were attached to the bubble. For each controlled contact time, ten measurements were repeated to determine attachment efficiency (expressed as a number of successful attachments in 10 observations). The contact time at which attachment efficiency is 100% represents attachment time (Albijanic et al., 2012).

3.4. Mineral liberation analysis

Mineral liberation analysis of the sized samples of (53–106 μm) concentrates was performed with a Mineral Liberation Analyser. For more details about this technique, the readers are referred to the relevant literature (Gu, 2003; Fandrich et al., 2007). Mineral liberation measurements based on cross–sectional area fraction of particles are generally given as cumulative liberation yield y (%) as proposed by Miller et al. (1982), which is the cumulative fraction of particles having a mineral composition of at least C. The 95% confidence interval of y is generally calculated using the standard deviation derived by Leigh et al. (1993), and given as follows:

$$\sigma(y) = 1.12y(1-y)\sqrt{\frac{1}{N_0}+\frac{1}{N_1}} \quad (1)$$

where N_0 is the number of particles with composition at least C and N_1 is number of particles with composition higher than C. The number of particles measured on one 2D areal section was about