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Minerals Engineering 18 (2005) 317–324
MINERALS ENGINEERING
This article is also available online at: www.elsevier.com/locate/mineng

The froth stability column: linking froth stability and flotation performance

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Received 14 May 2004; accepted 19 June 2004

Abstract

Froth structure and stability are known to play important roles in determining mineral flotation recovery and selectivity. However, measuring froth stability quantitatively, both at laboratory and industrial scales remains a significant challenge. A quantitative dynamic stability measure has previously been evaluated at laboratory scale. The technique is based on the Bikerman foam test and uses a non-overflowing froth column to quantify froth stability. At laboratory scale the froth stability measured in this way agreed very closely with other methods, and could be related to flotation performance.

In this paper, the froth stability column is tested at Northparkes, Australia. The dynamic froth stability Σ and froth stability factor β were measured under different operating conditions, and compared with the fraction of air overflowing the cell, α, which was measured using image analysis. The froth stability column results gave the same trends as image analysis. In particular the froth stability factor was found to be linearly related to the actual fraction of air overflowing the cell.

The metallurgical results clearly indicated that changes in air rate, froth depth and frother concentration result in variation in flotation performance that can be attributed to changes in froth stability. The results showed that high froth stability conditions occur at lower air flowrates, and result in improved flotation performance.

It is found that the froth stability column is an accurate and cost-effective method for quantifying froth stability, and for indicating changes in flotation performance.

Keywords: Froth flotation; Flotation bubbles; Flotation froths; Process instrumentation

1. Introduction

Froth structure (including the bubble size distribution, solids loading and liquid content) and froth stability (including the flow velocity and the fraction of air bursting on the surface of the froth) are known to play a significant role in determining the grade and recovery achieved from a flotation operation.

Previous studies (for example Banford et al., 1998; Ventura-Medina and Cilliers, 2002) have attempted to quantify various stability and structure measures, and to link these to the flotation recovery and selectivity. Ventura-Medina et al. (2003) recently related changes in the fraction of air overflowing the weir to variations in the performance of a copper flotation process. This confirmed the importance of froth stability on flotation performance and established the need for the direct measurement and monitoring of froth stability.

A multiplicity of dynamic and static methods has been proposed to measure the stability of foams. These are reviewed and evaluated by Bikerman (1973), who also proposed a simple, dynamic method in which the foam rises in an open column and the rise rate is measured. This test was adapted for mineral flotation froths by Barbian et al. (2003) and tested on laboratory scale.

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doi:10.1016/j.mineng.2004.06.010

In contrast to stable two-phase foams which do not reach an equilibrium height but continue to grow indefinitely, flotation froths reach a stable height in the column after a suitable growth period.

2. The froth stability column

The froth stability column is based on the dynamic stability test for non-overflowing froth columns, originally proposed by Bikerman (1973).

Measurements are carried out using a vertical column, which is inserted through the froth to below the pulp–froth interface in the flotation cell, adequately low to avoid froth leakage from the bottom. Once inserted, the froth rises up inside the column and the froth height, H, is measured as a function of time, t, using the pulp–froth interface as the reference. After some time, depending on the froth stability and operating conditions, the froth rise stops and it reaches a constant height, H_{max}.

Bikerman defines the dynamic stability factor, Σ, as ratio of the maximum volume of foam or froth generated to the air flowrate:

$$\Sigma = \frac{V_f}{Q} = \frac{H_{max} \times A}{Q} \tag{1}$$

V_f is the froth volume at equilibrium, Q is the gas flowrate to the cell, H_{max} is the froth height at equilibrium and A is the column cross-sectional area.

In addition to the maximum froth depth, the froth rise rate is important. The froth height in the froth stability column is recorded, visually or electronically, as a function of time and can be fitted by an exponential model of the form:

$$H(t) = H_{max}(1 - e^{-t/\tau}) \tag{2}$$

Since the equation accurately describes the observed behaviour, H_{max} can either be directly measured, or inferred from data taken during the rise period, in which two parameters (H_{max} and τ) are fitted.

The *froth rising velocity* $u(t)$ is given by variations in froth height as a function of time (dH/dt) at any particular time t.

$$u(t) = \frac{dH(t)}{dt} = \frac{H_{max}}{\tau} e^{-t/\tau} = \frac{H_{max} - H(t)}{\tau} \tag{3}$$

It is believed further that the froth rising velocity can be linked to *the fraction of bubbles bursting* on the top surface of the froth, a key parameter in froth modelling and plant operation. If the froth is highly stable, u (the rise velocity) is equal to the superficial gas velocity in the pulp J_g. However, since a fraction of bubbles burst in the column, the rise velocity at each height is progressively lower, by a factor $\beta(H)$ representing the fraction of air remaining in the froth at a given froth height H:

$$u(t) = \frac{dH(t)}{dt} = \beta(H)\frac{Q}{A} \tag{4}$$

Rearranging:

$$\beta(H) = \frac{dH(t)}{dt}\frac{A}{Q} = \frac{(H_{max} - H(t))}{\tau}\frac{A}{Q} \tag{5}$$

The stable fraction, β, can then be determined as a function of the froth height, while the relationship between $H(t)$ and H_{max} will also depend on frother concentration, air flowrate or even the position of the flotation cell down the bank.

2.1. Laboratory scale

The froth stability column was previously tested at laboratory scale (Barbian et al., 2003). The dynamic stability factor, Σ, was used to measure froth stability in the flotation of a Platinum Group Metal (PGM) ore from Amandelbult (Merensky reef), South Africa. The rate of froth growth and the maximum equilibrium height reached were measured for different air flowrates and frother concentrations. The maximum equilibrium froth height was found to increase when increasing air flowrate and frother concentration, however at high aeration rates and frother concentration the maximum equilibrium height decreases. Under these conditions the froth is not longer stable and collapses. Consequently, it was also found that the dynamic stability factor is affected by air flowrate and frother concentration.

Barbian et al. (2003) found that, on laboratory scale, the fraction of air bursting on the froth surface predicted from the stability tests agrees closely to that measured during flotation tests. Their findings suggest that if a relationship between the fraction of air overflowing the cell and flotation performance is known it is possible to manipulate the flotation variables to produce the optimal froth stability and flotation performance.

This work presents the application of the froth stability column to industrial scale. The aim of the study is to ascertain whether the technique is suitable for industrial application, and to develop a relationship between operational variables and flotation performance as a result of changes in froth measured stability.

3. Experimental system

Experiments were carried out in the rougher cells of the flotation circuit (Module 2) at Northparkes Mine, North Eastern Australia. The ore processed in Northparkes contains copper as sulphide minerals (mainly bornite Cu_5FeS_4, and chalcopyrite, $CuFeS_2$). The rec-