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Case studies on the performance and characterisation of the froth phase in industrial flotation circuits

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Abstract

This paper deals with two separate case studies investigating the froth phase performance and characterisation of two industrial rougher/scavenger flotation circuits. Froth phase performance was quantified using a mass balance approach to estimate froth zone recovery. Measured characteristics of the froth phase included frother solution concentration determined by gas chromatography, and the time taken for an equilibrium froth sample to decay to one-half of its original froth height. The latter measurement is referred to as the 'froth half-life' and is strongly linked to froth stability. Special methods and techniques developed to preserve frother in solution and to measure froth half-life are briefly described. The frother type in the first case study was a mixture of straight and branched alcohols, whilst the frother type in the second case study was a mixture of alcohols, aldehydes and triethoxybutane. The first case study focussed on a flotation circuit treating a low grade ore containing only a small fraction of floatable copper sulphide minerals, while the second case study focussed on a flotation circuit treating a higher grade complex sulphide ore containing significant quantities of chalcopyrite, galena, sphalerite and pyrite.

It was found that froth zone recovery of valuable mineral generally decreased down-the-bank of the two industrial rougher/scavenger circuits. Moreover, decreases in froth zone recovery significantly limit the overall cell recovery of valuable mineral achievable from the plant scavenger cells. However, the decrease in froth zone recovery could not be linked to the removal of frother from the pulp solution to the concentrate product in the preceding rougher flotation stages. Measurements of residual frother in solution suggested that, approximately, only 5–10% of the added frother was removed into the rougher/scavenger concentrate, with the remainder appearing in the scavenger tailings. This finding suggested there was apparently adequate frother in solution in the scavenger stages.

There was, however, a correlation to the froth half-life, with the froth half-life also generally decreasing down-the-bank. A simple, empirical model, based on the froth half-life and froth residence time of gas, is proposed here to predict froth zone recovery. Further, it is proposed that the froth stability, as measured by the froth half-life, is strongly linked to the presence of particles in the froth, with poorly mineralised scavenger froth characterised by a short half-life and, potentially, a low froth zone recovery. The importance of particles on froth stability was confirmed in separately conducted laboratory experiments. These experiments also demonstrated the wide variation in froth stability behaviour between different frother types.

Keywords: Flotation froths; Flotation frothers; Sulphide ores

1. Introduction

In flotation, the transport of hydrophobic particles attached to bubbles from the collection zone of the cell,

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where particle collection by bubbles occurs, to the concentrate launder is of key importance. Transport takes place via a froth phase in froth flotation. Frother surfactants are principally added to a flotation pulp so that a transient, mineralised froth is formed at the top of the flotation cell, forming the so-called froth phase. A transient froth is a prerequisite for the successful transport of mineral laden bubbles from the pulp zone/froth zone interface to the concentrate launder. It is desirable that the mineralised froth breaks down (i.e., the bubbles collapse or coalesce), once the froth reports to the concentrate launder. A froth which is overly unstable may cause significant loss of valuable mineral from the froth to the pulp phase and, subsequently, to the cell tailing stream. Conversely, an overly stable froth will cause problems in pumping, and may adversely impact mineral separation in subsequent flotation stages. Our research here is focussed on controlling froth stability to allow particle transport to take place, while also ensuring the froth breaks down once it enters the concentrate launder.

The recovery of particles attached to bubbles across the froth phase is referred to as froth recovery. Froth recovery can be defined in several ways. However, it is now accepted that the recovery of attached particles across the froth zone is best expressed in terms of the first order rate constants (Savassi et al., 1997):

$$R_{\mathrm{f}} = \frac{k}{k_{\mathrm{c}}} \tag{1}$$

In Eq. (1), R_{f} is the fractional froth recovery, k is the overall flotation cell first order rate constant, treating the collection and froth zones as a single phase, and k_{c} is the collection zone rate constant. It is noted that entrained particles are included in this particular definition. Entrainment is the phenomena of the recovery of mineral particles, which are not attached to air bubbles, by their unselective recovery with water (Johnson et al., 1974). However, in the context of this current paper, which principally focuses on hydrophobic value minerals, the contribution by entrainment is expected to be only minor.

This definition also provides an experimental approach to the measurement of froth recovery in which the overall flotation cell rate constant is determined as a function of froth height, or the froth residence time (FRT) of gas (Laplante et al., 1983; Vera et al., 1999). The froth residence time of gas is defined as

$$\mathrm{FRT} = \frac{\mathrm{FD}}{J_{\mathrm{g}}} \tag{2}$$

In Eq. (2), FD is the froth depth (cm) and J_{g} is the superficial gas velocity (cm/s), which is the gas flow per unit cross-sectional area of the flotation cell. In this approach, the overall flotation cell first order rate constant is measured as a function of froth residence time, with the collection zone rate constant, k_{c}, determined by extrapolation to zero froth depth. The ratio of the overall flotation cell first order rate constant, at any froth depth (FD), to the collection zone rate constant defines the froth recovery at that froth depth according to Eq. (1). This particular method, termed the mass balance approach, is used in the current study to determine froth recovery of the plant cells. It is recognised that in this approach, the froth recovery at zero froth height is assumed to be 100%. This may not be the case due to bubble bursting at the top of the froth, or inefficiencies in the lateral transport of particles in the froth, even at very shallow froth depths. However, for industrial cells it is an expedient approach, in the first instance, to obtain an estimate of froth recovery.

Both the physical scale of the froth (defined here by FRT) and froth type, exemplified by the froths stability, may control the froth recovery of attached particles. Froth residence time and froth height characterise the physical scale of the froth, whilst the frother type, frother concentration as well as the particle characteristics in the froth (e.g., particle size, particle contact angle, particle loading in the froth) may all control froth stability (Schwarz et al., 2002). A decrease in the carrying capacity of the froth, and the possibility that some mineral particles may become detached and be lost from the froth, has been observed from froth recovery measurements conducted at plant scale where there is continuous removal of froth in successive flotation cells (Savassi et al., 1997). The decrease in froth recovery seems particularly important in the scavenger flotation stages, where the froth has apparently low stability. In contrast, froth recovery in the initial stages of rougher flotation of a continuous separator is usually higher, and the froths apparently more stable. This particular aspect of the operation of flotation froths is the principal focus of this paper.

It is the purpose of this paper to determine if decreases in froth recovery in a continuous, industrial flotation separator may be linked to changes in froth stability, and to determine reasons for the change in froth stability with flotation cell number. Froth stability is used here to describe the general phenomena of thin film rupture, bubble coalescence and loss of froth volume. In this work, both the effect of particles contained within the froth, as well as frother type and concentration on froth stability has been investigated. In recent years there has been strong interest in modelling froth zone performance in laboratory flotation cells, in scale-up to a continuous flotation process, and in froth phase assessment in plant cells. Froth phase performance is better understood here in terms of froth recovery, R_{f}, and hence a specific objective of this work is to identify how physical factors, such as froth height, and chemical factors, such as frother concentration in solution and froth solids loading, control froth recovery. The exponential decay of froth recovery with an increase in froth retention (residence) time is well known and useful in terms of froth modelling (Gorain et al., 1998):

$$R_{\mathrm{f}} = 100 * \exp^{(-\beta * \mathrm{FRT})} \tag{3}$$

In Eq. (3), β is a parameter, which is arguably related to the rate at which bubbles coalesce and burst, or simply a parameter, which could depend on the physical and chemical froth factors. An expansion of the R_{f}–FRT relationship to account