



Considering the effect of pulp chemistry during flotation on froth stability

Nanji Sheni, Kirsten Corin*, Jenny Wiese

Centre for Minerals Research, Department of Chemical Engineering, University of Cape Town, South Africa



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ABSTRACT

Within the flotation process the pulp phase chemistry has a strong effect on the froth phase and therefore the manipulation of pulp chemistry factors such as the pulp potential (Eh), pH, dissolved oxygen (DO) and ionic strength (IS) can improve flotation performance. Stability column and batch flotation tests were performed in the presence and absence of depressant at high dosages; 500 g/t Carboxymethyl Cellulose (CMC) to investigate the effects of these pulp factors on froth stability and entrainment of the froth phase through PGM flotation of a South African PGM bearing ore. The base metal containing minerals chalcopyrite and pentlandite were also targeted for recovery. Increased IS, pH and Eh, and decreased DO resulted in improved froth stability and changes in the bubble size in the froth, with the exception of changes in DO resulting in no perceived effect on bubble size. Entrainment was found to only be significantly affected by an increase in Eh.

1. Introduction

The platinum mining industry has recently been negatively impacted by the global drop in the price of platinum group metals (PGMs), specifically in South Africa. For this reason, it is becoming increasingly important to improve flotation performance across the plants in South Africa. The country contains 95.5% of the world's known platinum reserves and produced about 72.0% of the world's platinum in 2013. However, this fell to about 68.0% in 2014 and has been predicted to fall even further due to the unrest experienced in its mines (U.S. Department of the Interior, 2015). It is therefore necessary to find new ways to increase the grades and recoveries of PGMs in the flotation process. A PGM bearing ore from South Africa was used in this study, the base metal containing minerals, chalcopyrite and pentlandite were also targeted.

1.1. Pulp chemistry factors

Pulp chemistry factors, with main focus on the pulp potential (Eh), pH, dissolved oxygen (DO) and ionic strength (IS) have significant effects on what is observed in and recovered from the froth phase. Each of these pulp factors have a significant effect on the overall flotation performance of the system. In previous work (Farrokhpay and Zanin, 2012; Manono et al., 2012; Chander, 2003; Kuopanportti et al., 1997; Ross and van Deventer, 1985) the individual effects of Eh, pH, DO and IS on flotation performance have been studied, however not much work exists on their combined effect on flotation performance.

The redox potential, also known as Eh, is “a measure of the tendency of a solution to be oxidising or reducing” (Hu et al., 2009). It aids in predicting the regions of optimal flotation and estimating the surface conditions of sulphide minerals (Goktepe, 2002). Factors that affect pulp potential include: the grinding conditions such as: purging with oxygen or nitrogen; the grinding media which could increase or reduce the galvanic interactions observed; collector addition during grinding; DO levels; the pH within the mill and the presence of other modifying agents (Corin et al., 2013; Chander, 2003).

The pH has the potential to enhance collector attachment to the mineral surface and a change in pH can chemically alter the surface chemistry of the minerals in the slurry through a change in the particle surface charges (Kawatra and Eisele, 2001). A decrease in pH causes an increase in attachment of sulphhydryl collectors such as xanthates, for example, with pyrite and chalcopyrite, the lower the pH the greater the rate of xanthate adsorption (Kuopanportti et al., 1997). However, as the pH changes, different sulphides experience collector attachment and varied degrees of hydrophobicity (Kawatra and Eisele, 2001). Changing the pH can result in changes in the pulp potential upper and lower limits for minerals (Hu et al., 2009) as well as changes in the froth (Farrokhpay and Zanin, 2012).

Depending on the mineral being floated and the collector used, the presence of oxygen may result in the formation of dixanthogen and other species essential for hydrophobicity. However, over-oxidation of the sulphide mineral surface can reduce mineral hydrophobicity and inhibit the separation of the mineral from gangue minerals during flotation (Shannon and Trahar, 1986; Guy and Trahar, 1985). Factors such

* Corresponding author.

E-mail address: Kirsten.corin@uct.ac.za (K. Corin).

as DO and Eh can be used to control and monitor the flotation process and the manipulation of these factors can improve selectivity (Kuopanportti et al., 1997). The standard concentration of DO at standard temperature and pressure (STP) is 8 mg O₂/L of water in contact with air (LennTech Water Treatment Solutions, 2015).

With regards to IS ions such as, Ca²⁺, Mg²⁺, Na⁺ and Cl⁻, common ions found in recycled plant water, have been seen to reduce the surface tension which in turn improves froth stability. These ions have frothing properties when in a slurry, by reducing the repulsive forces between the mineral particles and the air bubbles (Manono et al., 2012). An increase in IS has been found to increase froth stability and the entrainment of gangue minerals.

Certain salts and frothers share the ability to inhibit bubble coalescence. High salt content in plant water has been found to remove the need for the use of a frother in the flotation system and lower reagent consumption. However, frothers are still necessary as only small quantities of frother are needed for the same effect that large concentrations of salt would have during flotation (Quinn et al., 2007). Craig (2011) investigated the effects of electrolytes on the drainage properties of the froth and found that electrolytes that consist of an α cation and an α anion ($\alpha\alpha$) or a β anion and a β cation ($\beta\beta$) are the electrolytes that inhibit bubble coalescence. Whereas the $\alpha\beta$ combination did not inhibit coalescence. These α and β assignments represent the positions of the ions in the air-water interface, where α ions are depleted at the interface and β ions are adsorbed or accumulate at the interface (Craig, 2011; Marcelja, 2006; Craig et al., 1993a, 1993b).

1.2. Froth stability

There are a number of definitions of froth stability but for the purpose of this paper froth stability will be quantified using the dynamic stability factor proposed by Barbican et al., (2003) who modified the Bikerman test, that was initially created for 2-phase foams (Bikerman, 1973), to be used for froth flotation systems. The dynamic froth stability factor can then be calculated from this system using Eq. (1) (Bikerman, 1973). The equation shows that the dynamic froth stability factor, Σ , is a function of the volume of the foam, V_f , and the gas volumetric flow rate, Q , where H_{max} = the maximum equilibrium height achieved, and A = the cross-sectional area of the column (Bikerman, 1973):

$$\Sigma = \frac{V_f}{Q} = \frac{H_{max} \times A}{Q} \quad (1)$$

1.3. Entrainment

Entrainment is a chemically non-selective process as it results in the transport of hydrophobic and hydrophilic mineral particles to the concentrate without the attachment of the particles to air bubbles. It may occur simultaneously with true flotation and increases with a decrease in particle size (Cilek, 2009).

Water recovery has most commonly been associated with entrainment as it is the medium of transport used. Therefore, a direct correlation between water recovery and entrainment of fine particles to the concentrate is expected and is well observed (Vos et al., 2014) Eq. (2) (Subrahmanyam and Forssberg, 1988).

$$R_{gangue} = \varepsilon R_{water} \quad (2)$$

Where, R_{gangue} = the gangue recovered from the cell, R_{water} = the water recovered from the cell, ε = the probability of entrainment of gangue from the cell or the entrainment factor.

This study will focus on water recovery as a means of monitoring entrainment and will focus on the contributions of all four pulp factors to froth stability, entrainment and grades and recoveries of valuable minerals.

Table 1

Table of plant water salts in grams per litre used to make up a solution of ionic strength 0.0213 mol/L represented as 1 IS.

Chemical Salt	Concentration (g/L)
Magnesium Sulphate	0.615
Magnesium Nitrate	0.107
Calcium Nitrate	0.236
Calcium Chloride	0.147
Sodium Chloride	0.356
Sodium Carbonate	0.003
Ionic Strength (1 IS)	0.0213 mol/L

2. Experimental details

2.1. Water

Water of a known ionic strength is made to represent the type of water used in a typical flotation circuit in industry. Table 1 shows the salts and their concentrations (g/L) that are used to make up water of ionic strength 0.0213 mol/L represented as 1 IS. The plant water salts were supplied by Merck in powder form. Water noted as 5 IS was five times the concentration of each salt at 1 IS.

2.2. Reagents

Sodium hydroxide (NaOH) at 2 M was used to adjust the pH and was supplied by Merck. Sodium hypochlorite (NaClO), used as an oxidizing agent to adjust Eh, was supplied by Kimix as a stock solution of 12% and was used as received. The collector, sodium isobutyl xanthate (SIBX), frother, Senfroth 516, and depressant, carboxymethyl cellulose (CMC), were supplied by Senmin. The collector and depressant were received in powder form and the frother in liquid form. The collector and depressant were prepared as 1% solutions by mass and the frother was used as received.

2.3. Flotation experiments

A sample of Platinum Group Mineral (PGM) bearing ore with a top size of –4 mm was used to conduct all test work. A target grind of 60% passing 75 μ m was chosen for all the tests conducted. Representative 1 kg aliquots of ore were milled in an Eriez stainless steel 1 kg rod mill and 2 kg aliquots of ore were milled in a SALA stainless steel 3 kg rod mill for batch flotation tests and stability column tests respectively. The milled slurry from both mills was made up to 33% solids by adding synthetic plant water of ionic strength 1 IS.

The stability column was used and the dynamic stability factor was applied and calculated according to Eq. (1). The air flow rate of the column was maintained at 7 L/min. A pore-2 frit was used to regulate the bubble size. Reagents were added to a feed bucket and allowed to condition for both the 3-phase slurry and 2-phase solution prior to running each column test.

A 3L UCT Barker flotation cell was used for the batch flotation tests. Reagents were added to the cell and the air flow rate was maintained at 7 L/min. Four concentrates were collected at 2, 6, 12 and 20 min. The pulp chemistry was varied by changing the DO, pH, Eh and IS during the conditioning time, and solids and water recoveries were determined for all tests. The DO and pH of the system were measured using a TPS meter and the Eh using a HANNA meter. The DO concentration was controlled by using nitrogen as the flotation gas to reduce the oxygen concentration in the flotation cell to zero. The Eh was measured using a platinum electrode and expressed through the use of the standard hydrogen electrode (SHE) scale. The pH was adjusted using NaOH. The IS was controlled using the synthetic plant water salts concentration measured in ionic strength (IS). The Eh was manipulated using NaClO as this altered the Eh without changing the pH (Chimonyo, 2016). The

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