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The entrainment effect on the performance of iron ore reverse flotation

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ABSTRACT

An iron ore mineral processing plant in Brazil treating Itabirite ore was assessed by sampling a circuit consisting of Wemco 144 mechanical cells, as part of the AMIRA P9P collaborative research project. This paper presents and discusses the results of entrainability, water recovery and quartz and hematite grades associated to hydrodynamic parameters. The results indicated strong correlation between water recovery and hematite losses which was intensified by the operating conditions of the circuit.

A potential alternative to reduce the hematite losses through entrainment and to increase quartz removal was to modify the traditional circuit design to treat rougher and cleaner/recleaner tails in different stages. In addition, the scavenger residence time must be matched to the quartz floatability. Changes to design and operation of these circuits are needed to sustain concentrate recovery and grade as iron ores become finer.

1. Introduction

Froth flotation is an important concentration process in the separation of quartz (SiO_2) from hematite during fine iron ore beneficiation. Quartz is the main gangue material associated with hematite in iron ore and its grade is a key consideration for the final concentrate specification. Araújo et al. (2005) described three main routes for iron ore beneficiation through flotation, namely reverse cationic flotation of quartz, direct anionic flotation of iron oxides and reverse anionic flotation of activated quartz. For flotation of Brazilian itabirite ores, Lima et al. (2005) depicted that the most common route used by far was cationic reverse flotation where quartz was recovered to the froth (the "tailings" product) and iron oxides remain in the pulp phase (the "concentrate" product).

The typical feed to a flotation system applied in the cationic reverse flotation of quartz from hematite in the iron ore industry consists of particles in the size range between 10 μm and 300 μm. The slimes fraction (<10 μm) are removed using hydrocyclones prior to flotation and the top size is limited to 5–10% greater than 150 μm. The flotation of iron ores is performed in circuits consisting of mechanical cells, columns, or a combination of both types of machines which all have difficulty in collecting quartz particles with particle sizes above 150 μm. Therefore these systems feature the need for multiple stages and long residence times to maximise quartz flotation in order to obtain pulp phase concentrates with SiO_2 within market specifications while minimising the loss of Fe to the tailings (froth). The entrainment of fine Fe-bearing particles (<45 μm) into the froth can be one of the reasons for the difficulty in obtaining tailings with low Fe content (<12%) in traditional machines during the reverse flotation of quartz, and the extent of the problem in the iron ore industry in Brazil was investigated during a survey of an industrial iron ore circuit.

2. Theory

2.1. Reagents used in iron ore reverse flotation

Many studies have been done to investigate reagents for both collection of quartz and depression of iron oxides for the reverse flotation route (Turrer and Peres, 2010; Lima et al., 2005; Kar et al., 2013). Initially, in the early 1960s, fatty acids were employed as the collector and silicates were activated by ions of Ca^{2+} for the anionic reverse flotation route. Starch was used to depress iron oxides, mainly through dextrin. For the cationic reverse flotation of quartz, there was no need to activate the SiO_2 and amine started to be used as a collector for quartz instead of fatty acids. The primary amines have since been replaced by ether amines as the

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insertion of the polar group $(O—CH_2)_3$ increases the solubility of the collector. Depending on the iron ore mineralogy, a blend of mono and di-amine could be applied. The pH also plays an important role in the amine adsorption mechanism. As with the anionic route, cationic reverse flotation also uses starch as the iron oxide depressant and specifically for Brazilian iron ore, corn starch has been used widely (Araújo et al., 2005). There is no use of frothers in industrial circuits as the long chain C12 amines play the roles of collector and frother simultaneously.

2.2. Anionic versus cationic flotation

Ma et al. (2011) presented a study comparing the performance of the anionic and cationic reverse flotation routes. They concluded that the anionic route provided greater selectivity for the ultrafines (<10 μm) than the cationic route. However, the rate of quartz flotation was lower in the anionic route and iron oxides started to float to the froth (tailings) as the anionic flotation process proceeded. Hence the reverse cationic route produced higher iron oxide grades and recoveries in the final concentrate (pulp phase) than the anionic route. The high costs of the reagents for the reverse anionic route were also impeditive for its industrial use (Filippov et al., 2014; Araújo et al., 2005).

2.3. Effect of particle size on flotation

The particles in the feed to the flotation process will have a distribution of flotation probabilities based on their properties. Studies by Hewitt et al. (1994) showed that the probability of adhesion increases with decreasing particle size and with increasing degree of hydrophobicity, where the latter can be obtained with increased collector dosage. Thus, coarse particles have high probability of collision but due to their size and greater mass they are more prone to detachment due to turbulent forces present within the pulp phase. This mechanism helps to explain the difficulty in collecting coarse quartz particles during the reverse flotation process when traditional mechanical cells are employed and has driven the choice of operating conditions and circuit layout to maximise quartz recovery to the froth.

2.4. The role of entrainment in flotation

Entrainment of particles into the froth phase is another important factor in the performance of the flotation process, especially for fine particle recovery. Entrainment is the unselective entrapment of fine particles into the froth layer with the rising water (Smith and Warren, 1989) and it can be experienced by both hydrophobic and hydrophilic particles (Wang et al., 2015). Fig. 1 illustrates the entrainment in a flotation cell.

It has been found that the entrained gangue recovery in a direct flotation operation is often proportional to the water recovery (Thorne et al., 1976; Trahar, 1981), although there is sometimes a non-linear relationship at low water recoveries followed by a linear increase at higher water recoveries (Engelbrecht and Wooddburn, 1975; Zheng et al., 2006). Industrial flotation data can be used to develop an empirical relationship between recovery by entrainment and water recovery (Smith and Warren, 1989) of the form:

$$R_{ent,i} = \frac{Ent_i R_{water}}{1 - R_{water} + Ent_i R_{water}} \quad (1)$$

where

$R_{ent,i}$ is Bank recovery by entrainment of size class i
Ent_i is Entrainability of size class i
R_{water} is Bank recovery of water

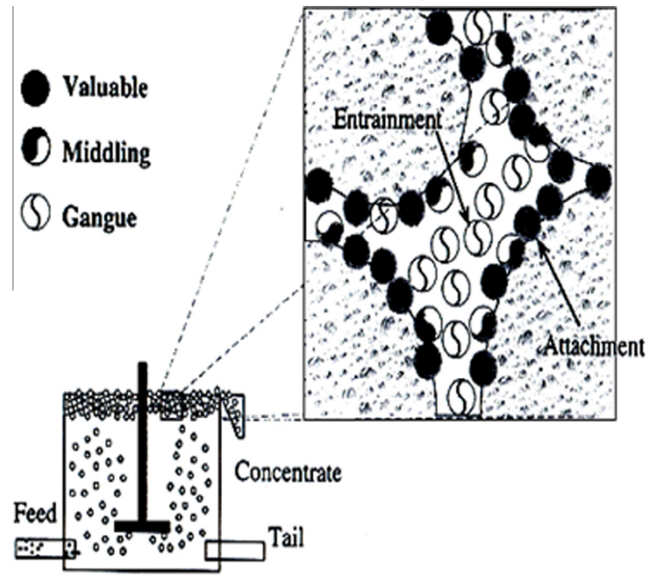

Fig. 1. Entrainment in a flotation cell (Smith and Warren, 1989).

The entrainment is controlled by: water partition (Johnson, 1972), solids percentage in the pulp (Yianatos et al., 2009), particle size (Smith and Warren, 1989) and froth (Engelbrecht and Wooddburn, 1975).

The work of Neethling and Cilliers (2009) confirmed the experimentally observed relationship between gangue and water recovery, including its dependence on particle size, by using physics-based models for the liquid and solids behaviour in the froth. It was concluded that there was a significant particle size effect on entrainment, in agreement with experimental observation.

Using this model, the recovery by entrainment was predicted as a function of the water recovery, as shown in Fig. 2. Fine particle recovery was directly proportional to water recovery whereas for coarse particles the slope was lower at low water recoveries and tended to intercept the water recovery axis rather than pass through the origin.

The model further predicted that the recovery by entrainment for a particular particle size would generally increase as the air rate in the flotation cell was increased and would decrease with an increase in froth depth. This was also observed experimentally in

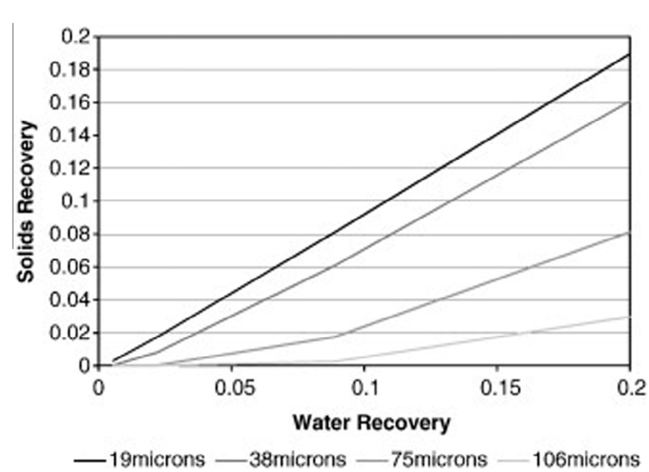

Fig. 2. Simulated entrained solids recovery versus water recovery for different particles sizes (Neethling and Cilliers, 2009).

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