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The observed effect of flotation operating conditions and particle properties on water recovery at laboratory scale

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ABSTRACT

The entrainment of fine gangue particles has become a critical issue in flotation nowadays when low quality and complex ores are processed. Water recovery contributes significantly to gangue entrainment and greatly affects concentrate grade. In this study, a factorial batch flotation experiment was performed to investigate the main and combined effects of gas flowrate, froth height, impeller speed and gangue particle density on water recovery using a mixture of liberated chalcopyrite and gangue minerals in a 3.5 L batch flotation cell.

Results show that water recovery was significantly affected by (1) froth height, (2) gas flowrate, (3) impeller speed, (4) the interaction between impeller speed and particle density, and (5) the interaction between gas flowrate and froth height (in the order of reducing effects). Interestingly, water recovery was less sensitive to gas flowrate as froth height was increased, and more sensitive to froth height as gas flowrate was increased. There was an increase in the amount of water entering the froth phase from the pulp when increasing impeller speed, especially in the context of high-density gangue mineral systems.

The identified effects and interactions and the effect of froth residence time on water recovery suggest that water recovery could be predicted effectively if both water drainage and water entering the froth from the pulp are considered. A model based on these two parameters was proposed in this paper.

1. Introduction

Froth flotation is an important mineral processing technique for physically separating particles based on a difference in surface wettability, and water is an integral component of the froth product obtained. In froth flotation, water plays a significant role in froth stability and mobility, and consequently determines froth recovery. In addition, water unselectively carries fine hydrophilic particles that are not attached to air bubbles into the concentrate in a process known as entrainment. The relationship between the amount of gangue minerals recovered by entrainment into the concentrate and water recovery is shown in Eq. (1) (Savassi, 1998). Excessive recovery of water to the concentrate always results in significant contamination of the product with gangue minerals as shown in Fig. 1 (Wang et al., 2016).

$$R_{ent} = \frac{ENT \cdot R_w}{1 + R_w \cdot (ENT - 1)} \quad (1)$$

where R_{ent} is the gangue recovery by entrainment, R_w is the water recovery, and ENT is the degree of entrainment representing the relative drainage of solids to water in the froth and the state of solids suspension in the pulp.

Water recovery is considered as a two-step process: transfer of water from the pulp to the froth and transfer of water from the froth to the concentrate. In the pulp of a conventional flotation cell, air is drawn into the cell and turned into swarms of small bubbles dispersed in all directions within the turbulent zone by an impeller. After a rapid attachment of valuable minerals to bubbles in the surfactant solution, these bubbles ascend and become metastable in the quiescent zone. With the continuous rising of ascending bubbles, water surrounding the air bubbles and in the wake of ascending bubbles starts to transfer across the pulp/froth interface to the froth (Gaudin, 1957; Moys, 1978; Hemmings, 1981; Bascur and Herbst, 1982; Smith, 1984; Yianatos et al., 1988; Smith and Warren, 1989). Therefore, the operating conditions in the pulp phase such as superficial gas flowrate, bubble size distribution,

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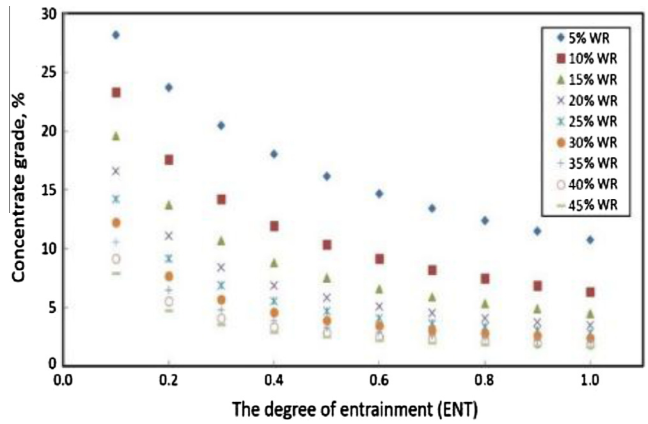

Fig. 1. The simulated concentrate grade at different water recoveries and *ENT* values in a rougher flotation test where copper recovery is constant and 90% (after Wang et al., 2016).

impeller speed, the concentration of surfactants, and the degree of bubble loading strongly influence the water entering the froth.

Only a fraction of the water that enters the froth is transferred to the concentrate due to water drainage. Three forces act to determine the water transport in the froth, namely gravity, viscous drag against the rising bubbles, and capillary suction arising from changes in froth structure (Plateau borders) (Neethling et al., 2003). As a consequence of these forces, some water is transferred to the concentrate, while the rest experiences drainage. Water obtained in the concentrate generally comes from the boundary layer water around bubbles and the interstitial water that can move freely in Plateau borders (Nguyen et al., 2003). The latter is a particularly important source of water in the concentrate as most water in the froth is contained in Plateau borders which are formed by the thin water films around bubbles (lamellae) meeting at 120° as shown in Fig. 2.

Water drainage is mainly due to drainage through Plateau borders, the collapse of froth causing rapid transfer of water downwards in the local area of froth, and sedimentation induced by shear activity (Cutting, 1989). The drainage depends primarily upon froth residence time, froth stability and fluid viscosity (Langberg, 1988). Froth residence time allows the interstitial water

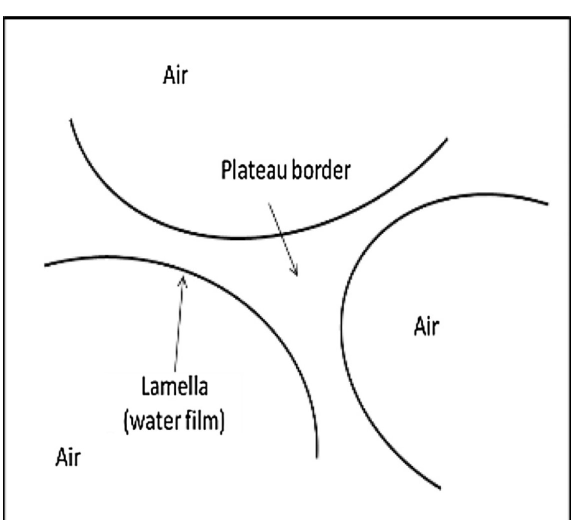

Fig. 2. Schematic representation of a Plateau border and its associated lamella (after Ross and Van Deventer, 1988).

between bubbles to drain out of the froth through Plateau borders back into the pulp. Froth stability refers to bubble coalescence and bubble bursting and depends on the type and concentration of chemical reagents used to stabilize the froth, the surface properties of particles in the froth (especially the hydrophobic particle properties such as size, shape and hydrophobicity as well as the mineralization), and the stresses induced by froth motion (Langberg, 1988; Savassi, 1998). The viscosity of fluid is a measure of its resistance to gradual deformation by shear stress or tensile stress, and in the froth it represents the resistance against water drainage.

Water recovery is related to many factors in both the pulp and the froth although the operational variables are the ones that may be adjusted to control and manipulate water recovery. Operational variables are often adjusted to achieve a desired flotation performance as they not only influence the "true flotation" but also have an impact on water recovery, and hence influence gangue recovery by entrainment.

The effects of froth height and gas flowrate on water recovery have been recognised for decades (Engelbrecht and Woodburn, 1975; Langberg and Jameson, 1989; Zheng et al., 2006a). The evaluation of current water recovery models by Zheng et al. (2006a) implied that water recovery may be more sensitive to froth height than to gas flowrate. In addition, Langberg and Jameson (1989) studied the effects of gas flowrate, froth height and bubble size on water recovery, and their experimental results showed that there was an interactive effect between gas flowrate and froth height on water recovery. In fact, it is not unusual to detect interactive effects between variables in froth flotation (Wang et al., 2016). It is worth noting that when an interactive effect is present, the impact of one factor depends on the level of the other factor, which indicates that interpretation of the main effect is incomplete or misleading (Stevens, 1999). Furthermore, interaction provides insights into the fundamental mechanism of a process.

Other operational variables such as impeller speed, pulp density and the presence of frothers also influence water recovery. Akdemir and Sönmez (2003) investigated the recovery of coal and ash as well as the entrainment in flotation and found that water recovery increased with increasing impeller speed and solid concentration in the pulp. Studies on frothers show that water recovery is not only dependent on frother concentration, but also on frother type (Rahal et al., 2001; Melo and Laskowski, 2007).

In the current study, a factorial experimental examination of the effects of some operational variables (gas flowrate, froth height and impeller speed) on water recovery in different gangue mineral systems was conducted in a 3.5 L batch flotation cell. The work is part of an extensive investigation of the effect of flotation operating conditions and particle properties on entrainment parameters (i.e. the degree of entrainment and water recovery). The effect of the operating conditions and particle properties in this study has been investigated and published previously with respect to the degree of entrainment (Wang et al., 2016). This paper presents the effect of these variables on water recovery. The combination of both papers provides insights into best modelling entrainment.

2. Experimental

2.1. Materials and reagents

The flotation feeds in the experiments were prepared artificially by mixing pure chalcopyrite with pure gangue minerals purchased from GEODISCOVERIES. Quartz (SG = 2.65) and hematite (SG = 5.26) were the two gangue minerals used in the experimental program. Sodium hydroxide (NaOH) was used to adjust the slurry pH to 9.5. Sodium ethyl xanthate (SEX), used as the collector, was supplied by Qingdao Lnt Chemical Co., Ltd. The collector dosage