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Effect of surfactant type on the entrainment factor and selectivity of flotation at laboratory scale

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ABSTRACT

In froth flotation, minerals report to the concentrate either by true flotation or entrainment. Previous research reported that flotation by entrainment is related to the amount of water that is transported to the concentrate (water recovery). On the other hand, plant operational experience indicates that frother type can be used to control the amount of water in the concentrate. In this work, a relationship between surfactant type and flotation by entrainment was obtained at laboratory scale using a batch flotation tests. The results indicate that the structure and molecular weight of surfactant influences the water reported to the concentrate, which is also related to the recovery of hydrophilic particles. The relationship between entrainment and water recovery is not unique, but depends on surfactant type. When comparing grade-recovery curves generated with different surfactants, the results show that there is an important effect of the surfactant type on the selectivity of the process.

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1. Introduction

Frothers, also called surfactants, are surface active reagents used in flotation to generate small bubbles and produce stable froths (Finch et al., 2006, 2008; Grau et al., 2005; Kracht and Finch, 2009). They can be grouped, according to their structure, into four families: aromatic alcohols; alkoxy types; aliphatic alcohols; and polyglycols, which may be represented by the general formula $R(X)_nOH$ where R may be H or C_nH_{2n+1} and X corresponds to CH_2CH_2O, $CH_2(CH_3)CHO$, or $CH_2CH_2(CH_3)CHO$, for polyethylene, polypropylene, and polybutylene respectively (Tan et al., 2005b).

Frother structure affects both bubble and froth behaviour, and also flotation performance (Pugh, 2000; Cho and Laskowski, 2002; Finch and Zhang, 2014; Tan et al., 2004, 2005a). Zhang et al. (2012), for instance, presented a link between frothers' ability to reduce bubble size, expressed in terms of critical coalescence concentration, CCC, and frother structure, characterised by hydrophile-lipophile balance (HLB) numbers. They found a correlation between CCC_{95}, i.e., the frother concentration producing a 95% reduction in bubble size from water alone, and the HLB number for different molecular structures. Nesset et al. (2012) had previously showed that CCC_{95} values correlate against HLB/Mw, where Mw is the frother molecular weight.

Laskowski et al. (2003), showed an effect of frother structure on froth behaviour, expressed as changes in the dynamic foamability index (DFI) for frothers of different molecular structure or molecular weight. The DFI, on the other hand, can be related to the water flotation rate constant (Melo and Laskowski, 2006), which translates into an effect of frother type on water transport to the froth (Melo and Laskowski, 2007). Moyo et al. (2007) found, at laboratory scale, that frothers have an effect on the water carrying capacity, i.e., on water recovery. Their results show that for a given gas holdup in the collection zone, different water carrying capacities can be obtained by changing frother type in the system.

By using sulphur containing frothers, analogous to the common oxygen containing frothers, Harris and Jia (2000) showed that changes in the HLB number, even for the same frother molecular structure, has an effect on concentrate grade and recovery.

1.1. Frothers and entrainment

In flotation there are two mechanisms by which particles report to the concentrate: true flotation, which corresponds to particles that float attached to bubbles; and entrainment, where particles are drawn to the froth and concentrate along with the water that accompanies the bubbles. While true flotation is a selective process, entrainment is not, and has a negative effect on the selectivity

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of the process, lowering the concentrate quality (Smith and Warren, 1989; Ross, 1990). The most important factors that affect entrainment are: recovery of water, particle size, solid content in the pulp, froth structure, froth residence time, and particle specific gravity (Savassi et al., 1998; Wang et al., 2015). Froth structure is affected by frother type (Savassi et al., 1998), which may explain the effect of frother type (structure) on flotation selectivity that has been reported in the literature (Klimpel and Isherwood, 1991; Gupta et al., 2007, 2009).

Trahar (1981) studied entrainment and found a relationship between entrainment and water recovery. The correlation can be described by a convex curve that tends to linearity in the case of fines (Zheng et al., 2006), which can be expressed as:

$$R_{ENT} = \mathrm{ENT} \cdot R_W \quad (1)$$

where ENT corresponds to the entrainment factor.

In a recent study, McFadzean et al. (2016) reported changes in the entrainment factor for different frothers, with a ratio of about 3:1 between the highest and lowest entrainment factors, determined for a polypropylene glycol and MIBC. The authors suggest that the behaviour is explained by changes in the froth structure and its capacity to hold small, hydrophilic particles. The current work supports their finding by showing that the entrainment factor is not unique, but depends on surfactant type. The frother types studied in this case correspond to aliphatic alcohols and polyethylene glycols.

2. Experimental

A series of flotation tests was carried out in a 5.1 L Labtech-Essa flotation cell. The amount of water reported to the concentrate was recorded for each flotation time interval in order to compute water recovery. Two kind of kinetics tests where performed: first with hydrophilic particles (quartz), and later with a synthetic ore, composed of quartz and a copper concentrate.

The quartz was crushed and ground down to 90% -400#. The particle size was then determined using laser diffraction analysis, giving an average value of d_{50} equal to 10.3 μm, with a standard deviation of 3.2% The copper concentrate, on the other hand corresponded to a final concentrate provided by a Chilean mining company. The XRD showed that the concentrate was composed mainly by chalcopyrite, with some pyrite and little amounts of silicate. The copper content of the concentrate was 29.3%. Since the samples corresponded to a final concentrate, the particle size d_{50} was also fine, under 10 μm.

2.1. Reagents

The surfactants were selected in order to represent two families of different molecular structure: aliphatic alcohols and polyethylene glycols, PEG, with the following generic formula, $H(OCH_2CH_2)_nOH$. Table 1 shows the reagents used, all of them from Sigma Aldrich. HLB numbers are included as a scale of surfactant solubility (Rao and Leja, 2004). The higher the HLB the more water-soluble (hydrophilic) the reagent. The HLB numbers in Table 1 were calculated using the Davies method (Davies, 1957).

Table 1
Surfactants.

Surfactant	Molecular weight	HLB number
Hexanol	102	6.1
MIBC	102	6.1
Heptanol	116	5.6
Octanol	130	5.1
PEG200	200	10.9
PEG300	300	11.7
PEG400	400	12.5

In the case of the kinetics tests with quartz and concentrate (synthetic ore), the collector used was Aeron 343 Xanthate, from Cytec, which corresponds to sodium isopropyl xanthate. The pH was adjusted with lime ($CaOH_2$).

2.2. Procedure

A first series of tests was performed only with quartz, at 17.8% solids, natural pH and 0.5 mmol/L of surfactant. The concentration was chosen so that all the surfactants produced enough froth in the system to perform the measurements. The impeller speed was set at 450 RPM, and a superficial gas velocity, J_g, of 0.56 cm/s was used. The cell was scrapped every 15 s to collect froth at the following time intervals: 0–1, 1–2, 2–4, and 8–12 min. In order to avoid any interference with the froth when adding reposition water, this was done through an orifice below the slurry-froth interface, using a peristaltic pump. The conductivity of the aerated slurry was measured to determine the gas holdup in the cell (Gomez and Finch, 2007).

After 12 min of flotation, the product, collected in trays, was weighted, filter, dried and weighted again to obtain both water, and mineral recovery. The water recovery was calculated dividing the mass of water collected in each tray by the mass of water in the cell at the beginning of the test.

In the case of the tests performed with synthetic ore, the procedure was the same, except that 85 g of concentrate were added, and a collector dose of 30 g/ton. The pH was adjusted with lime to 10.5. The dried samples were analysed in order to determine the content of copper and quartz, and to calculate the valuable (copper) and gangue (quartz) recovery. The surfactants used in these tests were Octanol and PEG300.

For those two reagents, images of 2D foams (water-air) were generated to compare their foamability. The foam was produced in an acrylic cell of 20 cm height, 15 cm wide and 1 cm depth equipped with a slot sparger for air dispersion, at a J_g of 2.5 cm/s. Note that since the system did not have solids, the gas flow rate had to be increased to generate foam compared to the flotation cell.

3. Results and discussion

Fig. 1 shows the recovery of hydrophilic particles (quartz) by entrainment against water recovery for the series of tests per-

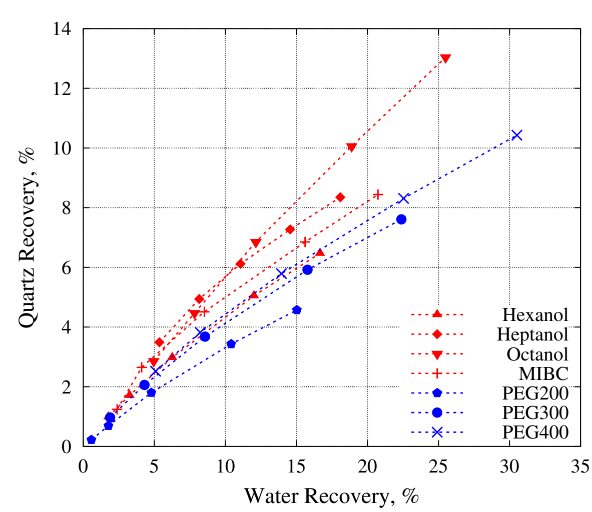

Fig. 1. Quartz recovery vs. water recovery for all surfactants.

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