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# Factors affecting the floto-elutriation process efficiency of a copper sulfide mineral

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ABSTRACT

Coarse mineral particles exhibit poor conventional flotation efficiency because of many factors, including the low carrying capacity of bubbles, bubble/particle adhesion problems due to cell turbulence, and low degrees of liberation (low hydrophobicity). Many attempts to improve the recovery of coarse fractions have been explored, such as floto-elutriation operating at a high solid content while dispersed in a fluidized (or expanded) bed formed with a continuous injection of compressed air and an uprising water flow. This work analyzed the comparative performances of floto-elutriation (FE) and conventional flotation (CF) on a classified copper sulfide mineral feed as an example of a difficult-to-liberate low-grade ore. Contrary to expectations, CF and FE (Hydrofloat) displayed similar particle recovery rates with feed size distributions for P80s of 130, 240 and 280 μm. However, metallurgical recoveries from classified fractions of −297+210 μm were 25% higher in FE than in CF and as expected, coarse (+297 μm) particles were not recovered in the CF, but in the FE. The recovery of fine fractions in the FE process was due to high hydraulic entrainment and surprisingly the recovery of intermediate and liberated fractions (+74−149 μm) was very low, due to its low air hold-up. However, the enhancement of the holdup in FE increased the recovery of these mid-sized fractions. Because of the hydraulic carryover caused by the bubbles and water elutriation, the metallurgical grades obtained in all cases were very low compared to conventional bench flotation. It is believed that this FE equipment works better with coarse, narrowly classified particles and high-grade feeds and that performance decreases for low-grade ores requiring high liberation. Certain features of these findings are visualized.



## 1. Introduction

The low flotation recovery of coarse particles is known to be caused by a high mass (which reduces the load carried by air bubbles), a low degree of liberation, a low collector adsorption (low hydrophobicity) compared to fine particles, and a low degree of dispersion in the pulp, thus allowing insufficient time for the capture by bubbles (Dunne, 2012; King, 1982; Schubert and Bischofberger, 1979; Gontijo et al., 2007; Ata and Jameson, 2013; Tabosa et al., 2013).

Some cited alternatives for recovering these fractions in rougher flotation units include i. feed splitting into coarse and fine fractions to treat them separately (Kohmuench et al., 2010); ii. increasing the particle residence time in flotation units (Dunne, 2012; Froth Flotation: A Century of Innovation, Part 4, 2007); iii. flotation with a negative bias (Barbery, 1989; Soto and Barbery, 1991; Soto, 1992; Brum, 2004); iv. performing a staged addition of the collector in rougher circuits (Reyes Bahena et al., 2006; Bazin and Proulx, 2001); and v. the use of new cells combining flotation and elutriation (Fosu et al., 2015; Awatey et al., 2014; Jameson, 2010; Kohmuench et al., 2007, 2010, 2013).

A Hydrofloat (a floto-elutriator) is a separator that combines both flotation and gravity separation. Because it employs fluidization, coarse particles are better dispersed than in turbulent mechanical flotation machines where centrifugal force pulls the coarse particles away.

As a result, the equipment allows for a better capture of coarser fractions by the bubbles, it can decrease the probability of bubble/-particle detachment, thus enhancing the recovery of difficult-to-treat larger particles. In recent years, this technology has been applied to industrial minerals, with several full-scale units installed to recover particles up to and exceeding 3 mm in diameter within the industrial mineral sector.

Many recent papers have shown examples of the applications, advantages and future trends of floto-elutriation cells and their similarities with elutriation columns or columns with negative bias.

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**Table 1**
Recent studies on mineral floto-elutriation (FE); some comparing to conventional flotation (CF).

| Author (year) | Process scale | Mineral/ore system | Separation parameters/general comments |
|---|---|---|---|
| Awatey et al. (2013, 2014) | Laboratory (FE and FC) | Sphalerite (+0.250–1.180 mm) | The contact angle required for flotation of sphalerite coarse particles in the CF was higher than in EF, and increased as particle size increased |
| | | Quartz particles (+0.250–1.180 mm) were used to build the fluidised-bed | The coarse sphalerite recovery increased with increasing the bed height, the superficial velocity of gas and water flow. The recovery was higher in the FE for particles larger than 0.450 mm |
| Kohmuench et al. (2013) | Laboratory (FE) (∅-cell diameter = 150 mm) | Copper/lead/zinc ore (0.800 × 0.200 mm) | Mass recovery = 13–26%<br>Recovery Cu = 70%; Enrichment ratio Cu = 3<br>Recovery Zn = 90%; Enrichment ratio Zn = 5<br>Recovery Pb = 90%; Enrichment ratio Pb = 4.8 |
| | Laboratory (FE and CF) | Copper ore (1.200 × 0.600 mm and 0.600 × 0.125 mm)<br>The feed grade was not given | FE (0.600 × 0.125 mm): Recovery = 93.5–99% Cu<br>FE (1.20 × 0.600 mm): Recovery = 70–78%<br>CF: Recovery = 2.0% |
| | Laboratory | Gold (0.500 × 0.100 mm) | Feed Grade = 3.6 g $t^{-1}$<br>Mass recovery = 0.7–2.0%<br>Gold recovery = 98%<br>Gold concentrate Grade = 400 g $t^{-1}$ |
| | Pilot (∅ = 400 mm) | Gold (0.500 × 0.100 mm) | Gold Recovery = 96–99%<br>Gold concentrate Grade = 175–500 g $t^{-1}$ |
| Testa et al. (2011) | Pilot (FE) | Phosphate (+0.150 mm) | Concentrate Grade = 30% $P_2O_5$<br>Apatite recovery = 90% |
| Kohmuench et al. (2007, 2010) | Laboratory (FE) (∅ = 100 mm) | Phosphate (Coarse: 0.710 × 0.425 mm; Ultracoarse: 1.20 × 0.710 mm) | Coarse: BPL Recovery = 98%; BPL Grade = 66.2%; Insolubles Grade = 8.1%<br>Ultracoarse: BPL Recovery = 96%; BPL Grade = 66.9%; Insolubles Grade = 10% |
| | Pilot (FE) (∅ = 300 mm) | Feed: coarse and ultracoarse | Coarse: BPL Recovery = 90–98%; BPL Grade = 60%; Insolubles Grade = 20%<br>Ultracoarse: BPL Recovery = 88–98%; BPL Grade = 64–69%; Insolubles Grade = 5–13% |
| | Full-Scale (Coarse: ∅ = 2.5 m) (Ultracoarse: ∅ = 1.2 m) | Feed: coarse and ultracoarse | Coarse: FE-BPL Recovery = 90%; CF-BPL Recovery = 80%;<br>Ultracoarse: FE-BPL Recovery = 97%; BPL Recovery = 64%. |

Table 1, shows some of the recent studies on coarse mineral flotation by FE.

This work measures the efficiency of a Hydrofloat on typical copper sulfide ore, where only intense grinding permits the liberation of valuables. A comparison with conventional flotation is conducted and some operating parameters are studied.

## 2. Experimental

### 2.1. Materials

#### 2.1.1. Copper sulfide ore

The copper ore used in the study corresponded to a sample composed primarily of chalcopyrite (45%) and bornite (55%). Feed grade varied between 0.9% and 1.1% Cu.

The sample was ground and wet-sieved at different size fractions and composites of different P80s (80% passing product in a given mesh) were prepared as described in Table 2. For flotation studies with very coarse particles, samples of +297 μm and −297 +210 μm were used.

### 2.2. Methods

#### 2.2.1. Particle size and copper content distribution

Particle size analyses of the feed and products of lab conventional flotation (CF) and floto-elutriation (FE) were performed by wet screening (duplicates) at 297 μm, 210 μm, 149 μm, 74 μm and 37 μm. The material retained on each sieve was dried in an oven at 60 °C for 24 h before weighing.

A copper chemical analysis was performed after acid sample digestion and analysis in a flame atomic absorption spectroscope (Varian, model AA110).

**Table 2**
Particle size distribution of the copper ore at different P80's composition.

| Particles size fraction (μm) | Mass % in each P80's composition | | | Grade Cu (%) |
|---|---|---|---|---|
| | 130 μm | 240 μm | 280 μm | |
| +297 | 1.7 | 7.3 | 10.4 | 0.6 |
| −297+210 | 3.2 | 11.5 | 15.4 | 0.8 |
| −210+149 | 10.8 | 24.1 | 31.1 | 0.9 |
| −149+74 | 27.8 | 27.5 | 23.1 | 1.0 |
| −74+37 | 21.9 | 12.5 | 9.3 | 1.5 |
| −37 | 34.6 | 17.1 | 10.8 | 1.7 |

Grades Cu P80's composition: 130 μm = 1.1%; 240 μm = 1.0%; 280 μm = 0.9%.

#### 2.2.2. Holdup measurements

Holdup (air % by volume) measurements were performed for a two-phase system (air/liquid) with different superficial air (0.2, 0.27, and 0.33 cm $s^{-1}$) and water (0.42, 0.63, and 0.84 cm $s^{-1}$) velocities. Determinations based on a bed expansion technique (Bahri et al., 2013) were performed with a sampler consisting of an acrylic cylinder endowed with two pistons spaced 120 mm from each other and fixed by a central axis (Fig. 1). These pistons, actioned by a rod, were inserted into the cylinder to trap a volume of the mixture (water + air). The trapped mixture between the pistons was weighed and the air volume calculated by the volume difference (cylinder and the collected volume).

#### 2.2.3. Conventional flotation studies – CF

Tests were performed in a 1.5 L capacity laboratory mechanical cell (Edemet®) with a pulp solution containing 30% solids (by weight) at a pH of 10.5, adjusted with lime ($Ca(OH)_2$). The pulp was conditioned under agitation (750 rpm) for two min with