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Recent Studies on the Application of Fluidised-Bed Flotation for Treating Sulphide Ores at a Coarser Grind

Massimiliano Zanin[1], Bellson Awatey[1] and Jaisen Kohmuench[2]

1. *University of South Australia*
2. *Eriez Flotation Division, USA*

ABSTRACT

Fluidised-bed flotation emerged in the last 15 years as a promising technology for the flotation of minerals at a much coarser particle size. The technology has been successfully implemented in several plants for the recovery of industrial minerals such as phosphate, potash, spodumene and diamonds. Recent research at the Ian Wark Research Institute, University of South Australia, investigated the application of fluidised-bed technology for the flotation of base metal sulphide ores (chalcopyrite and sphalerite), at grind sizes much coarser than typically carried out on a commercial scale, with the aim to reduce energy consumption by minimizing grinding costs. To that end, a laboratory-scale HydroFloat separator, provided by the Eriez Flotation Division, was used in the study. It is shown that fluidised-bed flotation provides a superior ability to float coarse sulphide mineral particles. Flotation recovery higher than 80% was achieved for sphalerite particles up to 1 mm, versus 40% recovery achieved using a conventional, mechanically agitated cell. Excellent recovery of both liberated and composite particles was also achieved during experiments using the HydroFloat to treat a coarse fraction of a typical copper ore. These studies present the possibility of employing fluidised-bed flotation cells in conventional flotation circuits for sulphide ores. The extent of utilizing this technology for flotation at coarser grinds will ultimately be dictated by the ore mineralogy. In the case of the copper ore investigated, losses of chalcopyrite were observed as the amount of fully-locked particles increased remarkably at coarser grind, and therefore regrinding of the HydroFloat tailings and subsequent scavenging was still needed to ensure high copper recovery. As such, it is necessary to balance liberation (for sufficient bubble collection) against the potential to produce a throw-away tailings.

Keywords: Fluidised-bed, flotation, coarse particles, copper ores

INTRODUCTION

For successful flotation to occur, three sub-processes have to happen: collision between particles and bubbles, attachment of the hydrophobic particles to bubbles, and stable attachment of the bubble-particle aggregate within the flotation cell until reaching the concentrate launder (Dai et al., 1999; Chipfunhu et al., 2011; Holtham and Cheng, 1991). In mechanically agitated cells, coarse particles suffer from low stability efficiency, i.e., they tend to detach from bubbles due to the high turbulence and inertia. For this reason, a maximum particle size exists in practice, above which flotation does not occur (Crawford and Ralston, 1988). Fluidised-bed flotation is a technology which was developed about 15 years ago to overcome this problem (Kohmuench et al, 2001). Fluidised-bed cells operate in the absence of turbulence. Particle-bubble aggregates are gently transported to the concentrate through the fluidised bed, allowing for much higher stability efficiency (Mankosa et al., 2003, Kohmuench et al., 2007). For this reason, much coarser particles can be floated compared to mechanical cells. A schematic representation of the HydroFloat separator (Kohmuench et al., 2013) is shown in Fig. 1.

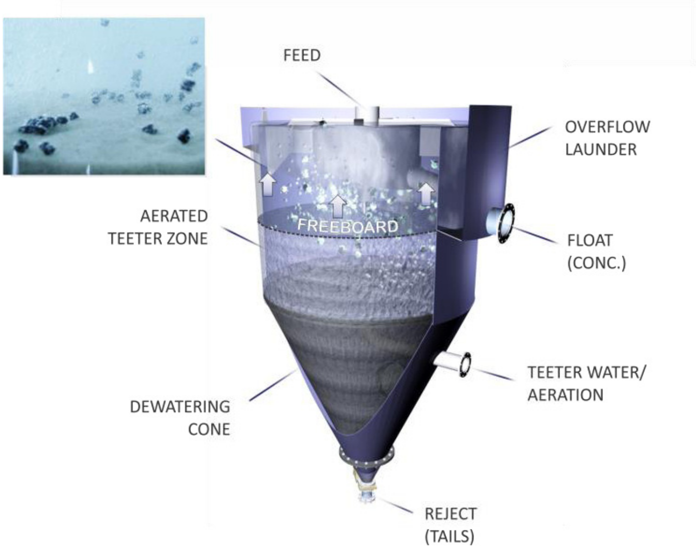

Figure 1 Schematic representation of the HydroFloat fluidised-bed separator (after Kohmuench et al., 2013).

A challenge of the technology is that the feed needs to be sized for the fluidised bed to form. An optimum top to bottom size ratio of 6:1 needs to be maintained in the HydroFloat, and therefore the fines need to be treated separately or a loss of selectivity will be apparent for the finest material. In this work, a flowsheet comprising size classification followed by flotation of the coarse fraction in HydroFloat and the fine fraction in mechanical Denver flotation cell has been used.

The technology has been successfully implemented in several plants for the recovery of industrial minerals such as phosphate, potash, spodumene and diamonds, at particle sizes as coarse as few millimetres. Previous work at the University of South Australia showed good ability of the HydroFloat in recovering coarse sphalerite, in single mineral experiments (Awatey et al, 2013).

Flotation of sulphide ores (sphalerite and chalcopyrite bearing ores) was also successfully undertaken (Awatey et al, 2013; Awatey et al, 2014; Awatey et al, 2015). Incorporating fluidised bed flotation at a much coarser grind in standard flotation circuits could provide significant benefits in terms of reducing energy consumption, which is one of the biggest issues in mineral processing (Daniel and Lewis-Gray, 2011), provided that no losses in recovery are determined. In this paper, the metallurgical benefits of integrating fluidised-bed flotation in a conventional flotation circuit are discussed with respect to the ores mineralogy.

MATERIALS AND METHODOLOGY

Ores

Highly Liberated Zinc Ore

A high grade sphalerite (ZnS) ore sample was obtained from a zinc mining company in the USA. The ore contains about 12% sphalerite (9.8 % Zn). Quantitative XRD analysis indicated that the major gangue mineral is dolomite (71 %), with 10% of quartz and minor traces of albite, calcite, chalcopyrite, galena and pyrite. The ore was crushed with laboratory gyratory and roll crushers and dry screened to generate four distinct size fractions (i.e., 850-1180 µm, 425-850 µm, 250-425 µm, and -250 um). The size fractions were then recombined to a known proportion to produce a very coarse flotation feed, with a P80 of 750 um (Figure 2). After crushing, most of the sphalerite particles in the ore appeared fully liberated when observed under both an optical and Scanning Electron Microscope (SEM). Only a minority of the sphalerite was locked in composites with gangue (Figure 3).

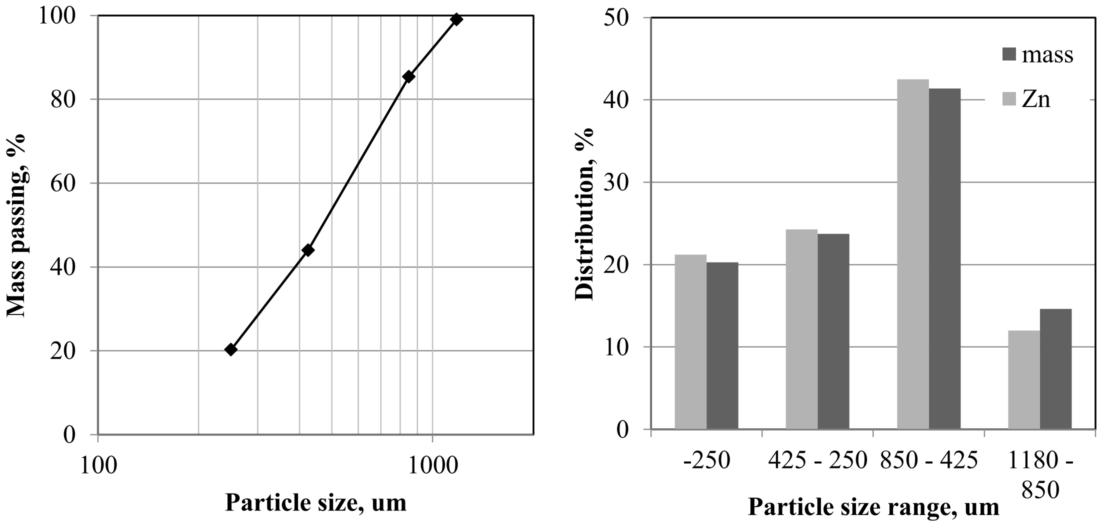

Figure 2 Particle size distribution (a) and mass and zinc distribution by particle size (b) for the sphalerite ore used in the study. The p80 of the particle size distribution is 750 µm.

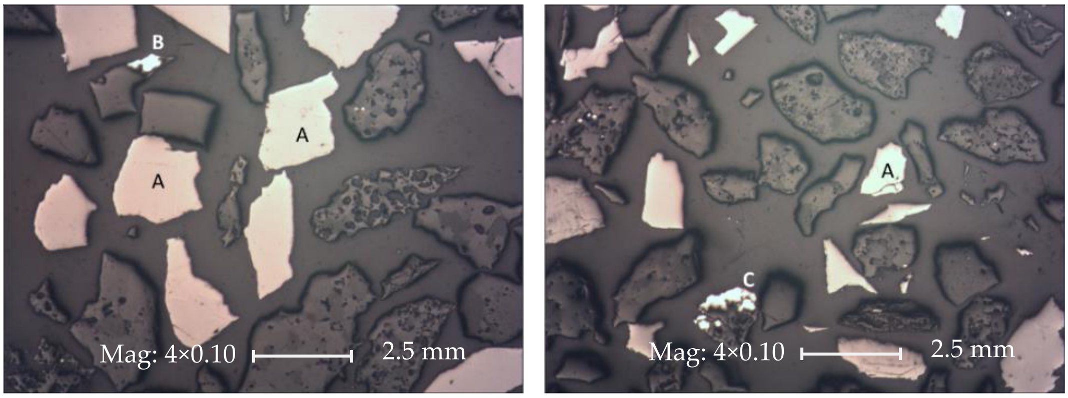

Figure 3 Optical microscope images showing predominant free (A) and few locked (B and C) sphalerite particles in the ore (adapted from Awatey et al, 2014).

Poorly Liberated Copper Ore

A high grade chalcopyrite ore was obtained from an Australian mine. The ore contained about 6% chalcopyrite, and 6% pyrite. The major non-sulphide gangue minerals were quartz (45%) and dolomite (25%). The ore was ground to a very coarse particle size distribution (d80 = 400 um, Figure 4a). After grinding, the ore showed about 60% of the copper in the -150 um size fraction, while the +150 um size fraction contained about 40% of the copper and 60% of the total mass (Figure 4b). The ore showed a typical disseminated mineralogical texture, with the fine particles being mostly fully liberated whereas the coarser size fractions showing complex locking texture and poor liberation (Figure 5). Liberation analysis indicated that a significant proportion of the chalcopyrite in the +150 um size fraction was very poorly liberated, the degree of locking increasing with particle size. Overall, only 53% of the +150 um size fraction was fully liberated (>90% liberation) (Table 1).

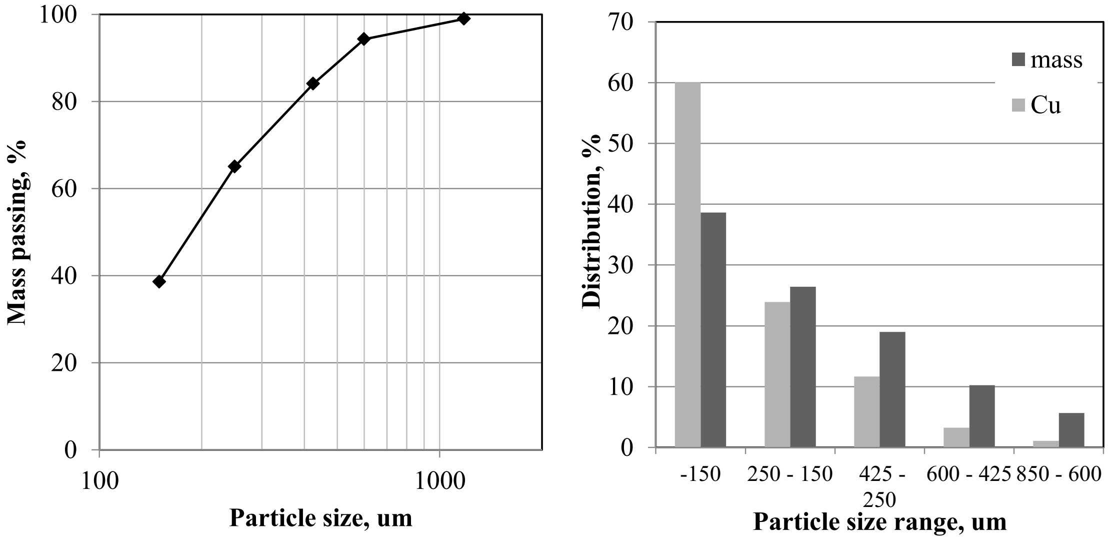

Figure 4 Particle size distribution (a) and mass and copper distribution by particle size (b) for the copper ore used in the study. The p80 of the particle size distribution is 400 µm.

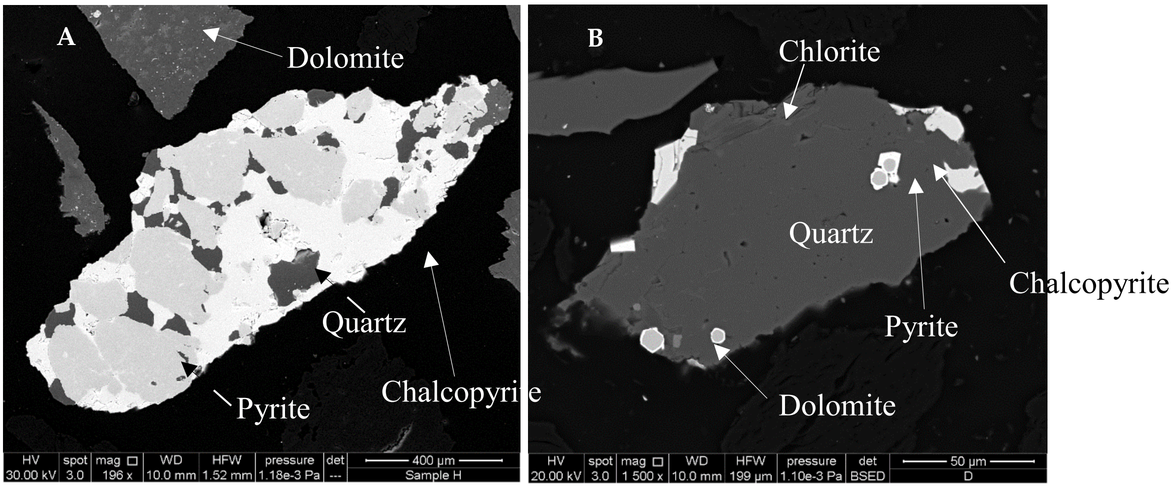

Figure 5 Locking texture in the copper ore (SEM). Predominant fine dissemination, with significant amount of poorly liberated particles in the coarser size fractions.

Table 1 Distribution of particles by degree of liberation in each size fraction of the copper ore.

Mass Chalcopyrite % in Fraction					
Normalised fractions		**<= 10%**	**10%-40%**	**40%-90%**	**>= 90%**
Fraction	**-850/+600**	61.2	38.4	0.2	0.3
	-600/+425	40.6	34.7	4.8	19.8
	-425/+250	16.6	20.6	14.4	48.5
	-250/+150	8.0	14.4	15.0	62.6
	Combined	14.5	18.5	13.6	53.4

Flotation Testing

Flotation tests were carried out on the two ores, using both a mechanical Denver flotation cell and a HydroFloat separator. The finer size fractions were sieved out before feeding the HydroFloat, because for the optimum formation of a fluidised bed in the separator, a top-to-bottom particle size ratio of about 6:1 needs to be maintained. For the Zn ore, the -250 um size fraction was sieved out, while for the Cu ore it was the -150 um size fraction. The fines were separately floated in a Denver flotation cell.

In a first series of flotation experiments, using the highly liberated Zn ore, comparison between the flotation response in the HydroFloat versus the Denver flotation cell was performed on a particle size basis. These tests were carried out by using copper sulphate as an activator for sphalerite and SIPX as a collector, at increasing concentrations (Awatey et al., 2014). The flotation performance of the HydroFloat on the poorly liberated Cu ore was also tested. In these tests, the flotation feed was conditioned with potassium amyl-xanthate (PAX) as a copper collector, and diesel oil as an extender (Awatey et al, 2015).

In a second series of tests, a flotation circuit was simulated in which the feed is ground very coarse (P80 = 750 and 400 um for the Zn and Cu ores, respectively), split into coarse and fine fractions (at 250 um and 150 um for the Zn and Cu ores, respectively), and the coarse fraction directed to a HydroFloat separator. The idea is to reduce the energy spent in grinding by rejecting a low grade fraction of the ore upfront, by means of the HydroFloat. The HydroFloat concentrate is then sent to regrinding (to a P80 = 150 um) and re-floated in Denver flotation cell. A schematic flowsheet is shown in Figure 6.

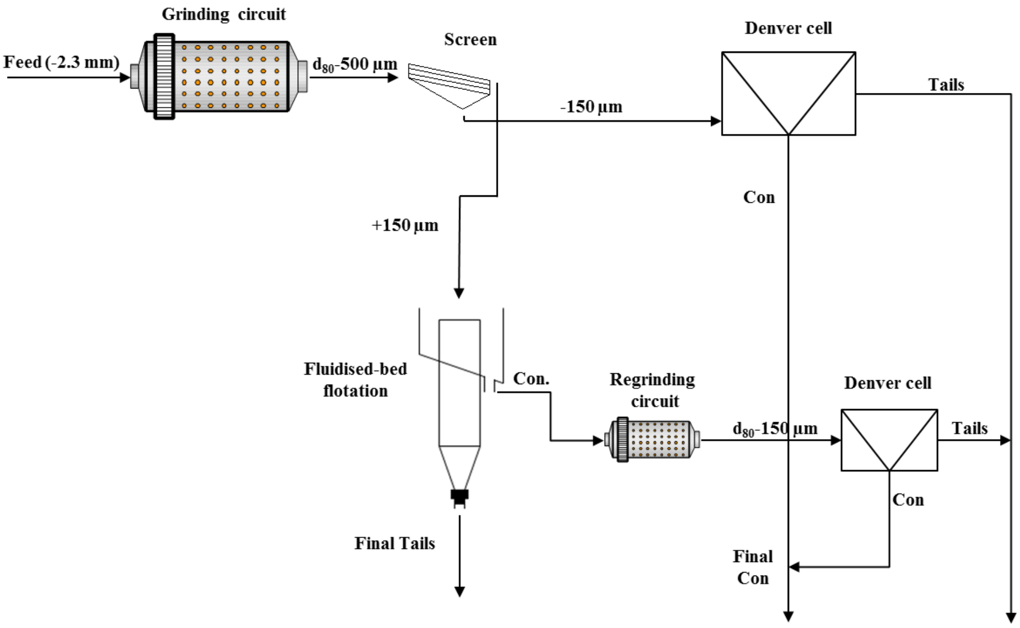

Figure 6 Flowsheet of the circuit simulated at laboratory scale for early rejection of the low grade coarse fraction of the ore (HydroFloat tailings, which are directed to final tails). Copper ore.

RESULTS AND DISCUSSION

Benchmarking the HydroFloat separator against mechanical cell

Figure 7 shows the size-by-size recovery of coarse sphalerite in the comparative tests in conventional mechanical cell (a) and in HydroFloat separator (b). It can be seen that fluidised bed flotation outperformed the Denver flotation cell. As collector concentration increased, sphalerite recovery >95% was achieved in the HydroFloat for the 560 um particles, and >85% for the 1000 um particles. In comparison, 80% and 40% recovery, respectively, were achieved in the Denver flotation cell. It is also noted that more collector was needed in the Denver flotation cell. This is likely to be due to the more efficient conditions in the HydroFloat, allowing for the recovery of particles at lower collector coverage and contact angle (Awatey et al., 2014).

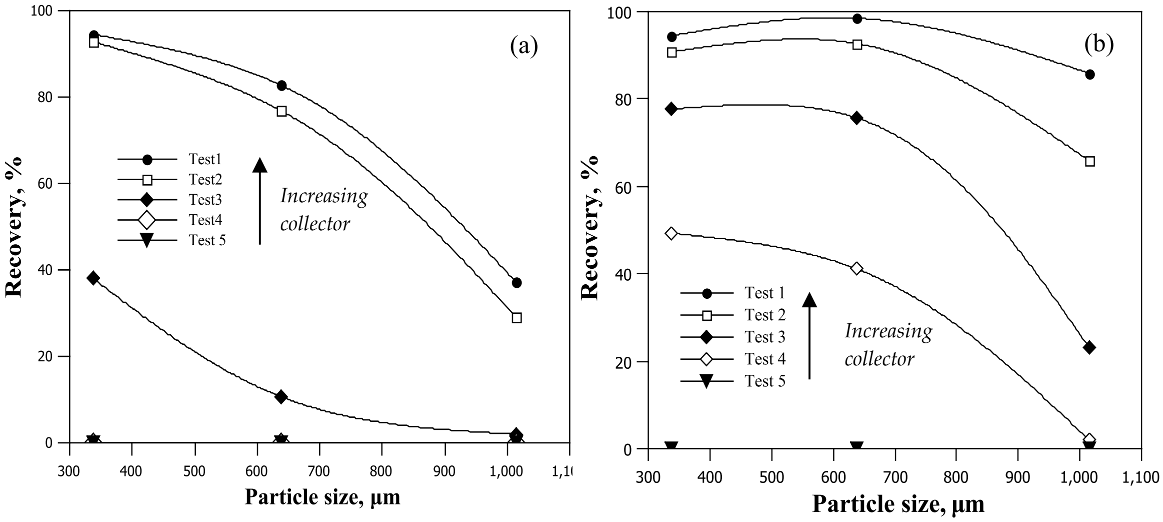

Figure 7 Recovery as a function of particle size for the (a) Denver flotation cell and the (b) fluidised-bed separator, at increasing collector concentration. Sphalerite ore (adapted from Awatey et al, 2014).

For the chalcopyrite ore, the recovery in the HydroFloat for particles from 250 um to 850 um in size was lower, ranging between 60% and 50% (Figure 8). Optical and mineralogical analysis of concentrate and tailings (not discussed here) showed that this is due to the intrinsic high amount of fully locked copper particles in the ore, which require finer grinding to expose the hydrophobic mineral.

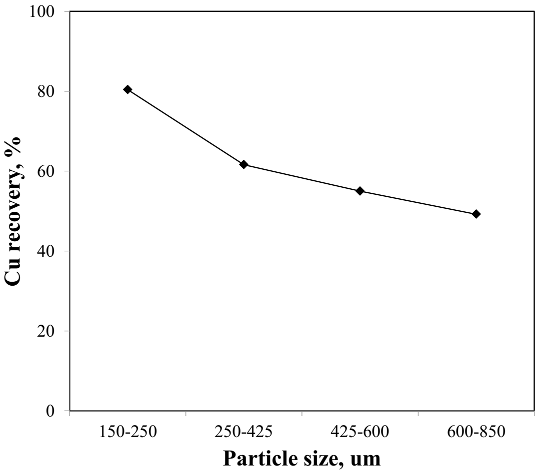

Figure 8 Recovery of copper against particles size for the split sample (+150 µm) of the copper ore in the HydroFloat separator.

These results show that coarse (up to 1 mm) sulphide mineral particles can be floated in a HydroFloat cell at very high recovery, provided they show high degree of liberation (sphalerite ore). Fluidised bed flotation outperformed mechanical cell for the coarse particle size ranges.

Simulation of a flotation circuit

Highly liberated Zn ore

The metallurgical balance of the circuit is shown in Figure 9. Zn grade and distribution is shown next to each stream. After screening, a significant amount of Zn is sent to the HydroFloat with the coarse fraction (almost 80% of the total Zn). Due to the high recovery of sphalerite in the HydroFloat (which is favoured by the high liberation of sphalerite up to the very coarse particle sizes), a throw-away stream (HydroFloat tails) assaying only 0.5% Zn is produced, losing only 3.7% of the total Zn. Overall, the circuit produced a combined rougher concentrate assaying 65.7% Zn, and recovering 92% of the total Zn. In this configuration, 70% of the feed mass is rejected as low grade tailings in the HydroFloat tails, avoiding unnecessary regrinding.

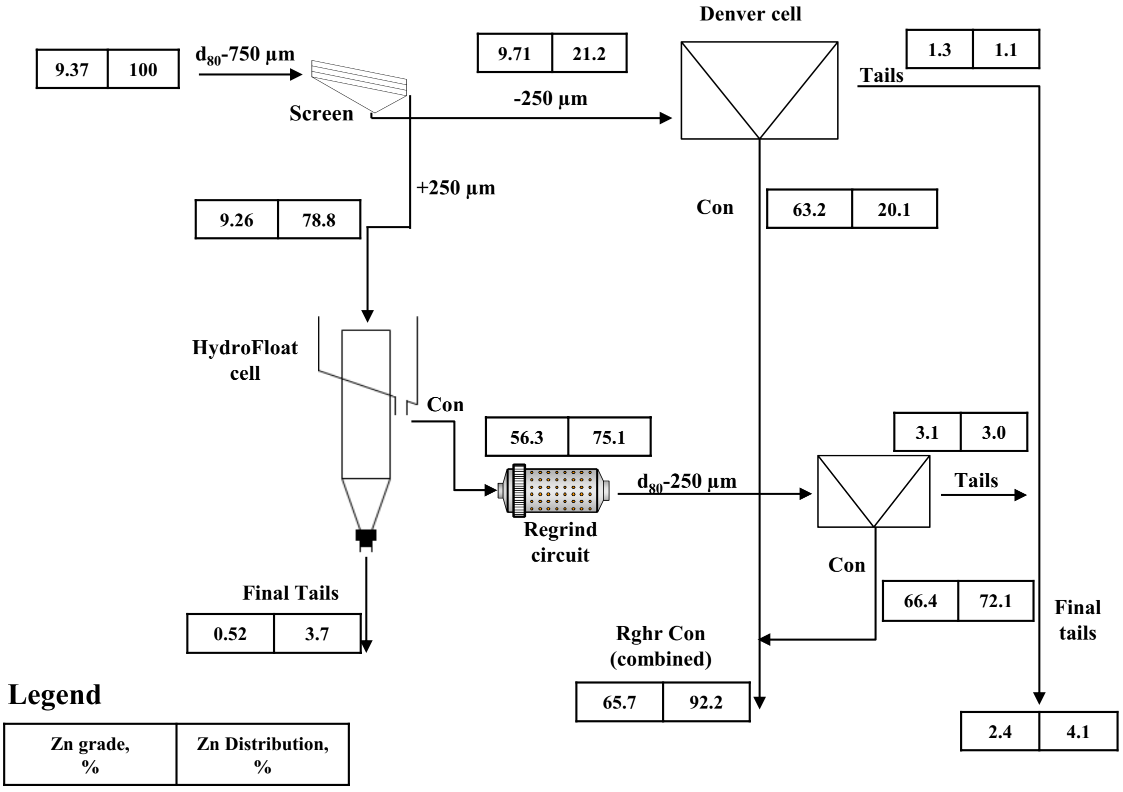

Figure 9 Metallurgical balance for the integrated flotation circuit comprising early rejection of coarse gangue in a HydroFloat. Highly liberated Zn ore.

Poorly liberated copper ore

In the case of the copper ore, liberation was a limiting factor. Recovery of the coarse Cu bearing particles in the HydroFloat is lower than for the Zn ore, and the HydroFloat tailings still contain about 1% Cu, which corresponds to 16% Cu losses (Figure 10). As a result, the total Cu recovery in the rougher concentrate was only 82%. In this case, the proposed configuration is uneconomical, since too much Cu is lost in the coarse composites in the HydroFloat. Finer primary grinding is needed to increase liberation.

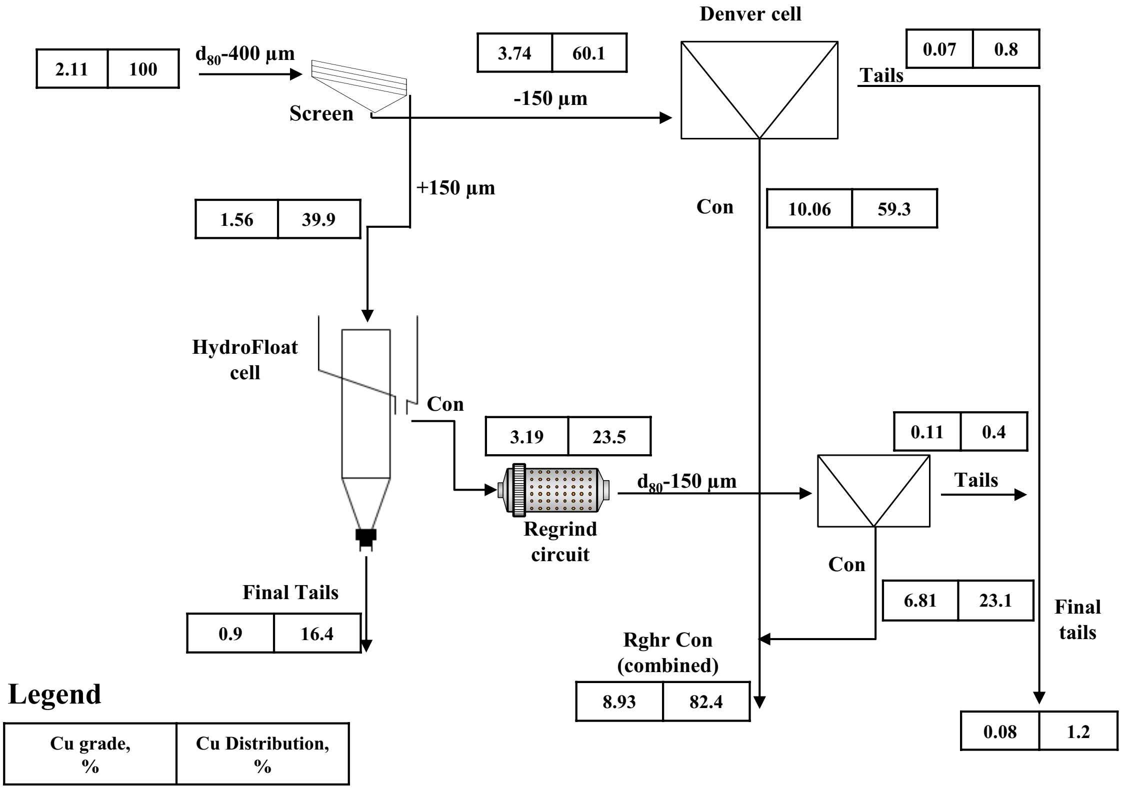

Figure 10 Metallurgical balance for the integrated flotation circuit comprising early rejection of coarse gangue in a HydroFloat. Poorly liberated Cu ore.

CONCLUSION

This study confirms that the HydroFloat fluidised bed flotation has superior potential compared to mechanical cells for the recovery of very coarse particle sizes (up to 1 mm for sulphide minerals).

The extent of utilizing fluidised bed technology for flotation at coarser grinds is however dictated by the ore mineralogy. While for the highly liberated Zn ore the technology showed very promising results, in the case of the copper ore investigated losses of chalcopyrite were observed as the amount of fully-locked particles increased remarkably at coarser grind, and therefore regrinding of the HydroFloat tailings and subsequent scavenging was still needed to ensure high copper recovery. As such, it is necessary to balance liberation (for sufficient bubble collection) against the potential to produce a throw-away tailings.

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