



# Influence of pulp aeration on the flotation of chalcopyrite with xanthate in chalcopyrite/pyrite mixtures



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## ABSTRACT

The impact of pulp aeration on chalcopyrite flotation in chalcopyrite–pyrite pulps containing different pyrite content (0–80 wt.%) and using xanthate as a collector is reported. Laboratory flotation tests showed significant improvement in chalcopyrite flotation performance under moderate aeration conditions but a significant decrease of performance under highly aerated conditions. The amount of air required to achieve good chalcopyrite flotation recovery correlated positively with the mass fraction of pyrite in the pulps. The greater the wt.% pyrite in the chalcopyrite–pyrite pulp, the longer the aeration time required. A simple model for xanthate and oxygen interactions with chalcopyrite and pyrite has been proposed which follows the trend of chalcopyrite flotation behaviour in chalcopyrite/pyrite mixtures under aerated conditions.

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## 1. Introduction

It is well-known that pulp oxygen content influences the flotation of sulphide minerals (Richardson and Walker, 1985). The exact role of oxygen in sulphide mineral (e.g. chalcopyrite, Cp) flotation is complicated and rather controversial (Heyes and Trahar, 1979). Various studies (Gaudin, 1974; Woods, 1984; Laajalehto et al., 1999) have shown strong oxygen involvement when it comes to collector (e.g. xanthate) adsorption onto sulphide mineral surfaces whilst others have demonstrated that strong flotation of sulphide minerals with xanthate can also occur with no or little oxygen present provided the Eh was high enough (Heyes and Trahar, 1979; Miller et al., 2006). The reduction of oxygen on value sulphide mineral surface changes the mineral rest potential and lowers the mineral surface hydration, making the mineral more anodic in the presence of xanthate and more hydrophobic according to Gaudin (1974), Rand (1977) and Ahmed (1978). In most copper flotation pulps, the concentration of oxygen is often affected by various reactive species, notably, dissolved metal ions from grinding media and other flotation reagents (collectors and modifiers). Furthermore, the electrochemical reactivity of the sulphide minerals present also contributes to oxygen consumption in the pulp. Recently, Nooshabadi and Rao (2013) have shown that hydrogen peroxide can also be produced by reduction of dissolved oxygen via superoxide anion formation in the flotation of chalcopyrite/pyrite mixtures, which also decreases the oxygen concentration in pulp. This subsequently decreases the

availability of oxygen for collector adsorption onto value sulphide mineral surface (Holmes and Crundwell, 2000; He et al., 2006). Pulp aeration with air restores the oxygen concentration in the flotation pulp, which is the reason why aeration tanks have been installed and used at several flotation plants (Spiral and Rosenblum, 1974; Kristall et al., 1994).

The flotation behaviour of sulphide mineral particles depends on the proportion of hydrophobic and hydrophilic species covering their surfaces, with flotation rate and recovery increasing with the degree of surface hydrophobicity. In the case of xanthate collectors and metal sulphide minerals, the hydrophobic species are chemisorbed xanthate and dixanthogen whilst the hydrophilic species are mainly metal oxide/hydroxide and sulphony species (Fornasiero et al., 1992; Fairthorne et al., 1997; Fornasiero and Ralston, 1992; Shen et al., 1998). It is believed that the presence of oxygen is critical for xanthate adsorption (Gaudin, 1974; Woods, 1976; Mielczarski et al., 1998). On the other hand oxygen can inhibit xanthate adsorption due to the formation of metal hydroxides at the mineral surface (Pomianowski and Leja, 1963; Senior and Trahar, 1991). If the adsorption of collector onto value sulphide mineral surface is via electrochemical mechanisms, then the key variables controlling these electrochemical reactions are both mixed potential and the concentration of oxygen at the mineral interface.

The benefit of pulp aeration in copper flotation systems has been reported (Houot and Duhamet, 1990). Generally, there is an optimum level of aeration (amount of oxygen) required for good flotation performance of copper sulphide minerals. Too little oxygen reduces the adsorption capacity of xanthate on to the minerals and its oxidation to dixanthogen (the only xanthate species found on the surface of

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chalcopyrite and pyrite) whilst too high oxygen concentration promotes the formation of iron and copper oxide/hydroxides on the sulphide mineral surface and therefore reduces its hydrophobicity and hence floatability (Richardson and Walker, 1985; Kuopanportt et al., 2000; He et al., 2006). For chalcopyrite, it is known that its floatability is enhanced by increasing flotation pulp oxidation potential through aeration. However, a very high oxidising potential has been found to be detrimental (Graham and Heathcote, 1982; Houot and Duhamet, 1990; Goktepe and Williams, 1995). Pyrite (Py) is known to be the most cathodic sulphide mineral; therefore, when in contact with other sulphide minerals, it draws electrons and serves as the cathodic site for oxygen reduction, which promotes the formation of metal oxide/hydroxide products that depresses pyrite flotation (Xu et al., 1995; Goktepe and Williams, 1995). As pyrite consumes more oxygen than chalcopyrite (Owusu et al., 2013b), it is therefore expected that chalcopyrite flotation will be affected by the percentage of pyrite in their mixed mineral pulps. The optimum level of aeration required may vary with the types (Abraitis et al., 2004) and proportions of pyrite in the ore, especially upon fine grinding.

The present work investigates the effect of pulp aeration on the floatability of chalcopyrite in chalcopyrite/pyrite mixtures containing different proportions (0–80 wt.%) of added pyrite after ultra-fine grinding. Generic correlation between optimum level of aeration for chalcopyrite flotation performance and percentage pyrite content is established. Finally, a reaction mechanism which embraces pyrite content, oxygen and xanthate concentrations and the solution species is proposed to account for the flotation behaviour observed in the laboratory.

## 2. Experimental

### 2.1. Materials and reagents

Chalcopyrite (Mannum Minerals) and pyrite (Peruvian Mine) minerals in particle size ranges 400–2000  $\mu\text{m}$  and 600–2000  $\mu\text{m}$ , respectively, were used for this study. The chemical compositions of these samples are reported in Tables 1. The XRD analysis shows that chalcopyrite contains 6.3% pyrite. Blends of the two samples in different ratios were used in this study.

Two types of grinding media, namely, stainless steel rods (10  $\times$  22 mm and 6  $\times$  16 mm) and ceramic beads ( $\varnothing$  3.5 mm) (Xstrata Technology, Australia) and grinding mills (Galigher mill and IsaMill) were used for this study. The steel rods were used as the medium for the Galigher laboratory mill during the primary grinding stage whilst the ceramic beads were used as the regrinding medium for the IsaMill. The collector sodium isopropyl xanthate (SIPX) and frother polypropylene glycol (Dowfroth 250; AR grade) were both obtained from Cytex (Stamford, USA). SIPX was further purified by dissolution in acetone and recrystallization from petroleum ether as described elsewhere (Montalti et al., 1991); its purity was determined from UV–visible spectroscopy to be greater than 98%. Analytical grade lime and demineralised water were used throughout the experiment (oxygen demand and flotation test), including pH/pulp conditioning and grinding purpose, respectively, unless otherwise stated.

**Table 1**  
Chemical composition of chalcopyrite and pyrite samples used for the study.

Mineral	Elements (mass %)								
	Zn	Fe	S	Ca	Cu	Si	Pb	Mn	Mg
Chalcopyrite	0.01	28.9	29.0	1.76	26.4	4.2	0.34	0.02	0.68
Pyrite	0.18	44.9	53.5	0.44	0.13	0.7	0.02	0.02	0.08

### 2.2. Experimental procedure

#### 2.2.1. Pulp chemistry

Dissolved oxygen (DO), (YSI membrane electrode), potential, (Pt–Ag/AgCl electrode) and pH (Glass combination electrode) electrodes connected to a multi-metre (TPS 90-FLMV, TPS Pty. Ltd.) were used to measure the DO concentration, pulp potential and pH, respectively. Standard buffer solutions of pH 7 and 10 were used to calibrate the pH electrode.

#### 2.2.2. Oxygen demand test

The details of the apparatus used for the oxygen demand test has been described previously (Spira and Rosenblum, 1974; Clarke et al., 2002; Greet et al., 2004; Owusu et al. (2013a). In each experiment, the IsaMill discharge pulp (either Cp or Cp/Py mixture) was transferred into an airtight container and stirred for 1 min to obtain a homogeneous pulp after which the initial readings for pulp potential, DO, and pH were recorded. The pulp pH was adjusted to 10.5 and then air purged at a rate of 3 dm<sup>3</sup>/min for 3 min, after which the air supply was cut off for 5 min. This cycle of air on and off was repeated several times until the oxygen concentration in the vessel reached equilibrium. The pulp pH, DO and pulp potential values were logged continuously at time intervals of 10 s. The pH was monitored but not kept constant in order to reproduce plant conditions.

#### 2.2.3. Mineral grinding and batch flotation

In each test, 200 g of mineral sample (Cp mineral or Cp/Py mixtures) was milled in a Galigher laboratory mill at 66 wt.% solid to obtain a particle size  $d_{80}$  of 105  $\mu\text{m}$  at pH 10 and then transferred to a 1.5 dm<sup>3</sup> flotation cell (Agitair LA-500R). SIPX, 200 g/t, was added to the pulp which was conditioned at pH 10.5 for 2 min. The conditioned pulp was further ground in a 1 dm<sup>3</sup> laboratory IsaMill (attrition mill) to produce a  $d_{80}$  of 20  $\mu\text{m}$ . The milling was carried out in two stages to mimic typical plant circuits (primary grinding, rougher flotation and regrinding of the rougher concentrate). Reagents were also added between the two milling stages with the intention of reproducing plant conditions.

The product from the attrition mill was transferred back to the 1.5 dm<sup>3</sup> flotation cell and conditioned with collector and frother without or with prior aeration stage. Different aeration times (24, 36, 48, 60 and 80 min) were tested in order to determine the optimum conditions for Cp recovery and Cp/Py separation. Additional 50 g/t SIPX, followed by 25 g/t Dowfroth frother were added and conditioned for 2 and 1 min, respectively. Impeller speed and pH during conditioning and flotation in the cell were maintained at constant 1000 rpm and 10.5, respectively for all experiments. The pulp pH was maintained at 10.5 to mimic plant conditions. Four flotation concentrates were collected after cumulative times of 1, 3, 6 and 10 min and at an air flow rate of 2.5 dm<sup>3</sup>/min. The flotation froth was scraped every 10 s. The dry masses of the four concentrates together with their tails were measured and the samples were assayed for their elemental compositions. Mineral particles recovered by true and entrainment were calculated using the method developed by Ross (1991).

### 2.3. Surface analysis

A Kratos Axis Ultra X-ray photoelectron spectrometer (XPS) with an AlK $\alpha$  monochromated X-ray source (1486.8 eV) operated at 130 W was used to measure the species present on the mineral surfaces. The surface analysis was conducted on the 80 wt.% Py mixture since this percentage of Py is more close to the real ore systems. For this, blocks of freshly fractured pure minerals of Cp and Py were placed in the pulp in the Cp–Py mineral mixture experiment during conditioning and were removed prior to aeration after pH adjustment to 10.5 and after 48 and 80 min of aeration for XPS analysis. Blocks were washed with a pH 10.5 solution to remove any suspended particles and were introduced immediately in the fore-vacuum of the XPS spectrometer.

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