

Depressing high-concentration pyrite in copper flotation

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Pyrite (FeS_2) is known as a major sulphide mineral in base metal ore deposits. It is usually to be depressed in copper flotation unless there are precious elements such as gold (Au) and silver (Ag) associated with it. The depression of pyrite has been a challenge in copper (Cu) flotation concentrators as it can be activated by Cu ions produced from copper sulphide oxidation. Raising grinding and flotation pH is prevalent in Cu flotation plants when a strong pyrite rejection is needed and the high pH facilitates pyrite surface oxidation which limits pyrite activation by copper ions. Following the decreasing global Cu head grades in copper ore deposits, pyrite concentration in copper ores has been increasing. A number of researchers pointed out that the increased pyrite contents in feeds enhances the galvanic interaction, creating a more favourable condition for Cu activation, and thus, promoting pyrite flotation (Lee et al., 2022; Zanin et al., 2019). Although high pulp pH is promising in depressing low-concentration pyrite (less than 5%) in copper flotation, whether it is capable of depressing a large proportion of pyrite is yet to be explored.

Some researchers have studied the mechanism of pyrite depression in alkaline conditions. In single pyrite flotation, pyrite recovery decreases as pH increases within an alkaline region ($> \text{pH } 7$) (Chen et al., 2011; Li et al., 2012; Yin et al., 2019). Some researchers also explored the separation between copper sulphides and pyrite in flotation at alkaline pH. For example, Yin et al. (2019) investigated the effect of pH on covellite and pyrite flotation and found that a high selectivity of covellite flotation against pyrite was achieved when flotation pH was greater than 10 as a result of strong pyrite depression. Flotation tests conducted by Chen et al. (2011) indicated that pyrite depression in chalcopyrite flotation was more substantial as pH increased from 7.5 to 11.5, showing a progressive improvement in chalcopyrite-pyrite separation. The depression effect of pyrite under

highly alkaline pH was owing to the formation of hydrophilic ferric hydroxide ($\text{Fe}(\text{OH})_3$) on the pyrite surface as a result of adsorption of hydroxyl ions (OH^-) and enhanced pyrite oxidation (Fuchida et al., 2022). According to Chen (2021), OH^- preferentially adsorbs onto pyrite surfaces with a negative potential barrier (ΔE), whereas the adsorption of OH^- onto chalcopyrite surfaces is more difficult with a positive barrier. In addition, the $\text{Fe}(\text{OH})_3$ coverage on pyrite surfaces also decreases the surface active sites, limiting the interaction of sulphur in pyrite with Cu ions and, thus, Cu activation on pyrite surfaces (Li et al., 2012; Mu et al., 2016). In these studies, pyrite depression by different pulp pH values was investigated either for a single mineral system, binary system with a one-to-one mineral weight ratio or a copper ore with a low pyrite feed grade ($< 5\%$). When a large proportion of pyrite is present, the anodic role of chalcopyrite coupled with pyrite is enhanced by the large cathode surface area in the chalcopyrite-pyrite galvanic couple, leading to a promotion of chalcopyrite oxidation and pyrite activation (Lee et al., 2022). It is unknown whether high pH that effectively depresses low-concentration pyrite could depress high-concentration pyrite.

Additionally, the galvanic interaction during grinding is intense due to a vast difference in rest potential between the hyper steel grinding media and sulphide minerals, and the grinding media-sulphide galvanic interaction directly governs the subsequent flotation behaviour (Huang and Grano, 2006; Rabieh et al., 2018); nevertheless, most of the previous studies did not perform grinding prior to flotation, which might have underestimated the extent of galvanic interactions. Therefore, the effect of pulp pH on a ternary grinding media-chalcopyrite-pyrite (GM-Cpy-Py) galvanic system and the subsequent chalcopyrite and pyrite flotation response were investigated in this research. Grinding and flotation tests were performed at different pulp pH values on a synthetic copper ore feed containing chalcopyrite, pyrite and quartz (Cpy-Py-Q) with the pyrite feed grade varying. The tri-phase GM-Cpy-Py galvanic interaction was investigated via electrochemical measurements, while sulphide mineral oxidation was quantified by ethylenediaminetetraacetic acid (EDTA) extraction.

The synthetic Cu ore was made to simulate an industrial grinding and flotation feed in laboratory. Chalcopyrite concentration in the Cpy-Py-Q mixture was fixed at 4.9% (corresponding to

a 1.7% Cu head grade), whereas pyrite concentration was either 5 or 25% to represent a low- or high-pyrite concentration in the feed, respectively, and the remaining composition of the feed was balanced by adding quartz. Grinding and flotation tests were performed on the synthetic copper feeds at different alkaline pH values. The grinding pulp pH was adjusted using sodium hydroxide (NaOH) to eventually produce a mill discharge with a pH value of 9, 10.5 or 11.5. After the slurry was transferred from the grinding mill to a mechanical flotation cell, the flotation pulp was adjusted with NaOH again to maintain the pH in mill discharge.

The flotation of Cpy-Py-Q mixture with 5% pyrite showed that pyrite was significantly depressed as pH increased from 9 to 10.5. On the other hand, pyrite flotation was promoted upon the same pH increment when pyrite feed grade was 25%. With a further increase in pH from 10.5 to 11.5, pyrite depression was further advanced in the flotation of Cpy-Py-Q mixture with 5% pyrite, producing a high Cu concentrate grade (above 20%). For the flotation of Cpy-Py-Q mixture with 25% pyrite, the floatability of pyrite was reduced in response to pH increment from 10.5 to 11.5, but the improvement of Cu concentrate grade was limited. The flotation results clearly indicated the decreased ability of high pH in depressing high-concentration pyrite in copper flotation when pyrite feed grade was high. Electrochemical studies and EDTA extraction suggested the electrochemical role change of contacting materials in GM-Cpy-Py galvanic systems when the pH increased from 9, to 10.5 and then to 11.5 directly influence the pulp chemistry, and hence, the subsequent mineral flotation performance.

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