学　位　論　文　内　容　の　要　旨

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学　位　論　文　題　名

Development of Agglomeration-Flotation for Finely Ground Copper Sulfides
(微粉砕した硫化銅鉱の造粒浮選法の開発)

Porphyry copper deposits (PCDs) are the main sources of copper (Cu), accounting for more than 60% of the annual production of Cu and are relatively low-grade, epigenetic, intrusion-related deposits that are commonly mined by open-pit methods. Despite their relatively low grades, PCDs have significant societal and economic impact due to their large size (up to billions of metric tons), long mine lives, and scale of mining operations. The ore containing chalcopyrite ($CuFeS_2$) in PCDs is generally processed by flotation to improve the Cu grade and remove the associated gangue minerals before smelting. In flotation, liberated Cu-bearing sulfide particles (e.g., chalcopyrite) are recovered via their selective attachment to air bubbles by changing their surface properties from hydrophilic to hydrophobic using collectors (e.g., xanthate). To maintain the high efficiency of Cu sulfide flotation, the ores have to be adequately ground to liberate Cu-bearing sulfide minerals from the unwanted gangue minerals. Recently, easily exploitable PCDs are very limited, which makes it unavoidable for mining industries to develop and exploit complex ore bodies with low grade and fine grain size. The ores containing fine-sized mineral grains require extensive grinding to achieve sufficient liberation that leads to the generation of large fractions of fines.

Despite its importance and widespread application in mineral processing, flotation still suffers from drawbacks, primary of which is its low recovery efficiency for fine particles (less than 10 μm for sulfides). In the flotation of fine particles, collisions between rising bubbles and the particles become poor because of the small mass and low momentum of the particles. Because of this, fine particles do not attach to bubbles, leading to substantial losses of recoverable minerals.

In this study, a new hybrid process of oil agglomeration—a method to increase the apparent size of particles—and flotation is proposed to reduce the substantial loss of fine chalcopyrite. Important factors like agitation strength, reagent dosage and stability of oil-water emulsion that affect the agglomeration-flotation process were investigated. In addition, a mathematical model for the flotation kinetics of agglomerated particles, which will be useful in designing and optimizing the agglomeration-flotation process, was developed. From the findings, a new process combining agglomeration and flotation using emulsified oil stabilized by surfactants that is cost-effective and could be easily integrated into conventional flotation circuits is proposed.

Chapter 1 describes the statement of the problem and the objectives of this study.

Chapter 2 reviews previous works about techniques to improve the recovery of fine particles in flotation, including micro-bubble flotation, column flotation, shear flocculation, carrier flotation, polymer flocculation, and oil agglomeration.

In Chapter 3, flotation experiments of finely ground chalcopyrite were carried out with and without oil-agglomeration as pretreatment and the kinetic data (time-recovery curves) were compared with the conventional first-order kinetic model for flotation. Agglomeration using kerosene as bridging liquid improved Cu recovery from 45 to 90% because the apparent size of particles after agglomeration increased from 4 to 10 μm. Without agglomeration, time-recovery curves determined by the experiments fitted well with the model calculations, but there were significant deviations between experimental results and model calculations for the agglomerated particles; that is, experimental flotation recoveries were much higher than those calculated by the model. The conventional first-order kinetic model does not consider particle size changes during flotation while the experimental results suggested that the size of agglomerates increased in the flotation cell. A new flotation model that combines agglomeration during flotation was proposed, which could predict the time-recovery of agglomeration-flotation.

In Chapter 4, the effects of agitation strength during agglomeration, kerosene dosage and potassium amyl xanthate (KAX) dosage on flotation were investigated. With increasing agitation strength, KAX and kerosene dosages, Cu recovery was further improved. High agitation strength produces smaller oil droplets and more stable oil-water emulsion which resulted in high Cu recovery.

In Chapter 5, a new agglomeration-flotation process using emulsified oil stabilized by surfactants is proposed. Although high agitation during agglomeration improved Cu recovery, it required high energy, which makes the process costly. Moreover, emulsified oil should be added to agglomeration vessel immediately because emulsified oil is inherently unstable. In a commercial plant, stability of emulsified oil is important to keep size of "droplets" minute for oil agglomeration. Because of this, the effects of surfactants on the size of droplets in emulsified oil were investigated. When surfactants were added, oil droplet size in emulsified oil became small and stable. The small size and stability of emulsified oil made the agglomerates bigger, allowing for high Cu recovery in flotation to be achieved. When emulsified oil with surfactants was used, special equipment with higher agitation strength during agglomeration is unnecessary, and thus, the process could be easily integrated into existing flotation circuits.

Chapter 6 summarized the important findings of this dissertation and its implications.