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Research paper

Optimizing Fine Copper and Zinc Recovery: A Flocculant-Assisted Flotation Approach Using Box-Behnken Design

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ABSTRACT

This study investigates the effectiveness of polyacrylamide (PAM) and sodium polyacrylate (PAS) as flocculants to improve the flotation recovery of fine copper (Cu) and zinc (Zn) particles. Addressing the challenges associated with fine particle separation (<50 μm)—including low collision efficiency and high reagent consumption—we employed a Box-Behnken Design (BBD) to optimize key parameters: flocculant dosage, agitation speed, and conditioning time. Results revealed that PAM achieved superior Cu recovery (67.0%) and separation efficiency (34.3%) under optimal conditions (20 g/t PAM, 150 g/m^3 frother, and 330 g/t collector), while PAS yielded enhanced Zn recovery (46.7%) at a dosage of 29 g/t. Kinetic modeling indicated that PAM-enhanced flotation conformed to the fully mixed reactor model, whereas PAS followed the classical model. These findings highlight the critical role of flocculants in promoting particle aggregation, selective hydrophobicity, and shear resistance, with PAM demonstrating superior performance in Cu recovery due to stronger floc formation. This research underscores the potential of customized flocculant application to optimize fine particle flotation, offering practical insights for more sustainable mineral processing with lower environmental impact.

1. Introduction

The flotation process is one of the primary methods for separating valuable minerals from their gangue in the mining industry [1]. Due to its high efficiency and ability to separate fine and valuable particles, this process is widely used in various mines [2]. One of the main challenges in flotation is the effective separation of fine and ultrafine mineral particles. Fine particles are generally defined as those smaller than 38 μm, while ultrafine particles are typically less than 10–20 μm [3,4]. These fine particles, which often arise during crushing and grinding processes, exhibit different behavior from coarser particles due to their high surface area, low mass, and increased surface energy. In this study, we focus on fine particles (<50 μm), which still pose significant challenges in flotation processes due to their reduced collision efficiency and high reagent consumption. Such problems decrease the efficiency of the separation process and result in higher chemical consumption. The loss of these fine particles as tailings not only leads to the wastage of mineral resources but also causes significant environmental issues due to the properties of these particles [5–8].

To address these challenges, numerous methods have been studied. Some researchers have improved the separation efficiency of fine particles by using advanced flotation cells such as column cells, Jameson cells, and reflux cells, which enhance bubble-particle collisions. These cells have demonstrated advantages over traditional cells by reducing water and energy consumption, decreasing retention time, and increasing separation efficiency, making them suitable replacements for conventional cells [7,9–13]. Others have attempted to increase particle size or reduce bubble size to enhance bubble-particle collisions. However, these methods face limitations such as low buoyancy forces and slow rise velocities, leading to longer flotation times and posing challenges for industrial application [3,14–18]

One approach that has garnered attention is the use of flocculants to increase the size of fine particles through the aggregation of valuable particles. Numerous studies have explored the role of flocculants in improving flotation. In a large part of the studies, the focus has been on increasing the effective size of fine particles through agglomeration and flocculation. This method has been used to increase the probability of effective particle collision with bubbles and improve adhesion between

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