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Editorial

Advances in Flotation Separation and Mineral Processing

Feng Jiang *, Li Wang and Mengjie Tian

School of Minerals Processing and Bioengineering, Central South University, Changsha 410083, China
* Correspondence: feng_jiang@csu.edu.cn

1. Introduction

Flotation is a key separation technology in mineral processing and is widely used for the selective recovery of valuable minerals. However, declining ore grades, finer mineral dissemination, and increasingly complex mineral associations have made efficient and selective flotation more difficult [1,2]. At the same time, conventional flotation may be ineffective for some complex primary and secondary resources [3]. Addressing these challenges therefore requires not only advances in flotation reagents and process intensification, but also the development of treatment processes suited to feed characteristics.

A central issue in flotation is the selective separation of minerals with similar surface properties and flotation responses. The separation of molybdenite from chalcopyrite is a representative example because the two minerals are commonly associated and both exhibit strong floatability. Conventional inorganic depressants can suppress chalcopyrite, but they often require high dosages and may be limited by insufficient selectivity, restrictive operating conditions, and environmental concerns [4,5]. The development of effective, low-toxicity organic depressants has become an important research direction. In particular, a clearer understanding of the relationships among molecular structure, selective adsorption, and flotation response is needed to guide the rational design of organic depressants.

Particle size is another important factor affecting flotation performance. Fine and ultrafine particles generally have low collision and attachment efficiencies with bubbles and are poorly recovered in conventional flotation systems [2]. Microbubble technology offers a promising means of improving fine-particle recovery by strengthening particle–bubble interactions. Its performance, however, depends on the combined effects of bubble characteristics, pulp conditions, reagent regimes, and energy input [6]. Therefore, the effective use of microbubble flotation requires the coordinated selection and control of these operating parameters.

For feeds that cannot be separated efficiently by flotation, process selection should be guided by mineralogy, phase composition, and the reaction characteristics of the target components [7,8]. Selective leaching, electrochemical transformation, thermal treatment, and other tailored processes may provide more suitable routes for the separation and recovery of valuable components. Bauxite residue illustrates this need for process-specific design: scandium is present at low concentrations and is closely associated with iron, aluminum, and titanium, so direct acid leaching commonly causes extensive impurity dissolution. In contrast, ammonium sulfate roasting followed by water leaching selectively converts scandium into a soluble phase, facilitating its separation from the complex residue matrix [9].

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Against this background, this Special Issue highlights recent theoretical developments and technological advances in flotation separation and mineral processing, with particular emphasis on flotation mechanisms, novel reagents, process intensification, the beneficiation of complex low-grade ores, and the valorization of secondary resources.

2. Overview of the Published Articles

This Special Issue comprises five articles covering flotation mechanisms, reagent chemistry, process intensification, selective chemical and electrochemical transformation, and the recovery of valuable components from metallurgical residues.

Jiang et al. (Contribution 1) evaluated 1-thioglycerol (1-TG) as a depressant in the chalcopyrite–molybdenite flotation system. Single-mineral and mixed-mineral flotation tests, under the tested conditions, indicated pronounced depression of chalcopyrite with a relatively limited effect on molybdenite. Contact-angle, zeta-potential, FTIR, and XPS measurements linked this response to chemical interaction between the thiol group and active Fe sites on the chalcopyrite surface, which increased surface hydrophilicity and limited subsequent collector adsorption. By linking flotation behavior to surface chemistry, the work offers a basis for the design and screening of selective depressants for copper–molybdenum systems.

Guzmán-Jarquín et al. (Contribution 2) investigated the flotation recovery of synthetic boehmite generated during electrocoagulation water treatment. The work establishes a clear causal sequence: the relative proportions of sodium dodecyl sulfate (SDS) and potassium oleate (PO) altered bubble size, which in turn changed the recovery response across boehmite particle-size classes. Increasing the SDS concentration produced a more microbubble-rich system and, under the reported conditions, yielded recoveries of up to 95% for particles smaller than 30 μm. By contrast, PO-rich systems generated larger bubbles and were more favorable for intermediate particle sizes. The study shows that reagent formulation can influence flotation through both surface chemistry and gas-dispersion characteristics, while extending flotation to the valorization of solids generated during water treatment.

Liu et al. (Contribution 3) developed an aluminum–sulfate-assisted sulfuric acid–hydrochloric acid mixed-leaching route for Bayan Obo rare-earth concentrate containing bastnaesite and monazite. The process preferentially decomposed bastnaesite while retaining monazite in the leach residue. Under the reported optimum conditions, the bastnaesite decomposition rate reached 96.83% and rare-earth leaching reached 71.95%. The subsequent flowsheet recovered rare-earth double salts, calcium sulfate, and cryolite, while monazite and phosphorus were enriched in the residue for subsequent alkaline decomposition and phosphorus recovery. By considering rare earths, aluminum, fluoride, and calcium together with the management of phosphorus-bearing residue, the work frames selective leaching as an integrated multi-element recovery problem rather than as an isolated dissolution metric.

Jasso-Recio et al. (Contribution 4) examined cathodic decomposition of chalcopyrite in 3 mol/L acetic acid under repeated cathodic polarization conditions. As the number of polarization cycles increased, Fe was progressively released from the chalcopyrite lattice and Cu-containing solid products, including Cu, Cu_2S, CuS, CuO, and copper acetate-type species, were detected. Their relative proportions depended on the applied energy conditions, and oxidation after removal from the electrochemical system may have contributed to the observed copper oxides. Under the specified conditions, the study provides mechanistic insight into the electrochemically controlled transformation of refractory chalcopyrite into more amenable copper-bearing species.

Wang et al. (Contribution 5) studied microwave-assisted carbothermal reduction in electric arc furnace dust, identifying temperature, holding time, and the C/Zn molar ratio

as key determinants of zinc removal rate, product composition, and kinetic behavior. At 1100 °C with a 60 min holding time and C/Zn = 4, the zinc removal rate reached 95.45%, accompanied by complete decomposition of the ZnO phases. Under the same temperature and holding-time conditions, increasing the C/Zn molar ratio from 4 to 5 increased the zinc removal rate from 95.45% to 96.66%. Isothermal kinetic analysis indicated a transition from an initial three-dimensional diffusion-controlled stage (0–30 min) to a later chemically controlled stage (30–60 min). These results delineate the process conditions and kinetic changes relevant to optimizing microwave-assisted zinc removal from electric arc furnace dust.

3. Summary and Outlook

Progress in flotation and mineral processing ultimately depends on the effective control of separation selectivity. In flotation systems, this requires the regulation of mineral–reagent and particle–bubble interactions. For complex feeds that are not amenable to flotation, suitable chemical, electrochemical, or thermal treatment processes must instead be selected according to the occurrence and reaction behavior of the target components. Future research should place greater emphasis on validating and optimizing these approaches so that their practical applicability can be more fully established.

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Conflicts of Interest: The authors declare no conflicts of interest.

List of Contributions

1. Jiang, F.; He, S.; Sun, W.; Luo, Y.; Tang, H. Efficient and Green Flotation Separation of Molybdenite from Chalcopyrite Using 1-Thioglycerol as Depressant. *Metals* **2025**, *15*, 299. https://doi.org/10.3390/met15030299.
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