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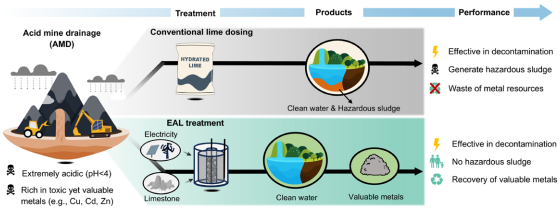

Localized Electro-Dissolution of Carbonate and Silicate Minerals Boosts Valuable Metal Extraction from Mine Wastewater

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Modern society heavily relies on mining to extract metal resources to produce electronics such as mobile phones, batteries, and electric cars. However, mining is often energy-intensive and environmentally unfriendly, leading to the production of large quantities of acidic mine drains (AMD). The current strategy for AMD treatment is mainly about dosing lime, which generates toxic heavy metal-loaded waste that requires careful disposal and wastes critical metal resources (e.g., Cu, Cd, Zn, and rare earth elements). Instead of simply focusing on AMD remediation, we propose viewing AMD as a source for metal extraction, shifting towards aqueous metal mining. To achieve this, we proposed a technique-feasible approach that combines natural alkaline minerals (e.g., limestone ($CaCO_3$) and wollastonite ($CaSiO_3$)) with electrodeposition, which spatially decouples H^+ neutralization at the anode from metal deposition at the cathode[1]. By strategically packing minerals within the anode region, anode-generated protons actively accelerate mineral dissolution and inhibit passivation layers by maintaining an acidic condition, while the cathode generates a localized high-pH microenvironment to facilitate heavy metal immobilization. In this way, we ensure that the removed valuable metals are not mixed with natural minerals or low-value precipitates, enabling efficient cathodic metal extraction (67.7-99.9%) without competing with H^+ reduction. More interestingly, the $CaCO_3$-electrolysis integrated system is proven effective in recovering rare earth elements during the actual AMD treatment. Beyond excellent resource-extraction performance, the treated AMD contains high concentrations of alkaline-earth ions (i.e., Ca^{2+} and Mg^{2+}) and has the potential to sequester CO_2 from the air. Taking the $CaSiO_3$-electrolysis system as an example, its effluent persistent alkalinity enabled the sequestration of approximately 140.8 g/m^3 of atmospheric CO_2. Our techno-economic analysis and life-cycle assessment indicated that the novel treatment reduced total costs by 17.9% and CO_2 emissions by 60.1% compared with the conventional lime-dosing treatment. After this treatment, the neutralized water and extracted metals could potentially offset industrial production. Overall, our established EAL system shows technical, economic, and ecological superiority in extracting valuable metals from AMD.

[1] Extraction of valuable metals from acid mine drainage by an electrochemically activated limestone system, Li, Weiquan & Lei, Yang (2025), ***Nature Communications*** 16(1), 6719.