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Green Mining Challenges: CRM Recovery from Acid Waters via Vacuum Evaporation Method

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The United Nations recognizes acid mine drainage (AMD) as one of the most urgent environmental issues that society will face in the coming decades. AMD constitutes one of the most persistent and toxic forms of water pollution worldwide. Its scale and growth are alarming, and more than 75% of mining districts are already affected. Beyond AMD, climate warming is triggering natural acid rock drainage (ARD), which leads to persistent, often unmonitored environmental degradation of low-resilience ecosystems and vulnerable communities. Concurrently, Critical Raw Materials (CRMs) are growing in importance for the economy, green transition, and digital transformation of the global community. Many States are promoting specific programs and implementing policies aimed at strengthening domestic capacity and diversifying international supply chain to remain competitive globally, and to avoid risks of supply disruption due to geopolitical tensions and trade restrictions.

With over 5,500 mining projects slated for construction by 2026, according to the Global Market Intelligence, the potential for unprecedented environmental pressure on aquatic ecosystems and water security is significant. We propose addressing this complexity through the 'Resource-Remediation Nexus': an integrated framework that transforms the burden of acidic water treatment into a circular economy opportunity for mineral recovery. By re-evaluating advanced water treatment technologies through this lens, we attempt to demonstrate how environmental sustainability and economic viability can converge to meet contemporary global demands. At the core of this approach is Continuous Vacuum Evaporation (CVE), which enables the reclamation of acidic mine waters with an efficiency exceeding 90%, simultaneously generating concentrates highly enriched in CRMs. Compared to conventional filtration and distillation methods, the CVE process stand out in treating ultra-acidic waters and solute loads above 30%, while maintaining low chemical and energy demands and minimizing non-recyclable waste. The main operational challenges include significant technological and initial capital expenditure costs and constrained volumetric flow rates, which define the primary areas for future optimization and scale-up. Current research incorporate upstream water discrimination via advanced filtration techniques, coupled with downstream metals selective separation utilizing a hybrid approach of microwave-assisted pyrometallurgy and (bio)leaching to maximize recovery of metals from the distillation concentrates, to finance operational costs.