

Sustainable CO₂ Mineral Carbonation by Acid Rainwater and Wastewater Utilization

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CO₂ mineral carbonation technologies have been extensively explored as a key strategy for mitigating anthropogenic greenhouse gas emissions. Previous studies have demonstrated significant CO₂ uptake at the laboratory scale by utilizing various solvents in the carbonation of industrial wastes. However, the overall net CO₂ balance of these processes remains uncertain. Additionally, these methods may present environmental concerns by producing secondary waste streams such as acidic residues and solid byproducts after the reaction. So, new practical engineering solutions are needed to achieve the highest total CO₂ uptake, making more sustainable carbonation. This study investigates the laboratory-scale application of acid rainwater and wastewater for CO₂ mineral carbonation using alkaline industrial waste (steel slag). Analysis of wastewater samples from the treatment facility confirmed the presence of Ca²⁺ and Mg²⁺. Additionally, the surface characterization of reference industrial waste from a local ferroalloy plant revealed a composition of (>35%) CaO and (>5%) MgO, indicating its suitability as a feedstock for carbonation processes. The sulfuric acid rainwater dissolved the mineral phases before CO₂ mineralization in a dual-liquid reactor. The monitoring of Dissolved Inorganic Carbon (DIC), Ca²⁺, and Mg²⁺ verified that the constant CO₂ uptake facilitated the CO₂ dissolution for further carbonate formation. The TGA and XRD analysis of the post-reaction product of precipitates has confirmed the formation of CaCO₃. The results suggest a novel engineering solution, presenting a sustainable strategy for CO₂ mitigation. This process enables a strategic approach for environmental challenges related to acid mine drainage, wastewater generation, and industrial alkaline waste by implementing the process within a controlled reactor to optimize efficiency. This research has been supported by research grants from the Ministry of Science and Higher Education of the Republic of Kazakhstan (BR24993138) and Nazarbayev University (211123CRP1605).