Pilot-Scale Passive Treatment Including Slag Reactors, as Adsorption Reactors, and Vertical Flow Reactors for Mine Drainages in Peru

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Abstract

Peru is the world's second-largest producer of Cu and Zn. Its porphyry copper deposits and hydrothermal multimetal ores contain a wide range of metals, which can lead to water contamination by Al, As, Cd, Fe, Mn, and Zn. To mitigate these impacts, eco-friendly, low-carbon, and cost-efficient treatment technologies are necessary for metalliferous mines.

Two mine drainages located in the Ancash Region, Peru, were investigated: the El Triunfo 1 (ET) adit drainage exhibited elevated concentrations of As (10.6 mg/L), Cd (0.042 mg/L), Cu (0.576 mg/L), Fe (64.3 mg/L), Mn (5.27 mg/L), and Zn (11.2 mg/L), and the Santa Teresita (ST) adit drainage contained elevated concentrations of Al (22.44 mg/L), Cu (0.346 mg/L), Fe (3.44 mg/L), Mn (41.3 mg/L), and Zn (7.89 mg/L). Pilot-scale passive treatment facilities — including successive alkalinity producing systems (SAPS) units, oxidation-settling ponds, a slag reactor, an aerobic wetland, and an As adsorption pond — were constructed and operated for approximately one year under varying flow rate conditions; optimal treatment performance was achieved at flow rates of 1.08 m^3/d (ET) and 2.31 m^3/d (ST). Additionally, the oxidation-settling ponds were converted into vertical flow reactors (VFR) to evaluate its As-removal performance.

Through the SAPS and oxidation-settling pond sequence effectively decreased Al and Fe concentrations, with removal efficiencies exceeding 99% for both elements. During treatment, Cu, Zn, and Cd concentrations were also reduced — Cu to below detection limit, Zn by >98%, and Cd by >99% — indicating effective coprecipitation with and adsorption onto freshly formed Fe (oxy)hydroxides. This coprecipitation–adsorption effect was also confirmed in adit drainage samples stored in a laboratory. Although the first-phase slag reactor did not sufficiently raise pH to remove Mn, the second-phase slag reactor — using a different type of steel slag — successfully increased pH to >11, enabling efficient Mn precipitation. Following a stabilization period of approximately 5–6 months, the pilot-scale slag reactor at the ET mine achieved Mn concentrations below 1.0 mg/L at hydraulic retention times (HRT) ≥17.6 h, while the ST mine achieved the same target at HRT ≥15.7 h. In the As adsorption unit containing adsorbent synthesized from coal mine drainage sludge, As concentrations were reduced to ≤0.1 mg/L at the ET mine at HRT of approximately 7 h or longer. Furthermore, the VFR installed at the ET site decreased As concentrations from 1.9 mg/L to 0.08 mg/L, demonstrating its effectiveness for As removal in Fe-rich mine drainage.

Given the diverse contaminants present in these mine drainages, the passive treatment technologies demonstrated here show strong potential for broader application to other mine sites affected by Al, As, Cd, Cu, Fe, Mn, and Zn. Under optimised flow rate and HRT conditions — specifically HRT ≥17.6 h for the slag reactor and HRT ≈7 h for the As adsorption unit — effluent quality met Peruvian regulatory discharge limits for the target metals, supporting the feasibility of scale-up at similar polymetallic mine drainage sites.

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