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Effects of Permeability and Pyrite Distribution Heterogeneity on Pyrite Oxidation in Flooded Lignite Mine Dumps

The role of sedimentary heterogeneity on reactive transport processes is becoming increasingly important as closed open-pit lignite mines are converted into post-mining lakes or pumped hydropower storage reservoirs. Flooding of the open pits introduces constant oxygen-rich inflows that reactivate pyrite oxidation within internal mine dumps. A reactive transport model coupling groundwater flow, advection-diffusion-dispersion, and geochemical reactions was applied to a 2D cross-section of a water saturated mine dump to determine the processes governing pyrite oxidation. Spatially correlated fields representing permeability and pyrite distributions were generated via exponential covariance models reflecting the end-dumping depositional architecture, supported by a suite of scenarios with systematically varied correlation lengths and variances. Simulation results covering a time span of 100 years quantify the impact of heterogeneous permeability fields result in preferential flow paths, which advance tracer breakthrough by ~15 % and increase the cumulative solute outflux by up to 39 % relative to the homogeneous baseline. Low initial pyrite concentrations (0.05 wt %) allow for deeper oxygen penetration, extending oxidation fronts over the complete length of the modeling domain. Hereby, high initial pyrite concentrations (0.5 wt %) confine reactions close to the inlet. Kinetic oxidation allows for more precise simulation of redox dynamics, while equilibrium assumptions substantially reduce the computational time (>10 ×), but may oversimplify the redox system. We conclude that reliable risk assessments for post-mining redevelopment should not simplify numerical models by assuming average homogeneous porosity and mineral distributions, but have to incorporate site-specific spatial heterogeneity, as it critically controls acid generation, sulfate mobilization, and the timing of contaminant release.

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