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Aqueous Speciation Modeling and Experiments to Understand Mobility and Recovery of Rare-Earth Elements and Associated Critical Minerals from Acid Mine Drainage

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Discharges from coal mines that have low pH, hereinafter identified as acid mine drainage (AMD), commonly have elevated concentrations of sulfate (SO_4), transition metals (Fe > Mn > Zn > Ni > Co > Cu > Cr > Cd), other metals (Al > Pb > Ga > Tl > In), and the lanthanide rare-earth elements, yttrium, and scandium (REYs: Y > Ce > Sc > Nd > La > Gd > Dy > Sm > Pr > Er > Yb > Eu > Ho > Tb > Tm > Lu). The REYs occur as trace cations having predominant +3 oxidation state in AMD, with tendency to form aqueous and surface complexes. Dissolved REYs concentrations generally decrease as the pH increases, especially at pH > 5, accumulating with Fe, Al, and Mn that precipitate from AMD as hydrous metal oxides (HMeO). Various strategies that control oxidation and neutralization reactions may be effective for concentrating and recovering REYs from AMD.

This presentation demonstrates the PHREEQ-N-AMDTreat+REYs water-quality modeling tools to evaluate key variables affecting the speciation of REYs, Fe, Al, Mn, SO_4, and other solutes plus the formation of solids containing REYs. The models utilize the wateq4fREYsKinetics.dat database, which was expanded from wateq4f.dat provided with PHREEQC to include thermodynamics data on REYs aqueous and surface species plus REYs solid phases (hydroxide, carbonate, phosphate, sulfate, and oxalate compounds). Surface species for REYs plus other cations and anions are computed using the diffuse double layer model for hydrous ferric oxide (HFO), hydrous aluminum oxide (HAO), and hydrous manganese oxide (HMO), which constitute the total HMeO sorbent mass. New surface speciation constants for HFO and HAO recently were developed to account for the adsorption of REYs from acidic SO_4-bearing solutions. The reactions, which include ternary complexes with SO_4, accurately describe the observed attenuation of trivalent REYs and various divalent cations by HFO, HAO, and HMO. By combining the PHREEQ-N-AMDTreat+REYs water-quality modeling with the AMDTreat 6.0 cost-analysis model, a user may (1) identify and evaluate strategies for AMD treatment that result in effective REYs recovery and (2) estimate costs for installation and operation of the proposed treatment.