Development of a Modular Passive Treatment System and Evaluation of Reactive Substrates for Reducing Seasonal Effects of Acid Rock Drainage: Potential Application of Nanoparticles, Chelators, and Low Isoelectric Point Substrates

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Project Description and Objectives:

Generation of acid rock drainage (ARD) continues to significantly impact water resources around the globe. Passive treatment systems have been developed as lower-cost remediation alternatives, but seasonality of flow, acidity, and metal concentrations present challenges for passive systems. The objective of this research was to develop a modular passive treatment system that could be used in conjunction with other treatment systems for ARD remediation. The project goal was to design a modular treatment system to provide a flexible tool for reducing variation in metal inputs to a primary treatment system. A functionalized, synthetic silica fiber (3-aminopropyl)triethoxysilane (APTES) + silica felt (Si+APTES)) and a natural silicate mineral (clinoptilolite) were selected as final reactive substrates after evaluation of a range of substrates and surface modifications, including metal and silicate surfaces and metal and silica nanoparticles and common chelators.

Applicability to Mining Reclamation:

The results of this study provide a blueprint for a low-cost, modular treatment system for improving the efficacy of ARD remediation. Additionally, Si+APTES and clinoptilolite were shown to be effective substrates for treatment of ARD ≥ pH of 3.

Methodology:

The modular system was designed as a cartridge system that could be expanded to a desired treatment level (contact time) through addition of multiple units/cartridges (Fig. 1). A prototype containing clinoptilolite was deployed at a site in the Great Falls Coal Field of Montana, and the hydraulic performance and iron removal were monitored over 24 hrs in 2- and 6-cartridge configurations. Influent volumes and contact times are dependent upon the hydraulic gradient and number of cartridge units.

The silicate substrates as treatment materials were evaluated in the laboratory through permeability, batch sorption, and flow column experiments. Results from batch sorption experiments were compared to Langmuir and Freundlich isotherm models to compare sorption processes.

Effect of pH on iron sorption by Si+APTES and clinoptilolite was studied in batch sorption experiments over a pH range of 2.5–4.0. Retention of previously sorbed iron on clinoptilolite was evaluated through batch desorption experiments in natural, ultrapure, and Ni-rich waters at temperatures of 5 and 20 ºC and pH values of 2.0, 4.0, and 7.0.

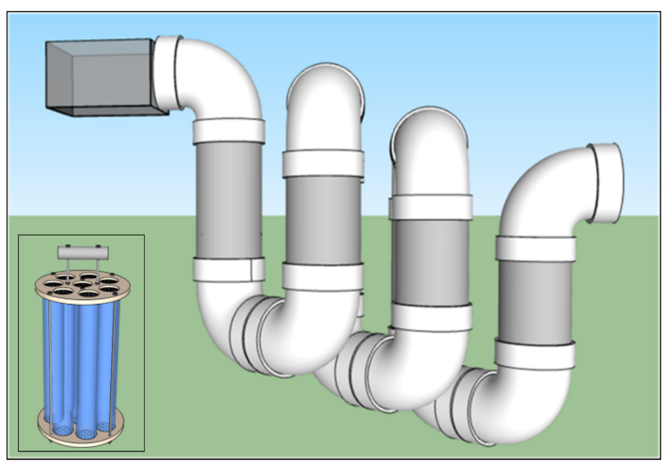

Fig. 1. Modular treatment system in a 6-cartridge configuration. Insertable/removable, reactive material cartridge shown in insert. The cartridge fits the gray tubular portions of the system for desired expansion and ability to refresh a cartridge through individual tube access.

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Highlights:

Important conclusions of the study include:

1. Integrating complimentary treatment systems and flexibility of treatment system design, particularly a modular design that allows for refreshing of the reactive material, can reduce the impact of metal concentration seasonality on primary treatment systems.
2. Si+APTES has a higher metal specific sorption, but the greater permeability, surface area, and ion-exchange properties of clinoptilolite, make these natural zeolite grains a better choice for passive treatment of ARD under higher flow conditions.
3. Both Si+APTES and clinoptilolite have potential as reactive substrates for treatment of mildly acidic (pH ≥ 3.0) ARD. Iron sorption is negligible at a pH of 2.5 for these substrates and generally increases as pH increases to 4.0 (Fig. 3).
4. Iron sorbed to clinoptilolite will remain captured (no temperature or competing ion influence) unless a substantial decrease in pH occurs.

Results and Findings:

The modular treatment system was designed for relatively easy installation and expansion through construction of cartridge-containing units utilizing readily available, 25-cm PVC tubing. The reactive material cartridges can be removed and refreshed without removal of the system.

Si+APTES demonstrated high specific sorption of iron during batch sorption experiments and has potential as a reactive material for treatment of low-flow, mildly acidic (pH ≥ 3.0) ARD. The performance of clinoptilolite during permeability, batch sorption, and column experiments indicates this material is better suited for treatment of higher flow, mildly acidic (pH ≥ 3.0) ARD.

Field deployment of a clinoptilolite prototype permitted a flow rate of 4 L/min without obvious leaks or flow bypass. Limited flow rate was a result of a lack of hydraulic head rather than a lack of permeability. Field ARD pH of 2.5 protonated the clinoptilolite within the treatment system and limited iron removal. Desorption experiment results indicate that decreasing pH has greatest effect on iron desorption.

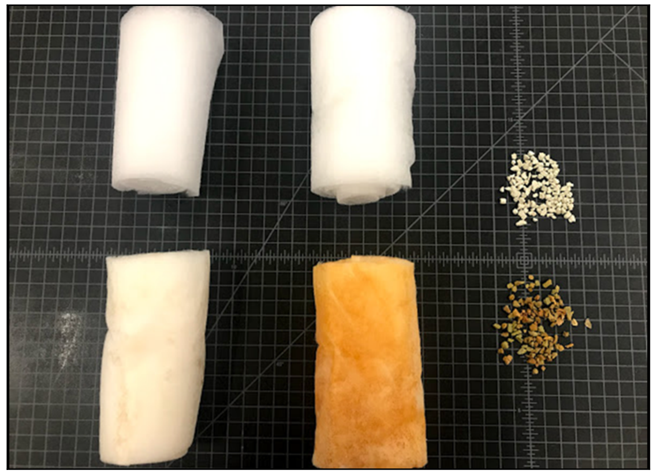

Fig. 2. (Left to right): 12 g of bare silica felt, 12 g of Si+APTES, and 5.4 g of clinoptilolite before (top row) and after (bottom row) batch sorption experiments. Orange color is due to sorbed and precipitated Fe-(oxyhydr)oxides.

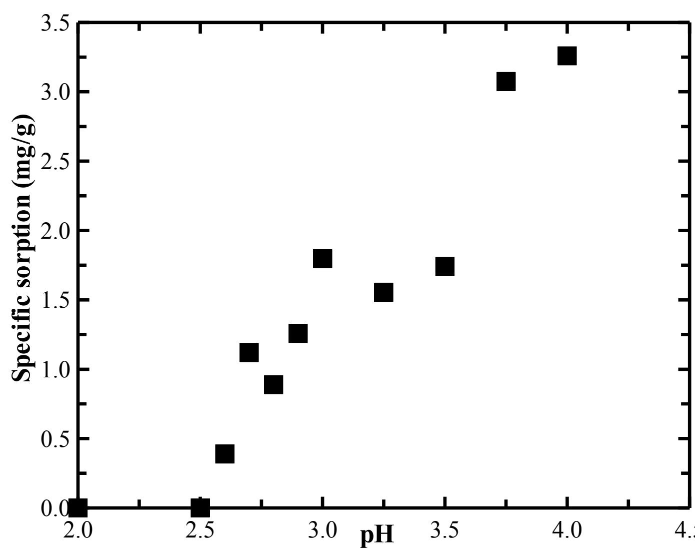

Fig. 3. Fe sorption on clinoptilolite at various pH levels.

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