Project Title: Metal removal capabilities of passive bioreactor systems: effects of organic matter and microbial population dynamics

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EPA Project Officer: Mitch Lasat
Project Period: October 1, 2001 – September 30, 2003
Project Amount: EPA $234,760; Cost Share $52,861; Project Total $287,621

Goal: The overall goal of this project is to evaluate the effect of organic matter characteristic on microbial population distributions and metal concentration in passive reactive zones and develop modeling tools for design and analysis.

Objectives:
1. To evaluate the physical, chemical and biological composition of the components used to create the permeable reactive zones.
2. To determine the effect of the organic substrate characteristics on effluent metal concentration.
3. To determine the effect of the substrate and time on variations in microbial population.
4. To develop mathematical models (numerically solved) to relate metal removal and transport to various system parameters.

Approach:

Limitations of previous research have included:
• Focus on initial metal removal rates rather than on performance longevity
• Limited examination of only sulfate-reducing bacteria
• Lack of systematic design protocol (e.g., substrate selection and residence time)
• No modeling tool to facilitate design and analysis

Tasks that we have initiated are:

• Characterization of chemical, physical and biological characteristics of substrate material.

• Correlation of substrate characteristics to sustainable activity of sulfate reduction coupled with metals removal in mini-column experiments.
• Investigation of the microbial community structure using activity and molecular methods. Target organism are sulfate reducers and non-sulfate-reducing microbial groups, such as cellulolytic bacteria, fermenters, syntrophs, and methanogens

• Development of a specific mathematical model that captures the most important aspects of the processes and a numerical implementation of this mathematical model. This implemented model is expected to be added as a new “package” to an existing transport model. Finally, this numerical model will be tested for different conditions, including porous media heterogeneity.

**Results**

A conceptual model of the key microbial processes in anaerobic passive reactive zones has been developed. Microbial growth and substrate utilization models and stochiometries have been developed for the key processes. Kinetic parameters for the models still need to be developed.

Baseline column studies have been done to establish a working experimental system that performs similarly to studies by others (Wildeman et al., 1995; Waybrant et al., 2002). Columns exhibited the familiar rapid early rate of sulfate reduction followed by a decline in sulfate reduction rate with time. The column design will be used for subsequent experiments on identification of key microbial processes.

Preliminary characterization of organic substrate based on organic carbon, volatile solids, nitrogen and phosphorus contents have been completed. These characteristics are not sufficient to establish needed design criteria.

Preliminary metal sorption data had been developed for organic substrates in batch and column tests. Sorption data will be used in model calibration.

Basic numerical modeling studies and tests have been performed to become familiar with the USGS MODFLOW-2000 and MT3DMS 4.0 models that will be used to model aquifer configurations including heterogeneities using a stochastic approach.

The reaction sub-routine in the MT3DMS model is being evaluated to the extent that it can be modified to handle the specific reactions corresponding to the chemical and biological processes associated with the particular type of permeable-reactive-zone being evaluated in this study.

One of the expected results is the addition of a new “package”, corresponding to the simulation of the specific biological processes, to the existing MT3DMS framework, which will be used in different simulations of the PRB environment.

**Future Work**

Understanding the relationship between system performance and microbial, chemical and physical processes is essential to the design of anaerobic passive biosystems for effective long-term operation. Future work targeting this effort are listed below.
• Analyze substrate components individually for long-term bioavailability  Characterization methods used for biomass to energy conversion field will be evaluated (e.g., cellulose and lignin versus xylans and glucomanans)
• Identify microbial communities and activities
• Validate conceptual model of key microbial processes
• Examine effects of cold temperatures on substrate bioavailability and reaction rates
• Characterization of metal sorption to organic and inorganic substrates.
• Evaluation of microbial structure through the use of molecular techniques

Some studies have indicated that laboratory-to-field scale transition of the permeable reactive zone technology is less than 100 percent successful due, in part, to field-scale aquifer heterogeneities that render the PRB less effective and less efficient relative to the laboratory. Development of predictive models for fate and transport of metals through passive reactive zones that can account for heterogeneities is essential. Future work that target this effort are listed below.

• Completing the mathematical model for kinetics of sulfate reduction and metals reduction and uptake (including biotic and abiotic processes);
• Developing a numerical solution for the proposed mathematical model;
• Implementing the numerical solution into the MT3DMS 4.0 environment (as an additional package) using programming language FORTRAN;
• Utilizing an existing algorithm (University of Wisconsin PhD Thesis) for introducing aquifer heterogeneity (stochastic approach) into MODFLOW 2000;
• Testing the numerical model for different conditions.

Publications/Presentations


Personnel

Faculty
Although the project has numerous PIs, initial activity on the project has primarily involved the six faculty listed above and interactions with faculty on Project 1. Increased participation with the other project PIs and participants is a goal of the summer 2002 meetings.
Post Doctoral Associate
A post doctoral associate will be hired by Fall 2002 with the primary responsibility of adapting existing molecular protocols for application to samples from passive reactive zones.

Students
Students currently supported by the project are:
Jason Seyler (CSM)
Miranda Logan (CSM)
Paulo Hemsi (CSU)

An additional visiting student from Ecole Nationale Superieure De Chemie De Rennes, France is working on the project this summer:
Marie-Helene Robustelli

Another graduate student and a student hourly worker will be supported by the project for AY2002/2003 at CSU:
Not identified

Another student will join the project on a part-time basis for AY2002/2003 at CSM:
Julie Ventker

References