IMPROVED SULFATE-REDUCING BIOREACTORS FOR THE REMEDIATION OF HIGH TOTAL DISSOLVED SOLIDS DRAINAGE ASSOCIATED WITH COAL MINING AND PROCESSING IN THE U.S.

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Project Description and Objectives

This project investigated the geochemistry and microbiology of an existing anaerobic, sulfate-reducing bioreactor (ASRB)-based passive treatment system, the Tab-Simco Project, constructed near Carbondale, in Southern Illinois, USA. This research evaluated the potential limiting factors to bioreactor treatment through a series of incubation experiments using test reactors whereby the effect of simple versus complex carbon sources on AMD was assessed. Improved bioreactor evaluation methods, including applications of isotope geochemistry, inorganic geochemistry, and microbiology, were employed to assess, monitor, and improve the efficiency of bioreactor treatment processes.

Applicability to Mining and Reclamation

The Tab-Simco passive treatment system has been treating coal-generated acid mine drainage (AMD) with high total dissolved solids (total dissolved solids > 4,000 mg/L) since 2007. Weathering of coal overburden and coal waste associated with historic mines has in some cases resulted in the production of AMD characterized by low-pH and high concentrations of sulfate, iron, aluminum, manganese, along with elevated levels of trace metals (i.e., As, Cd, Cu, Cr, Ni, Pb and Zn). Passive remediation of AMD to levels that meet the surface water quality standards has proved both technologically and economically challenging. Development of low-cost passive and/or semi-passive treatment technologies will improve remediation of these coal mine AMD and reduce environmental impacts.

Methodology

Field experiments using ***in situ*** continuous-flow reactors were conducted at Tab-Simco abandoned mine land (AML) site to compare the remediation efficiency of simple versus complex carbon sources on in abating coal mine-generated AMD. Five bioreactor test cells containing various mixtures of herbaceous and woody organic substrates (R2-R6) along with one control reactor containing only limestone (R1) were constructed using six 210-liter (55-gal.) polyethylene barrels. These reactors were monitored over 400 days in order to evaluate the physical, geochemical, and microbiological parameters, which controlled the anaerobic organic substrate bioreactors efficiency in removing AMD contaminants. The organic substrate-based reactors (R2-R6) were built by placing 25 liters (6.6 gal. or ~48 kg) of limestone at the bottom of the barrels and then adding mixtures of herbaceous (hemicellulose) and woody (ligneous) organic substrates with a total uncompressed volume of 125 liters (33 gal.). Organic substrates used in these experiments were materials available in the region and included leaf compost (LC), grass clippings (GC), spent brewing grain (SBG), maple wood chips (MWC) and maple sawdust (MSD). The organic material was classified as containing herbaceous (i.e. LC, GC and SBG) or ligneous (i.e. MWC and MSD) composition. Additionally, 15.6 liters (4-gal.) of livestock manure and 7.8 liters (2-gal.) of whey powder were mixed into the organic material to inoculate sulfate-reducing bacteria and provide an immediate source of low molecular weight organic compounds. At the top of the bioreactors, the remaining 54 liters (11.9 gal) were open to the surrounding atmosphere and provided space for the AMD to pool (termed the "acid pond"). Field measurements (pH, ORP, conductivity, temperature, D.O.) were performed at the AMD influent, as well as the "acid pond" and effluent discharge of each reactor. Laboratory tests included total alkalinity, dissolved sulfide and ferrous iron within 24 hours along with the anions sulfate, chloride, fluoride and phosphate and the metals Al, Fe, Mn, Cu, Sr, Cd, Ni, Zn, Ca, Mg, and K within hold times prescribed by standard methods. Filtered samples were analyzed at the mass spectrometry facility at Indiana University Bloomington for sulfur isotopes. Samples were also collected from a series of lateral sampling ports and the effluent discharge of each reactor one week after the experiment began and after 12 months of operation. Pyro-sequencing of bacterial communities was then performed at the SIU Department of Microbiology.

Highlights

All bioreactor test cells established sulfate-reducing bacteria (SRB) populations that contributed to enhanced removal of SO_4, Fe, and trace metals (i.e. Cu, Cd, Zn, Ni) by forming Fe-oxyhydroxide precipitates, adsorption, co-precipitation (e.g. Zn/Ni-Ferrites), and bio-induced sulfide mineralization. The highest remediation efficiency of dissolved SO_4, Fe, Al and Mn was obtained in the predominantly herbaceous bioreactors (containing LC, GC and SBG).

Results/Findings

To determine whether substrate variations produced differences in remediation, experimental results from all bioreactors (R2-R6) were group in the following three categories:

1) *Dominantly Ligneous Reactors* (R2, R3)
2) *50/50 Mix*: a Ligneous/Herbaceous Mixture (R4)
3) *Dominantly Herbaceous Reactors* (R5, R6)

Parameters were then ranked as first (blue shading), second (light green shading) and third (red shading) by comparing each bioreactor type against one another (Table 1). Of the ten parameters the dominantly herbaceous reactors (R5, R6) ranked 1^{st} and thus were determined as the most favorable organic substrate in terms of short-term remediation efficiency.

The extrapolation of the test cell results to the full-scale Tab-Simco bioreactor indicated that, over the course of one year, the predominantly herbaceous bioreactors would remove ~75,600 kg (83.3 s. tons/yr.) SO_4, 21,800 kg (24 s. tons/yr.) Fe, 8,000 kg (8.8 s. tons/yr.) Al, and 77 kg (170 lb./yr.) Mn, which represents a 21.7 wt.%, 41.5 wt.%, 81.8 wt.% and 9.4 wt.% increase in SO_4, Fe, Al, and Mn, respectively, removal efficiency compared to the predominantly ligneous bioreactors. These results imply that ASRB technologies are promising in remediation of poor-quality AMD derived from certain abandoned coal mines and increasing herbaceous content of bioreactors can significantly enhance contaminant sequestration at least in the short-term.

However, in order to further enhance ASRB remediation capacity, future designs must optimize not only the organic carbon substrate, but also include a pretreatment component in which the a portion of dissolved Fe and Al are removed from the influent AMD prior to entering the bioreactor. This is necessary because: 1) seasonal variations in redox conditions could induce dissolution of the previously formed, redox sensitive minerals, and 2) microbial-mediated sulfate reduction may be inhibited by the high surface area of the Fe/Al-oxyhydroxides which will precipitate in large volumes within the bioreactor.

Website Information:
The final project report and links to supporting documents can be found at:
http://www.osmre.gov/programs/tdt/appliedscience/projects.shtm

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Table 1: Bioreactor performance based on substrate composition

Parameter	Ligneous (R2, R3)	50/50 Mix (R4)	Herbaceous (R5, R6)
PH	4.77	4.98	5.11
% Iron Removal	38.92	40.60	55.08
% Sulfate Removal	28.49	28.42	34.40
% Aluminum Removal	83.24	83.65	91.08
% Manganese Removal	0.24	-1.80	2.10
% Nickel Removal	69.55	73.81	73.81
% Zinc Removal	87.87	87.48	85.13
% Copper Removal	77.87	81.80	84.78
%Cadmium Removal	93.32	82.73	91.20
Alkalinity (meq as $CaCO_3$)	369.14	317.48	436.70
Overall Rank	2nd	3rd	1st

Test bioreactor cells (blue) and the limestone-only control (white) installed within the Tab-SImco full-scale bioreactor's inlet waterway.