United States
Environmental Protection
Agency

SUPERFUND INNOVATIVE TECHNOLOGY EVALUATION

Technology Evaluation Bulletin

Compost-Free Biological Treatment of Acid Rock Drainage

Technology Description: Drs. Glenn Miller and Tim Tsukamoto of the University of Nevada Reno (UNR) have developed a compost-free bioreactor technology in which sulfate-reducing bacteria are nurtured to generate sulfides which scavenge dissolved metals to form metal sulfide precipitates. Unlike compost bioreactors, this technology uses a liquid carbon source and a rock matrix rather than a compost or wood chip matrix which is consumed by bacteria and collapses over time. The benefits include better control of biological activity and improved hydraulic conductivity and precipitate flushing.

The U.S. Environmental Protection Agency (EPA), in cooperation with the state of California, Atlantic Richfield Company, and UNR evaluated the compost-free bioreactor treatment of acid rock drainage (ARD) at the Leviathan Mine Superfund Site located in a remote, high altitude area of Alpine County, California. The biological treatment system was evaluated from 2003 though 2005, while operating in both gravity flow and recirculation modes of operation. The system neutralized acidity and precipitated metal sulfides from ARD at flows ranging up to 24 gallons per minute on a year-round basis.

EPA evaluated the biological treatment systems' ability to neutralize acidity and to reduce concentrations of target metals in the ARD to below EPA-mandated discharge standards. The primary target metals were aluminum, arsenic, copper, iron, and nickel; and the secondary target metals were cadmium, chromium, lead, selenium, and zinc. Historically, the concentrations of the five primary target metals in ARD released into Aspen and Leviathan Creeks have exceeded EPA-mandated discharge levels by up to 580 fold, contributing to fish and insect kills in the creek and downstream receiving waters.

Biological treatment of ARD relies on the biologically mediated reduction of sulfate to sulfide followed by metal sulfide precipitation. Biologically promoted sulfate-reduction has been attributed to a consortium of sulfate-reducing bacteria, which at Leviathan Mine utilizes ethanol as a carbon substrate to reduce sulfate to sulfide. This process generates hydrogen sulfide, elevates pH to about 7, and precipitates divalent metals as metal sulfides. The following general equations describe the sulfate-reduction and metal sulfide precipitation processes.

$$2CH_3CH_2OH + 3SO_4^{2-} \rightarrow 3HS^- + 3HCO_3^- + 3H_2O \quad (1)$$

$$2CH_3CH_2OH + SO_4^{2-} \rightarrow 2\,CH_3COO^- + HS^- + H_2O \quad (2)$$

$$HS^- + M^{2+} \rightarrow MS + 2H^+ \quad (3)$$

Here ethanol is the carbon source and sulfate (SO_4^{2-}) is the terminal electron acceptor in the electron transport chain of sulfate-reducing bacteria. Reaction No.1 causes an increase in alkalinity and a rise in pH, while reaction No.2 results in the generation of acetate (CH_3COO^-) rather than complete oxidation to carbonate. Hydrogen sulfide (HS^-) then reacts with a variety of divalent metals (M^{2+}), resulting in a metal sulfide (MS) precipitate.

At Leviathan Mine, the compost-free bioreactor treatment system consists of a pretreatment pond, two gravity-flow bioreactors, two settling ponds, and an aeration channel. Operated in gravity flow mode, ARD is introduced to the pretreatment pond, where sodium hydroxide is added to adjust the influent pH of 3.1 up to 4.0, and ethanol is added as a carbon source. ARD from the pre-treatment pond then flows through Bioreactor No.1 (12,500 total and 5,300 cubic foot active volume) and Bioreactor No.2 (7,000 total and 3,000 cubic foot active volume) to biologically reduce sulfate to sulfide. Excess sulfide generated in the first bioreactor is passed, along with partially treated ARD water, through to the second bioreactor for additional metals removal. Precipitates in effluent from the second bioreactor are settled in a 16,400 cubic foot continuous flow settling pond.

Operated in recirculation mode, metal-rich influent ARD is combined with sulfide-rich water discharged from the second bioreactor as well as sodium hydroxide to precipitate metals in the settling pond rather than in the bioreactors. A portion of the settling pond supernatant containing minimal residual metals and excess sulfate is pumped to the first bioreactor and combined with ethanol feed stock to promote additional sulfate reduction to sulfide in the two bioreactors.

The effluent from the continuous flow settling pond then flows to a 150 foot by 2 foot rock lined aeration channel to promote degassing of residual hydrogen sulfide and oxygenation of the effluent prior to discharge. Precipitate slurry is periodically flushed from the bioreactors to prevent plugging of the river rock matrix (gravity flow mode) and is settled in an 18,100 cubic foot flushing pond. Settled solids from the flushing pond are periodically dewatered using bag filters.

Waste Applicability: Conventional methods of treating ARD involve lime addition, which neutralizes acidity and precipitates metals. Active lime treatment appears to be applicable in situations where flow rates are moderate to high and the treatment season is short. However, the innovative passive compost-free bioreactor is not constrained by seasonal conditions and can be scaled to treat low to moderate flows, which are typical of many ARD sites. The compost-free bioreactor technology generates relatively small quantities of sludge, in comparison to the larger sludge yield of lime treatment technologies.

Evaluation Approach: Evaluation of the compost-free bioreactor technology occurred between November 2003 and July 2005. Multiple sampling events were conducted during operation of the bioreactor treatment system. During each sampling event, EPA collected chemical data from the system influent and effluent streams, documented metals removal and reduction in acidity between the bioreactors, settling ponds, and aeration channel, and recorded operational information pertinent to the evaluation of the treatment system. The treatment system was evaluated independently, based on removal efficiencies for primary and secondary target metals, comparison of effluent concentrations to EPA-mandated discharge standards, and on the characteristics of and disposal requirements for the resulting metals-laden solid wastes.

The primary objectives of the technology evaluations were:

- Determine the removal efficiencies for primary target metals over the evaluation period

- Determine whether the concentrations of the primary target metals in the treated effluent are below the discharge standards mandated in the EPA Action Memorandum for this site

In addition, the following secondary objectives were intended to provide additional information that will be useful in evaluating the technologies:

- Document operating parameters and assess critical operating conditions necessary to optimize system performance

- Monitor the general chemical characteristics of the ARD water as it passes through the treatment system

- Evaluate operational performance and efficiency of solids separation systems

- Determine capital and operation and maintenance costs

Evaluation Results: The compost-free bioreactor treatment system was shown to be extremely effective at neutralizing acidity and reducing the concentrations of the 5 target and 5 secondary metals in the ARD flows at Leviathan Mine to below EPA-mandated discharge standards. During the demonstration, pilot testing to determine optimal sodium hydroxide addition resulted in exceedance of discharge standards for iron; however, after optimization iron concentrations in effluent met discharge standards. The solids generated by this technology were not found to be hazardous under state or federal standards or pose a threat to water quality. A table summarizing average influent and effluent concentrations and removal efficiencies for the 5 target metals is provided below.

Key findings from the evaluation of the treatment system, including complete analytical results, operating conditions, and a cost analysis, will be published in a Technology Capsule and an Innovative Technology Evaluation Report.

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	Primary Target Metals					Secondary Water Quality Indicator Metals				
	Aluminum (mg/L)	Arsenic (mg/L)	Copper (mg/L)	Iron (mg/L)	Nickel (mg/L)	Cadmium (mg/L)	Chromium (mg/L)	Lead (mg/L)	Selenium (mg/L)	Zinc (mg/L)
Gravity Flow Configuration										
Influent	37.47	0.002	0.691	117.2	0.487	0.0006	0.012	0.004	0.014	0.715
Effluent	0.103	0.005	0.005	***4.89***	0.066	<0.0002	0.008	0.005	***0.011***	0.016
Removal Efficiency	99.7	NC	99.3	95.8	86.6	65.3	NC	NC	NC	97.8
Recirculation Configuration										
Influent	40.03	0.007	0.795	115.8	0.529	0.0006	0.011	0.004	0.012	0.776
Effluent	0.053	0.007	0.005	***2.7***	0.070	<0.0002	0.006	0.003	***0.009***	0.009
Removal Efficiency	99.9	NC	99.4	97.7	86.8	NC	42.5	41.3	NC	98.9
EPA Standard	**2.0**	**0.15**	**0.016**	**1.0**	**0.094**	**0.004**	**0.31**	**0.005**	**0.005**	**0.21**

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