Semi-Passive Bioreactors for Treatment of Acid Mine Drainage

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Abstract Semi-passive sulfate-reducing bioreactors (SPSRBs) provide unattended treatment of metals and sulfate contaminated water for extended periods of time. Sulfate-reducing bacteria consume alcohol and reduce sulfate to sulfide for metal-sulfide precipitation. Alcohols are delivered to supply the bacteria with a carbon and energy source continuously. A matrix with large pore spaces is utilized to reduce plugging and short circuiting. Metals are removed outside of the bioreactor in a settling pond by mixing treated water containing sulfide with untreated water containing metals. Water, essentially free of metals, is then pumped to the bioreactor for sulfide generation and sulfide precipitation in a seperate pond. Two semipassive bioreactors are presented, both are affective at removing metals at concentrations greater than 100 mg/L to below discharge criteria.

Key Words bioreactors, acid mine drainage, acid rock drainage, sulfate reduction, sulfate reducing bacteria, water treatment, mining remediation, passive treatment systems, and wetlands

Introduction

Sulfate-reducing bioreactors utilize sulfate-reducing bacteria to reduce sulfate to sulfide (Tuttle et al. 1969, Wakao et al. 1979, Wildman and Lauden 1989) which subsequently precipitates metals as metal sulfides (Miller 1950; Eger 1994). Most bioreactors are constructed with a passive design which does not require power and utilize a matrix that contains organic substrate such as manure or wood chips to provide the carbon and energy source for sulfate-reducing bacteria. The lifetime of these reactors is limited by the amount of available carbon for sulfate reduction and by the pore space available for metal precipitation and maintenance of hydraulic conductivity (Tsukamoto and Miller 1999).

Tsukamoto and Miller developed a semi-passive system that utilizes inexpensive liquid carbon sources such as alcohol, ethylene glycol and biodiesel waste (Tsukamoto and Miller 1999, Zamzow et al. 2006, Tsukamoto and Miller 2005, Miller and Tsukamoto 2004) in conjunction with an inert matrix that supports the growth of bacteria. Systems can also be designed with a mechanism for flushing of the metal sulfides from the system. This article focuses on two semi-passive bioreactors that were designed as an alternative to active treatment on remote sites in order to reduce costs. These systems require some power to pump water for circulation which enables the removal of metals outside of the bacterial matrix. Both of these systems can operate effectively, unmanned for extended periods of time, which reduces long term operation and maintenance costs.

Methods

Two semi-passive bioreactor systems were designed, constructed and are currently treating acid mine drainage. Both systems are located at remote sites and treat water year-round unmanned for extended periods of time. The design of the two systems are similar, however they differ in the source water that is being treated, the chemistry and flow to the systems, and the location of the settling pond with respect to the bioreactor. Both systems utilize a rock matrix for the bioreactor and incorporate a settling pond for removal and storage of metal sulfide sludge separate from the bioreactor. The rock size is slightly larger in the Nacimiento system. The carbon and energy source utilized by the bacteria on both sites is ethanol. Both systems are supplemented with sodium hydroxide to increase pH and promote metal sulfide precipitation. Both systems are equipped with system alarms and scada for remote monitoring.

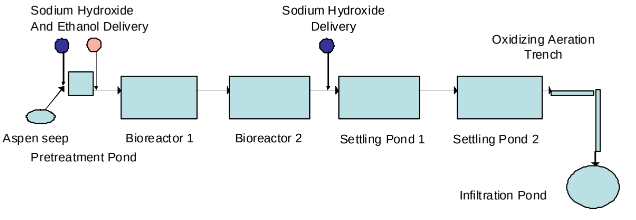
Leviathan Bioreactor

The Leviathan Mine treatment system includes a collection trench, five ponds (a pretreatment pond, two bioreactor ponds and two settling ponds) and an aeration/discharge channel. (See Figure 1). The working volume and the calculated residence times for the system components are listed in Table 1.

***Table 1** Residence Time and Working Volume for Leviathan Bioreactor*

System Component		Working Volume	Calculated Residence Time (38 Lpm)
Pretreatment Pond		100 ft^3	0.5 days
Pond 1		5,300 ft^3	3.5 days
Pond 2		3,000 ft^3	1.5 days
Settling Pond 1		16,500 ft^3	8.5 days
Settling Pond 2		18,000 ft^3	9.4 days
	Totals	**42,900** ft^3	**23 days**

***Figure 1** Designed Gravity Flow Schematic*



The system was operated as designed (as a gravity system that utilizes no power) from spring 2003 through May 2004. In this configuration, sodium hydroxide was added prior to the water entering the pretreatment pond where metal hydroxide precipitate was captured. Water was then diverted into the bioreactors where sulfate-reducing bacteria consumed ethanol and converted sulfate to sulfide. In this mode of operation some of the metals were precipitated as metal sulfides. However the majority of the iron sulfide did not precipitate due to a low operating pH within the bioreactors. Additional sodium hydroxide was added prior to the water entering the settling pond 1, where the remainder of the iron was precipitated from solution as iron sulfide and was settled out. In this mode of operation the pretreatment pond required frequent flushing which added maintenance to the system and made winter operation under freezing conditions more difficult.

A recirculation mode of operation began in 2004. Under this mode of operation, the untreated water was mixed with effluent from the bioreactors in settling pond 1 (Figure 1) When the sulfide-laden water from the bioreactors mixed with the untreated AMD from the Aspen Seep and sufficinet sodium hydroxide to increase the pH to near 7.0, metal-sulfides precipitated and settled. Metals-free water still containing sulfate was then pumped to the influent of the bioreactors (Figure 2).

Operation in this mode eliminated the need to flush the pretreatment pond and greater than 95% of the metals were removed in settling pond 1, thus isolating the precipitates from the bioreactors. The addition of pumps for recirculation and a diesel generator required maintenance, however, overall maintenance of the bioreactor system is decreased due to the isolation of sludge in Pond 3.

Nacimiento Bioreactor

The Nacimiento Mine treatment system includes a well field, a pump transfer station, a settling pond, a bioreactor and an aeration cascade and discharge channel. (See Figure 3). The working vol-

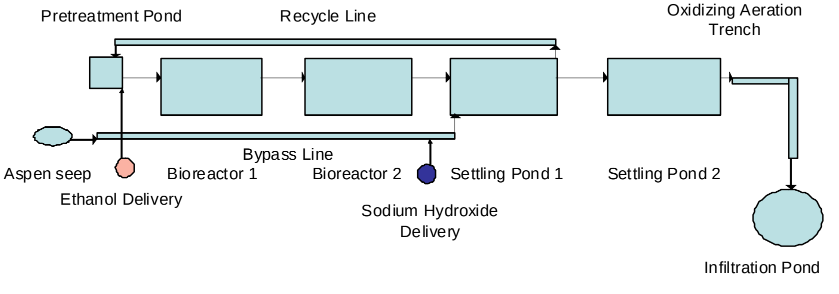
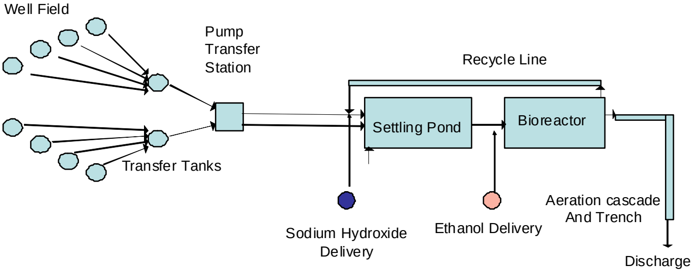


***Figure 2** Recycle Flow Schematic*

***Table 2** Residence Time and Working Volume for Leviathan Bioreactor*

System Component		Working Volume	Calculated Residence Time (240 Lpm)
Settling Pond		117,000 ft^3	7.5 days
Bioreactor		50,000 ft^3	3.2 days
	Totals	**167,000** ft^3	**10.7 days**

***Figure 3** Nacimiento Flow Schematic*



ume and the calculated residence times for the system components are listed in Table 2. The Nacimiento system also requires a pump to circulate sulfide laden water; however the bioreactor is located downstream from the settling pond. In this design all of the water must pass through the bioreactor prior to discharge. This results in lower discharge sulfate concentrations and decreases the chance of a system should the system lose sodium hydroxide or ethanol delivery.

Results

Both systems effectively treat sulfate and metals contaminated water to discharge standards with unattended operation for extended periods of time (Table 3). The Leviathan system has operated for several winters with site visits for system maintenance occurring at a frequency of one to two visits per month with minimal system upsets. The Nacimiento system flows are currently being ramped up during system start-up and acclimation with site visits of approximately three hours, three days per week. Once the system reaches operational capacity it is expected that site visit duration will decrease and the frequency will decrease to once per week, assuming the chemistry of the well field remains fairly stable. The Leviathan system is designed to treat up to 60 L/min and the Nacimiento system is designed to treat up to 450 L/min.

Although these systems can be overloaded with acidity the chance of this occurring is decreased when compared with typical passive systems because they are supplemented with sodium hydroxide to maintain a consistent pH at which the bacteria thrive. Due to the large system volume and biological activity, significant buffering exists within the system which minimizes the effects of an upset in alcohol or sodium hydroxide delivery allowing the system monitoring to be monitored less frequently than most active systems.

***Table 3** Average Influent and Effluent Concentrations of Constituents of Concern (Dissolved Metals mg/L)*

Sample Location	Number of sampling events	pH	Sulfate	Al	Cu	Fe	Ni	Zn
Leviathan Mine Influent*	7			40.0 4.837**	0.795 0.187**	116 13**	0.529 0.034**	0.776 0.052**
Leviathan Mine Effluent*	7			0.0527 0.026**	0.0046 0.003**	2.704 3.0**	0.0697 0.044**	0.0089 0.007**
Leviathan Discharge Objective*				4.000	0.026	2.000	0.840	0.210
Nacimiento Mine Influent	9	4.91	884	2.35 1.83**	17.84 25.12**	61.6 0.041**	0.09 0.041**	4.44 2.239**
Nacimiento Mine Effluent	9	6.89	385	<0.05***	0.004 0.002**	0.07 0.039**	0.0032 0.001**	0.0083 0.004**
Nacimiento Discharge Objective		6.6-8.8	NA	0.087	0.0152	NA	0.088	0.198

*Data from EPA 2006
**Standard deviation
*** 4 values detected all at less than 0.056 mg/l and an average concentration of .036 mg/L

During 2004 both modes of operation were utilized. During gravity mode operations an average of 218 mg/L of sodium hydroxide and 544 mg/L of ethanol were added. During recycle mode operations an average of 181 mg/L of sodium hydroxide and 633 mg/L of ethanol were added. The average flow in 2004 was 32 Lpm and on average 346 mg/L of sulfate were removed.

Conclusions

Historically sulfate-reducing bioreactors have been misapplied as a walk away solution to treating water with high metals concentrations. Passive systems can be effective at treating water with low metals concentrations for extended periods of time. However, the numerous system failures that have occurred due to overloading with metals and acidity have led to scepticism in the industry. Alternatively active treatment systems can treat water with very high acidity and metals loading, but often requires significant maintenance resulting in high costs in perpetuity. Semi-passive systems bridge the gap between passive bioreactors and active treatment technologies. To be sustainable these systems must incorporate a long term supply of carbon and energy source and a mechanism for metal sludge removal and management. The systems are ideal for remote applications with moderate to high acidity and metals loading. When acidity is too high sodium hydroxide supplementation may lead to detrimental concentrations of sodium in the effluent and an inability to meet discharge requirements for TDS. In those cases it is often more cost effective to use active lime precipitation treatment which also utilizes a less expensive alkalinity source.

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