United States
Environmental Protection
Agency

SUPERFUND INNOVATIVE
TECHNOLOGY EVALUATION

Technology Evaluation Bulletin

Active and Semi-Passive Lime Treatment of Acid Mine Drainage

Technology Description: Lime treatment of acid mine drainage (AMD) and acid rock drainage (ARD) is a relatively simple chemical process where low pH AMD/ARD is neutralized using lime to reduce acidity and precipitate dissolved metals as metal hydroxides. The U.S. Environmental Protection Agency (EPA), in cooperation with the state of California and Atlantic Richfield Company, evaluated lime treatment of AMD and ARD at the Leviathan Mine Superfund Site located in a remote, high altitude area of Alpine County, California. Two treatment systems were evaluated in 2002 and 2003; an active lime treatment system operated in two modes, a Biphasic mode for treatment of AMD with high metals concentrations at flows up to 700 liters per minute (L/min), and a Monophasic mode for treatment of a combined AMD/ARD with high metals concentrations at flows up to 250 L/min; and a semi-passive Alkaline Lagoon for treatment of ARD with relatively low metals concentrations at flows up to 110 L/min. EPA evaluated each lime treatment systems' ability to neutralize acidity and to reduce concentrations of five primary target metals (aluminum, arsenic, copper, iron, and nickel) and five secondary water quality indicator metals (cadmium, chromium, lead, selenium, and zinc) in the AMD and ARD to below EPA-mandated discharge standards. Historically, the concentrations of the five primary target metals in AMD and ARD released into Leviathan Creek have exceeded EPA-mandated discharge levels by up to 3,000 fold, resulting in fish and insect kills in the creek and downstream receiving waters.

Lime treatment chemistry involves reaction of excess lime with AMD or ARD (usually at a pH of 2 to 3), to raise solution pH to 7.9 to 8.2. At elevated pH, metal hydroxides and gypsum (calcium sulfate) precipitate from the AMD/ARD as shown in the following reaction:

$$Ca(OH)_{2\,(s)} + Me^{2+}/Me^{3+}{}_{(aq)} + H_2SO_4 \rightarrow Me(OH)_2/Me(OH)_{3\,(S)} + CaSO_{4\,(S)} + H_2O \quad (1)$$

Where Me^{2+}/Me^{3+} = dissolved metal ion in either a +2 or +3 valence state

At Leviathan Mine, the active lime treatment system consists of reaction tanks, flash/flocc mixing tanks, plate clarifiers, a filter press, and a settling pond. Operated in Monophasic mode, the active treatment system was evaluated for its ability to treat a combined, moderate ARD/AMD flow without regard to the type of metal or concentration. In this case, the resulting solid waste stream exhibited hazardous waste characteristics due to high arsenic and nickel concentrations, requiring disposal in a treatment, storage, and disposal (TSD) facility. Operated in Biphasic mode, the active lime treatment system was evaluated for its ability to treat a high AMD flow where concentrations of arsenic were relatively high. The overall chemical reaction is the same as for the Monophasic mode; however, metals precipitation is conducted in two phases. In Phase I, the active treatment system is held at a pH of 2.8 to 3.0 creating a small quantity of precipitate containing high arsenic concentrations, which when dewatered, exhibits hazardous waste characteristics and requires off site disposal in a TSD facility. In Phase II, the pH is raised to 7.9 to 8.2 and the remaining metals are precipitated, creating a much larger quantity of solid waste; however, arsenic concentrations are low enough that the Phase II solid waste is not classified as a hazardous waste and can be disposed of on site. Separating the arsenic into a smaller solid waste stream significantly reduces materials handling and disposal costs.

The Alkaline Lagoon treatment system is a continuous flow, lime contact system, which was evaluated for its ability to treat low flow ARD with relatively low metals content. The system consists of air sparge/lime contact tanks where initial flocc formation occurs, bag filters to capture approximately 60 percent of the flocc, and a multi-cell settling lagoon for extended lime contact with the remaining dissolved metals and precipitation of metal hydroxide. The solids captured in the bag filter and settled in the lagoon are not classified as a hazardous waste and can be disposed of on site.

Waste Applicability: Conventional methods of treating AMD and ARD involve the capture, storage, and batch or continuous treatment of water using lime addition, which neutralizes acidity and precipitates metals. Lime treatment technology is applicable to precipitation of any metal the solubility of which is pH sensitive. The active lime and alkaline lagoon treatment systems are simply improvements to conventional lime treatment technology. Either treatment system can be modified to treat wastes of varying metals type or content in a single or multi-step process. Active lime treatment appears to be applicable in situations where flow rates are high and the treatment season is short, while the semi-passive alkaline treatment lagoon favors a lower flow rate and extended treatment season.

Evaluation Approach: Evaluation of the lime treatment technologies occurred between June 2002 and October 2003, separated by winter shutdown. During operation of the lime treatment systems, multiple sampling events were conducted for each of the treatment systems. During each sampling event, EPA collected metals data from each system's influent and effluent streams, documented metals removal and reduction in acidity within each system's unit operations, and recorded operational information pertinent to the evaluation of each treatment system. The treatment systems were 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. Removal efficiencies of individual unit operations were also evaluated.

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

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 AMD or ARD water as it passes through the treatment system
- Evaluate operational performance and efficiency of solids separation systems
- Document solids transfer, dewatering, and disposal operations
- Determine capital and operation and maintenance costs

Evaluation Results: Both treatment systems were shown to be extremely effective at neutralizing acidity and reducing the concentrations of the 10 target metals in the AMD and ARD flows at Leviathan Mine to below EPA-mandated discharge standards. In general, removal efficiencies for the 10 target metals exceeded 90 percent. In addition, the active Biphasic treatment system was shown to be very effective at separating arsenic from AMD prior to precipitation of other metals, subsequently reducing the total volume of hazardous solid waste produced by the treatment system. Three tables summarizing the outcome of the technology evaluations are provided.

Table 1. Active Lime Treatment System Removal Efficiencies: Biphasic Operation in 2002 and 2003

Target Metal	Number of Sampling Events	Average Influent Concentration (μg/L)	Standard Deviation	Average Effluent Concentration (μg/L)	Standard Deviation	Exceeds Discharge Standards (Y/N)	Average Removal Efficiency (%)	Range of Removal Efficiencies (%)
Primary Target Metals								
Aluminum	12/1	381,000	48,792	1,118	782	N	99.7	99.2 to 99.9
Arsenic	12/1	2,239	866	8.6	1.9	N	99.6	99.2 to 99.8
Copper	12/1	2,383	276	8.0	2.5	N	99.7	99.4 to 99.8
Iron	12/1	461,615	100,251	44.9	66.2	N	100	99.9 to 100
Nickel	12/1	7,024	834	34.2	15.4	N`	99.5	99.2 to 99.9
Secondary Water Quality Indicator Metals								
Cadmium	12/1	54.4	6.1	0.70	0.28	N	98.7	97.5 to 99.4
Chromium	12/1	877	173	5.7	12.2	N	99.3	93.8 to 99.9
Lead	12/1	7.6	3.6	2.0	1.1	N	78.3	69.2 to 86.7
Selenium	12/1	4.3	3.9	3.8	1.5	N	NC	NC
Zinc	12/1	1,469	176	19.3	8.9	N	98.7	97.4 to 99.4

NC = Not calculated as influent and effluent concentrations were not statistically different
μg/L = Microgram per liter

Table 2. Active Lime Treatment System Removal Efficiencies: Monophasic Operation in 2003								
Target Metal	Number of Sampling Events	Average Influent Concentration (μg/L)	Standard Deviation	Average Effluent Concentration (μg/L)	Standard Deviation	Exceeds Discharge Standards (Y/N)	Average Removal Efficiency (%)	Range of Removal Efficiencies (%)
Primary Target Metals								
Aluminum	7	107,800	6,734	633	284	N	99.5	99.0 to 99.8
Arsenic	7	3,236	252	6.3	3.5	N	99.8	99.7 to 99.9
Copper	7	2,152	46.4	3.1	1.5	N	99.4	99.0 to 99.7
Iron	7	456,429	49,430	176	130	N	100.0	99.9 to 100.0
Nickel	7	2,560	128	46.8	34.7	N	97.9	95.7 to 99.3
Secondary Water Quality Indicator Metals								
Cadmium	7	26.1	14.1	0.2	0.027	N	99.1	98.4 to 99.7
Chromium	7	341	129	3.0	3.8	N	99.0	95.6 to 99.8
Lead	7	6.2	3.6	1.6	1.3	N	74.6	48.3 to 89.8
Selenium	7	16.6	13.6	2.1	0.43	N	93.1	91.0 to 94.4
Zinc	7	538	28.9	5.6	3.6	N	98.9	97.7 to 99.6

μg/L = Microgram per liter

Table 3. Alkaline Lagoon Treatment System Removal Efficiencies in 2002								
Target Metal	Number of Sampling Events	Average Influent Concentration (μg/L)	Standard Deviation	Average Effluent Concentration (μg/L)	Standard Deviation	Exceeds Discharge Standards (Y/N)	Average Removal Efficiency (%)	Range of Removal Efficiencies (%)
Primary Target Metals								
Aluminum	8	31,988	827	251	160	N	99.2	98.0 to 99.5
Arsenic	8	519	21.9	5.8	3.2	N	98.9	97.6 to 99.5
Copper	8	13.5	2.5	5.5	2.0	N	58.3	27.7 to 74.5
Iron	8	391,250	34,458	148	173	N	100	99.9 to 100
Nickel	8	1,631	47.0	22.6	10.3	N	98.6	97.2 to 99.1
Secondary Water Quality Indicator Metals								
Cadmium	8	0.2988	0.0035	0.4	0.1	N	NC	NC
Chromium	8	19.3	2.0	2.3	0.9	N	88.5	83.1 to 92.3
Lead	8	5.1	1.2	1.7	0.8	N	66.4	37.7 to 78.9
Selenium	8	3.3	1.6	3.2	1.3	N	NC	NC
Zinc	8	356	6.6	14.2	8.6	N	96.0	90.6 to 98.2

NC = Not calculated as influent and effluent concentrations were not statistically different
μg/L = Microgram per liter

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

For further information contact:

Edward Bates, U.S. EPA Project Manager
EPA National Risk Management Research Laboratory
Office of Research and Development
26 West Martin Luther King Dr.
Cincinnati, OH 45268
(513) 569-7774
bates.edward@epa.gov

United States
Environmental Protection
Agency

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Research Laboratory
Cincinnati, OH 45268

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