United States
Environmental Protection
Agency

SITE Technology Capsule

Active and Semi-Passive Lime Treatment of Acid Mine Drainage

Abstract

As part of the Superfund Innovative Technology Evaluation (SITE) program, U.S. Environmental Protection Agency's (EPA's) National Risk Management Research Laboratory (NRMRL), in cooperation with EPA Region IX, the state of California, and Atlantic Richfield Company (ARCO) evaluated lime treatment of acid mine drainage (AMD) and acid rock drainage (ARD) at the Leviathan Mine Superfund site located in Alpine County, California. EPA evaluated two lime treatment systems in operation at the mine in 2002 and 2003: an active treatment system operated in Biphasic and Monophasic modes, and a semi-passive Alkaline Lagoon treatment system. The treatment systems utilize the same chemistry to treat AMD and ARD, specifically the addition of lime to neutralize acidity and remove toxic levels of metals by precipitation. The primary metals of concern in the AMD and ARD include aluminum, arsenic, copper, iron, and nickel; secondary water quality indicator metals include cadmium, chromium, lead, selenium, and zinc.

The technology evaluation occurred between June 2002 and October 2003, during the operation of both the active lime treatment system (in Biphasic and Monophasic modes) and the semi-passive Alkaline Lagoon treatment system. The evaluation consisted of multiple sampling events of each treatment system during 6 months of operation separated by winter shutdown. Throughout the evaluations, EPA collected metals data on 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. EPA evaluated the treatment systems independently, based on removal efficiencies for primary and secondary target metals, comparison of effluent concentrations to discharge standards mandated by EPA in 2002, and on the characteristics of resulting metals-laden solid wastes. Removal efficiencies of individual unit operations were also evaluated.

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 discharge standards. Although the influent concentrations for the primary target metals were up to 3,000 fold above the EPA discharge standards, both lime treatment systems were successful in reducing the concentrations of the primary target metals in the AMD and ARD to between 4 and 20 fold below the discharge standards. In general, removal efficiencies for the 5 primary target metals exceeded 95 percent. In addition, the active treatment system operated in Biphasic mode was shown to be very effective at separating arsenic from the AMD prior to precipitation of other metals, subsequently reducing the total volume of hazardous solid waste produced by the treatment system. Separating the arsenic into a smaller solid waste stream significantly reduces materials handling and disposal costs.

Based on the success of lime treatment at the Leviathan Mine site, the state of California will continue to treat AMD at the site using the active lime treatment system in Biphasic mode and ARCO will continue to treat ARD using the semi-passive Alkaline Lagoon treatment system.

Introduction

In 1980, the U.S. Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as Superfund. CERCLA is committed to protecting human health and the environment from uncontrolled hazardous waste sites. In 1986, CERCLA was amended by the Superfund Amendments and Reauthorization Act (SARA). These amendments emphasize the achievement of long-term effectiveness and permanence of remedies at Superfund sites. SARA mandates the use of permanent solutions, alternative treatment technologies, or resource recovery technologies, to the maximum extent possible, to clean up hazardous waste sites.

State and Federal agencies, as well as private parties, have for several years now been exploring the growing number of innovative technologies for treating hazardous wastes. EPA has focused on policy, technical, and informational issues related to exploring and applying new remediation technologies applicable to Superfund sites. One such initiative is EPA's SITE program, which was established to accelerate the development, demonstration, and use of innovative technologies for site cleanups. Technology Capsules summarize the latest information available on selected innovative treatment, site remediation technologies, and related issues. These capsules are designed to help EPA remedial project managers and on-scene coordinators, contractors, and other site cleanup managers understand the types of data and site characteristics needed to effectively evaluate a technology's applicability for cleaning up Superfund sites.

This capsule provides information on new approaches to the use of lime addition to reduce the concentration of toxic metals and acidity in AMD and ARD at Leviathan Mine. The active and semi-passive lagoon treatment systems implemented by the state of California and ARCO were specifically designed to treat high flow rates of AMD and ARD containing thousands of milligrams per liter (mg/L) of heavy metals at a pH as low as 2.0 that would otherwise be released to the environment. The site also poses operational challenges associated with its remote location and winter weather conditions that require shutdown of site operations from late fall through late spring. This capsule presents the following information that documents the evaluation of the two lime treatment systems:

- Project background
- Technology description
- Performance data
- Process residuals
- Technology applicability
- Technology limitations
- Site requirements
- Technology status
- Sources of further information

Project Background

Leviathan Mine is a former copper and sulfur mine located high on the eastern slopes of the Sierra Nevada Mountain range, near the California-Nevada border. The mine occupies approximately 102 hectares on the northwestern flank of Leviathan Peak, at an elevation of about 2,150 meters. The mine site is drained by Leviathan and Aspen creeks, which combine with Mountaineer Creek 3.5 kilometer below the mine to form Bryant Creek, a tributary to the East Fork of the Carson River. Intermittent mining of copper sulfate, copper, and sulfur minerals since the mid 1860s has resulted in extensive AMD and ARD at Leviathan Mine. During the process of converting underground workings into an open pit mine in the 1950s, at least 22 million tons of overburden and waste rock were removed from the open pit mine and distributed across the site. Oxidation of sulfur and sulfide minerals within the mine workings and waste rock forms sulfuric acid (H_2SO_4), which liberates toxic metals from the mine wastes creating AMD and ARD. AMD and ARD at Leviathan Mine contain very high concentrations of toxic metals, including arsenic. The arsenic concentration in the AMD is relatively high in comparison to the arsenic concentration in the ARD, which is a significant factor in selecting the type of lime treatment applied to each source of acid drainage.

Historically, the concentrations of five primary target metals, aluminum, arsenic, copper, iron, and nickel in the AMD and ARD released to Leviathan Creek have exceeded EPA discharge standards up to 3,000 fold. When released from the Leviathan Mine site, elevated concentrations of these metals have resulted in fish and insect kills in Leviathan Creek, Bryant Creek, and the east fork of the Carson River. However, in 1984 the state of California significantly reduced the quantity of toxic metals discharging from the mine site through physical actions. Work conducted at the site included partially filling and grading the open pit, building retention ponds to contain the AMD, building a channel under-drain (CUD) system to capture ARD, and rerouting Leviathan Creek through a concrete diversion channel to reduce contact with waste rock. To further reduce the amount of toxic metals discharging from the mine site, the state of California implemented the active lime treatment system in 1999 to treat AMD that collects in the retention ponds.

Because of the high concentration of arsenic in the AMD, the state of California chose to operate the active treatment system in Biphasic mode. This allows removal of arsenic separately from the other target metals, resulting in a smaller quantity of hazardous solid waste that must be disposed of off site. In 2001, ARCO implemented the semi-passive Alkaline Lagoon treatment system to treat ARD from the CUD. The Alkaline Lagoon system operates in a single phase resulting in one solid waste stream. Because the ARD is relatively low in arsenic, the solid waste stream generated by the Alkaline Lagoon system is non-hazardous; therefore costly off site disposal is not necessary.

Technology Description

Lime treatment of AMD and ARD is a relatively simple chemical process where low pH AMD/ARD is neutralized using lime to precipitate dissolved iron, the main component of AMD and ARD, and other dissolved metals as metal hydroxides and oxy-hydroxides. In the active lime treatment system, the precipitation process is either performed in a single stage (Monophasic mode), or two stages (Biphasic mode). In Monophasic mode, the pH of the AMD/ARD is raised to precipitate out all of the target metals resulting in a large quantity of metals-laden sludge. The precipitation occurs under 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

The optimum pH range for this precipitation reaction is between 7.9 and 8.2. Along with metal hydroxides, excess sulfate in the AMD/ARD precipitates with excess calcium as calcium sulfate (gypsum). However, because sulfate removal is not a goal of the process, the treatment system is optimized for metals removal, leaving excess sulfate in solution. The Monophasic mode of operation was used to treat a mixture of AMD and ARD with varying concentrations of metals. The active lime treatment system operated in Monophasic mode requires about 1.3 grams lime to neutralize 1 liter of the combined AMD/ARD. The active lime treatment system consists of reaction tanks, flash/flocc mixing tanks, plate clarifiers, and a filter press. Because of elevated arsenic concentrations, the resulting solid waste exhibits hazardous waste characteristics and typically requires off site disposal at a treatment, storage, and disposal (TSD) facility. The Monophasic configuration of the active lime treatment system is shown in Figure 1-1.

The active lime treatment system operated in Biphasic mode is preferred at Leviathan Mine for treating AMD where concentrations of arsenic are relatively high. In this case, the active lime treatment system creates a small quantity of precipitate from the first reaction phase (Phase I) that contains a high concentration of arsenic and a large quantity of low-arsenic content precipitate. Separating the arsenic into a smaller solid waste stream significantly reduces the cost of disposal. In Biphasic mode, lime is added to raise the pH high enough to reach the 56 percent iron removal equivalence point, which occurs in the ferric iron hydroxide buffering zone. In this zone, ferric iron precipitates from solution as ferric hydroxide under the following reaction:

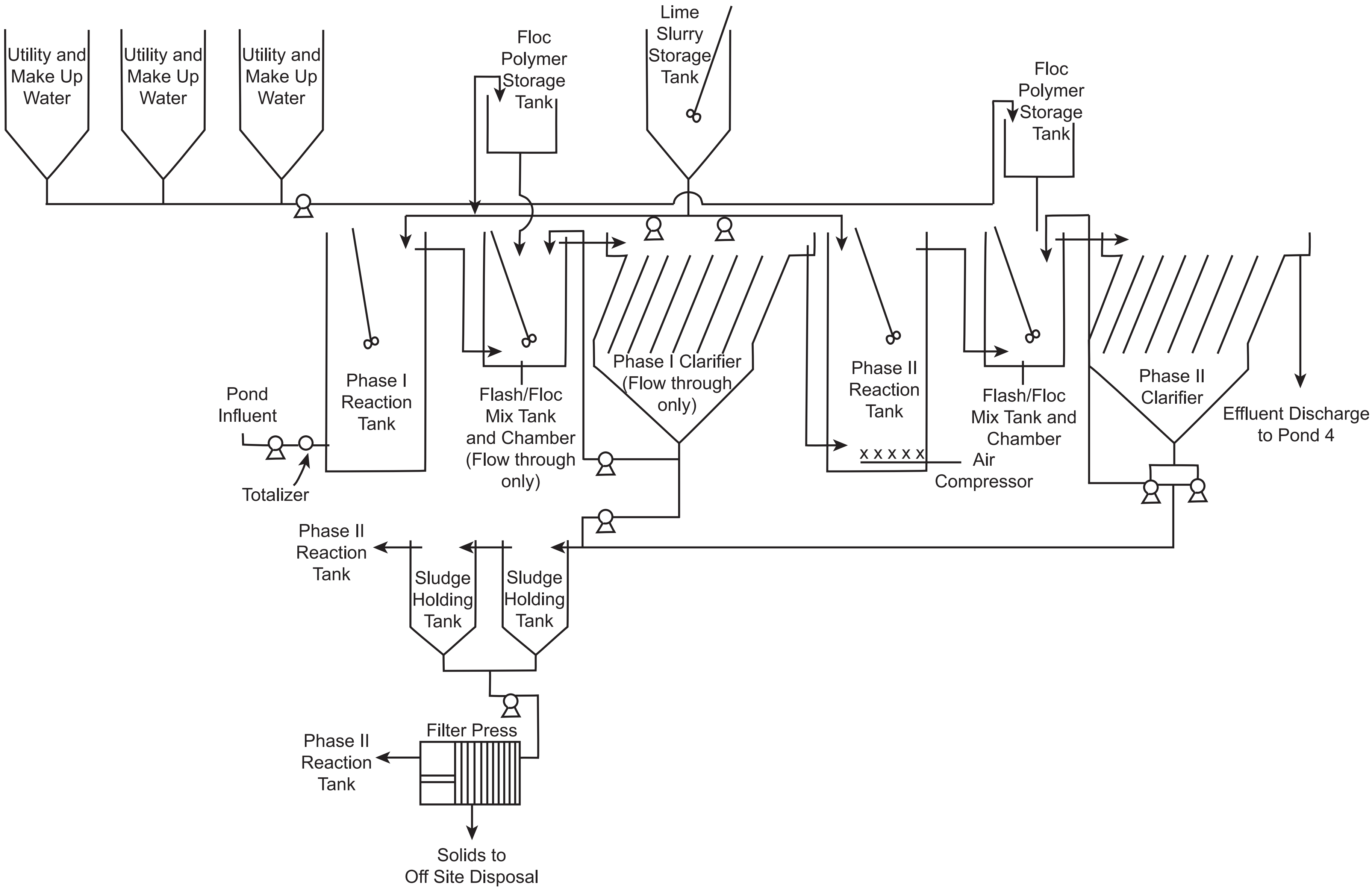
$$3Ca(OH)_{2\,(s)} + 2Fe^{3+}{}_{(aq)} \rightarrow 3Ca^{2+}{}_{(aq)} + 2Fe(OH)_{3\,(s)} \quad (2)$$

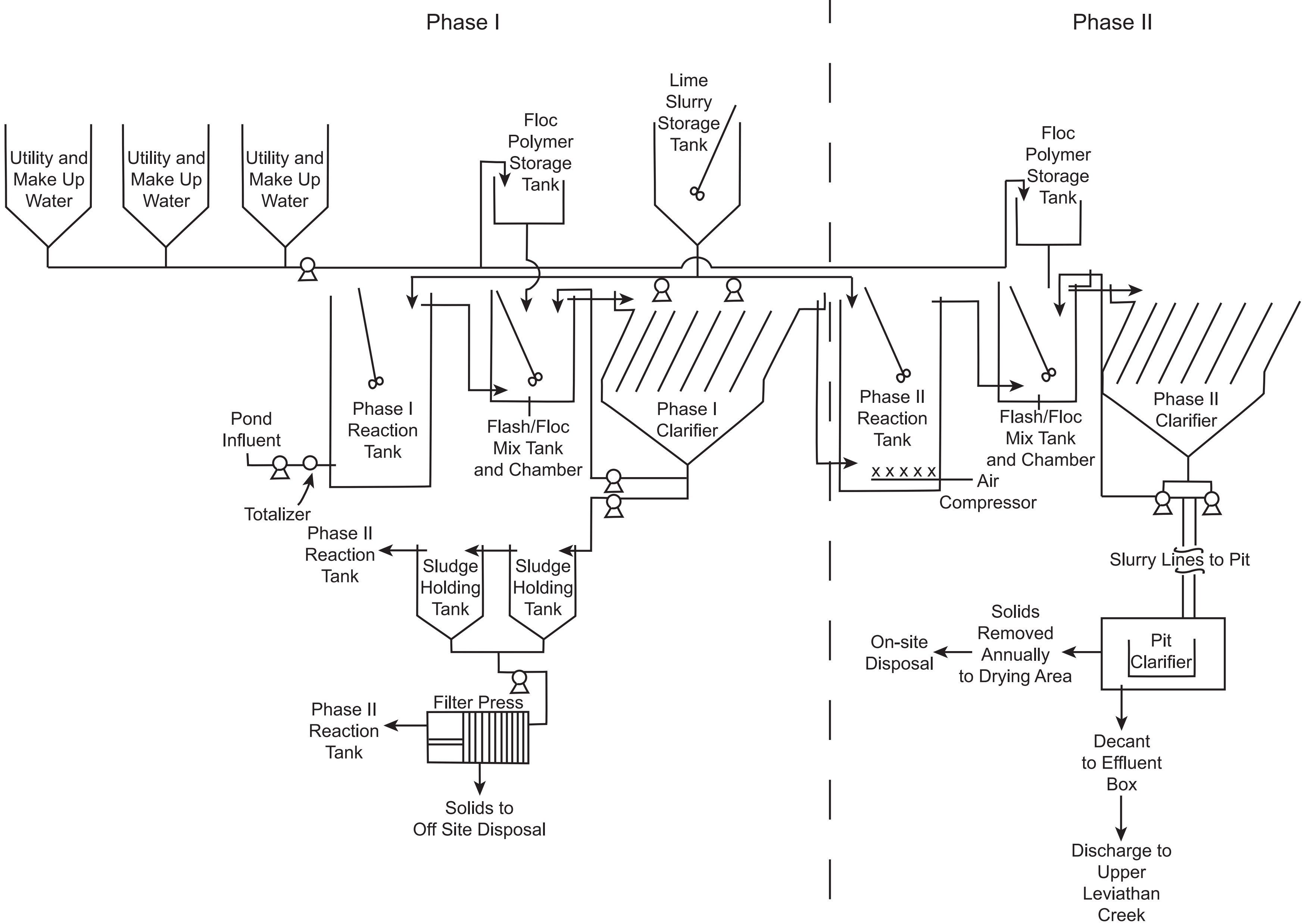
The optimum pH range for this precipitation reaction is between 2.8 and 3.0. During precipitation, a large portion of the arsenic adsorbs to the ferric hydroxide precipitate. The solution pH remains nearly constant in this zone as long as excess soluble iron is available to buffer the addition of lime. Given enough reaction time, it is in this zone (the 56 percent iron removal equivalence point) that maximum arsenic removal occurs. The small quantity of iron and arsenic rich precipitate generated is dewatered using a filter press. After dewatering, the small amount of Phase I filter cake generated exhibits hazardous characteristics due to the high concentration of arsenic and is typically shipped off site for disposal at a TSD facility.

In Phase II of the Biphasic process, the pH is further raised through lime addition to precipitate out the remaining target metals forming a large quantity of Phase II sludge, as described in Reaction (1). Again, the optimum pH range for the second precipitation reaction is between 7.9 and 8.2. The Phase II sludge typically does not exhibit hazardous waste characteristics because the majority of the arsenic was removed in Phase I. The Phase II pit clarifier sludge is typically disposed of onsite. The active lime treatment system operated in Biphasic mode uses about 4.5 grams of lime to neutralize 1 liter of AMD. The Biphasic configuration of the active lime treatment system utilizes the same equipment as the Monophasic configuration, though operated in a two-step process, and includes the addition of an extended settling pit clarifier, as shown in Figure 1-2.

The Alkaline Lagoon treatment system is a continuous flow, lime contact system, also designed for metal hydroxide precipitation. This system was designed to treat the ARD at Leviathan Mine, which has low arsenic content. The system consists of air sparge/lime contact tanks where initial precipitation occurs, bag filters capture approximately 60 percent of the precipitate. The system relies on iron oxidation during mechanical aeration, optimization of lime dosage, and adequate cake thickness within each bag filter to filter precipitate from the treated ARD. The system also includes a multi-cell settling lagoon for extended lime contact and final precipitation of metal hydroxides. Bag filter and lagoon solids are typically disposed of on site. The reaction chemistry is the same as the active lime treatment system operated in Monophasic mode, as described in Reaction (1). The Alkaline Lagoon system requires about 1.6 grams of lime to neutralize 1 liter of ARD. A process flow diagram for the Alkaline Lagoon lime treatment system is presented in Figure 1-3.

Active Lime Treatment System Operation: Influent to the active lime treatment system consists of AMD pumped out of the on site retention ponds. In the Biphasic mode (Figure 1-2), influent is pumped from Pond 1 at a flow rate of up to 700 liters per minute (L/min) into the 40,000 liter Phase I reaction tank. Lime is then added to raise the pH to approximately 2.8 to 3.0. In this pH range, a portion of the dissolved ferrous iron is oxidized to ferric iron and precipitates out of solution (as


Utility and Make Up Water
Utility and Make Up Water
Utility and Make Up Water
Floc Polymer Storage Tank
Lime Slurry Storage Tank
Floc Polymer Storage Tank
Pond Influent
Totalizer
Phase I Reaction Tank
Flash/Floc Mix Tank and Chamber (Flow through only)
Phase I Clarifier (Flow through only)
Phase II Reaction Tank
x x x x x
Air Compressor
Flash/Floc Mix Tank and Chamber
Phase II Clarifier
Effluent Discharge to Pond 4
Phase II Reaction Tank
Sludge Holding Tank
Sludge Holding Tank
Filter Press
Phase II Reaction Tank
Solids to Off Site Disposal


Phase I
Phase II
Utility and Make Up Water
Utility and Make Up Water
Utility and Make Up Water
Floc Polymer Storage Tank
Lime Slurry Storage Tank
Floc Polymer Storage Tank
Pond Influent
Totalizer
Phase I Reaction Tank
Flash/Floc Mix Tank and Chamber
Phase I Clarifier
Phase II Reaction Tank
x x x x x
Air Compressor
Flash/Floc Mix Tank and Chamber
Phase II Clarifier
Phase II Reaction Tank
Sludge Holding Tank
Sludge Holding Tank
Filter Press
Phase II Reaction Tank
Solids to Off Site Disposal
Slurry Lines to Pit
Pit Clarifier
Solids Removed Annually to Drying Area
On-site Disposal
Decant to Effluent Box
Discharge to Upper Leviathan Creek

ferric hydroxide) along with the majority of dissolved arsenic. The process solution then flows to a 4,000 liter flash/flocc mixing tank where a polymer flocculent is added to promote growth of ferric iron hydroxide and adsorbed arsenic flocc. The process solution then flows into the 40,000 liter Phase I clarifier for flocc settling and thickening. Supernatant from the Phase I clarifier flows into the Phase II reaction tank for additional lime treatment of remaining acidity and target metals. The thickened ferric iron hydroxide and arsenic solids are periodically pumped from the bottom of the Phase I clarifier into sludge holding tanks, and then into a batch filter press for dewatering. The small volume of arsenic-laden Phase I filter cake is disposed of as a hazardous waste at an off site TSD facility. Supernatant from the sludge holding tanks and filtrate from the filter press are pumped to the Phase II reaction tank for additional treatment. The total hydraulic residence time for Phase I of the active lime treatment system is about two hours at maximum flow rate.

To complete the precipitation of metals during Biphasic operation, the pH of the process solution in the 40,000 liter Phase II reaction tank is raised to approximately 7.9 to 8.2 by adding additional lime. The process solution then flows to a 4,000 liter flash/flocc mixing tank where a polymer flocculent is added to promote growth of the metal hydroxide flocc. The process solution then flows into a 40,000 liter Phase II clarifier. The slurry is pumped from the bottom of the Phase II clarifier uphill to the 3.1 million liter pit clarifier, located within the mine pit, for extended settling. Supernatant from the pit clarifier that meets the discharge standards is released by gravity flow to Leviathan Creek. If the supernatant from the pit clarifier does not meet discharge standards, it is returned to Pond 1 for additional treatment. The non-hazardous metals-laden precipitate is dewatered, air dried, and removed from the pit clarifier every three years, and disposed of on site. The total hydraulic residence time for Phase II of the active lime treatment system is about 3 to 6 days.

The active lime treatment system operated in the Monophasic mode (Figure 1-1) utilizes the same process equipment as the system operated in Biphasic mode; however, the precipitation process results in a single “output stream” of metals-laden precipitate that is thickened in the Phase II clarifier and dewatered using a batch filter press. Other changes include a lower influent flow rate of up to 250 L/min due to hydraulic residence time and thickening limitations of the Phase II clarifier, and a difference in the makeup of the source water (a mixture of low-arsenic content ARD and high-arsenic content AMD). Because of the elevated arsenic concentrations in the source water, the resulting filter cake from operation of the active lime treatment system in Monophasic mode exceeds state hazardous waste criteria and must be disposed of at an off site TSD facility.

Semi-passive Alkaline Lagoon Treatment System Operation: ARCO first tested the Alkaline Lagoon treatment system in 2001 for treatment of ARD recovered from the CUD. During operation of the Alkaline Lagoon treatment system (Figure 1-3), the ARD from the CUD is pumped to the head of the Alkaline Lagoon treatment system, which is located on a high density polyethylene (HDPE)-lined treatment pad along the north berm of the treatment lagoon. The influent is pumped uphill from the CUD at a flow rate up to 120 L/min into three 4,000 liter lime contact reactors; the reactors have a combined hydraulic residence time of 100 minutes at maximum flow rate. Lime is added to each of the lime contact reactors to raise the pH to about 8.0. The reactors are sparged with compressed air to provide vigorous mixing of the lime/ARD solution. Air sparging also helps to oxidize ferrous iron to ferric iron, which reduces lime demand. During sparging, metal hydroxide flocc forms within the reaction tanks. The process solution then flows by gravity through a series of six 5- by 5-meter spun fabric bag filters to remove the metal hydroxide flocc.

The bag filtration process relies on the build up of filter cake on the inside of each bag to remove progressively smaller flocc particles. Effluent from the bag filters, including soluble metals, unreacted lime, and flocc particles too small to be captured, flows by gravity into the 5.4 million liter multi-cell settling lagoon. The settling lagoon is divided into two sections using an anchored silt fence. Unsettled solids are captured on the silt screen between the two cells. The settling lagoon typically provides a hydraulic residence time of 415 hours at a flow rate of 120 L/min. This extended residence time facilitates contact of any remaining dissolved metals with unreacted lime. Effluent from the settling lagoon that meets EPA discharge standards is periodically discharged to Leviathan Creek. The non-hazardous precipitate captured in the bag filters and settled in the lagoon is periodically recovered, air dried, and stored onsite.

Performance Data

The evaluation of the lime treatment systems at Leviathan Mine was conducted between June 2002 and October 2003; focusing on two primary objectives. The first objective was to determine the removal efficiencies for the primary metals of concern and the secondary water quality indicator metals. The second objective was to determine whether the concentrations of the primary metals in the effluent from the lime treatment systems were below EPA discharge standards, as presented in Table 1.

The data evaluation was designed to address both primary objectives and included both descriptive and inferential statistics. Descriptive summary statistics of the data were calculated to screen the sample data for possible outliers; these statistics

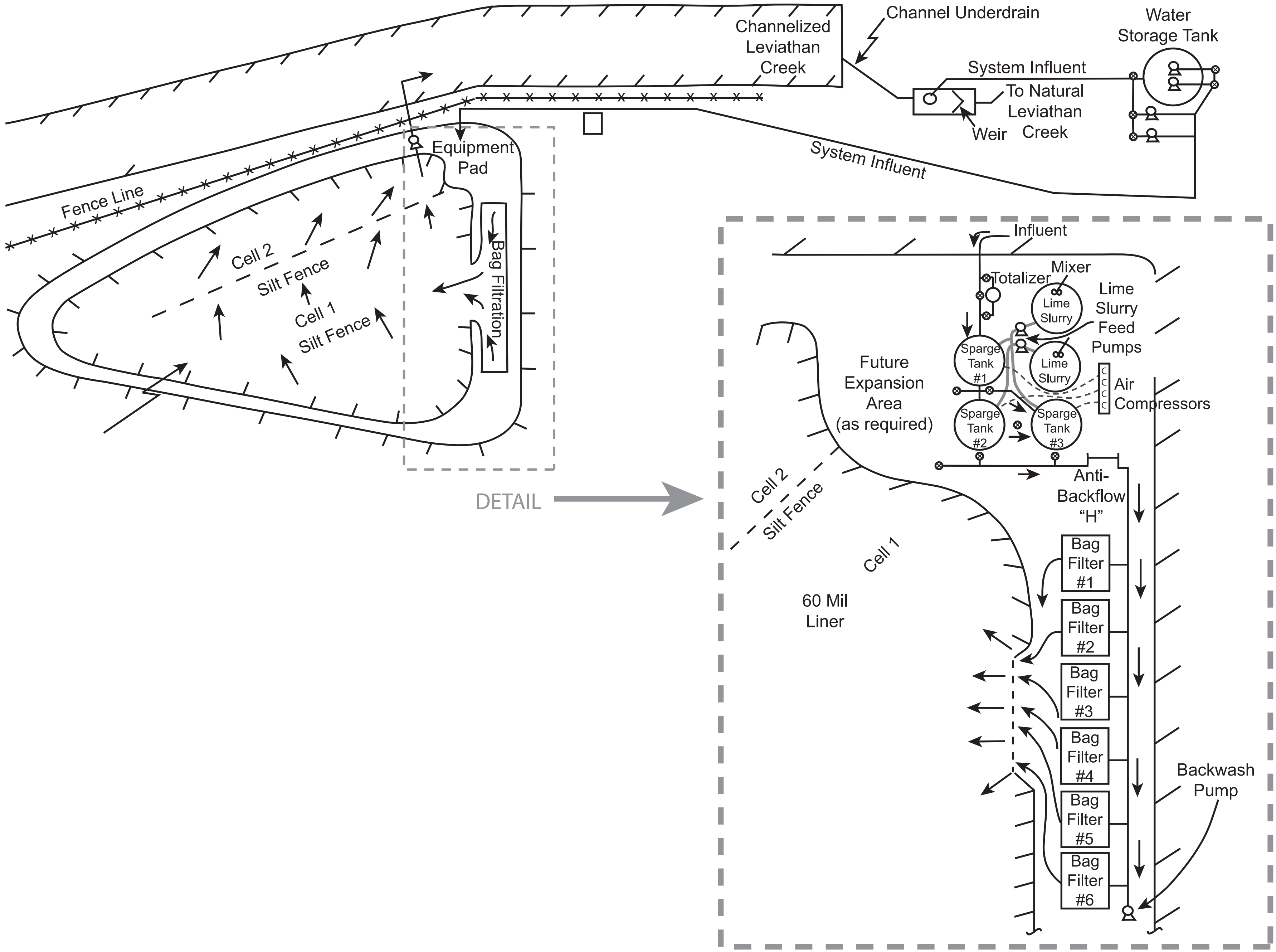

Channel Underdrain
Water Storage Tank
Channelized Leviathan Creek
System Influent
To Natural Leviathan Creek
Weir
System Influent
Fence Line
Equipment Pad
Cell 2
Silt Fence
Cell 1
Silt Fence
Bag Filtration
DETAIL
Influent
Totalizer
Mixer
Lime Slurry
Lime Slurry Feed Pumps
Lime Slurry
Sparge Tank #1
Sparge Tank #2
Sparge Tank #3
Air Compressors
C
C
C
C
Future Expansion Area (as required)
Anti-Backflow "H"
Cell 2
Silt Fence
Cell 1
60 Mil Liner
Bag Filter #1
Bag Filter #2
Bag Filter #3
Bag Filter #4
Bag Filter #5
Bag Filter #6
Backwash Pump

Table 1. EPA Discharge Standards for Metals of Concern at Leviathan Mine		
Target Metals	Maximum (a) (µg/L)	Average (b) (µg/L)
Primary Target Metals		
Aluminum	4,000	2,000
Arsenic	340	150
Copper	26	16
Iron	2,000	1,000
Nickel	840	94
Secondary Water Quality Indicator Metals		
Cadmium	9.0	4.0
Chromium	970	310
Lead	136	5.0
Selenium	No Standard	5.0
Zinc	210	210

(a) Maximum concentration based on a daily composite of three grab samples
(b) Average concentration based on four daily composite samples
µg/L = microgram per liter

included the mean, median, range, variance, and standard deviation. To successfully calculate removal efficiencies for each metal, influent concentrations must be significantly different than effluent concentrations. A paired t-test was applied to the data collected during each sampling event to determine if the influent and effluent concentrations were statistically different. Where influent and effluent concentrations for a particular metal were not statistically different, removal efficiencies were not calculated for that metal. In addition, removal efficiencies were not calculated for individual influent/effluent data pairs when both concentrations for a metal were not detected.

Tables 2 through 4 present the average and range of removal efficiencies for filtered influent and effluent samples collected from each treatment system during the evaluation period. A summary of the average influent and effluent metals concentrations for each treatment system is also presented. The results of a comparison of the average effluent concentration for each metal to the EPA discharge standards is also presented; where a "Y" indicates that either the maximum concentration (based on a daily composite of three grab samples) and/or the average concentration (based on four daily composite samples) was exceeded; and an "N" indicates that neither discharge standard was exceeded.

Although the influent concentrations for the primary target metals were up to 3,000 fold above EPA discharge standards, both lime treatment systems were successful in reducing the

Table 2. 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 3. 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 4. 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								

concentrations of the primary target metals in the AMD and ARD to between 4 and 20 fold below the discharge standards. In addition, the concentrations of the secondary water quality indicator metals in the AMD and ARD were reduced to below the discharge standards. The active lime treatment system operated in the Biphasic mode treated 28.3 million liters of AMD using 125 tons of lime. The active lime treatment system operated in the Monophasic mode treated 17.4 million liters of combined AMD and ARD using 23.8 tons of lime. The Alkaline Lagoon system treated 12.3 million liters of ARD using 19.4 tons of lime.

For both modes of the active lime treatment system, the average removal efficiency for the primary target metals was 99.6 percent over 20 sampling events. For the Alkaline Lagoon treatment system, with the exception of copper, the average removal efficiency for the primary target metals in the ARD was 99.2 percent over eight sampling events. Removal efficiencies for selenium in the AMD flow and selenium and cadmium in the ARD flow were not calculated because the influent and effluent metals concentrations were not statistically different. In the case of lead in both the AMD and ARD flows and copper in the ARD flow, concentrations were near or below the EPA discharge standards in the influent; therefore, the systems were not optimized for removal of these metals resulting in lower removal efficiencies.

The lime treatment systems are extremely effective at neutralizing acidity and reducing metals content in AMD and ARD, with resulting effluent streams that meet EPA discharge standards for the primary target metals and the secondary water quality indicator metals. Based on the success of lime treatment at the site, the state of California will continue to treat AMD at the site using the active lime treatment system in Biphasic mode and ARCO will continue to treat ARD using the semi-passive Alkaline Lagoon treatment system.

A more detailed evaluation of the lime treatment technology, including discussion of secondary project objectives, is presented in the Innovative Technology Evaluation Report (ITER).

Process Residuals

There is one process residual associated with lime treatment of AMD and ARD. The process produces a large quantity of metal hydroxide sludge and filter cake. During operation in Biphasic mode, the active treatment system produced 43.8 dry tons of Phase I filter cake consisting mainly of iron and arsenic hydroxides and 211.6 dry tons of Phase II sludge consisting of metal hydroxides high in iron, aluminum, copper, nickel, and zinc. In addition, gypsum is also a component of the Phase II sludge. During operation in Monophasic mode, the active treatment system produced 20.4 dry tons of filter cake consisting of metal hydroxides and gypsum. The semi-passive Alkaline Lagoon treatment system produced 12.6 dry tons of sludge consisting of metal hydroxides and gypsum.

The solid waste residuals produced by the treatment systems were analyzed for hazardous waste characteristics. Total metals and leachable metals analyses were performed on the solid wastes for comparison to California and federal hazardous waste classification criteria. To determine whether the residuals are California hazardous waste, total metals results (wet weight) were compared to Total Threshold Limit Concentration (TTLC) criteria. To determine whether the residuals pose a threat to water quality, metals concentrations in Waste Extraction Test (WET) leachate samples were compared to Soluble Threshold Limit Concentration (STLC) criteria. To determine if the residuals are a Resource Conservation and Recovery Act (RCRA) waste, Toxicity Characteristic Leaching Procedure (TCLP) results were compared to TCLP limits. The hazardous waste characteristics determined for the solid waste streams are presented in Table 5. With the exception of the Phase II pit clarifier sludge produced in 2003, the solid waste streams that failed the TTLC, STLC, or TCLP criteria were transported to an off site TSD facility for disposal. Solid waste streams that passed both state and federal hazardous waste criteria were disposed of in the mine pit.

Technology Applicability

Lime treatment of AMD and ARD at Leviathan Mine was evaluated based on nine criteria used for decision making in the Superfund feasibility study process. Results of the evaluation are summarized in Table 6. The active and semi-passive lime treatment systems evaluated were specifically designed to treat AMD and ARD at the mine site to meet EPA discharge standards. In addition to the five primary target metals of concern, EPA identified the following metals as secondary water quality indicator metals: cadmium, chromium, lead, selenium, and zinc. The lime treatment systems implemented at Leviathan Mine were also successful at reducing concentrations of these metals in the AMD and ARD to below EPA discharge standards. Either treatment system can be modified to treat wastes with varying metals concentrations and acidity.

Technology Limitations

In general, the limitations of the lime treatment systems implemented at Leviathan Mine were not related to the applicability of the technology, but rather to operational issues due to weather conditions, maintenance problems, and the remoteness of the site. Because of the sub-freezing temperatures encountered in the high Sierras during the winter months, the lime treatment systems were required to be shut down from late fall through late spring. The systems must be completely drained and winterized to prevent damage to pumps, tanks, and system piping. The process of winterizing and de-winterizing either treatment system is time consuming and manpower intensive.

During extended operation of the lime treatment systems, lime storage tanks, reaction tanks, lime transfer and process water pumps, feed and transfer piping, and process monitoring probes were very susceptible to lime and gypsum fouling. The treatment systems were maintenance intensive and had to be monitored regularly to maintain proper operating conditions. In several instances, sections of piping were replaced, pumps were upgraded, and monitoring devices were replaced due to gypsum fouling. Continued optimization of lime dosage and equipment improvements would likely reduce downtime associated with lime and gypsum fouling.

The remoteness of the site also created logistical challenges in maintaining operation of the lime treatment systems. Consumable materials, such as lime and diesel fuel (to power generators), were stored in bulk at the site. In one instance, a shipment of lime had to be diverted to a secondary route because of traffic issues; the diversion resulted in a half-day delay in the delivery of the lime. During operation of the treatment systems in early fall and late spring, unexpected freezing temperatures can cause pipe breakage. In addition, early and late snowfall events can prevent site access. Careful planning is essential to maintain supplies of consumable materials and replacement equipment at a remote site such as Leviathan Mine.

Table 5. Determination of Hazardous Waste Characteristics for Solid Waste Streams at Leviathan Mine								
Treatment System	Mode of Operation	Operational Year	Solid Waste Stream Evaluated	Total Solid Waste Generated	TTLC	STLC	TCLP	Waste Handling Requirement
					Pass or Fail	Pass or Fail	Pass or Fail	
Active Lime Treatment System	Biphasic	2002	Phase I Filter Cake	22.7 dry tons	F	F	P	Off site TSD Facility
			Phase II Pit Clarifier Sludge	118 dry tons	P	P	P	On site Disposal
		2003	Phase I Filter Cake	21.1 dry tons	F	P	P	Off site TSD Facility
			Phase II Pit Clarifier Sludge	93.6 dry tons	P	F	P	On site Storage
	Monophasic	2003	Filter Cake	20.4 dry tons	F	F	P	Off site TSD Facility
Semi-Passive Alkaline Lagoon Treatment System		2002	Bag Filter Sludge	Estimated 12.6 dry tons	P	P	P	On site Storage

STLC = Soluble Threshold Limit Concentration
TTLC = Total Threshold Limit Concentration
TSD = Treatment, Storage, and Disposal
TCLP = Toxicity Characteristic Leaching Procedure

Site Requirements

To conduct full-scale lime treatment of AMD and ARD, the main site requirement at the Leviathan Mine site was developing adequate space for the treatment systems, staging areas, and support facilities. For the active treatment system, space is needed for reagent storage tanks, make-up water tanks, reaction tanks, clarifiers, flocc mix tanks, sludge holding tanks, a filter press, and various pumps and piping. Overall, the space requirement for the active treatment system is about 800 square meters. In Biphasic mode, the active system includes the use of the pit clarifier, which covers about 1,400 square meters. For the active treatment system operated in Monophasic mode, the pit clarifier is not utilized. For the Alkaline Lagoon treatment system, about 1,000 square meters is needed for placement of reagent storage tanks, reaction tanks, air compressors, bag filters, and various pumps and piping. Also necessary is a large extended contact settling lagoon capable of containing at least 3 days' worth of partially treated ARD. The settling lagoon at Leviathan Mine covers about 4,000 square meters and has a total volume of 5.4 million liters.

Additional space is needed for storage of consumable materials, spare parts and equipment, for loading and unloading equipment, supplies and reagents, and for placement of operating facilities such as portable office trailers, health and safety facilities, and power generating equipment. Separate "staging areas" were established at the active lime treatment and Alkaline Lagoon treatment system areas. The staging area for the active lime treatment system covers about 2,000 square meters and is located adjacent to the treatment system. In addition, the state of California operates two portable office trailers at the site; one trailer is used as a base of operations and the second is used as a field laboratory. A subcontractor also maintains a portable office trailer and portable toilet in the active lime treatment system area. Other on site equipment includes five Conex boxes for storage of site materials, one 15-cubic meter trash bin, a 4,000-liter diesel fuel tank, a 2,000-liter gasoline tank, and a 180 kilowatt (KW) diesel generator. The Alkaline Lagoon treatment system staging area is located adjacent to the settling lagoon and consists of about 800 square meters. The staging area includes a portable office trailer, portable toilet, three Conex boxes, a 4,000-liter and 1,400-liter diesel tank, and two diesel generators - a 150 KW main unit and a 45 KW backup unit.

The main utility requirement for the lime treatment systems is electricity, which is used to operate electrical and hydraulic pumps, stirrer motors, air compressors, process monitoring equipment, portable office trailers, and site lighting. Each lime treatment system at Leviathan Mine requires up to 20 KW-hours of electricity for continuous operation. The main generators run continuously during operation of both treatment systems. Satellite phone service is also required due to the remoteness of the site.

Technology Status

The technology associated with the active and semi-passive lime treatment systems is not proprietary, nor are proprietary reagents or equipment required for system operation. Both systems have been demonstrated at full-scale and currently operational at Leviathan Mine. The treatment systems are undergoing continuous refinement and optimization to address lime delivery and scaling problems. Because of the success of lime treatment at Leviathan Mine, the state of California

Table 6. Feasibility Study Criteria Evaluation for Lime Treatment Systems at Leviathan Mine	
Criteria	**Technology Performance**
Overall Protection of Human Health and the Environment	Lime treatment has been proven to be extremely effective at reducing concentrations of aluminum, arsenic, copper, iron, nickel, and other dissolved metals which can significantly degrade the quality of surface water receiving AMD and ARD at the Leviathan Mine site. The lime treatment systems evaluated at Leviathan Mine reduced the concentrations of toxic metals in AMD and ARD, which was historically released to Leviathan Creek, to below EPA discharge standards, which were established to protect water quality and the ecosystem in Leviathan Creek and down-stream receiving waters. Resulting metals-laden solid wastes, that are determined to be hazardous based on state or federal criteria, are transported to an approved off site TSD facility for proper disposal, again protecting human health and the environment from these hazardous materials.
Compliance with Applicable or Relevant and Appropriate Requirements (ARAR)	Both lime treatment systems are compliant with EPA discharge standards for the Leviathan Mine site. However, the effluent from the treatment systems does not meet the primary maximum contaminant limit (MCL) for aluminum or the secondary MCL for iron, which could easily be met with additional lime dosing. Hazardous process residuals are handled in accordance with Resource Conservation and Recovery Act and/or state of California hazardous materials transportation and disposal regulations.
Long-term Effectiveness and Performance	The active lime treatment system has been in operation at Leviathan Mine since 1999 and the semi-passive alkaline lagoon since 2001. After implementation of the active treatment system in 1999, no overflows of metals-laden AMD have occurred from the mine site. The treatment systems continue to be operated by the state of California and ARCO. Long-term optimization of the lime treatment system will likely reduce maintenance issues related to gypsum precipitation and lime feed problems in the process equipment, which are the major performance issues for the systems. Neither system is operational during the winter months due to freezing conditions and limited site access. During winter shutdown, ARD is discharged to Leviathan Creek, while AMD is captured and stored in the on site retention ponds. Return of ARD to the creek limits long term effectiveness of the treatment process; however, this can be addressed by capturing the ARD flow and redirecting it to the storage ponds during the winter months, or through construction of a heated year round treatment system.
Reduction of Toxicity, Mobility, or Volume through Treatment	Lime treatment significantly reduces the mobility and volume of toxic metals from AMD and ARD at Leviathan Mine. The dissolved toxic metals are precipitated from solution, concentrated, and dewatered removing toxic levels of metals from the AMD and ARD. However, lime treatment does produce a significant quantity of solid waste. Solid wastes generated from the lime treatment systems that are determined to be non-hazardous are disposed of on site. Solid wastes that exceed state or federal hazardous waste criteria are transported to an approved off site TSD facility for proper disposal.
Short-term Effectiveness	The resulting effluent from the lime treatment systems does not pose any risks to human health. The hydrated lime solution and the metal hydroxide precipitates, each having hazardous chemical properties, may pose a risk to site workers during treatment system operation. Exposure to these hazardous chemicals must be mitigated through engineering controls and proper health and safety protocols.
Implementability	The lime treatment technology relies on a relatively simple chemical process and can be constructed using readily available equipment and materials. The technology is not proprietary, nor does it require proprietary equipment or reagents. Once installed, the systems can be optimized and maintained indefinitely. Winter shut downs and startups and routine maintenance all require significant time and manpower. The remoteness of the site also necessitates organized, advanced planning for manpower, consumables, and replacement equipment and supplies.
Cost	Capital cost for the construction of the active lime treatment system was $864,847. The cost to construct the semi-passive Alkaline Lagoon was $188,415. The operation and maintenance (O&M) costs associated with the treatment systems are: $16.97 per 1,000 liters at an AMD flow rate of 638.7 liters per minute (L/min) for the Biphasic system; $20.97 per 1,000 liters at a combined AMD/ARD flow rate of 222.6 L/min for the Monophasic system; and $16.44 per 1,000 liters at an ARD flow rate of 78.7 L/min for the Alkaline Lagoon system. Costs for construction and O&M of each treatment system are dependent on local material, equipment, consumable, and labor costs, required discharge standards, and hazardous waste classification and disposal requirements.
Community Acceptance	The lime treatment technology presents minimal to no risk to the public since all system components are located at and treatment occurs on the Leviathan Mine site, which is a remote, secluded site. Hazardous chemicals used in the treatment system include lime and diesel fuel. These chemicals pose the highest risk to the public during transportation to the site by truck. The diesel generators create the most noise and air emissions at the site, again, because of the remoteness of the site, the public is not impacted.
State Acceptance	The state of California selected and is currently operating the active lime treatment system in Biphasic mode, which indicates the State's acceptance of the technology to treat AMD. Furthermore, the state of California concurs with the treatment of ARD by ARCO using the Alkaline Lagoon treatment system. However, the state of California has expressed concern about the return of ARD to Leviathan Creek during the winter months. Capture and on site storage of ARD over the winter months or year-round treatment would alleviate state concerns and is currently being evaluated by ARCO.

and ARCO are also evaluating the potential effectiveness, implementability, and costs for year-round treatment. Applied to other AMD- or ARD-impacted sites, the lime treatment systems would require only bench scale testing to assess liming requirement and flocculent dosage (as applicable) prior to design and construction of operational systems.

Sources of Further Information

The ITER (EPA/540/R-05/015) for lime treatment of AMD at Leviathan Mine is available; the document provides more detailed information on the lime treatment technologies, a detailed discussion of capital and operation and maintenance costs, and a more thorough discussion of the evaluation results.

EPA Contacts:

Edward Bates, U.S. EPA Project Manager
U.S. Environmental Protection Agency
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

Kevin Mayer, U.S. EPA Remedial Project Manager
U.S. Environmental Protection Agency Region IX
75 Hawthorne Street, SFD-7-2
San Francisco, CA 94105
(415) 972-3176
mayer.kevin@epa.gov

Atlantic Richfield Contact:

Roy Thun, Project Manager
BP Atlantic Richfield Company
6 Centerpointe Drive, Room 6-164
La Palma, CA 90623
(661) 287-3855
thunril@bp.com

State of California Contact:

Richard Booth, Project Manager
California Regional Water Quality Control Board
Lahontan Region
2501 Lake Tahoe Blvd.
South Lake Tahoe, CA 96150
(530) 542-5474
RBooth@waterboards.ca.gov

References

Tetra Tech EM Inc (Tetra Tech). 2002. 2002 Technology Evaluation Plan/Quality Assurance Project Plan, Leviathan Mine Superfund Site, Alpine County, California.

Tetra Tech. 2003. 2003 Technology Evaluation Plan/Quality Assurance Project Plan, Leviathan Mine Superfund Site, Alpine County, California.

United States
Environmental Protection
Agency

National Risk Management
Research Laboratory
Cincinnati, OH 45268

Official Business
Penalty for Private Use
$300

EPA/540/R-05/015a
May 2006