

High Efficiency Modular Treatment of Acid Mine Drainage Field Applications at Western U.S. Sites with the Rotating Cylinder Treatment System (RCTS)

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The most common practice for treatment of acid mine drainage is lime precipitation. This process neutralizes and oxidizes the acidic water in oxidation reactors with the addition of lime. Hydroxide precipitation of most metals occurs as the pH is increased to near 8 s.u.. Ferrous iron, however does not precipitate to an acceptable concentration at pH 8 unless it is oxidized ferric iron. The rate of ferrous to ferric iron conversion is slow at low to moderate pH and increases exponentially as the pH increases. Conventional systems typically utilize compressors to provide oxygen and mixers in the reaction tanks to dissolve lime slurry and to aid in the oxidation process. The Rotating Cylinder Treatment System (RCTS) utilizes rotating perforated cylinders contained in troughs or cylinders to oxidize and mix the lime slurry with the acid mine drainage. These systems have been tested on multiple sites in the Western U.S. to treat water containing dissolved iron concentrations at up to 7 grams/L. The system is also effective at treating net alkaline drainage containing dissolved ferrous iron and supersaturated bicarbonate without the addition of neutralizing agents.

Key words: oxidation, aeration, lime treatment systems, acid mine drainage, acid rock drainage, water treatment, mining remediation, and gas exchange

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Introduction

Lime precipitation is the most common and proven treatment method for acid mine drainage. These systems utilize the basic composition of lime to precipitate metals as metal hydroxides and calcium to remove sulfate as gypsum. Lime slurry is often delivered at

concentrations to increase the pH to near 8 s.u. At this pH most metals will precipitate efficiently from solution. However, ferrous iron will not precipitate to an acceptable concentration unless oxidized and converted to ferric iron (USEPA 1983).

The oxidation of ferrous to ferric iron is on the order of days at pH less than 6. However, as the pH is increased the rate of oxidation increases exponentially (Singer and Stumm 1969). It is therefore, advantageous to raise the pH sufficiently to convert the ferrous iron to ferric (Wilmoth 1977). The oxidation rate is also dependant upon the ferrous iron activity and the activity of the oxidant (first order with respect to both) (Singer and Stumm 1969). Using conventional methods the oxidation typically occurs in large reaction vessels in which air is bubbled into the water with diffusers. The bubbles are then broken up with mixing rotors which also provide the agitation for lime dissolution.

The RCTS replaces the reaction vessels, compressors, diffusers and agitators found in conventional systems. The oxidation and mixing is accomplished by passing the untreated acid mine drainage and lime slurry through a trough, in which a perforated cylinder rotates. As the cylinder rotates a film of water adheres to the inner and outer surfaces where gas exchange occurs. In addition, water bridges across the perforations for additional gas exchange.

The agitation is provided primarily by the impact of the perforations with the water flowing through the trough. Air is forced into the water where additional gas transfer can occur. The turbulents that are produced provide efficient lime mixing and dissolution.

The RCTS treatment system was implemented and tested on several sites in the Western U.S.. At the Rio Tinto site, extremely concentrated acid mine drainage was treated with dissolved iron concentrations of several grams/L. A system was also mobilized at the Leviathan Mine site where a batch system was implemented to treat ~ 700,000 gallons in less than 80 hours. At the Nevada city site, net alkaline water containing ~10 mg/L was treated without the addition of any base.

RCTS Test Units

RCTS units are designed for specific applications. All of the units presented are mobile and modular and can be placed in series to provide the mixing and gas exchange required at each individual site.

Four Rotor RCTS Test Units

Four rotor units are designed to provide oxygen and the residence time necessary to oxidize iron from solution. These units are utilized when the metal precipitate must be captured and a separate reaction pond is either sized inadequately or non-existent. A 600 gallon capacity unit and a 1200 gallon capacity unit were utilized in these tests (see figures 1 & 2).

RCTS-HS High Speed Test Units

Single cylinder RCTS-HS units spin at a higher rpm and are designed to provide more aggressive agitation and mixing for applications where a high rate of gas exchange is needed and or a high rate of flow must be treated. Figure 3 shows the RCTS-HS unit used at the Leviathan Mine.

Figure1. The 600 gallon capacity and 1200 gallon capacity units at the Rio Tinto Mine Site



Figure 2. Iron oxidation from ferrous to ferric in the first two cylinders of the four rotor unit.



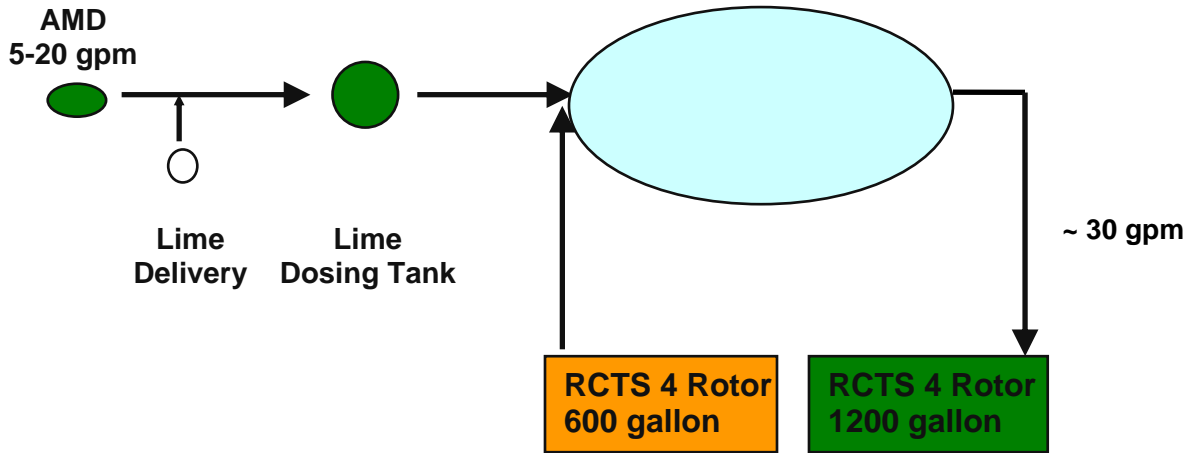
Figure 3. The RCTS-HS utilized at the Leviathan Mine.



The Rio Tinto Mine site

Two four-rotor RCTS units were implemented in series to treat acid mine drainage containing more than 7 grams/L of dissolved metals and 24 grams/L of sulfate at the Rio Tinto Mine. Lime slurry was mixed with impacted water in a lime dosing tank to raise the pH from approximately 2.6 Standard Units (SU) to approximately 8.5 SU. The water from the flash reactor tank was then mixed with RCTS effluent prior to deliver to a settling pond. The pH adjusted mixture from the settling pond was then fed into the RCTS system. The influent water flowed through each cell in series. Mixing resulted in an increase in pH and dissolved oxygen. The RCTS units that were used each consisted of four cells. Each cell contained perforated rotating cylinders which were coupled together in series to ensure complete oxidation occurred. The treated effluent was discharged from the last cell and was mixed with pH adjusted water from the flash reactor tank prior to flowing to the settling pond where the majority of metals precipitated and settled from solution. During the treatment process field water quality parameters were recorded and samples of untreated and treated water were submitted to a laboratory for analysis. The flow rate to the system ranged from 5 to 20 gallons per minute (gpm) during two treatment events. The flow to the RCTS system was approximately -----gpm.

Figure 1. Schematic of the 2005 Rio Tinto water treatment utilizing two RCTS units, a lime dosing tank and a settling pond.



Results

The RCTS treatment system was effective at removing metals to below applicable water standards at the site. Dissolved metals concentrations were removed from more than 8 g/L to less than 0.2 mg/L with the exception of manganese which was reduced from up to 96 mg/L to less than 0.58 mg/L. The total system operated on less than -----watts of electricity.

Date	Sample location	Al	As	Cd	Cu	Fe	Mn	Zn	Sulfate
7-26-05	Influent	793	0.03	0.359	314	6890	96	79.4	24,180
8-5-05	Influent	540	nd	0.338	228	4990	80.3	60	17,600
9-28-05	Influent	325	nd	0.198	139	2940	58.2	36.5	9,710
7-26-05	Effluent	0.10	nd	0.0005	0.005	nd	0.52	nd	2,410
8-5-05	Effluent	0.08	nd	0.0002	0.002	0.05	0.41	nd	1,800
9-28-05	Effluent	0.07	nd	0.0002	0.009	nd	0.58	nd	2,390

The Leviathan Mine Site

The goal of this project was to quickly treat approximately 900,000 gallons of impacted water contained in a pond, to allow the water to be discharged, thus reducing the risk of pond overflow to Leviathan Creek during spring runoff. The treatment system consisted of an RCTS-HS (rotating cylinder treatment system- high speed) unit, two one-hundred-gallon lime slurry tanks, a lime delivery pump, and 3-2" water delivery pumps. Water was pumped to the RCTS-HS at a rate of 44-160 gpm.

The treatment concept was to pump water from Pond 3 to the RCTS-HS where lime was added to the water and the dissolved ferrous iron was oxidized. The high pH water and precipitated solids were then either gravity fed back to the pond or pumped and mixed back into the pond.

Initially, it was assumed that the acidity of the water was low, due to the low iron concentrations in the water and the lime addition rate was controlled to minimize the amount of unreacted lime that was added to the pond. During treatment it was noted that the effluent was white in color due to particles in the water, which was thought to consist of unreacted lime, gypsum and aluminum. It was recognized on the third day of treatment that the acidity was higher than initially assumed (due to high concentrations of aluminum in the water) and lime slurry needed to be added at a higher flow rate. At that time the lime addition rate was increased and on day 5 an additional influent pump was added which allowed the lime to be delivered at an even higher rate. Between day 4 and day 8 the flow through the RCTS-HS was increased to 95-160 gpm and lime was added at an average rate of 1900 lbs per day. During the treatment process field water quality parameters were recorded and samples of treated water were submitted to a laboratory for analysis.

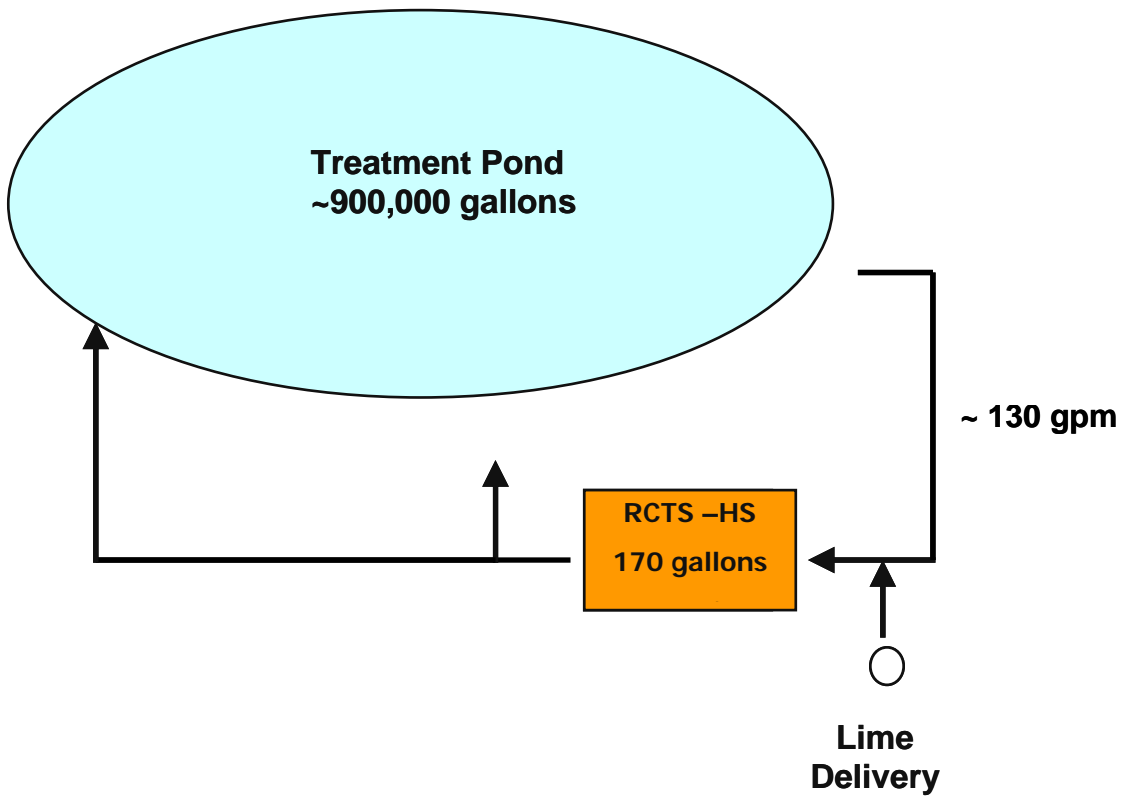
Results

The RCTS treatment system was mobilized within 3 days of notification and was effective at treating the impacted water in the holding pond as a batch. The acidity measured after 10% of the lime had been added, was 1600 mg/L, therefore the estimated acidity at the start of the treatment was ~1760 mg/L. Given this acidity, the total amount of lime needed to raise the pond to pH 8 assuming 100% efficiency is ~13,200 lbs. Overall, 14,375 lbs of lime was added over 15 days which represents a lime neutralization efficiency of greater than 89%.

Table 2 shows field measurements for the treatment period. The drop in pH from day to day is due to a complication that exists with the liner in this holding pond. The pond liner is covered with approximately 0.2 m of sand which holds considerable acidity. This acidity consumes alkalinity and over time the pond pH drops. This complicates neutralization because the pH drops significantly if lime is not added for extended periods of time. Therefore the discharge had to occur shortly after neutralization to minimize the mobilization of acidity. Approximately 800,000 gallons were treated in approximately 80 hours and the water was subsequently discharged from the pond to provide additional storage for the site. Table 4 displays metal concentrations before and after treatment. It is important to note that the pond was not mixed at the time the untreated sample was taken. The sample was taken near the edge of the pond toward the surface. Therefore the actual concentrations were likely considerably higher overall in the pond.

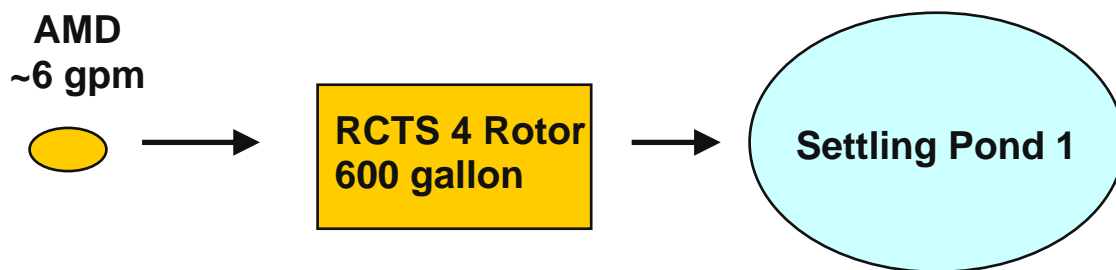
Hours operated	Pound lime added (cumulative)	Beginning pH	Ending pH
1	50 (50)	2.87	3.01
8	300 (350)	2.92	3.72
7	400 (750)	3.25	4.90
7.5	800 (1550)	3.62	4.30
8	1500 (3050)	3.70	4.47
8	1000 (4050)	3.66	4.86
8	1900 (5950)	3.65	4.16
8.5	2850 (8800)	4.13	4.43
8	2250 (11050)	4.57	6.97
8	800 (11850)	5.23	8.80
4	150 (12000)	6.59	9.25
8	850 (12850)	4.29	5.20
7.5	1000 (13850)	4.78	8.14
10.5	400 (14250)	5.58	7.72
12	125 (14375)	6.18	6.99

Date	Sample location	Al	As	Cd	Cu	Fe	Mn	Zn
5-24-05	Untreated (un-mixed)	209	0.01	0.0399	1.89	17.3	10.4	0.881
6-20-05	Treated	0.25	0.005	0.01	0.01	0.1	0.23	0.02



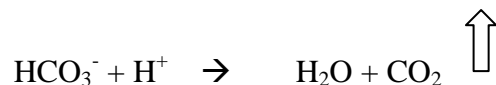
The Empire Mine Site

The goal of this test was to determine if the RCTS could be utilized to precipitate iron and co-precipitate arsenic from solution at the Empire Mine Site. An RCTS-Hs unit was implemented to treat a portion of this net alkaline mine drainage containing approximately 4.290 mg/L of iron and 0.047 mg/L of arsenic. It was initially proposed that sodium hydroxide would be added to the influent of the RCTS unit to raise the pH from 6.6 s.u. to approximately 8 s.u.. Mixing resulted in an increase in pH and dissolved oxygen. The RCTS units that was used consisted of four cells with a 600 gallon capacity. During the treatment process field water quality parameters were recorded and samples of untreated and treated water were submitted to a laboratory for analysis. The flow rate to the system was approximately 6 gallons per minute (gpm).



Results

The RCTS treatment system was effective at precipitating and removing iron from 4.29 mg/L to 0.08 mg/L. It was proposed that sodium hydroxide would be added to raise the pH from 6.6 s.u. to approximately 8 s.u.. However, sodium hydroxide addition was not necessary due to degassing of carbon dioxide from the water. The following equation describes how the pH increases as supersaturated carbon dioxide is degassed from solution.



Arsenic was also removed from 0.047 mg/L to 0.025 mg/L. It was proposed that additional arsenic could be removed with the addition of a small quantity of ferrous iron.

Conclusions

The RCTS treatment systems were effective at treating several different types of mineral mine drainage. Treatment of highly concentrated acid mine drainage was achieved to discharge objectives using minimal power and lime and space. An RCTS-HS unit was rapidly mobilized to treat moderate strength acid mine drainage in a minimal amount of

time. A 600 gallon unit was utilized to remove dissolved iron from net alkaline water by degassing carbon dioxide and consuming acidity without the addition of lime or caustic.

These systems are energy efficient and provide thorough mixing for efficient lime dissolution. Previous tests at the Rio Tinto mine showed lime efficiencies above 98%. Lime efficiencies at the Leviathan Mine were greater than 89% despite the fact that excess lime was added in the RCTS (RCTS effluent pH was greater than 12 s.u.) This additional alkalinity allowed much of the neutralization to occur within the pond.

The RCTS also provides greater oxygen addition per energy consumed than conventional systems. Mechanical surface aeration systems provide 3.0-3.5 lbs of oxygen per horsepower hour, while submerged turbine aerators utilizing dual impeller turbines provide 2.5-3.0 pounds of oxygen per horsepower hour. Previous testing with the 600 gallon four rotor unit showed approximately 9 pounds of oxygen delivered per horsepower hour given the following conditions. The unit operated on two cylinders and used approximately 0.375 watts of electricity and oxidized ~ 5,000 mg/L of iron at a flow rate of 10 gallons per minute.

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