TREATMENT OF MINE DRAINAGE WITH THE ROTATING CYLINDER TREATMENT SYSTEM™ (RCTS™): MULTIPLE APPLICATIONS

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Abstract: Mine drainage commonly contains elevated dissolved ferrous iron and manganese. The oxidation of these metals from their reduced forms to their oxidized forms is a common component of most treatment systems because the oxidized forms precipitate from solution more readily and at a lower pH. This oxidation is typically accomplished by pumping air with compressors and mixing the air and water with agitation mixers in large tanks. Although this method of treatment is effective, it requires significant power and a large amount of space to house the reaction tanks. The Rotating Cylinder Treatment System™ (RCTS™) (US Patent No. 7,011,745) utilizes shallow troughs that contain the water being treated and rotating perforated cylinders to transfer oxygen and agitate the water. This technology has been implemented on multiple sites. When compared with conventional systems it, requires less power and less space, is more effective at mixing and requires less maintenance associated with scaling, all of which results in lower overall costs. In addition, the oxidation reaction times are shortened and treatment can be achieved at a lower pH. These systems are portable, and can be sized to suit the oxidation requirements of each individual site.

Key words: oxidation, aeration, lime precipitation, acid mine drainage, acid rock drainage, water treatment, mining remediation

Introduction

Lime is commonly used to precipitate metals from mine water because of its low cost, its ability to remove sulfate, and the favorable settling properties of the resultant precipitates. This process typically referred to as "Lime Precipitation" utilizes lime, or calcium hydroxide ($Ca(OH)_2$) to increase the pH of the contaminated water which facilitates the oxidation and/or precipitation of dissolved metals as metal hydroxides and oxides. Although lime precipitation has many inherent advantages, conventional and high density systems are often difficult to control without constant monitoring and are not efficient at dissolving lime which is delivered to the acid mine drainage (AMD) as slurry. As the lime is added the precipitated metals coat the surface of the lime particle and trap unutilized lime within the particle. This problem is solved by the RCTS™ due to the system's aggressive mixing.

Iron and Manganese chemistry

At low pH iron and manganese exist primarily in their reduced forms. In order to precipitate dissolved manganese and iron from the water, the pH must be increased (Wilmoth 1977). The oxidized form of iron will precipitate at a lower pH than the reduced form (see Figure 1). It is even more crucial to oxidize manganese for removal and a higher pH is required (Stumm and Morgan 1981).

Figure 2 displays the pH dependence of iron and manganese precipitation. Also note that the pH for manganese removal is higher than that for iron removal. In addition, the rate of iron and manganese oxidation is enhanced at higher pH (Singer and Stumm 1969). Figure 3 displays the pH dependence of the rate of oxidation for iron and manganese.

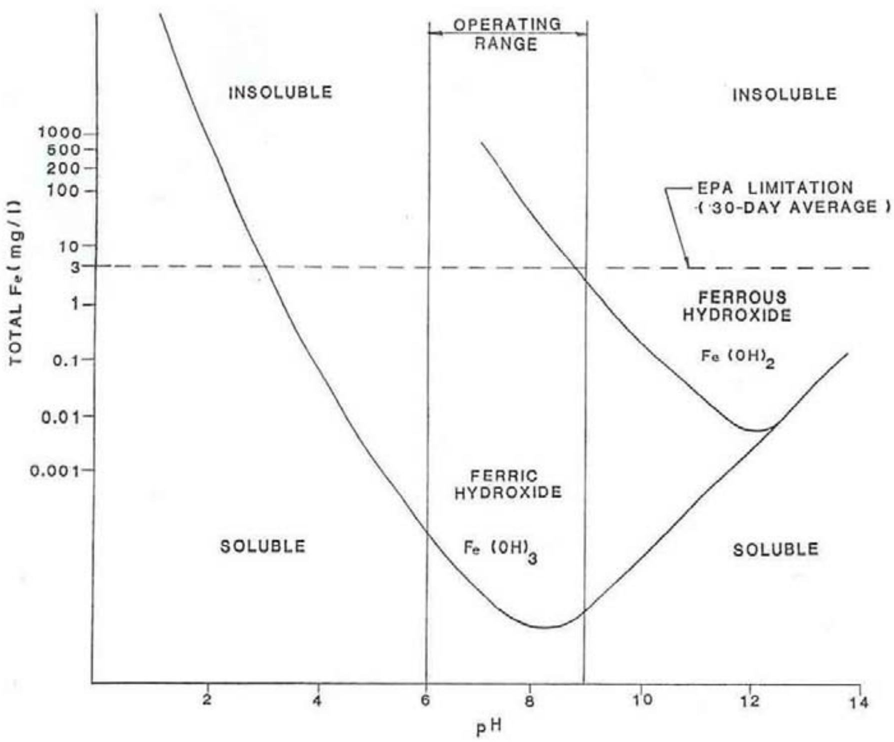

Figure 1. pH vs Total Iron Solubility Diagram for Ferrous and Ferric Hydroxide Precipitation. Note the Minimum Solubility for Manganese Precipitation is Between pH 9 and 10. (Taken from USEPA 1983).

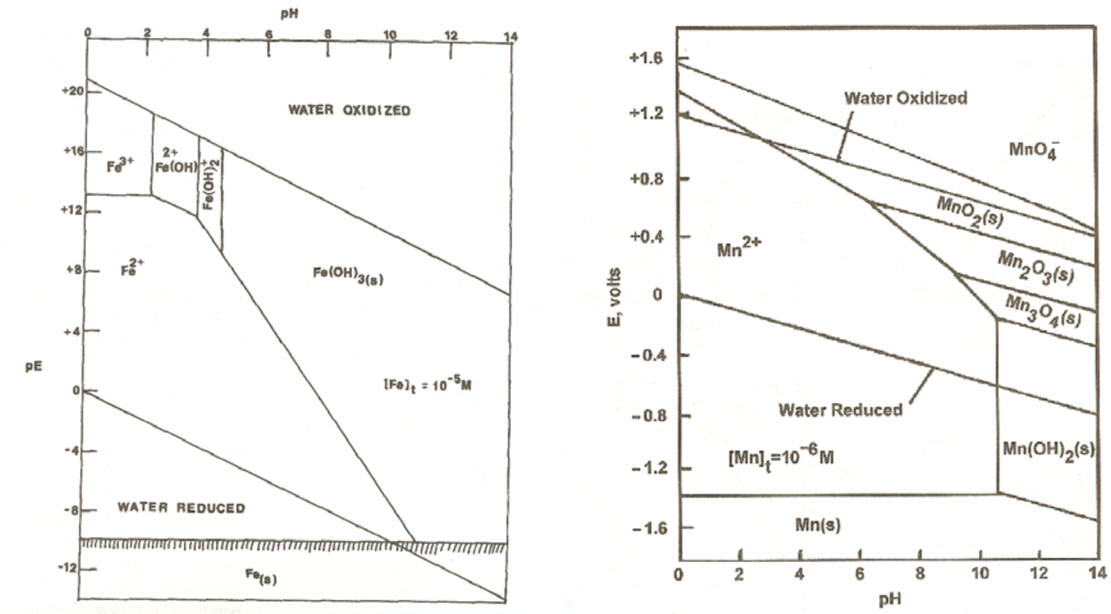

Figure 2. pH-pE Stability Diagrams for Iron and Manganese (Taken From Faust and Aly 1981)

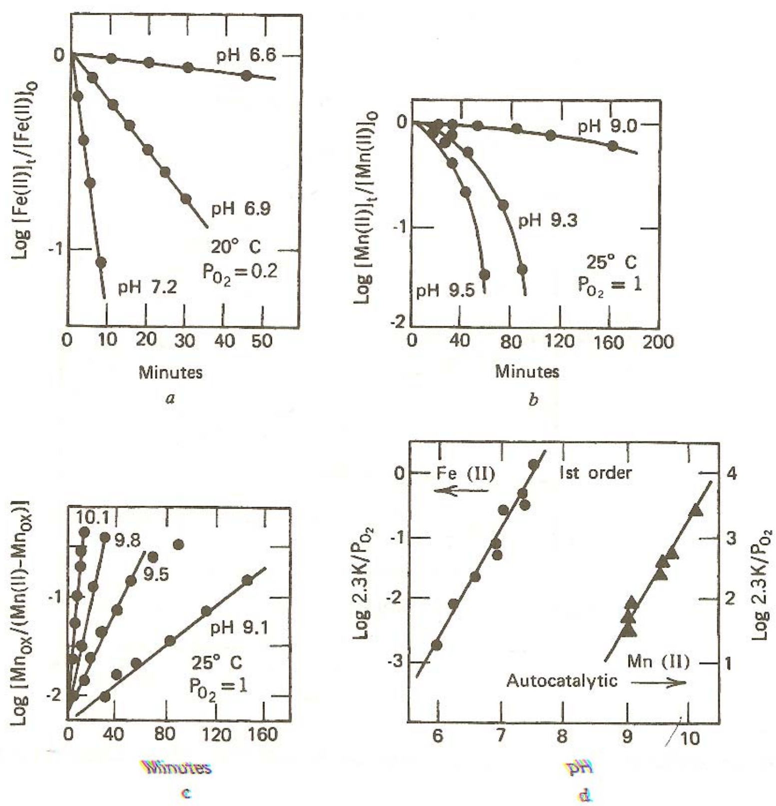

Figure 3. The Effect of pH on Oxidation Rates for Iron and Manganese. All experiments were conducted at dissolved iron and manganese concentrations of less than 5 x 10-4 M. (a) oxygenation of Fe 2+ in bicarbonate solutions (b) oxygenation of Mn 2+ in bicarbonate solutions (c) oxidation of Mn 2+ in bicarbonate solutions (autocatalytic plot) (d) Effect of pH on oxidation rates (taken from Faust and Aly 1981)

The RCTS Technology

The Rotating Cylinder Treatment System™ (RCTS^{TM}) was originally developed by Ionic Water Technologies, Inc. (IWT) to treat concentrated acid mine drainage containing ferrous iron concentrations of 4,000 to 7,000 mg/L at the Rio Tinto Mine. The technology has developed through various configurations and prototypes. Using EPA's formula for oxygen transfer it was found that the RCTS^{TM} delivered approximately 9 pounds of oxygen per horsepower-hour (Tsukamoto and Moulton 2006). 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 (USEPA 1983).

The RCTS^{TM} aeration concept is different from traditional aerations systems. Rather than injection of air into water, the RCTS^{TM} introduces water to air in a thin film clinging to the rotating perforated cylinder and when the perforations impact the water it is aggressively agitated and bubbles are forced into the water. This unique system of aeration replicates natural aeration and eliminates the need for costly compressors and blowers. In addition to the low energy consumption of this system, the aeration is relatively unaffected by sediment, scaling, and related maintenance issues of alternative aeration technologies.

For sites that have a consistent flow and chemistry, a timer or variable frequency drive is utilized in combination with an innovative grinder pump for lime slurry delivery control rather than pH controllers which often give inaccurate readings just hours after calibration.

The effectiveness of the RCTS^{TM} aeration allows for precipitation of iron and manganese at a lower pH than conventional systems. In addition, the RCTS^{TM} system achieves near 100% lime utilization due to the aggressive mixing and sheer forces present in the cylinder (Tsukamoto and Moulton 2005). Two benefits arise from this: 1) lower lime consumption due to the utilization of all of the available alkalinity in the introduced lime, and 2) less sludge production resulting from less lime usage per unit of alkalinity required.

The Leviathan Mine Site

The Leviathan Mine is located on the eastern slope of the Sierra Nevada, in Alpine County, California, USA. Four large ponds were constructed to contain water contaminated with AMD. Pond 1, Pond 2 North and Pond 2 South (the upper ponds) drain into Pond 3 during an overflow event. When full, Pond 3 overflows to Leviathan Creek. All of the ponds receive direct precipitation, most of which comes in the form of snow during the winter. In addition, the upper ponds receive acidic drainage from an adit and a pit under-drain (PUD).

In 2005, TKT (now IWT) was contracted to provide emergency treatment at Pond 3 due to higher than normal precipitation at the site. Approximately 900,000 gallons of AMD at pH 2.8 s.u. containing high concentrations of aluminum and low concentrations of iron were treated. The sludge that was generated in 2005 was not removed and remained in the pond at the time of the emergency treatment in 2006.

In 2006 TKT/IWT was again contracted to provide emergency treatment. TKT was authorized to start the mobilization process on April 5, 2006. The road was inspected on April 6 and was plowed to remove snow on April 9. Eighteen pallets of lime (45,000 pounds) were delivered to the Nevada/California border and were shuttled to the site via four-wheel drive equipment on April 12 and 13. The RCTS-30HS^{TM} unit and lime delivery system was mobilized to the site on April 14. Treatment began at 11:30 a.m. on April 14 and by 10 a.m. on April 15 the discharge pH was 8.3 s.u. AMD was continually treated at a flow rate of up to 1220 Lpm over a period of approximately 85 days during which time the influent chemistry changed dramatically.

Results

More than 28 million litres of AMD were treated over 85 days of emergency treatment. The system operated on less than 1,600 watts of electricity and was placed on a footprint of approximately 3m x 10m. On average, a two man crew was on site 4.6 hours per day. This included time on site during discharge which had to be continuously monitored. The RCTS-30HS™ not only controlled the pH of the discharged water, it was also effective in the removal of metals in a cost effective, energy efficient manner. Table 1 displays the treatment rates that were achieved as water with different chemistry was encountered. Because of the emergency nature of the project, the only requirement was to ensure that a pH between 6 and 9 was discharged, however, we were able to meet the sites daily maximum discharge requirements with the exception of one sample that slightly exceeded the iron standard.

Table 1: Average treatment rates achieved as water with different chemistry was encountered.

Water Type	Dates Encountered	Average Treatment Rate	Iron mg/L	Copper mg/L	Zinc mg/L	Nickel mg/L	Aluminum mg/L
Mostly rain and snow melt (low acidity, low metals concentrations)	April 14 To May 8 (21 Days)	~136 gpm (up to 740 gpm)	Mostly Fe^{2+} 1 to 21	0.110	0.065	0.310	2 to 310
High in acidity and high in metals concentrations	May 9 To July 4 (58 Days)	~33 gpm	Mostly Fe^{2+} 21 to 610	1.7 to 1.9	0.91 to 0.92	4.5 to 4.7	310 to 490
High in acidity and high in metals concentrations	July 5 To July 10 (5 Days)	~83 gpm (up to 330 gpm)	Mostly Fe^{3+} Up to 610	4.1 to 4.8	1.2 to 1.5	7.0	Up to 490

The Empire Mine Site

An RCTS™ -Four Rotor unit was utilized 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. The goal was to precipitate iron and co-precipitate arsenic from the water. The RCTS™ unit that was used consisted of four cells with a total capacity of 600 gallons. The flow rate to the system was approximately 6 (gpm).

The RCTS™ unit was effective at precipitating and reducing iron from 4.29 mg/L to 0.08 mg/L without the addition of base due to degassing of carbon dioxide from the water which resulted in consumption of acidity. Arsenic was also reduced from 0.047 mg/L to 0.025 mg/L.

The Sunshine Mine

The RCTS-60HS^{TM} mixing and aeration technology is currently being used to treat dewatering mine water from the Sunshine Mine in Northern Idaho. The "Sunshine Mine water" has a slightly basic pH, with low acidity and elevated concentrations of suspended iron and dissolved manganese.

IWT conducted a demonstration to determine the effectiveness of treatment prior to permanent installation. For this demonstration, lime ($Ca(OH)_2$) was added to neutralize the acidity and increase the pH of the water. At elevated pH, dissolved manganese is less soluble and precipitates as a manganese oxide. Because the pH was basic and the water was partially aerated prior to treatment, the iron which is more insoluble at near neutral pH had already oxidized and precipitated. The highly oxidizing conditions within the RCTS^{TM} and the addition of lime resulted in precipitation of the manganese. The solids were then settled and samples of the eluent were collected and analyzed for total arsenic, iron and manganese concentrations.

Project Objectives

The specific objectives of this demonstration were to:

1. Determine the feasibility of treating the Sunshine Mine Water to NPDES permit limits with the use of the RCTS^{TM} technology ;
2. Determine the appropriate pH range, to maximize metals removal;
3. Obtain an estimate of chemical consumption;
4. If possible, determine operational capacity of each unit;
5. Assess the settling properties of the sludge that was generated.

Treatment System Composition

The treatment system utilized for the demonstration was an RCTS-60HS, two 500-gallon lime slurry mixing tanks, a lime slurry pump and a 230 gpm rated submersible pump. "Sunshine Mine water" was collected in a sump that was hydraulically connected to the tailings pond via a channel. Lime slurry and "Sunshine Mine water" were pumped to the front of the RCTS -60HS^{TM} unit. As the lime and untreated water traveled through the RCTS -60HS^{TM} unit, it was aggressively mixed and aerated. As the lime dissolved and oxidation occurred, the manganese precipitated from solution. The treated effluent was gravity fed back to the tailings storage pond. Samples were taken from the RCTS-60HS^{TM} effluent in 5 gallon containers. Samples were then drawn from the eluent following different settling times. Samples were analyzed on site with a HACH kit and at American Analytical Services in Osburn, Idaho.

Results

The pH values that were tested for the demonstration were between 7 and 10. High pH values are necessary to remove manganese. The results from the demonstration show that the system was effective at removing manganese from solution (Tables 2 and 3). Ideally a pH higher than 9.5 would be targeted to get the most effective removal of manganese. However, the discharge limit for pH is 9.5 and therefore increasing the pH above this level would result in a violation. Based on this data IWT recommended that a settled pH of ~9.3 be the target. However, it was demonstrated that a settled pH between 8.8 and 10.00 was effective at removing metals to below the NPDES discharge limits of 0.503 for manganese and 1.115 for iron.

Table 2. Manganese removal results from the Sunshine Mine RCTS demonstration

Discharge pH	Influent Mn	pH 1 hr	Mn 1 hr Filtered	Mn 1 hr	pH 3 hr	Mn 3 hr	pH 1 day	Mn 1 day	pH 2 day	Mn 2 day
8.5	18.1	8.40	16.4	16.6	8.37	16.5	8.35	16.1	8.03	13.80
9	18.6	8.66	14.4	12.4	8.55	8.27	8.42	5.43	8.25	4.44
9.25	17.9	8.74	2.35	4.38	8.71	3.58	8.52	1.86	8.38	1.46
9.5	18.5	9.12	0.317	0.814	8.92	0.481	8.82	0.221	8.63	0.24
9.75	19.1	9.58	0.053	0.291	9.47	0.154	9.3	0.025	8.99	0.02
10	19.2	9.74	0.053	0.349	9.68	0.175	9.62	0.024	9.29	0.02
10.25	19.6	10.02	0.076	0.201	9.94	0.126	9.7	0.024	9.44	0.02
avg	18.7									

Table 3. Iron removal results from the Sunshine Mine RCTS demonstration

Discharge pH	Influent Fe	pH 1 hr	Fe 1 hr filter	Fe 1 hr	pH 3 hr	Fe 3 hr	pH 1 day	Fe 1 day	pH 2 day	Fe 2 day
8.5	1.19	8.40	0.459	1.01	8.37	0.689	8.35	0.33	8.03	0.214
9	1.72	8.66	1.34	1.65	8.55	0.504	8.42	0.126	8.25	0.05
9.25	0.616	8.74	0.082	0.63	8.71	0.426	8.52	0.282	8.38	0.05
9.5	1.39	9.12	0.181	0.86	8.92	0.5	8.82	0.05	8.63	0.05
9.75	1.36	9.58	0.155	0.604	9.47	0.479	9.3	0.087	8.99	0.05
10	2.2	9.74	0.062	0.365	9.68	0.25	9.62	0.05	9.29	0.05
10.25	1.66	10.02	0.116	0.265	9.94	0.154	9.7	0.05	9.44	0.05
avg	1.4									

Treatment Sludge Characteristics

Sludge settling rates were estimated by adding the treated water to a graduated cylinder and monitoring the sludge water interface. Settling rates were estimated from changes in the elevation of the water-sludge interface over time. Settling rates were calculated using only the flocculent settling zone, and excluded the compression-settling zone. Settling rates were approximately 0.25 feet per minute; however, a fine cloudy white precipitate remained in suspension and was settled out in approximately 4 hours.

Conclusions

The following conclusion can be drawn from this demonstration:

1. The hydraulic retention times for RCTS-60HS™ ranged from 2 to 4 minutes.
2. NPDES standards for manganese were achieved at pH values between 8.8 and 10 at low and high hydraulic retention times.
3. Given the chemistry at the time of the test at 600 gpm, the annual lime usage was estimated at 54 tons per year ($8,678 per year at $0.08/lb).
4. The operational capacity of the unit could not be determined with the pump that was utilized to pump "Sunshine Mine water" to the unit. This pump was operated without valve restriction and treatment was maintained to NPDES discharge objectives. An operational capacity of 500 gpm has since been determined, which results in a hydraulic retention time of approximately 1 minute.
5. Sludge settling properties appear to be sufficient for pond settling.

The RCTS™ has been shown to be effective at treating both acid mine drainage and net alkaline drainage. In some cases the water may be treated without the addition of base due to the systems ability to efficiently degas carbon dioxide while at the same time oxidizing iron and manganese. All of the current RCTS™ systems are mobile or can be installed as a permanent system.

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