MULTIPLE SITE EVALUATION OF RCTS™ ACID MINE DRAINAGE TREATMENT, EMERGENCY MOBILIZATION AND LIME UTILIZATION[1]

Timothy Tsukamoto[2] and Vance Weems

Abstract. Thorough oxidation and mixing is required for treatment of acid mine drainage on many sites. This is accomplished in the rotating cylinder treatment system (RCTS™) by passing acid mine drainage and a neutralizing agent through a containment cell in which a perforated cylinder rotates. As the cylinder rotates, a thin film of water adheres to the inner and outer surfaces and 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 containment cell. The turbulence that is produced provides efficient mixing, which reduces chemical consumption due to more efficient use of the available alkalinity, and less sludge produced.

Metals removal effectiveness, energy requirements, and chemical consumption were characterized in four field tests. In all of these, the RCTS™ effectively precipitated metals and increased pH and did so at a lower cost than conventional systems. At sites that compared the RCTS™ with conventional treatment, the RCTS™ system required substantially less energy, chemical, labor and residence time. A direct comparison with a conventional system at the Leviathan Mine demonstrated that the RCTS system used 69% less power for aeration and mixing and was more effective at oxidizing metals. The system used 41% less lime to achieve a similar discharge pH. In addition, the RCTS™ systems can be mobilized quickly to remote locations where conventional systems cannot easily be installed. System installation time was typically less than one day.

Additional Key Words: ARD, MIW, AMD, mining impacted water, acid rock drainage, acid mine drainage, water treatment, rotating cylinder treatment system, metals remediation, green remediation, lime precipitation, lime neutralization, lime efficiency, mining economics

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2 Timothy Tsukamoto, Ph.D., is the Director of Technology, Ionic Water Technologies Inc, 9468 Double R Boulevard #A Reno, NV 89505 , Vance Weems is the Operations Manager at Ionic Water Technologies Inc.

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Introduction

Lime Precipitation

Lime is the most important chemical used throughout the world for pollution control (Hassibi 1999). Lime precipitation is the most common form of active treatment for acid mine drainage (AMD). This process neutralizes sulfuric acid and precipitates metals as metal hydroxides. Sulfate is also precipitated as gypsum if sulfate concentrations are sufficiently high. The two most commonly used forms of lime are CaO (quicklime) and $Ca(OH)_2$ (hydrated lime). Quicklime or CaO is often used on sites with high lime demand, due to its ability to be fed reliably with a silo. Hydrated lime or $Ca(OH)_2$ is often used at sites with lower lime requirements.

Lime is often delivered at concentrations to increase the pH to near 8. At this pH, most metals will precipitate efficiently from solution. However, Fe^{2+} and Mn will not precipitate to a concentration at which it can be discharged unless it is oxidized and converted to ferric iron (USEPA 1983). On sites that are regulated for Mn, conventional treatment requires a pH of greater than 9.5 to remove Mn. On these sites iron will also oxidize rapidly and will precipitate. However, if significant Al or As is present at sufficient concentrations these elements may not be removed. In addition, many sites require a discharge pH less than 9.0. In order to overcome these obstacles AMD is often treated in more than one stage. This allows precipitation reactions to be optimized. However, it adds complexity to the treatment system.

Using conventional methods, the oxidation and mixing 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 (USEPA 1983).

Lime Efficiency

Conventional lime precipitation systems often are not efficient in lime use. Lime is not very soluble, particularly under alkaline conditions. If mixing is not adequate, as the lime is added, the precipitated metals will coat the surface of the lime particles and trap unused lime within the particle. In addition, the presence of dissolved carbonic acid consumes excess lime when present.

RCTS™ Technology

The Rotating Cylinder Treatment System (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 containment cell, 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 containment cell. Air is forced into the water where additional gas transfer can occur. The turbulence that is produced provides efficient lime mixing and dissolution. In addition, excess carbonic acid is degassed from solution. As a result less lime is consumed and less sludge is produced.

This paper reports the results of field trials of the RCTS™ technology. Direct comparisons of the RCTS™ with conventional lime treatment are provided for three projects (Rio Tinto Mine 2002, Leviathan Mine 2004 and Leviathan Mine 2006). The ability to respond quickly for emergency treatment is highlighted at two sites (Leviathan Mine 2006 and Landusky 2008).

Project Descriptions

Rio Tinto Mine 2002

A treatability study was conducted at the Rio Tinto Mine Site, located in northeastern Nevada. The study compared the RCTS™ technology with a conventional system to treat AMD from a hydraulic control pond (HCP). The AMD in the HCP had low pH (2.07 to 2.78), high acidity (2057 mg/L to 1064 mg/L) and high concentrations of Al (120 mg/L to 616 mg/L), Fe (806 mg/L to 4560 mg/L), Cu (80.5 mg/L to 237 mg/L) and Zn (14.4 mg/L to 74.7) Table 1. The differences in chemistry are due to the stratification within the HCP. The Fe was primarily present as Fe^{2+} (reduced iron) particularly in the deep water from the HCP.

One of the primary objectives of this treatability study was to compare the RCTS™ with a conventional lime precipitation system with respect to treatment effectiveness, lime utilization and sludge generation. Because the chemistry and flows that were treated differed throughout the study, lime effectiveness was calculated by determining the lime utilization efficiencies. The conventional system was operated on 9 days between 9-18-02 and 10-10-02. The RCTS system was operated on 6 days between 10-2-02 and 10-15-02.

Conventional Treatment System. The conventional system used two 1890 liter (500 gallon) tanks with a working volume of 1325 liters (350 gallon working volume). The tanks were installed in series and the lime slurry was delivered to the first tank only. Both reaction tanks were actively aerated. Initially, aeration was provided by mechanical agitation and an air compressor. It soon became apparent that the compressor alone supplied sufficient aeration and the mechanical agitators were turned off. A submersible sump pump transferred the contents of the first reactor tank to the second reactor tank. Lime slurry was supplied to the reactor from two, 380-liter (100 gallon) lime slurry-holding tanks each equipped with mechanical agitators. Effluent was discharged from the second reactor tank to a settling pond. Solid separation occurred within this pond. The pond did not have a surface discharge and lost treated water by infiltration to groundwater. Influent samples were taken from a sampling port in the feed line to the system. Treated effluent was taken from the discharge line and was allowed to settle 24 hours prior to sampling.

The RCTS™ System. The RCTS™ consisted of a small 76 liter (20 gallon) lime dosing tank and a dual 61 cm (24 inch diameter) RCTS™ system operated at 40 rpm. The total working volume of the RCTS™ system was ≈ 227 liters(60 gallons). Lime slurry was added to the lime-dosing tank and was then pumped via a submersible sump pump in the reaction tank to the front of the RCTS™ system. The lime AMD mixture was mixed and aerated within the RCTS™ system and was discharged to a settling pond. Influent samples were taken from a sampling port in the feed line to the system. Treated effluent was taken from the discharge line and was allowed to settle 24 hours prior to sampling.

Treatment Effectiveness. The results from the treatability study demonstrated that both treatment systems were effective at removing dissolved metals from solution. The percent removal of Al, Cu, Fe, and Zn were all in excess of 99%. Although Mn removal was not targeted, 83 to 99% of the Mn was removed at the pH values tested.

Lime Utilization. Because the chemistry and flow varied throughout the test, lime utilization effectiveness was determined to provide a comparison matrix for the efficiency of the treatment systems. The lime utilization effectiveness was calculated by dividing the actual lime dose by the theoretical amount of lime that would be required to neutralize the influent acidity. A value > 1 indicates that more lime was added than would be required to consume the influent acidity and a value < 1 indicates that less lime was added than would be required to consume the influent acidity. These data are presented in Table 2.

For the tank reactor system, the lime utilization effectiveness ranged from 0.79 to 3.22. There was no discernable relationship between lime utilization and flow rate or influent acidity. For the RCTS™, the lime utilization effectiveness ranged from 0.8 to 1.4. The lime utilization effectiveness increased when a portion of the effluent was circulated to the front of the RCTS system (Table 2).

It is important to compare RCTS treatment with conventional treatment on dates in which similar water was treated (from 10-2-02 to 10-10-02). During this time period the effectiveness for the conventional system varied from 1.59 to 2.26 with an average effectiveness of 2.02. The residence time varied from 20 to 38 minutes with average of 26 minutes. The effectiveness for the RCTS system varied from 1.13 to 1.41 with an average effectiveness of 1.27. The residence time varied from 2 to 7 minutes with average of 4 minutes.

<u>Sludge Generation.</u> The ratio of the volume of sludge to the volume of water treated by the tank reactor system ranged from 257 to 2305 liters per 3785 liters treated (68 to 609 gallons per 1000 gallons treated). The variability in this estimate is due to the differences between treating the deep poor-quality HCP water and the surficial better-quality HCP water. The average ratio of the volume of sludge to the volume of water treated for the surficial and deep waters were 466 liters and 1722 liters per 3785 liters treated, respectively (123 and 455 gallons per 1000 gallons treated, respectively). The ratio of the volume of sludge to the volume of water treated by the RCTS™ ranged from 227 liters to 507 liters per 3785 treated (60 to 134 gallons per 1000 gallons treated) and averaged 375 liters per 3785 liters treated (99 gallons per 1000 gallons treated).

Figure 1. RCTS Unit at the Rio Tinto Mine.

Table 1. Metals concentrations for Rio Tinto treatability study; the first set of readings, with the effluent ID of TP, represent the conventional treatment system.

		Dissolved Influent Concentration (mg/L)								Dissolved Effluent Concentration (mg/L)								% Removal							
Effluent Sample I.D.	Date	TDS	Al	As [2]	Cd	Cu	Fe	Mn	Zn	TDS	Al	As [2]	Cd	Cu	Fe	Mn	Zn	TDS	Al	As [2]	Cd	Cu	Fe	Mn	Z
TP-3	9/18/02	29200	616	0.025	0.450	237	4560	109	74.7	10300	0.3 U	0.005	0.001 U	0.04	0.05 U	3.91	0.05 U	64.73	99.95	80.00	99.78	99.98	99.99	96.41	99
TP-4	9/19/02	26500	541	0.025	0.384	209	3730	94.5	63.9	6510	0.2 B	0.0025	0.0005 U	0.047	0.15 B	2.2	0.025 U	75.43	99.96	90.00	99.87	99.98	99.99	97.67	99
TP-5	9/23/02	26800	562	0.025	0.430	217	4240	104	69.2	9770	0.3 B	0.0025	0.0005 U	0.033	0.0025 U	5.6	0.025 U	63.54	99.95	90.00	99.88	99.98	99.99	94.62	99
TP6	9/24/02	24900	514	0.025	0.420	200	3890	96.3	59.8	8630	0.4 B	0.015	0.0025 U	0.015 U	0.025 U	3.49	0.025 U	65.34	99.92	40.00	99.40	99.99	99.99	96.38	99
TP-7[1]	9/25/02	N/A	509	N/A	0.370	199	N/A	N/A	59.2	N/A	0.196	N/A	0.0012 B	0.019	N/A	N/A	0.03 B	N/A	99.96	N/A	99.68	99.99	N/A	N/A	99
TP-8	10/1/02	9680	186	0.003	0.178	82.7	1040	44.4	23.7	5790	0.258	0.0025	0.0011 B	0.03	0.75	6.02	0.03 B	40.19	99.86	0.00	99.38	99.96	99.93	86.44	99
TP-9	10/4/02	9900	184	0.006 B	0.175	86.6	1180	43.1	23.1	3540	0.97	0.0015	0.0005 U	0.013 B	0.05	0.005 U	0.04 B	64.24	99.47	75.00	99.71	99.98	99.99	99.99	99
TP-10-20	10/9/02	10100	189	0.005	0.187	87.7	1320	44.5	24.1	5760	0.179	0.0015	0.0009	0.0089	0.16	5.82	0.018	42.97	99.91	70.00	99.52	99.99	99.99	86.92	99
TP-13-40	10/10/02	6660	120	0.005 B	0.106	63.9	806	29	14.4	4990	0.153	0.008	0.0007 B	0.012	0.45	4.32	0.03 B	25.08	99.87	-60.00	99.34	99.98	99.94	85.10	99

		Dissolved Influent Concentration (mg/L)								Dissolved Effluent Concentration (mg/L)								% Removal							
Effluent Sample ID	Date	TDS	Al	AS	Cd	Cu	Fe	Mn	Zn	TDS	Al	As	Cd	Cu	Fe	Mn	Zn	TDS	Al	As	Cd	Cu	Fe	Mn	Z
RCTS-2	10/2/02	9440	179	0.003	0.172	80.5	1010	42.69	22.9	5830	0.45	0.0025	0.0016	0.146	1.92	8.93	0.065	38.24	99.75	0.00	99.07	99.82	99.81	79.08	99
RCTS-3-4	10/3/02	9370	182	0.005 B	0.171	83	1030	43.5	24	5170	0.114	0.0025	0.0016 B	0.013	0.09 B	10.4	0.02 B	44.82	99.94	50.00	99.06	99.98	99.99	76.09	99
RCST-4-7	10/3/02	9370	182	0.005 B	0.171	83	1030	43.5	24	3850	0.254	0.001	0.00025 U	0.01	0.05 B	2.8	0.02 B	58.91	99.86	90.00	99.85	99.99	99.99	93.56	99
RCTS-5	10/8/02	11100	184	0.005	0.201	84	1340	45.9	26.3	6400	0.172	0.0015	0.0012	0.011	0.025 U	7.45	0.021	42.34	99.91	70.00	99.40	99.99	99.99	83.77	99
RCTS-150	10/10/02	10100	189	0.005	0.106	87.7	1320	44.5	24.1	5500	0.1 U	0.0015	0.0012	0.013	0.07 B	7.49	0.025 U	45.54	99.95	70.00	98.87	99.99	99.99	83.17	99
RCTS-6-10PH	10/10/02	10100	189	0.005	0.106	87.7	1320	44.5	24.1	5630	0.0025 U	0.0025	0.00025 U	0.01	0.025 U	0.05 U	0.02 B	44.26	99.99	50.00	99.76	99.99	99.99	99.89	99
RSTS-8	10/14/02	10400	220	0.005 B	0.192	98.7	1560	50.4	27	5280	0.147	0.009	0.0011 B	0.013	0.1 B	5.59	0.02 B	49.23	99.93	-80.00	99.43	99.99	99.99	88.91	99
RSTS-9	10/15/02	9960	201	0.0025 B	0.182	91.2	1400	45.9	24.6	5490	0.141	0.005	0.0017 B	0.015	0.2	10.6	0.02 B	44.88	99.93	-100.00	99.07	99.98	99.99	76.91	99

[1] Incomplete lab data for HCP-IN (9/25/02) and TP-7

[2] Arsenic concentration below dection limtits, values equal to 1/2 Method Dectection Limit (MDL), unless otherwise noted

U-Analyte concentration below dection limit, value equal to 1/2 MDL

B-Analyte concentration detected as value between MDL and Practical Quantitation Limit (PQL)

Table 2. Lime effectiveness and flow

Effluent Sample I.D.	Date	Flow Rate (GPM)	Residence Time Within Treatment System (min)	Observed Lime Rate (mg Ca(OH)2/L)	Influent Acidity (mg CaCO3/L)	Influent Acidity (mg Ca(OH)2/L)	Effectiveness (ratio of lime used/acidity)	Notes
TP-3	9/18/2002	10	100	11905	13600	10064	1.18	
TP-4	9/19/2002	20	50	16839	12000	8880	1.90	20 gpm operation
TP-5	9/23/2002	10	100	31250	13100	9694	3.22	10 gpm operation
TP6	9/24/2002	10	100	17037	12300	9102	1.87	
TP-7	9/25/2002	10	100	9716	11500	8510	1.14	
TP-8	10/1/2002	10	100	6410	10900	8066	0.79	
TP-9	10/4/2002	20	50	7797	4740	3508	2.22	20 gpm operation
TP-10-20	10/9/2002	20	50	4972	4230	3130	1.59	
TP-13-40	10/10/2002	38	26.3	4646	2780	2057	2.26	38 gpm operations
RCTS-2	10/2/2002	2	30	4398	4230	3130	1.41	2 gpm operation
RCTS-3-4	10/3/2002	4	15	3958	4120	3049	1.30	4 gpm operation
RCTS-4-7	10/3/2002	7	8.6	3452	4120	3049	1.13	
RCTS-5	10/8/2002	5	12	4286	4640	3434	1.25	5 gpm inflow, recirculation rate @ 2gpm (9:45-12:00), 5gpm (12:30-13:45) sample collected @ 13:45
RCTS-150	10/10/2002	2	30	3858	4207	3113	1.24	lime usage based on operating conditions on 10/9/02 (2gpm inflow)
RSTS-8	10/14/2002	4	15	3189	4430	3278	0.97	5 gpm inflow (11:15-14:30), 4 gpm inflow (14:30-16:00), recirculation rate @ 1 gpm (14:30-15:30), 2 gpm (15:30-16:00)
RSTS-9	10/15/2002	4	15	3125	5260	3892	0.80	recirculation rate @ 2 gpm (10:00-11:30), 0 gpm (11:30-15:00)

Leviathan Mine 2004

A treatability study (Tsukamoto 2004) was conducted at the Leviathan Mine Site, located on the Eastern slope of the Sierra Nevada Mountains in California. The study compared the RCTS™ technology with a conventional system to treat AMD. The AMD had a pH near 4.8, and total metals concentration of near 500 mg/L, most of which was dissolved Fe^{2+}. The RCTS™ was compared with conventional lime precipitation with respect to treatment effectiveness and lime use.

Conventional Treatment System. The conventional system used four 3785 liter (1000 gallon) tanks in series. All four reaction tanks were actively aerated by four 20 cfm air compressors coupled to diffusers. Lime slurry was supplied to the first reactor tank from a 3785 liter (1000 gallon) lime slurry holding tank equipped with mechanical agitators. Effluent was discharged from the fourth reactor tank through one or more filter bags to a settling pond.

RCTS™ System. The RCTS™ used the same lime mixing tank as the conventional system. In addition, the first reactor tank (from the conventional system) was used as a lime-dosing tank. The RCTS™ system consisted of a 4 rotor RCTS™ system with a working volume of ≈2270 liters (600 gallons) plus the 3875 liter (1000 gallon) dosing tank received air from a 0.5663 cubic meters per minute (20 cubic feet per minute) compressor. Lime slurry was added to the lime-dosing tank and was then pumped via a submersible sump pump in the reaction tank to the front of the RCTS™ system. At this point, the treated water was passed through one or more filter bags to a settling pond.

Treatment Effectiveness. Both treatment systems were effective at removing dissolved metals from solution. The percent removal of Al, Cu, Fe, and Zn were in excess of 99%.

Lime Consumption by the Conventional System. The average mass of lime added per day during operation of the conventional system was ≈ 180 Kg (398 lbs) per day. The average volume of water treated per day 166,230 L. This equates to 1,086 mg of lime added per liter of water treated. During this period the average pH at the system effluent was pH 7.8 and the average pH at the filter bag effluent was 8.12. The average flow was ≈ 115 liters (30.38 gallons) per minute and the average influent pH was 4.73. The average dissolved oxygen (DO) at the effluent was 4.22 mg/L.

Lime Consumption by the RCTS™ System. The average lime added during the operation of the RCTS™ was ≈ 106 Kg (233 lb) per day. The average volume of water treated per day was 109,484 L. This equates to 707 mg of lime added per liter of water treated. During this period, the average pH at the system effluent was 8.12 and the average pH at the filter bag effluent was 8.11. The average flow was ≈ 103 liters (27.33 gallons) per minute and the average influent pH was 4.86. The average DO at the system effluent was 7.86 mg/L.

When the RCTS™ stand-alone period is compared with the conventional system stand-alone period, we note a 41% reduction in lime consumption even with a slightly higher effluent pH and significantly higher DO concentrations in the effluent from the RCTS™ system.

Power Consumption by the Conventional System. The aeration and mixing component of the conventional tank reactor system consisted of four air compressors. The air compressors delivered approximately 2.265 cubic meters per second (80 cubic feet per second) of air into the four reactor tanks through fine bubble diffusers. The four air compressors were operated on 480 volt (V) 3 phase power drawing approximately 18 amperes (A) total or approximately 8640 watts (W).

Power Consumption by the RCTS™ System. The RCTS™ treatment system used two 1.5 hp gear reduced motors and operated on 220 V single phase power drawing approximately 12 A total or 2640 W.

Table 3. Comparison of RCTS™ with conventional tank system in 2002 at the Leviathan Mine

	Hydraulic capacity (gallons)	Average flow rate (gpm)	System residence time (minutes)	Influent pH	Effluent pH	Filter bag pH	Effluent DO (mg/L)	Average lime used per day (lbs)	Average lime conc. (mg/L)
Conventional Tank Reactor System	4000	30.38	131.67	4.73	7.88	8.12	4.22	398	1086
Rotating Cylinder Treatment System	1600, includes dosing tank	27.33	58.54	4.86	8.12	8.11	7.86	233	707

Leviathan Mine 2006

The Lahontan Regional Water Quality Control Board seasonally treats AMD that emanates from an adit and pit underdrain at the Leviathan Mine. The AMD is captured in a series of lined ponds throughout the year. Because the ponds are open to the environment, they also capture a significant amount of snow and rain. Since 1999, the LRWQCB and its contractors have treated the water/AMD mixture contained in the storage ponds using a conventional system that was originally designed to treat highly evapoconcentrated AMD with high As concentrations. The system used a biphasic configuration (2 stage pH adjustment and 2 stage sludge separation) until 2005 when the system was converted to monophasic treatment to simplify the system and enable higher treatment rates.

Figure 2. Conventional treatment system at the Leviathan Mine.

The winter of 2006 was exceptionally wet and TKT Consulting (now IWT) was contracted to treat and discharge AMD to prevent untreated AMD from overflowing to Leviathan Creek (Tsukamoto 2006). The RCTS™ system was used because it could be mobilized and operational early in the spring, whereas the existing plant could not be operated until mid-summer. TKT was informed to start the mobilization process on April 5, 2006. TKT inspected the road the next day. The RCTS-HS system and lime delivery system were mobilized from Boise, Idaho to Reno, Nevada on April 7. The road was plowed to remove snow on April 9, and 18 pallets of lime were delivered to the Nevada/California border and were shuttled to the site via four-wheel drive equipment on April 12 and 13. Treatment began on April 14 and by 10 a.m. on April 15 the average pH of the holding pond was 8.4.

In 2006, approximately 28.4 million liters (7.5 million gallons) of AMD were treated with the RCTS™. The conventional treatment facility treated approximately 13.2 million gallons of AMD. Although the water quality varied during the operation of the RCTS™, during the last 7 days of operation the RCTS™ system was treating AMD from the same pond and at the same time as the existing treatment plant.

Figure3. RCTS system at the Leviathan Mine.

The RCTS™ system operated between 4-14-2006 and 7-10-2006. The conventional system operated between 6-27-2006 and 8-25-2006. The influent AMD analysis is provided in Table 4. The pH and metals concentrations in the influent were relatively consistent over the treatment span of the conventional system.

Table 4. Influent water quality (mg/L)(Leviathan 2006)

Date	pH	Al	As	Cd	Co	Cr	Cu	Fe	Pb	Mn	Ni	Zn	TDS	Sulfate
7-3-08	2.70	460	12	0.085	2.4	1.8	3.8	1000	0.0057	13	6.7	1.3	9800	6400
7-10-08	2.50	440	11	0.074	1.5	1.5	3.2	920	0.0039	12	6.4	1.2	8500	5800
7-17-08	2.50	430	7	0.065	2.3	1.4	2.4	790	0.0032	11	5.7	1.0	7400	5300
7-24-08	2.60	400	5.6	0.064	2.2	1.2	2.3	720	0.0032	10	6.0	1.1	6400	4900
7-31-08	2.54	460	6.3	0.082	1.7	1.4	2.6	890	0.0024	10	6.3	1.2	8000	6700
8-7-08	2.48	410	4.6	0.065	1.8	1.1	2.4	590	0.0021	6.1	ND	0.760	7300	5700

Conventional Treatment System. The conventional system was designed for biphasic treatment of highly concentrated acid mine drainage (US EPA 2006). The system used two 37850 liter (10,000 gallon) reaction tanks and two flash floc tanks with two clarifiers, each with a volume of approximately 18925 liters (5,000 gallons). Lime slurry was delivered to the first tank to achieve a pH of approximately 3.2 and then to the second reaction tank to achieve a discharge pH between 7.2 and 8.7. Both reaction tanks were actively aerated. All six vessels received either mechanical mixing or pump circulation. Effluent was discharged from the second clarifier tank to a settling/filtration pond.

The aeration and mixing component of the conventional system consisted of aeration and mechanical mixers in each of the reactor tanks and mechanical mixers or circulation pumps in the each of the clarifiers and flash floc tanks. The total reaction volume of the system was approximately 113,515 liters (30,000 gallons).

RCTS™ System

The RCTS-30HS system consisted of a 36 inch diameter x 20 ft housing in which a 30" perforated cylinder was rotated at 80 rpm with a 5 hp gear reduced motor. The total working volume of the RCTS™ system was ≈130 gallons. Lime slurry was added to the influent end of the RCTS™ system. Effluent was discharged to a settling pond.

Table 5. Comparison of RCTS and conventional treatment

	Average Metals Concentrations, pH, Acidity (mg/L) and Lime utilization								
Treatment System	**Influent pH**	**Influent Acidity* mg/L $CaCO_3$**	**Inf Al**	**Inf Fe**	**Inf Mn**	**Inf Zn**	**Inf Cu**	**Effluent pH**	**Average Lime Concentration $Ca(OH)_2$ ($CaCO_3$)**
RCTS (During the time period that both systems were operating simultaneously)	2.43	5247	450	960	12.5	1.25	3.5	8.16	1,601 (2,161)
Conventional (During the entire span of the conventional system operation in 2006)	2.53	4780	433	818	10.35	1.09	2.78	7.8	3,300 (4,455)

* Acidity calculated based on the displayed metals using AMDTreat Software

Treatment Effectiveness

Both treatment systems were effective at removing dissolved metals from solution. The percent removal of Al, Cu, Fe, Ni and Zn were in excess of 99%.

Lime Consumption of the Conventional System. The conventional system used 179 dry tons of lime and treated ≈13.2 million gallons of AMD. This corresponds to 73,700 gallons of water treated per ton during 2006 at an average lime concentration of 3300 mg/L. During this period, the average pH at the discharge was 7.8. The average flow was 199 gpm and the average influent pH was pH 2.53.

Lime Consumption of the RCTS™ System. The RCTS™ mobile system used 3.675 dry tons of lime and treated ≈550,000 gallons of AMD between 7-3-2006 and 7-10-2006 (the time period that both systems were operating). This corresponds to 149,700 gallons of water treated per ton at an average lime concentration of 1601 mg/L. The average pH during discharge was 8.16, the average flow was ≈55 gpm, and the average influent pH was pH 2.43. IWT established that a high treatment rate of ≈330 gpm could be achieved with the RCTS-30HS system; however, treatment at this rate was limited to several hours at a time due to the capacity of the lime dosing system.

Landusky 2008

Spectrum Engineering, out of Billings, Montana was hired by the Department of Environmental Quality to manage the reclamation of the bankrupt Zortman and Landusky mine sites. During 2008, Spectrum Engineering rehabilitated dredged reaches of Swift Gulch and Little Bighorn Creek located north of the former Landusky Mine in north-central Montana.

Settling basins were also installed near the headwaters of Swift Gulch to capture Fe-rich seeps and provide some oxidation prior to being piped to a treatment pad downstream. Two settling ponds were constructed to allow the settling of precipitated metals prior to reentering the swift Gulch drainage.

An RCTS-60HS was mobilized to Swift Gulch on 9-15-08. The system was set-up with a 3 man crew in 6 hours. Treatment began on 9-16-08 at approximately 11 a.m.. The goal of the project was to test the system for 2 months prior to winter shut-down. IWT provided the initial start-up. IWT and Spectrum Engineering crews worked together to operate the system. The

RCTS™ system was purchased after 3 weeks of testing. An additional RCTS™ system was purchased to remove metals from leach pad effluent prior to biological treatment.

<u>Treatment System</u>

A single RCTS-60HS™ was used to treat the ≈60 gpm of AMD that occurs in Swift Gulch. A generator was supplied to power the system, which operated on ≈7.5 KW. Lime slurry was used at varied concentrations to determine the best treatment for the Swift Gulch system.

<u>Results</u>

The RCTS™ system was effective at neutralizing the AMD and precipitating metals. The settling ponds were effective at capturing the precipitated solids. Table 5 displays sampling results from Spectrum Engineering.

Table 5. Water Quality results from Swift Gulch (dissolved metals)

	pH	Acidity	Al	As	Cd	Cu	Fe^{tot}	Fe^{2+}	Mn	Ni	Zn
Influent (at capture system)	3.0	369	6.90	0.032	0.0054	0.34	81	81	10.3	0.66	7.84
RCTS™ effluent	7.4	NA	0.04	ND	0.0002	0.004	ND	ND	5.81	0.102	0.018
Settling pond	7.8	NA	0.03	ND	0.0002	0.004	ND	ND	5.33	0.101	0.032
Discharge	6.9	NA	ND	ND	0.0003	0.005	ND	ND	0.011	0.005	0.133

-NA = not applicable, pH less than 4.5

- ND = not detected at the reporting limit

Summary

All of the treatment systems that were tested were effective at precipitating metals and increasing pH. The RCTS™ system is compact and can be mobilized and set up in hours. AMD was treated after ≈6 hours of set-up time on the two projects that required a fast response. On all three comparison projects, the RCTS™ system used substantially less energy and required less residence time within the aeration and mixing portion of the treatment system. Although the flow and the chemistry varied on the Rio Tinto project, the RCTS™ system had a lime effectiveness of 0.8 to 1.4 with an average effectiveness of 1.15. The conventional treatment system had a lime effectiveness of 0.79 to 3.22 with an average effectiveness of 1.80. Based on this data, on average the RCTS™ was 36% more efficient with respect to lime utilization than the conventional system. On the Leviathan 2004 project, the RCTS™ used 41% less lime per day while treating 10% less water per day and raising the pH to a higher value and oxidizing the Fe more effectively. On the Leviathan 2006 project, the RCTS™ treated ≈149,700 gallons of water per dry ton of lime added while the conventional system treated ≈73,700 gallons of water per dry ton of lime added. This reflects a 51% difference in lime efficiency.

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