Treatment of Acid Mine Drainage (Lime Precipitation)

-The addition of lime:
  1. to raise the pH and precipitate metals as hydroxides
  2. to precipitate sulfate as gypsum

-Requires:
  1. oxygen addition if dissolved ferrous iron is present
     Oxygen addition is typically accomplished with compressors
     and air diffusers placed in reaction tanks.
  2. thorough mixing due to it’s low solubility and slow dissolution rate.
     Mixing is typically accomplished with mixers inside of reaction tanks.

-Typically labor intensive due to the requirements listed above
Iron Hydroxide Solubility vs pH

The solubility of iron hydroxide varies with pH. The graph shows two distinct regions:

- **Insoluble Region**: Between pH 2 and 6, iron hydroxide is insoluble, with its solubility decreasing as pH increases. This region is labeled as 'Ferric Hydroxide' (Fe(OH)$_3$).
- **Soluble Region**: Above pH 6, iron hydroxide becomes soluble, with its solubility increasing as pH increases. This region is labeled as 'Ferrous Hydroxide' (Fe(OH)$_2$).

The graph also includes an EPA limitation for a 30-day average (3 mg/L) which is shown by a dotted line.
Aluminum Hydroxide Solubility vs pH
Iron Hydroxide Solubility vs pH

The graph illustrates the solubility of iron hydroxide as a function of pH. Iron hydroxide is soluble in acidic conditions (pH < 6) and becomes insoluble in more basic conditions (pH > 6). The EPA limitation is indicated as a dashed line, representing the 30-day average concentration. The graph shows that ferric hydroxide is soluble at low pH and insoluble at high pH. Ferrous hydroxide is soluble at high pH and insoluble at low pH.
DESIGN AND OPERATIONAL CONCEPT OF THE RCTS TREATMENT SYSTEM

• Rotating perforated cylinders add oxygen from the atmosphere to the water

• Compressors and blowers are eliminated

• Aggressive agitation maximizes reagent efficiency
Improved Oxygen Addition

Provides more oxygen per energy consumed than conventional systems
mechanical surface aeration systems provides 3.0-3.5 lbs of oxygen per horsepower hour (USEPA 1983)

submerged turbine aerators utilizing dual impeller turbines provide 2.5-3.0 pounds of oxygen per horsepower hour (USEPA 1983)

600 gallon four rotor RCTS provided approximately 9 pounds of oxygen per horsepower hour

\[ O_2 = Q_w \times F_e \times 7.14 \times 10^{-5} \]

\( O_2 = \) Theoretical \( O_2 \) demand (lb \( O_2/hr \))
\( Q_w = \) Acid mine drainage flow rate (gal/min)
\( F_e = \) \( Fe^{2+} \) initial concentration (mg/L)

Operated on two cylinders powered by 0.375 hp and oxidized ~ 5,000 mg/L of iron at a flow rate of 10 gallons per minute.
Four Rotor RCTS Unit
Single Rotor High Speed RCTS Unit (RCTS-HS)
RCTS TECHNOLOGY AT THE RIO TINTO MINE IN NORTHEASTERN NEVADA 2003
Highly concentrated AMD

- The RCTS treated AMD with Fe\(^{2+}\) concentrations approaching 4,900 mg/l.

- Acidity was in excess of 12,500 mg/l.

- Sulfate concentrations were in excess of 18,000 mg/l.
Treatment Schematic 2003 RCTS 4 Rotor
Rio Tinto Mine

AMD ~10-24 gpm

RCTS 4 Rotor 600 gallon

Lime Delivery

Settling Pond 1
RIO TINTO MINE IN 2003

- 600 Gallon Prototype Unit met all Water Quality Standards applicable at the site
- Specific experiments undertaken for the Hybrid RCTS-Sulfate Reducing System
- Aluminum concentrations of 546 mg/l were removed to 0.009 mg/l during this experiment by the RCTS
### Treatment Results 2003 RCTS 4 Rotor Rio Tinto Mine

Table 2.4.1. 2003 RCTS Results

#### Dissolved Influent Concentrations

<table>
<thead>
<tr>
<th>Date</th>
<th>TDS</th>
<th>Al</th>
<th>As</th>
<th>Cd</th>
<th>Cu</th>
<th>Cr</th>
<th>Fe</th>
<th>Mn</th>
<th>Se</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/19/03</td>
<td>6510</td>
<td>124</td>
<td>0.0066</td>
<td>0.0964</td>
<td>53.7</td>
<td>0.0126</td>
<td>833</td>
<td>27.4</td>
<td>0.23</td>
<td>16.5</td>
</tr>
<tr>
<td>9/20/03</td>
<td>6960</td>
<td>133</td>
<td>0.0077</td>
<td>0.0968</td>
<td>57.9</td>
<td>0.0134</td>
<td>931</td>
<td>29.4</td>
<td>&lt;0.05U</td>
<td>17.9</td>
</tr>
<tr>
<td>9/21/03</td>
<td>24200</td>
<td>528</td>
<td>0.024</td>
<td>0.338</td>
<td>215</td>
<td>0.044</td>
<td>4640</td>
<td>86.5</td>
<td>&lt;0.2U</td>
<td>62.1</td>
</tr>
<tr>
<td>9/22/03</td>
<td>23300</td>
<td>540</td>
<td>0.026</td>
<td>0.342</td>
<td>220</td>
<td>0.044</td>
<td>4790</td>
<td>89.1</td>
<td>&lt;0.2U</td>
<td>64.7</td>
</tr>
<tr>
<td>9/22/03</td>
<td>25200</td>
<td>546</td>
<td>0.026</td>
<td>0.340</td>
<td>222</td>
<td>0.044</td>
<td>4870</td>
<td>90.8</td>
<td>&lt;0.2U</td>
<td>65.2</td>
</tr>
</tbody>
</table>

#### Dissolved Effluent Concentrations

<table>
<thead>
<tr>
<th>Date</th>
<th>TDS</th>
<th>Al</th>
<th>As</th>
<th>Cd</th>
<th>Cu</th>
<th>Cr</th>
<th>Fe</th>
<th>Mn</th>
<th>Se</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/19/03</td>
<td>4240</td>
<td>0.246</td>
<td>&lt;0.005U</td>
<td>0.0006</td>
<td>0.016</td>
<td>0.0006</td>
<td>&lt;0.05</td>
<td>3.54</td>
<td>&lt;0.001U</td>
<td>0.06</td>
</tr>
<tr>
<td>9/20/03</td>
<td>4500</td>
<td>0.247</td>
<td>&lt;0.005U</td>
<td>0.0007</td>
<td>0.017</td>
<td>0.0015</td>
<td>&lt;0.05</td>
<td>4.18</td>
<td>&lt;0.001U</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>9/21/03</td>
<td>8780</td>
<td>0.109</td>
<td>&lt;0.005U</td>
<td>&lt;0.0005</td>
<td>0.019</td>
<td>0.0019</td>
<td>&lt;0.05</td>
<td>3.35</td>
<td>0.001</td>
<td>0.05</td>
</tr>
<tr>
<td>9/22/03</td>
<td>7380</td>
<td>0.077</td>
<td>&lt;0.005U</td>
<td>&lt;0.0005</td>
<td>0.020</td>
<td>0.0019</td>
<td>&lt;0.05</td>
<td>2.57</td>
<td>&lt;0.001U</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>9/22/03</td>
<td>12300</td>
<td>0.009</td>
<td>&lt;0.001U</td>
<td>0.025</td>
<td>0.093</td>
<td>0.004</td>
<td>&lt;0.10</td>
<td>52.2</td>
<td>&lt;0.001U</td>
<td>0.70</td>
</tr>
<tr>
<td>9/24/03</td>
<td>9810</td>
<td>0.068</td>
<td>&lt;0.002U</td>
<td>&lt;0.0005</td>
<td>0.010</td>
<td>&lt;0.002U</td>
<td>&lt;0.10</td>
<td>3.46</td>
<td>0.001</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>9/24/03</td>
<td>9780</td>
<td>0.071</td>
<td>&lt;0.002U</td>
<td>&lt;0.0005</td>
<td>&lt;0.010</td>
<td>&lt;0.002U</td>
<td>&lt;0.10</td>
<td>3.46</td>
<td>0.001</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>
THE RIO TINTO MINE (4-ROTOR) TREATMENT 2004
Treatment Schematic 2004 RCTS 4 Rotor x 2

AMD ~22 gpm

RCTS 4 Rotor 1200 gallon

RCTS 4 Rotor 600 gallon

Settling Pond 1

Lime Delivery
THE RIO TINTO MINE
RCTS-HS 2004
The RCTS-HS prototype was utilized for an emergency water level adjustment of a hydraulic control pond in November of 2004.
Treatment Schematic 2004 RCTS –HS
Rio Tinto Mine

AMD Up to 53 gpm

Lime Delivery

Lime Dosing Tank

Settling Pond 1

RCTS –HS 170 gallons

~ 30 gpm
## TYPICAL RESULTS

**mg/l**

<table>
<thead>
<tr>
<th>INFLUENT</th>
<th>Unit Type</th>
<th>Al</th>
<th>As</th>
<th>Cd</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/4/04</td>
<td>RCTS 4 Rotor x 2</td>
<td>491</td>
<td>nd</td>
<td>.32</td>
<td>202</td>
<td>4170</td>
<td>77.5</td>
<td>54.6</td>
</tr>
<tr>
<td>10/6/04</td>
<td>RCTS 4 Rotor x 2</td>
<td>433</td>
<td>.03</td>
<td>.278</td>
<td>209</td>
<td>3550</td>
<td>82.6</td>
<td>50.9</td>
</tr>
<tr>
<td>11/9/04</td>
<td>RCTS-HS</td>
<td>683</td>
<td>.03</td>
<td>.365</td>
<td>293</td>
<td>4800</td>
<td>109</td>
<td>74.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EFFLUENT</th>
<th>Unit Type</th>
<th>Al</th>
<th>As</th>
<th>Cd</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/4/04</td>
<td>RCTS 4 Rotor x 2</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>.037</td>
<td>.74</td>
<td>4.51</td>
<td>.07</td>
</tr>
<tr>
<td>10/6/04</td>
<td>RCTS 4 Rotor x 2</td>
<td>nd</td>
<td>nd</td>
<td>.002</td>
<td>.097</td>
<td>.11</td>
<td>9.54</td>
<td>.09</td>
</tr>
<tr>
<td>11/9/04</td>
<td>RCTS-HS</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>.003</td>
<td>nd</td>
<td>4.88</td>
<td>nd</td>
</tr>
</tbody>
</table>
Results:

- The RCTS met all Federal Water Quality Standards applicable at the site in a single stage pH adjustment of the influent.

- The RCTS-HS met all Federal Water Quality Standards applicable during this emergency lagoon type treatment.

- Treated ~22 gallons/min (RCTS 4 rotor x 2)
  ~53 gallons/min (RCTS-HS)

- Operated on less than 1600 watts of electricity.

- Lime slurry efficiency ~98%
RIO TINTO MINE
2005
RIO TINTO MINE
2005
RIO TINTO MINE
2005

AMD 5-20 gpm
Lime Delivery
Lime Dosing Tank

RCTS 4-Rotor
600 gallon

RCTS 4-Rotor
1200 gallon

~ 35 gpm
## TYPICAL RESULTS

### mg/l

<table>
<thead>
<tr>
<th>Date</th>
<th>Sample Location</th>
<th>Al</th>
<th>As</th>
<th>Cd</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
<th>Zn</th>
<th>Sulfate</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/19/2005</td>
<td>Influent</td>
<td>726</td>
<td>nd</td>
<td>0.340</td>
<td>320</td>
<td>6780</td>
<td>87.3</td>
<td>73.6</td>
<td>24,100</td>
</tr>
<tr>
<td>7/19/2005</td>
<td>Effluent</td>
<td>0.2</td>
<td>nd</td>
<td>nd</td>
<td>0.005</td>
<td>nd</td>
<td>1.01</td>
<td>nd</td>
<td>4110</td>
</tr>
<tr>
<td>7/26/2005</td>
<td>Influent</td>
<td>793</td>
<td>0.03</td>
<td>0.359</td>
<td>314</td>
<td>6890</td>
<td>96</td>
<td>79.4</td>
<td>24,180</td>
</tr>
<tr>
<td>7/26/2005</td>
<td>Effluent</td>
<td>0.1</td>
<td>nd</td>
<td>0.0005</td>
<td>0.005</td>
<td>nd</td>
<td>0.52</td>
<td>nd</td>
<td>2,410</td>
</tr>
<tr>
<td>8/5/2005</td>
<td>Influent</td>
<td>540</td>
<td>nd</td>
<td>0.338</td>
<td>228</td>
<td>4990</td>
<td>80.3</td>
<td>60</td>
<td>17,600</td>
</tr>
<tr>
<td>8/5/2005</td>
<td>Effluent</td>
<td>0.08</td>
<td>nd</td>
<td>0.0002</td>
<td>0.002</td>
<td>0.05</td>
<td>0.41</td>
<td>nd</td>
<td>1,800</td>
</tr>
<tr>
<td>8/11/2005</td>
<td>Influent</td>
<td>297</td>
<td>nd</td>
<td>0.210</td>
<td>130</td>
<td>2840</td>
<td>63.9</td>
<td>36.7</td>
<td>10,200</td>
</tr>
<tr>
<td>8/11/2005</td>
<td>Effluent</td>
<td>0.13</td>
<td>nd</td>
<td>nd</td>
<td>0.01</td>
<td>nd</td>
<td>0.2</td>
<td>nd</td>
<td>1,950</td>
</tr>
<tr>
<td>8/18/2005</td>
<td>Influent</td>
<td>305</td>
<td>nd</td>
<td>0.200</td>
<td>128</td>
<td>2950</td>
<td>58.1</td>
<td>35.2</td>
<td>10,900</td>
</tr>
<tr>
<td>8/18/2005</td>
<td>Effluent</td>
<td>0.114</td>
<td>nd</td>
<td>nd</td>
<td>0.014</td>
<td>0.06</td>
<td>0.2</td>
<td>nd</td>
<td>2,070</td>
</tr>
<tr>
<td>9/7/2005</td>
<td>Influent</td>
<td>572</td>
<td>nd</td>
<td>0.301</td>
<td>248</td>
<td>5110</td>
<td>67.4</td>
<td>57.5</td>
<td>17,600</td>
</tr>
<tr>
<td>9/7/2005</td>
<td>Effluent</td>
<td>0.26</td>
<td>nd</td>
<td>nd</td>
<td>0.018</td>
<td>0.40</td>
<td>0.23</td>
<td>nd</td>
<td>2,560</td>
</tr>
<tr>
<td>9/23/2005</td>
<td>Influent</td>
<td>325</td>
<td>nd</td>
<td>0.198</td>
<td>139</td>
<td>2940</td>
<td>58.2</td>
<td>36.5</td>
<td>9,710</td>
</tr>
<tr>
<td>9/23/2005</td>
<td>Effluent</td>
<td>0.07</td>
<td>0.001</td>
<td>0.0002</td>
<td>0.009</td>
<td>nd</td>
<td>0.58</td>
<td>nd</td>
<td>2,390</td>
</tr>
<tr>
<td>9/30/2005</td>
<td>Influent</td>
<td>279</td>
<td>nd</td>
<td>0.230</td>
<td>131</td>
<td>2570</td>
<td>51.9</td>
<td>32.3</td>
<td>9,910</td>
</tr>
<tr>
<td>9/30/2005</td>
<td>Effluent</td>
<td>0.04</td>
<td>0.001</td>
<td>0.0002</td>
<td>0.011</td>
<td>nd</td>
<td>0.581</td>
<td>nd</td>
<td>2350</td>
</tr>
</tbody>
</table>

### Table 1. Treatment Results for the Rio Tinto Mine 2005 Concentrations (mg/L)
RCTS TECHNOLOGY AT THE LEVIATHAN MINE 2004
Treatment Schematic 2004 RCTS 4 Rotor
Leviathan Mine

AMD 25-30 gpm

RCTS 4 Rotor
1200 gallon

Lime Delivery

Filtration Bags

Settling Pond 1
The RCTS treated 25-30 gpm Fe\(^2\) concentrations of 300 to 400 mg/l.

Lime slurry efficiency was 41% better than the conventional tank reactor system onsite.

Influent residence time within the RCTS was 75% less than the conventional tank reactor system onsite.

Water Quality Standards were met by the RCTS in a single stage pH adjustment.

The RCTS operated on less than 1600 watts of electricity during treatment operations.
RCTS TECHNOLOGY AT THE LEVIATHAN MINE EMERGENCY BATCH TREATMENT 2005
Treatment Schematic 2004 RCTS –HS
Northeastern Nevada

Treatment Pond
~900,000 gallons

Up to 130 gpm

RCTS –HS
170 gallons

Lime Delivery
RCTS TECHNOLOGY AT THE LEVIATHAN MINE EMERGENCY BATCH TREATMENT 2005

- Mobilize the system in 3 days
- The RCTS treated ~800,000 gallons of AMD in approximately 90 hours.
- Acidity ~ 1,300 mg/L mostly aluminum
- All applicable Water Quality Standards were met
- The RCTS operated on less than 1600 watts of electricity during treatment operations
- Lime efficiency > 89%
RCTS TECHNOLOGY AT THE LEVIATHAN MINE EMERGENCY BATCH TREATMENT 2005
RCTS TECHNOLOGY AT THE LEVIATHAN MINE EMERGENCY BATCH TREATMENT 2006
Flow ~ 6 gpm
pH ~ 6.6
iron ~ 4 mg/L
arsenic ~ 0.05 mg/L
Goals:

- To oxidize and precipitate the iron and co precipitate arsenic from solution.

- It was initially proposed that sodium hydroxide would be added to raise the pH from 6.6 approximately 8.0.

- The addition of base was not necessary (Degassing of carbon dioxide from the water)

\[
\text{HCO}_3^- + \text{H}^+ \rightarrow \text{H}_2\text{O} + \text{CO}_2
\]
Treatment Schematic RCTS 4 Rotor Empire Mine

AMD
~6 gpm

→ RCTS 4 Rotor 600 gallon

→ Settling Pond 1
Results:

Iron concentrations were reduced from 4290 µg/L to 80 µg/L. (without base addition)

The ferrous iron concentration was not sufficient to co-precipitate all of the arsenic from solution. Arsenic was reduced from 47 µg/L to 25 µg/L.

Suggested adding Ferrous iron to co-precipitate arsenic
Summary

- Can be rapidly mobilized.
- Efficient lime utilization
- Can reduce sludge production.
- Requires 60% to 90% less expended energy than conventional treatment.
- Less space required.
- Can treat as a batch or continuous.