Anaerobic Biochemical Reactor (BCR) Treatment of Mining-Influenced Water (MIW): Evaluation of Reduction in Concentrations of Metals and Aquatic Toxicity

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Presentation Outline

• BCR Treatment
• Research Questions
• Study Sites
• Methods
• Metals Removal
• Aquatic Toxicity (Acute)
• Concluding Remarks

BCR Treatment

• Passive / semi-passive treatments
  • Natural processes
    • Minimal or no energy requirement
    • Solar
  • Biochemical reactor
    • Previously (and sometimes still) called sulfate-reducing bioreactor
    • Sometimes called anaerobic wetland
    • But, no vegetation

BCR Treatment

• Overall goal of remediation is to minimize environmental and human health impacts

• Evaluation of BCR treatment generally through metal removal efficiency
  • Percentage of dissolved metals removed by the system
    • $100\% \times (\text{influent concentration} - \text{effluent concentration}) / \text{influent concentration}$

BCR Treatment

• Chemical, biological, and physical processes
  • Reduction, precipitation, adsorption, retention
  • Hay, straw, wood chips, sawdust, compost ethanol, waste milk, limestone, manure...
  • Aerobic polishing
    • Increase oxygen
    • Decrease BOD
    • Settle solids
      • Some release of sulfide precipitates, which oxidize and re-precipitate as metal oxyhydroxides
      • Degas sulfide and ammonia
Anaerobic Biochemical Reactor (BCR) Treatment of Mining-Influenced Water (MIW): Evaluation of Reduction in Concentrations of Metals and Aquatic Toxicity

Research Questions Asked

• Are the effluents from the different pilot BCRs toxic (i.e., are there adverse effects to either test species that is statistically different from control water)?
• Is the toxicity reduced, relative to the influent?
• If effluents are toxic, is there a toxicant identifiable?

Study Sites

- Luttrell Repository, Helena, MT
- Peerless Jenny King, Helena, MT
- Park City Biocell, Park City, UT
- Standard Mine, Crested Butte, CO

Luttrell Repository (MT)
- Upper Ten-mile Creek Superfund site
- 2002
- 7,644 ft AMSL
- 1.5 gpm treated
- Al, As, Cd, Co, Cu, Fe, Mn, Zn

Peerless Jenny King (MT)
- Upper Ten-mile Creek Superfund site
- 2003
- 7,600 ft AMSL
- 20-25 gpm treated
- Cd, Fe, Zn

Peerless Jenny King (MT)
- Upper Ten-mile Creek Superfund site
- 2003
- 7,600 ft AMSL
- 20-25 gpm treated
- Cd, Fe, Zn

Park City Biocell (UT)
- Prospector drain in Silver Creek Watershed
- 2008
- 6,900 ft AMSL
- 29 gpm treated
- Cd, Zn
Anaerobic Biochemical Reactor (BCR) Treatment of Mining-Influenced Water (MIW): Evaluation of Reduction in Concentrations of Metals and Aquatic Toxicity

**Park City Biocell (UT)**
- Prospector drain in Silver Creek Watershed
- 2008
- 6,900 ft AMSL
- 29 gpm treated
- Cd, Zn

**Standard Mine (CO)**
- Crested Butte
- 2007
- 11,000 ft AMSL
- 1.2 gpm treated
- Cd, Cu, Fe, Pb, Mn, Zn

**Methods**
- Triplicate influent and effluent samples from Luttrell, PJK, and Park City
- Duplicate influent and effluent samples from the Standard Mine BCR and from the APC

**Methods**
- Filtered metals (0.45 µm) – inductively coupled plasma – optical emission spectroscopy (ICP-OES)
- Sulfate – ion chromatography
- Total sulfide – ion selective electrode
- Total ammonia – gas sensing electrode
Anaerobic Biochemical Reactor (BCR) Treatment of Mining-Influenced Water (MIW): Evaluation of Reduction in Concentrations of Metals and Aquatic Toxicity

Methods

- Whole effluent toxicity tests (WET)
- Series of dilutions of the influent and effluent water samples
- Acute 48-hr LC<sub>50</sub>
- Percentage of water mixed with moderately hard dilution water
- Ceriodaphnia dubia [water flea]
- Pimephales promelas [fathead minnow]
- Control survival > 90%

Influent Metals Concentrations

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Site</th>
<th>Luttrell</th>
<th>FR</th>
<th>Park City</th>
<th>Standard Mine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al (mg/l)</td>
<td>18 ± 0.3</td>
<td>BMIDL</td>
<td>BMIDL</td>
<td>BMIDL</td>
<td>BMIDL</td>
</tr>
<tr>
<td>As (mg/l)</td>
<td>2.5 ± 0.03</td>
<td>BMIDL</td>
<td>BMIDL</td>
<td>BMIDL</td>
<td>BMIDL</td>
</tr>
<tr>
<td>Cd (mg/l)</td>
<td>1.6 ± 0.11</td>
<td>BMIDL</td>
<td>BMIDL</td>
<td>BMIDL</td>
<td>BMIDL</td>
</tr>
<tr>
<td>Cu (mg/l)</td>
<td>27 ± 0.1</td>
<td>BMIDL</td>
<td>BMIDL</td>
<td>BMIDL</td>
<td>BMIDL</td>
</tr>
<tr>
<td>Fe (mg/l)</td>
<td>27 ± 0.3</td>
<td>0.17 ± 0.015</td>
<td>BMIDL</td>
<td>BMIDL</td>
<td>BMIDL</td>
</tr>
<tr>
<td>Ni (mg/l)</td>
<td>0.33 ± 0.003</td>
<td>BMIDL</td>
<td>BMIDL</td>
<td>BMIDL</td>
<td>BMIDL</td>
</tr>
<tr>
<td>Pb (mg/l)</td>
<td>BMIDL</td>
<td>BMIDL</td>
<td>BMIDL</td>
<td>BMIDL</td>
<td>BMIDL</td>
</tr>
<tr>
<td>Zn (mg/l)</td>
<td>270 ± 15</td>
<td>1.2 ± 0.09</td>
<td>8.4 ± 0.15</td>
<td>17 ± 0.6</td>
<td>25 ± 9</td>
</tr>
<tr>
<td>SO&lt;sub&gt;4&lt;/sub&gt; (mg/l)</td>
<td>4.6 ± 1.1 (g/l)</td>
<td>49 ± 13.8</td>
<td>642 ± 59</td>
<td>254 ± 9</td>
<td></td>
</tr>
</tbody>
</table>

Influent & Effluent Water Chemistry

<table>
<thead>
<tr>
<th>Parameter [average]</th>
<th>Luttrell</th>
<th>FR</th>
<th>Park City</th>
<th>SM-BCR</th>
<th>SM-APC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Influent pH</td>
<td>3.6 ± 0.23</td>
<td>6.7 ± 0.08</td>
<td>6.3 ± 0.13</td>
<td>6.1 ± 0.06</td>
<td></td>
</tr>
<tr>
<td>DO (mg/l)</td>
<td>4 ± 0.8</td>
<td>3 ± 0.1</td>
<td>5 ± 0.1</td>
<td>6 ± 0</td>
<td></td>
</tr>
<tr>
<td>Effluent pH</td>
<td>6.6 ± 0.12</td>
<td>7.8 ± 0.04</td>
<td>7.2 ± 0.10</td>
<td>6.7 ± 0.06</td>
<td>8.6 ± 0.07</td>
</tr>
<tr>
<td>DO (mg/l)</td>
<td>3.3 ± 0.24</td>
<td>3 ± 0.3</td>
<td>2 ± 0.1</td>
<td>5.6 ± 0.45</td>
<td>1 ± 0</td>
</tr>
</tbody>
</table>

Percentage Metals Removal

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Site</th>
<th>Luttrell</th>
<th>FR</th>
<th>Park City</th>
<th>SM-BCR</th>
<th>SM-APC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al %</td>
<td>99 ± 1</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>As %</td>
<td>98 ± 2</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>Cd %</td>
<td>99 ± 10</td>
<td>n/a</td>
<td>96 ± 12</td>
<td>100 ± 3</td>
<td>100 ± 3</td>
<td></td>
</tr>
<tr>
<td>Cu %</td>
<td>100 ± 0.3</td>
<td>n/a</td>
<td>94 ± 9</td>
<td>94 ± 9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe %</td>
<td>99 ± 2</td>
<td>90 ± 12</td>
<td>n/a</td>
<td>-266 ± -518</td>
<td>100 ± 10</td>
<td></td>
</tr>
<tr>
<td>Ni %</td>
<td>94 ± 5</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>Pb %</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>94 ± 16</td>
<td>91 ± 17</td>
<td></td>
</tr>
<tr>
<td>Zn %</td>
<td>100 ± 13</td>
<td>94 ± 11</td>
<td>100 ± 3</td>
<td>100 ± 3</td>
<td>100 ± 3</td>
<td></td>
</tr>
<tr>
<td>SO&lt;sub&gt;4&lt;/sub&gt; %</td>
<td>72 ± 29</td>
<td>-78 ± 137</td>
<td>-5 ± 8</td>
<td>39 ± 4</td>
<td>72 ± 5</td>
<td></td>
</tr>
</tbody>
</table>

Acute Aquatic Toxicity
Anaerobic Biochemical Reactor (BCR) Treatment of Mining-Influenced Water (MIW): Evaluation of Reduction in Concentrations of Metals and Aquatic Toxicity

**Acute Aquatic Toxicity**
- What caused acute toxicity in Luttrell and Standard Mine BCR effluent samples?
- Low dissolved oxygen?
  - SM-BCR field average 0.6 mg/l DO; Luttrell field average 0.3 mg/l DO
  - Test units must have >4 mg/l
  - Generally >6 mg/l
- Metals, sulfide, ammonia?

**Concentrations calculated at observed LC50’s**

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Cu (ug/l)</th>
<th>Zn (ug/l)</th>
<th>H2S (mg/l)</th>
<th>NH3 (ug/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LR-EFF-A</td>
<td>NA</td>
<td>NA</td>
<td>61</td>
<td>26</td>
</tr>
<tr>
<td>LR-EFF-B</td>
<td>NA</td>
<td>NA</td>
<td>27</td>
<td>9.3</td>
</tr>
<tr>
<td>LR-EFF-C</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>3.2</td>
</tr>
<tr>
<td>SM-BCR-A</td>
<td>NA</td>
<td>NA</td>
<td>1.29</td>
<td>0.06</td>
</tr>
<tr>
<td>SM-BCR-B</td>
<td>NA</td>
<td>NA</td>
<td>0.74</td>
<td>0.1</td>
</tr>
<tr>
<td>Comparison</td>
<td></td>
<td></td>
<td></td>
<td>31.4</td>
</tr>
</tbody>
</table>

**Comparison Values**
- Cu: 29.2 ± 9.6
- Zn: 725 ± 0.002
- H2S: 200 - 5000
- NH3: 0.002 - 5000

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Cu (ug/l)</th>
<th>Zn (ug/l)</th>
<th>H2S (mg/l)</th>
<th>NH3 (ug/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LR-EFF-A</td>
<td>NA</td>
<td>NA</td>
<td>0.13</td>
<td>0.58</td>
</tr>
<tr>
<td>LR-EFF-B</td>
<td>NA</td>
<td>NA</td>
<td>0.53</td>
<td>1.83</td>
</tr>
<tr>
<td>LR-EFF-C</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>1.28</td>
</tr>
<tr>
<td>SM-BCR-A</td>
<td>NA</td>
<td>NA</td>
<td>0.298</td>
<td>0.01</td>
</tr>
<tr>
<td>SM-BCR-B</td>
<td>NA</td>
<td>NA</td>
<td>0.087</td>
<td>0.01</td>
</tr>
<tr>
<td>Comparison</td>
<td></td>
<td></td>
<td></td>
<td>31.4</td>
</tr>
</tbody>
</table>

**Comparison Values**
- Cu: 29.2 ± 9.6
- Zn: 725 ± 0.002
- H2S: 200 - 5000
- NH3: 0.002 - 5000

**Note:** NA = none detected in undiluted sample
- Dissolved H2S and NH3 calculated from total values, temperature, and pH
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Concluding Remarks

• Results suggest toxicity from dissolved hydrogen sulfide gas
  • Effluents more toxic to fathead minnow than to the C. dubia
  • Fathead minnow known to be more sensitive to dissolved gases than C. dubia
  • Dissolved H₂S concentrations above species mean acute values
  • Toxicity from 100% sample removed with aeration at Standard Mine and reduced at Luttrell

• Other BCRs may have different toxicants, depending on:
  • Contaminants present and efficiency of removal
  • Concentrations of dissolved gases and pH of the effluent

Concluding Remarks

• BCR treatment is effective at removing significant proportions of metals from MIW, but aquatic toxicity may still be present

• Sufficient in-field aeration following BCR treatment is an important step to remove potential toxicants resulting from the processes occurring within BCR cells

• Combining chemical and biological monitoring can lead to better treatment system designs
  • To meet the goal of minimizing environmental and human health impacts

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  • Mark Smith – McConnell Group [deceased, prior contractor to U.S. EPA ORD]

• Others:
  • Pegasus and McConnell Group – contractors to EPA
  • Regional RPM’s
  • City of Park City, UT
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