Life Cycle Assessment Analysis of Various Active and Passive Acid Mine Drainage Treatment Options

Dr. James Stone
Tyler Hengen & Maria Squillace
South Dakota School of Mines & Technology
Department of Civil and Environmental Engineering
Acknowledgements

University Supervisors

• Dr. James Stone
  – South Dakota School of Mines & Technology, Rapid City, SD

• Dr. Aisling O’Sullivan
  – University of Canterbury, Christchurch, New Zealand

Funding Sources

• New Zealand Government
  – Technology New Zealand
    (Foundation for Research, Science & Technology)

• Solid Energy New Zealand Ltd

• Coal Association of New Zealand

• University of Canterbury
  – Department of Civil & Natural Resources Engineering
Project Location

- Stockton Coal Mine, New Zealand
- West Coast on the South Island
- New Zealand’s largest open cast coal mine

AMD Monitoring Sites

- 13 Sites
  - 10 seep locations
  - Effluent from 3 sediment ponds

- Primary water chemistry parameters
  - Dissolved metals
  - pH
  - Sulfate
  - Acidity

- Community agreed on compliance levels of pH≥4.0 and 1 mg/L Al 99% of the time
Manchester Seep Description

- Candidate site for assessing AMD treatment methods
- Reportedly not influenced by active or future mining

<table>
<thead>
<tr>
<th></th>
<th>Median</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow (L/s)</td>
<td>1.84</td>
<td>0.35</td>
<td>10.5</td>
</tr>
<tr>
<td>pH</td>
<td>2.8</td>
<td>2.5</td>
<td>3.3</td>
</tr>
<tr>
<td>DO (mg/L)</td>
<td>9.6</td>
<td>8.1</td>
<td>10.9</td>
</tr>
<tr>
<td>DO (% Saturation)</td>
<td>82</td>
<td>73</td>
<td>94</td>
</tr>
<tr>
<td>Eh (mV)</td>
<td>709</td>
<td>691</td>
<td>744</td>
</tr>
<tr>
<td>Calculated Acidity (mg/L as CaCO₃)</td>
<td>426</td>
<td>88</td>
<td>728</td>
</tr>
<tr>
<td>Diss Fe (mg/L)</td>
<td>63</td>
<td>4.3</td>
<td>143</td>
</tr>
<tr>
<td>Diss Al (mg/L)</td>
<td>33</td>
<td>7.4</td>
<td>57</td>
</tr>
<tr>
<td>Sulphate (mg/L)</td>
<td>428</td>
<td>101</td>
<td>692</td>
</tr>
</tbody>
</table>
AMD Treatment Scenario Overview

- Passive Treatment Methods
  - Mussel Shell Bioreactor
    - Waste product in NZ from large fishery industry
    - Adds alkalinity and reduces metal concentrations

- Active Treatment Methods
  - Lime Dosing
  - Lime Slaking Plant

Evaluating treatment methods using LCA... What is LCA?

LCA History and Background

- Life Cycle Assessment (LCA) - approach to quantifying the environmental impacts of a scenario
- “Cradle to Grave”
  - Compile inventory
  - Evaluating potential impacts
  - Interpreting results to make informed decision

www.solidworks.com
LCA Input Value Definitions

- **Material Transport**
  - Transport energy from source to mine site (kgkm)

- **Raw Materials**
  - (kg of material)

- **Construction Energy**
  - Earth excavation and substrate emplacement (m³ of material)

- **Process Energy**
  - Pumped drainage or chemical additions if applicable to scenario (kwhr)

- **AMD Treatment Method**

- **Disposal of waste after project life**
  - (m³ of material)

**Functional Unit:** kg acidity removed/day
Impact Category Selection and Functional Unit

- SimaPro 7.3 (Netherlands)
- Midpoint category selection:
  - Indicators chosen between inventory results and endpoints
  - Impact assessment translated into environmental themes
  - Less uncertainty
- Endpoint category selection:
  - Environmental relevance linked into issues of concern
  - Higher uncertainty - easier to understand and interpret
Midpoint Categories

- Climate Change
  - Change in weather patterns
- Terrestrial Acidification
  - Deposition of wet and dry acidic components

Endpoint Categories

- Damage to Human Health
  - Respiratory diseases
  - Cancer
- Damage to Ecosystems
  - Dying forests
  - Extinction of species

Typical effects of acid rain (scienceclarified.org)
Bioreactor Scenario

- Sulfate reducing environment in bioreactor lowers acidity and precipitates metal
- Dimensions: 32 m (w) x 40 m (l) x 2 m (d)
- Substrate: 30 vol. % mussel shells, 30 vol. % bark, 25 vol. % post peel, 15 vol. % compost
- AMD gravity-fed from sedimentation pond receiving Manchester Seep AMD
- Flow into bioreactor is 2.29 L/s
- Designed to remove 85.2 kg acidity as CaCO$_3$/day
- 16.9 year lifetime

Bioreactor Scenario Modifications

- Mussel shell bioreactor with modified transport
  - ½ transport distances for all materials
- Mussel shell bioreactor with process energy
  - Pump added for non-gravity fed AMD
- Modified substrate bioreactor
  - Volume of mussel shell substrate replaced by limestone
- Mussel shell leaching bed
  - Mussel shells only substrate included in bioreactor design
Lime-Dosing Scenario

• Ultra-fine limestone (UFL) neutralizes acidity and precipitates metals from Mangatini stream
  – Finely ground limestone (CaCO$_3$)
  – Gravity fed slurry fed into stream

• Natural flow of Mangatini stream is 0.4 m$^3$/s

• Treats 17,800 kg acidity as CaCO$_3$/day

• Consumes 11,000 tonnes UFL per year

• Only material inputs are ultrafine limestone and a prefabricated silo for storing the limestone

Lime Slaking Plant Scenario

- Lime slaking utilizes hydrated lime for AMD treatment
  - Calcium oxide slaked with water
  - Hydrated Lime: Ca(OH)₂
- EPA Design Manual: Neutralization of Acid Mine Drainage
- Designed using parameters from lime dosing scenario
- Consumes 6,200 tonnes hydrated lime/year
- Includes: Equalization basin, lime storage and feed system, flash mix tank, aeration tank, settling basin with sludge removal

http://www.aditnow.co.uk
Preliminary Climate Change Results

- Passive treatments show unusually high impacts.

- Disposal for passive treatment buried in sanitary landfill
- Lime-dosing proved to have the least environmental effect
Sanitary landfill disposal accounted for over 95% of impacts
Climate Change Results - Onsite Disposal

- Redesigned scenario for on-site disposal – more realistic
- Significantly reduced passive treatment impacts
Quicklime air emissions: CO, CO2, heat, particulates, sulfur dioxide
## Limestone vs. Quicklime Material Preparation

<table>
<thead>
<tr>
<th>Crushed Limestone</th>
<th>Quicklime</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Process Energy</strong></td>
<td><strong>17x the process energy of crushed limestone</strong></td>
</tr>
<tr>
<td>• Crushing</td>
<td>• Crushing, milling, cyclone filtering,</td>
</tr>
<tr>
<td>• Washing</td>
<td>dedusting, storage,</td>
</tr>
<tr>
<td>• Transportation by conveyor belt</td>
<td>• Crusher, roller mill, dedusting plant,</td>
</tr>
<tr>
<td><strong>Heavy Machinery</strong></td>
<td>cyclone, small silo</td>
</tr>
<tr>
<td>• 2 crushers</td>
<td></td>
</tr>
<tr>
<td>• 2 sieves</td>
<td></td>
</tr>
<tr>
<td>• 2 small silos</td>
<td></td>
</tr>
</tbody>
</table>
Purchased energy scenario and Lime Slaking – require large amounts of coal over project lifetime.
Transportation Distances

- **160 km**: concrete
- **250 km**: bark, post peel, compost, bedding material
- **400 km**: Christchurch: mussel shells, liner, steel
- **550 km**: limestone, hydrated lime
Transport is the main contributor to damage to human health in most scenarios.

Bioreactor uses waste materials – shows minimal impact.
Lime Dosing Damage to Human Health Network

Air emissions associated with articulated engine: carbon dioxide, nitrogen oxides, carbon monoxide, methane; minimal soil and water emissions
Process energy larger contributor to bioreactor versus lime dosing and lime slaking.
Process Energy Breakdown

• **Bioreactor with Purchased Energy**
  - Pumps AMD constantly
  - 3822 kWh/kg acidity removed per day

• **Lime Dosing**
  - Pumps only chemical addition, AMD gravity fed
  - 83 kWh/kg acidity removed per day

• **Lime Slaking**
  - Pumps chemical addition and AMD
  - 911 kWh/kg acidity removed per day

Bioreactor: $260/ kg acidity removed per day
Lime Dosing: $6/ kg acidity removed per day
Lime Slaking: $62/ kg acidity removed per day

Picture: earthmagazine.org  Energy Costs: eia.gov
Conclusions

• Passive versus Active Treatments
  – Efficiency based on treatment abilities
  – Environmental impacts
• Limestone vs. quicklime
• Utilize locally sourced and waste materials
• On-site disposal vs. sanitary landfill
• Largest contributor- gravity fed AMD and chemical additions in placement of pumps
• Factors to consider- economic, social, environmental
  – Scope of LCA
Recommendations

• AMD Treatment approach dependent on a number of items:
  – Amount of AMD
  – Material costs
  – Available sources of alkalinity
  – Local waste materials
  – Site suitability for feeding AMD

• Use LCA as a piece of the puzzle to determine the best treatment option for the site

http://www.earthlife.org
Thank you for your time.

Questions?

Contact Information:

Dr. James Stone- james.stone@sdsmt.edu
Maria Squillace- maria.k.squillace@mines.sdsmt.edu
Tyler Hengen- tyler.hengen@mines.sdsmt.edu