Ore Mining and Resource Recovery

Mark Dopson
Lecture

- Mining metal ores
- Traditional metal recovery
- Biological sulfide ore dissolution
- Metal recovery from biomining
- Waste & remediation
- Conclusions
Mining Metal Ores

- Mining is the extraction of valuable minerals or other geological materials from the earth
- Has been occurring since prehistoric times

Chalcolithic copper mine in Timna Valley, Negev Desert (http://commons.wikimedia.org)
Mining Metal Ores

What are the different types of mines?
Underground Mining
Open Cast Mining
Lecture

• Mining metal ores
• Traditional metal recovery
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• Metal recovery from biomining
• Waste & remediation
• Conclusions
Mill (Grinding)

- A mill is a device that breaks solid materials into smaller pieces by grinding, crushing, or cutting.

- Grinding occurs using mechanical forces to alter the structure by overcoming the interior bonding forces.

Ball Mill (Grinding)
Mineral Flotation

- Froth flotation is a process for selectively separating hydrophobic materials from hydrophilic materials.
- “Single most important operation used for the recovery and upgrading of sulfide ores”
- Separates sulfide mineral from gangue

"FICell" http://commons.wikimedia.org
Zinc Refining

- Five general stages: roasting / leaching, purification, electrowinning, and casting

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**Metal concentrate**
Metal concentrate from mines usually comprises approximately 50 per cent zinc.

**Roasting**
The concentrate is roasted in a furnace in order to remove all sulphur dioxide. The result is what is known as calcine, which comprises approx. 60 per cent zinc. The so-called direct leaching method enables the roasting stage to be eliminated.

**Leaching**
The calcine is leached with sulphuric acid in order to precipitate out and filter off the iron content. The result is a zinc sulphate solution with small amounts of impurities.

**Solution purification**
The zinc solution is purified in three stages to remove any copper, cobalt, nickel and cadmium content, after which it contains approximately 150 grams of zinc per litre of solution.

**Electrowinning**
The zinc is separated out of the solution using electrical current and then adheres to cathode plates. The result is zinc cathodes with a zinc content of around 99.995 per cent.

**Casting**
The zinc cathodes are smelted in electrical furnaces and then cast to form zinc ingots. The ingots are sold as is or alloyed in line with specific customer requirements.

http://www.boliden.com
Copper Refining

- Copper smelters have no uniform process & often tailored for specific raw materials. Smelting and converting are however a common denominator.
Electrolytic Refining

- Copper is obtained by electrolysis
- Anode is impure copper & thin sheet of pure copper is cathode
- Electrolyte is an acidic solution of copper sulfate
- By passing electricity through the cell, copper is dissolved from the anode and deposited on the cathode
Lecture

• Mining metal ores
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• Conclusions
Biomining

- Use of microorganisms for breakdown of minerals
- More environmentally friendly than traditional techniques (sustainable)
- Economically advantageous - industrial reality
Microbial Facilitated Pyrite Dissolution

Chemical oxidation:

\[ \text{FeS}_2 + \frac{7}{2}\text{O}_2 + \text{H}_2\text{O} \rightarrow \text{Fe}^{2+} + 2\text{SO}_4^{2-} + 2\text{H}^+ \]

Oxidation by Ferric Iron:

\[ \text{FeS}_2 + 14\text{Fe}^{3+} + 8\text{H}_2\text{O} \rightarrow 15\text{Fe}^{2+} + 2\text{SO}_4^{2-} + 16\text{H}^+ \]

Fe\[^{3+}\] provided by microbes:

\[ 14\text{Fe}^{2+} + \frac{7}{2}\text{O}_2 + 14\text{H}^+ \rightarrow 14\text{Fe}^{3+} + 7\text{H}_2\text{O} \]
Bioleaching Reactions

**Thiosulfate mechanism**

\[ \text{FeS}_2 \xrightarrow{\text{Fe}^{3+}} \text{Fe}^{2+} \]

\[ \text{M}^{2+} + \text{S}_2\text{O}_3^{2-} \]

\[ \text{SO}_4^{2-} + \text{H}^+ \]

**Polysulfide mechanism**

\[ \text{CuFeS} \xrightarrow{\text{Fe}^{2+}} \text{Fe}^{3+} \]

\[ \text{M}^{2+} + \text{S}_n^{2-} \]

Methods of Bioleaching

Tributsch, Hydrometallurgy (2001) 59:177-185
Effect of Bacteria on Bioleaching

Brock, Biology of Microorganisms (1997)
## Table 1 Commercial copper heap bioleaching operations

<table>
<thead>
<tr>
<th>Plant and location/owner</th>
<th>Cathode copper production (t/year)</th>
<th>Operational status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lo Aguirre, Chile/Sociedad Minera Pudahe</td>
<td>15,000</td>
<td>1980–1996 (ore depleted)</td>
</tr>
<tr>
<td>Mount Gordon (formerly Gunpowder), Australia/Aditya Birla</td>
<td>33,000</td>
<td>1991–2008 (on care and maintenance)</td>
</tr>
<tr>
<td>Lince II, Chile/Antofagasta plc</td>
<td>27,000</td>
<td>1991–2009 (high mining costs)</td>
</tr>
<tr>
<td>Mt. Leyshon, Australia (formerly Normandy Poseidon)</td>
<td>750</td>
<td>1992–1995 (stockpile depleted)</td>
</tr>
<tr>
<td>Cerro Colorado, Chile/BHP-Billiton</td>
<td>115,000</td>
<td>1993–present</td>
</tr>
<tr>
<td>Girilambone, Australia/Straits Resources and Nord Pacific</td>
<td>14,000</td>
<td>1993–2003 (ore depleted)</td>
</tr>
<tr>
<td>Ivan-Zar, Chile/Compañía Minera Milpro</td>
<td>10,000–12,000</td>
<td>1994–present</td>
</tr>
<tr>
<td>Punta del Cobre, Chile/Sociedad Punta del Cobre</td>
<td>7,000–8,000</td>
<td>1994–present</td>
</tr>
<tr>
<td>Quebrada Blanca, Chile/Teck Resources</td>
<td>75,000</td>
<td>1994 present</td>
</tr>
<tr>
<td>Andacollo Cobre, Chile/Teck Resources</td>
<td>21,000</td>
<td>1996–present</td>
</tr>
<tr>
<td>Dos Amigos, Chile/CEMIN</td>
<td>10,000</td>
<td>1996–present</td>
</tr>
<tr>
<td>Skouriotissa Copper, Cyprus/Hellenic Copper</td>
<td>8,000</td>
<td>1996–present</td>
</tr>
<tr>
<td>Cerro Verde, Peru/Freeport McMoran</td>
<td>54,200</td>
<td>1997–present</td>
</tr>
<tr>
<td>Zaldívar, Chile/Barrick Gold</td>
<td>150,000</td>
<td>1998–present</td>
</tr>
<tr>
<td>Lomas Bayas, Chile/Xstrata</td>
<td>60,000</td>
<td>1998–present</td>
</tr>
<tr>
<td>Monywa, Myanmar/Myanmar No. 1 Mining Enterprise</td>
<td>40,000</td>
<td>1998–present</td>
</tr>
<tr>
<td>Nifty Copper, Australia/Aditya Birla</td>
<td>16,000</td>
<td>1998–present (oxide/sulfide)</td>
</tr>
<tr>
<td>Equatorial Tonopah, Nevada/Equatorial Tonopah, Inc.</td>
<td>25,000 (projected)</td>
<td>2000–2001 (failed)</td>
</tr>
<tr>
<td>Morenci, Arizona/Freeport McMoran</td>
<td>380,000</td>
<td>2001–present</td>
</tr>
<tr>
<td>Zijinshan Copper, China/Zijin Mining Group</td>
<td>20,000</td>
<td>2005–present</td>
</tr>
<tr>
<td>Lisbon Valley Mining Company, Utah</td>
<td>10,000</td>
<td>2006–present</td>
</tr>
<tr>
<td>Jinchuan Copper, China/Zijin Mining Group</td>
<td>10,000</td>
<td>2006–2009</td>
</tr>
<tr>
<td>Whim Creek and Mons Cupri, Australia/Strate Resources</td>
<td>17,000</td>
<td>2006–present</td>
</tr>
<tr>
<td>Spence, Chile/BHP Billiton</td>
<td>200,000</td>
<td>2007–present</td>
</tr>
<tr>
<td>Tres Valles, Chile/Vale SA</td>
<td>18,500</td>
<td>2010–present</td>
</tr>
</tbody>
</table>

## Industrial Gold Biomining

<table>
<thead>
<tr>
<th>Plant and location</th>
<th>Process</th>
<th>Treatment capacity (t/day)</th>
<th>Operational status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fairview, South Africa</td>
<td>BIOX®</td>
<td>62</td>
<td>1986–present</td>
</tr>
<tr>
<td>Sao Bento, Brazil</td>
<td>BIOX®</td>
<td>150</td>
<td>1990–(currently under care and maintenance)</td>
</tr>
<tr>
<td>Tamborauque, Peru</td>
<td>BIOX®</td>
<td>60</td>
<td>1990–present</td>
</tr>
<tr>
<td>Harbour Lights, Australia</td>
<td>BIOX®</td>
<td>40</td>
<td>1991–1994 (mine depleted)</td>
</tr>
<tr>
<td>Wiluna, Australia</td>
<td>BIOX®</td>
<td>128</td>
<td>1993–present</td>
</tr>
<tr>
<td>Sansu, Ghana</td>
<td>BIOX®</td>
<td>960</td>
<td>1994–present</td>
</tr>
<tr>
<td>Youanmi, Australia</td>
<td>BacTech</td>
<td>120</td>
<td>1994–1998 (mine depleted)</td>
</tr>
<tr>
<td>Coricancha, Peru</td>
<td>BIOX®</td>
<td>60</td>
<td>1998–2008</td>
</tr>
<tr>
<td>Beaconsfield, Australia</td>
<td>BacTech</td>
<td>70</td>
<td>2000–present</td>
</tr>
<tr>
<td>Laizhou, China</td>
<td>BacTech</td>
<td>100</td>
<td>2001–present</td>
</tr>
<tr>
<td>Olimpiada, Russia</td>
<td>Tank reactors</td>
<td>8220</td>
<td>2003–present</td>
</tr>
<tr>
<td>Fosterville, Australia</td>
<td>BIOX®</td>
<td>211</td>
<td>2005–present</td>
</tr>
<tr>
<td>Suzdal, Kazakhstan</td>
<td>BIOX®</td>
<td>196</td>
<td>2005–present</td>
</tr>
<tr>
<td>Bogoso, Ghana</td>
<td>BIOX®</td>
<td>820</td>
<td>2007–present</td>
</tr>
<tr>
<td>Jinfeng, China</td>
<td>BIOX®</td>
<td>790</td>
<td>2007–present</td>
</tr>
<tr>
<td>Kokpatas, Uzbekistan</td>
<td>BIOX®</td>
<td>1069</td>
<td>2008–present</td>
</tr>
<tr>
<td>Agnes, South Africa</td>
<td>BIOX®</td>
<td>20</td>
<td>2010–present</td>
</tr>
</tbody>
</table>

Types of Biomining

- *In situ*
- Heap
- Stirred tank reactors (STR’s)
**In situ Bioleaching**

- Process where ore is treated without removing the rock to the surface

- Relies on fracturing the ore by blasting thus, producing voids to allow free solution flow

- The solution is collected at the bottom of the mine and processed for metals recovery

- Application not widespread as requires very specific ore body characteristics
In situ Bioleaching
Heap Bioleaching

- Heaps are formed by stacking crushed rock into constructed piles
- Oxygen can be added to enhance bio-oxidation
- Acidic solutions carry away the biooxidized products such as copper or iron
- First employed for secondary copper minerals in large dumps, now applied to a wide range of ores
Heap Bioleaching
Heap Bioleaching

http://www.geobiotics.com/
Heap Bioleaching
Tank Bioleaching

- Bacterial oxidation of ground mineral slurry can be carried out in aerated agitated vessels

- Due to capital costs usually only used for high grade ores

- Oxidation kinetics are much higher than *in situ* or heap systems
Tank Bioleaching

http://bioshale.brgm.fr/
The Chalcopyrite Conundrum

- 2005 world copper production increased to 16 million tons per annum

- Due to lack of remaining high grade ores need to process low grade ores, overburden and waste

- The majority of the world's copper reserves are in the form of chalcopyrite (CuFeS₂)

- Bioleaching of CuFeS₂ has poor metal recoveries due to passivation (inhibitory layer on the surface)
The Chalcopyrite Conundrum

- Hypothetical 4-stage model describing the breakdown of chalcopyrite

- Can metal release be increased by removing the passivating layer?

Biomining Microorganisms

What characteristics would biomining microorganisms need?
Biomining Microorganisms

- Need to survive the sulfuric acid produced in the process
- Resist the high metal concentrations
- Oxidize ferrous iron and sulfur compounds
- Need to form a biofilm on the mineral surface
Microbial Adaptations to Low pH

$pH \approx 6.5$

$pH$ 0.5 to 3

$\Delta pH = pH_{in} - pH_{out}$

Membrane resistant to $H^+$

Metals e.g. Cu, Cd, As

Acidophiles often highly metal resistant
## Metal Resistance

<table>
<thead>
<tr>
<th>Micro-organism</th>
<th>Metal concentration whereby metabolic activity occurs (^{(mM)^*})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>As(III)</td>
</tr>
<tr>
<td><strong>Neutrophilic bacteria</strong></td>
<td></td>
</tr>
<tr>
<td><em>Escherichia coli</em></td>
<td>4(^{a})</td>
</tr>
<tr>
<td><strong>Acidophilic bacteria</strong></td>
<td></td>
</tr>
<tr>
<td><em>Acidiphilium cryptum</em></td>
<td>ND</td>
</tr>
<tr>
<td><em>Acidiphilum multivorum</em></td>
<td>30(^{d})</td>
</tr>
<tr>
<td>‘<em>Acidiphilium symbioticum</em>’ KM2</td>
<td>ND</td>
</tr>
<tr>
<td>‘<em>Acidiphilium symbioticum</em>’ H8</td>
<td>ND</td>
</tr>
<tr>
<td><em>Acidiphilum angustum</em></td>
<td>ND</td>
</tr>
<tr>
<td><em>Acidiphilum</em> strain GS18h</td>
<td>ND</td>
</tr>
<tr>
<td><em>Acidocella aminolytica</em></td>
<td>ND</td>
</tr>
<tr>
<td><em>Acidocella facilis</em></td>
<td>ND</td>
</tr>
<tr>
<td><em>Acidocella</em> strain GS19h</td>
<td>ND</td>
</tr>
<tr>
<td><em>Acidithiobacillus ferrooxidans</em></td>
<td>84(^{f})</td>
</tr>
<tr>
<td><em>Sulfobacillus thermosulfidooxidans</em></td>
<td>ND</td>
</tr>
<tr>
<td><strong>Acidophilic archaea</strong></td>
<td></td>
</tr>
<tr>
<td>‘<em>Ferroplasma acidarmanus</em>’</td>
<td>13(^{k})</td>
</tr>
<tr>
<td><em>Metallosphaera sedula</em></td>
<td>1(^{m})</td>
</tr>
<tr>
<td><em>Sulfobatus acidocaldarius</em></td>
<td>ND</td>
</tr>
<tr>
<td><em>Sulfolobus solfataricus</em></td>
<td>ND</td>
</tr>
</tbody>
</table>
Metal Homeostasis & Resistance

1. Metal uptake
2. Excretion
3. Storage
4. Toxic metal uptake

Metalloproteins

Hg$^+$
Hg$^{2+}$
AsO$_4^{3-}$
PO$_4^{3-}$
AsO$_4^{3-}$
Iron Oxidizers

Fe$^{3+}$ provided by microbes:

$$14Fe^{2+} + \frac{7}{2}O_2 + 14H^+ \rightarrow 14Fe^{3+} + 7H_2O$$

- Mineral oxidation originally thought to be due to *Acidithiobacillus ferrooxidans*

- Molecular techniques have revealed other iron oxidizers are more important (especially in STR's)

Sulfur Oxidizers

Reduced inorganic sulfur compounds:

\[ S^0 + \frac{3}{2}O_2 + H_2O \rightarrow H_2SO_4 \]

- Found in almost all metal leaching environments despite not oxidizing Fe\(^{2+}\)
- *At. thiooxidans* (mesophile) and *At. caldus* (moderately thermophilic)
- Oxidizes reduced inorganic sulfur compounds in the main acid producing reactions
Acidithiobacillus caldus

Mineral bioleached - cells on the surface and no sulfur

Chemically leached - large sulfur deposits on the surface

Acidithiobacillus caldus

Mixed Populations

- Do not get the idea that bioleaching occurs by a single species of microorganism

- A mixed culture will ALWAYS out-compete a single microorganism

- Get synergistic relationships between complex communities of heterotrophic and autotrophic microorganisms
Biofilms

Planktonic cells can be flushed away, often into suboptimal growth conditions

Cells form EPS which aids surface attachment

Close proximity to energy sources i.e. pyrite

Source of carbon from other community members?

Resistance to metals, pH, oxygen fluctuations?

Pyrite ore

$Fe^{3+}$ $Fe^{2+}$

$Fe^{3+}$ $Fe^{2+}$
Acidophiles and Biofilms

- Microorganisms in biofilms demonstrate increased resistance to antimicrobial agents

- Most microorganisms tend to grow within biofilms

Attachment to Minerals

- CLSM image of a pyrite grain colonized with cells of *At. ferrooxidans* after 1 week of incubation
- Cells attach to fractures in the mineral grain

Lecture

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- Biological sulfide ore dissolution
- Metal recovery from biomining
- Waste & remediation
- Conclusions
Metal Recovery

- Precipitation of metals such that they may be recovered for economic gain

- A research goal for metal recovery is that sulfate reduction is carried out at low pH allowing selective metal precipitation

- Can use low pH sulfate reduction in bioreactors at industrially viable rates
**Active / Biotic - Sulfidogenic Bioreactors**

\[
2\text{CH}_3\text{CHOHCOO}^- + \text{SO}_4^{2-} \rightarrow 2\text{CH}_3\text{COO}^- + 2\text{HCO}_3^- + \text{H}_2\text{S}
\]

\[
\text{Zn}^{2+} + \text{H}_2\text{S} \rightarrow \text{ZnS} + 2\text{H}^+
\]

- Bacteria catalyze dissimilatory reduction of sulfate to sulfide, generating alkalinity by transforming a strong acid (sulfuric) into a weak acid (hydrogen sulfide).

- The reduction of sulfate removes toxic metals from AMD, since as many (e.g. Zn, Cu, and Cd) form highly insoluble sulfides
Active / Biotic - Sulfidogenic Bioreactors

- Sulphur
- Nutrients

Bioreactor → H₂S

Clarifier

Contaminated water → Contactor

Metal Sulphide product → Effluent

Alkali source (if required)
Low pH Sulphidogenic Bioreactors

• **Goal** is the precipitation of metals such that they may be recovered for economic gain

• A critical factor for metal recovery is that sulfate reduction is carried out at low pH allowing selective metal precipitation

• Can use low pH sulfate reduction in bioreactors at industrially viable rates
Low pH Sulphidogenic Bioreactors

• If the bioreactor works at low pH the majority of the metals will remain in solution - aiding subsequent metal recovery
Low pH Sulphidogenic Bioreactors

- As the pH decreases then the concentration of iron in the recovered nickel is reduced from 99.8% to 17.7%

Table 5 – The measured and modeled (with OLI) Ni and Fe recovery percentages.

<table>
<thead>
<tr>
<th>Time [days]</th>
<th>pH Sulfide in reactor liquor [mM]</th>
<th>Metal recovery</th>
<th>Measured</th>
<th>Modelled</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ni [%]</td>
<td>Fe [%]</td>
<td>Ni [%]</td>
</tr>
<tr>
<td>7</td>
<td>4.9</td>
<td>97.7</td>
<td>17.7</td>
<td>&gt;99.9</td>
</tr>
<tr>
<td>8</td>
<td>5.0</td>
<td>98.6</td>
<td>59.2</td>
<td>&gt;99.9</td>
</tr>
<tr>
<td>9</td>
<td>6.7</td>
<td>&gt;99.9</td>
<td>98.0</td>
<td>&gt;99.9</td>
</tr>
<tr>
<td>10</td>
<td>6.8</td>
<td>&gt;99.9</td>
<td>99.9</td>
<td>&gt;99.9</td>
</tr>
<tr>
<td>11</td>
<td>7.5</td>
<td>&gt;99.9</td>
<td>99.8</td>
<td>&gt;99.9</td>
</tr>
</tbody>
</table>

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- Conclusions
Environmental Impact

- Excavation of large tracts of land - open cut mining
- Derelict sites - many abandoned mines that cause problems
- Solid waste - large excavations require disposal of waste rock and tailings, a source of ARD
Mining Accidents

- Cornwall, UK
  50 000 m³ AMD

- Seville, Spain
  5 000 000 m³ pyrite waste

- Romania
  100 000 m³ cyanide/heavy metal waste

Kaksonen Ph.D. Thesis 2004
TALVIVAARA LEAK - NEWS STREAM

After a short essential introduction, you can find links to latest news and resources in English:

For years the local people and activists have brought up the fundamental violation of environmental legislation in case of Talvivaara: the extraction of uranium has been part of the operation of the mine from the very beginning, but uranium wasn’t mentioned by a single word in Talvivaara’s environmental impact assessment procedure - and there was not a single word about uranium in the environmental permit that was granted. Nevertheless Talvivaara has been allowed to extract hundreds of tonnes of uranium per year from black schist ore - since 2009.

We encourage shareholders not to support the poisoning and ruining of our lakes and rivers.

And we encourage international media to pay close attention to what is really happening in Finland.
Waste & Remediation

• Uncontrolled bioleaching from mines and waste products can cause acid mine drainage (AMD)

• AMD is found where the ore is dominated by metal sulfides

• In 1989, it was estimated that ca. 19,300 km of streams and rivers, and ca. 72,000 ha of lakes worldwide had been seriously damaged by AMD/ARD

• AMD in Sweden comes from many disused metal mines e.g. Kristineberg
Problems Associated with AMD

- Must be regulated in mining operations so acid generation is minimised

- Mining companies must ensure no acid generation after their mining activities have finished - very costly

- AMD is a critical current environmental problem due to a large number of abandoned mines with significant long term (decades or centuries) of acid-generating potential

- Aquatic habitats are particularly susceptible to damage from run-off from AMD impacted sites
Environmental Effects of AMD

• Heavy metals are leached into solution

• Heavy metals will precipitate into sediments of rivers and lakes

• Low pH will be toxic to many forms of life

• Heavy concentrations of Fe results in precipitation as 'yellowboy', covers aquatic life - smothers it
Iron Mountain, USA

Sample solution chemistry and conditions of acid mine drainage waters from Iron Mt. Mine.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>38 °C</td>
</tr>
<tr>
<td>pH</td>
<td>0.52</td>
</tr>
<tr>
<td>Fe</td>
<td>21220 mg/L</td>
</tr>
<tr>
<td>SO$_4^{2-}$</td>
<td>118000 mg/L</td>
</tr>
<tr>
<td>Al</td>
<td>2150 mg/L</td>
</tr>
<tr>
<td>Zn</td>
<td>2280 mg/L</td>
</tr>
<tr>
<td>Mg</td>
<td>815 mg/L</td>
</tr>
<tr>
<td>Cu</td>
<td>301 mg/L</td>
</tr>
<tr>
<td>Cd</td>
<td>16 mg/L</td>
</tr>
<tr>
<td>As</td>
<td>62 mg/L</td>
</tr>
</tbody>
</table>

(Nordstrom and Alpers 1990)
Iron Mountain, USA

<table>
<thead>
<tr>
<th>Metal</th>
<th>Water Standard (mg/l)</th>
<th>Iron Mountain (mg/l)</th>
<th>Fold over</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>1</td>
<td>301</td>
<td>301</td>
</tr>
<tr>
<td>Zinc</td>
<td>3</td>
<td>2280</td>
<td>760</td>
</tr>
<tr>
<td>Cadmium</td>
<td>.005</td>
<td>16</td>
<td>3,200</td>
</tr>
<tr>
<td>Arsenic</td>
<td>.005</td>
<td>62</td>
<td>12,400</td>
</tr>
</tbody>
</table>
Iron Mountain, USA

Courtesy Jill Banfield, University California, Berkely, USA
Comparison of Treatment Techniques

What do you think is cheaper – prevention or remediation?
Comparison of Treatment Techniques

Passive

Chemical

Low tech biological

High tech biological

Integrated processes

Remediation

Waste

Cost

Liability

Slide courtesy Martijn Bijmans
Prevention of AMD

- Flooding/sealing of underground mines
- Underwater storage of mine tailings
- Land-based storage in sealed waste heaps
- Blending of mineral wastes
- Total solidification of tailings
- Application of anionic surfactants
- Microencapsulation (coating)
AMD Prevention

• Must be regulated in mining operations so acid generation is minimized

• Mining companies must ensure no acid generation after their mining activities have finished - very costly

• AMD is a critical environmental problem due to abandoned mines with significant long term (decades or centuries) of acid-generating potential
Water Cover to Prevent AMD
Water Cover
Dry Cover to Prevent AMD

- Dry cover designed to minimize air and water contact with the waste
Dry Cover


• Dry cover minimizes air and water contact with the waste

• Zones revealed during excavation of dry covered tailings

• Areas of oxidized tailings are evident
Remediation of Mines & AMD

- **Abiotic**
  - "Active" systems: aeration and lime addition
  - "Passive" systems: e.g., anoxic limestone drains

- **Biological**
  - "Active" system
    - Off-line sulfidogenic bioreactors
  - "Passive" systems
    - Aerobic wetlands
    - Compost reactors/wetlands
    - Permeable reactive barriers
    - Packed bed iron-oxidation bioreactors

Johnson & Hallberg, Sci Tot Environ (2005) 338: 3-14
AMD at Iron Mountain

Mine effluent was previously responsible for significant pollution of the Sacramento river

Drainage from the mine is now treated at source, and the metals precipitated from solution

Courtesy Jill Banfield, University California, Berkely, USA
Active / Abiotic – Aeration & Lime

• Active chemical treatment can remediate AMD

• Addition alkaline material raises its pH

• High operating costs and problems with disposal of the produced sludge
Permeable Reactive Bioreactors

- Designed to treat subsurface flows
- Water flows from the contaminant through the barrier where bioremediation occurs
- Some reactions occur as for sulfidogenic bioreactors

Bioremediation of Mining Wastewater

- Process water from molybdenum flotation may produce thiosalts
- New tailings dam has tighter limits for effluent pH & metals
- Requires control of acid generating inorganic sulfur compounds
Bioremediation of Mining Wastewater

• Thiosalts can be chemically generated in the flotation process and tailings pond

• Sulfuric acid can be generated by complete microbial oxidation to sulfate

• Thiosalts are released to downstream recipients (releases acid generating potential)

• Thiosulfate can be removed with hydrogen peroxide (Advantages: reliable & efficient; Disadvantages: high chemical costs & handling of hydrogen peroxide)

• Replace peroxide with biological system
Bioremediation of Mining Wastewater

- Biological oxidation can require longer residence time (especially at low temperatures)

- Can reduce residence time by adding external microorganisms or by retaining the biomass

- Utilize acidophiles so reactor can be at low pH

Conceptual flowsheet
Electrochemical Bioremediation

- Conversion of wastes (organic/inorganic) to electrical energy
- Utilise electricity to recover metals from production and waste streams
- Reduces high electricity costs in electrowinning

https://asunews.asu.edu
Mining Wastewater as Electron Donor

- 2000 $m^3$/hour process wastewater (tailings sludge) produced

- Produces thiosalts that are a substrate for acidophiles
MFC Operation With Tailings Water

100 % tailings water

Control (synthetic media)

- A whole cell potential (▲) can be generated using a continuous flow of tailings water
Summary of Remediation Options

Schematic illustration on causes and remedies for AMD/ARD
Lecture

• Mining metal ores
• Traditional metal recovery (smelting)
• Biological sulfide ore dissolution
• Metal recovery from biomining
• Waste & remediation

• Conclusions
“The Take Home Message”

What is the “take home message”? 
Conclusions

• Traditional mining techniques are costly and can cause environmental damage

• Acidophilic microorganisms are utilized in the biohydrometallurgical process of biomining

• Bioleaching and mine wastes cause industrial pollution - AMD

• Remediation options include passive and active systems