BIOHEAP LEACHING
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Short history of bioleaching

• Copper recovery from mine waters in the Mediterranean area 3000 years ago
• Heapleaching in Spain in big scale 300 years ago
  – the process was seen as natural degradation
  – some rivers got their names by their red color (Rio Tinto, Tintillo...)
• The role of bacteria in bioleaching was shown in 1947
• In the beginning of 1950’s *Thiobacillus ferrooxidans* and *Thiobacillus thiooxidans* were indentified (nowadays *Thiobacillus* has been renamed to *Acidithiobacillus*)
• In 1950’s copper dump leaching
• In 1960’s the first industrial copper heapleaching operation
• First industrial gold bioleaching plant in 1980’s
• Nowadays about 40 plants in industrial use for copper, gold, zinc, cobalt, uranium
• Talvivaara is the first one producing nickel
What is bioleaching?

• Conversion of insoluble metal sulfides into water-soluble metal sulfates.

• Current understanding:
  – mineral oxidation is driven by chemistry rather than biology.
    At higher temperature – faster chemistry etc.

• Role of microorganisms in mineral biooxidation:
  – Microbes produce the leaching chemicals.
  – Microbes also provide the most efficient reaction space for bioleaching to occur.
Bioleaching is mostly contact leaching

Contact leaching rather than direct (biological/enzymatic) or indirect (chemical)

ferrous–ferric cycling within the EPS, releases thiosulfate or sulfur depending on mineral type

small pieces of mineral and colloidal sulfur are released into solution, used as energy source by unattached bacteria
Bioleaching technology – bacterially-assisted conversion of sulphides, liberating metals and generating reaction heat

• The bacteria oxidise ferrous iron (Fe2+) and sulphur (S) to produce ferric iron (Fe3+) and sulphate (SO42-)
• The Fe3+ in turn reacts with the sulphide minerals to produce Fe2+ and S
• Bacteria are classified according to temperature at which they are active namely:
  – Mesophiles (30 - 42 °C)
  – Moderate thermophiles (45 - 50 °C)
  – Extreme thermophiles (65 - 85 °C)
Important facts and factors regarding sulfide leaching, particularly bioleaching

• Oxidation sequence pyrrhotite (Fe$_{1-x}$S), pentlandite ((Ni,Fe,Co)$_9$S$_8$), ZnS, CuFeS$_2$, FeS$_2$
• Galvanic interactions between sulfides, e.g. pentlandite promotes pyrrhotite, chalcopyrite promotes pentlandite, pyrite promotes chalcopyrite
• Fe$^{2+}$ oxidizing bacteria can accelerate oxidation rate of Fe$^{2+}$ in acidic solutions by up to 10$^6$
• Incomplete oxidation of sulfide entity results in formation of polythionates and elemental sulfur which can passivate sulfides
• Passivation tendency of CuFeS$_2$ can be overcome or reduced by leaching in a lower solution oxidation potential range
Bioleaching microbes

• Acidophiles or active in acidic conditions (pH 1 – 3)
• Get their energy by oxidizing iron and/or inorganic sulphur compounds
• Get the carbon needed for growth from the carbon dioxide in air
• Can often tolerate high metal concentrations
Bioleaching microbes

- Sulfolobus
- Leptospirillum ferrooxidans

10,000,000,000 bacteria in a teaspoon of solution

1 µm
Characteristics of heap reactors from a microbial perspective

• Non-uniform – aeration, irrigation, nutrient addition, pH etc. are highly variable
• Difficult to control – inoculation, rate of leaching, ambient temperature, different areas of heap in different phases of the leaching cycle
• Many different ecological niches present, therefore potentially a large variety of microorganisms
• Mineral biooxidation slow, biofilms present, no strong selection for rapidly growing organisms
Main factors affecting bioleaching

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<th>Factor</th>
<th>Effect</th>
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<tr>
<td><strong>Physicochemical</strong></td>
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| Temperature pH and to keep ferric     | - affects leaching rate, microbial composition and activity  
| Oxygen reactions                      | - needs to be low to obtain the fastest leaching rates and to keep ferric iron and metals in solution  
|                                       | - electron acceptor needed in chemical and biological oxidation                                                                                                                                         |
| **Microbiological**                   |                                                                                                                                                                                                       |
| Microbial diversity cultures          | - mixed cultures tend to be more robust and efficient than pure                                                                                                                                          |
| Population density                    | - high population density tends to increase the leaching rate                                                                                                                                          |
| Metal tolerance                       | - high metal concentrations may be toxic to metals                                                                                                                                                   |
| **Mineral**                           |                                                                                                                                                                                                       |
| Composition                           | - provides electron donor and trace elements                                                                                                                                                         |
| Particle size                         | - affects the available mineral/liquid contact area                                                                                                                                                   |
| Surface area                          | - leaching proportional to the increase in mineral surface area                                                                                                                                         |
| Porosity                              | - cracks and pores in the particles give rise to the internal area                                                                                                                                     |
| Presence of other metal sulfide       | - mineral having the lowest potential is generally oxidized first                                                                                                                                     |
Benefits of bioleaching

• Simple and inexpensive process. Substantially lower capex and opex than in traditional smelting and refining processes
• No sulfur dioxide emissions as in smelters
• No need for high pressure or temperature
• Leaching residues less active than in physico-chemical processes
• Ideal for low grade sulfide ores – lower cut-off rate possible
Bioleaching techniques

Low-grade ores
Low Costs
Poor control
Long leaching time
Large volumes

in situ  dump  heap  vat  reactor

Concentrates
High costs
Good control
Short leaching time
Small volume
Benefits of bioleaching for Talvivaara

- Inexpensive process requires only air, water and microbes to work
- Easily expanded — increase in number of heaps
- Substantially lower capex and opex than in traditional smelting and refining processes
- Ideal for low grade sulphide ores — lower cut-off rate required
- Cleaner and more environmentally friendly process compared to smelting (by-pass process stage)
BIOHEAPLEACHING AND TALVIVAARA’S PRODUCTION PROCESS

Lassi Lammassaari
Chief Operations Officer
Bioheapleaching in Talvivaara

- A natural, cost-effective and environmentally friendly process utilising locally occurring bacteria
  - Leaching process accelerated through crushing, aeration and irrigation
  - Acidity of leaching solution controlled by sulphuric acid to provide ideal conditions for bacteria
- Process run in two stages
  - Primary leaching for 18 months; expected nickel recovery approx. 80%
  - Secondary leaching for additional 3.5 years; total expected nickel recovery >90%
- Technology proven in a 17,000 tonne on-site pilot operated from 2005 through 2008
- Experience from production scale heap in line with performance of the pilot heap
  - Similar leaching kinetics
  - Thermal reactions very strong – winter is no problem, temperature control during summer important
Bioheapleaching Process
Bioheap leaching in operation

- Irrigation
- Aeration
- Heap
- Pregnant Leach Solution
Current status of bioheapleaching in Talvivaara

- Primary heap sections 1 and 2 completed
  - Leaching performance improving strongly in 2010
  - Targeted nickel grade in solution at steady state operation 3 g/l; current grade fed to metals plant approx. 2 g/l
Nickel Leach Profiles

• Leach Section 1
  – Age 11-23 months
  – Aeration poor
  – Temperature 50 -> 20 C winter 2010

• Leach Section 2
  – Age 3-11 months
  – Partially double aeration pipes
  – Temperature 50 -> 34 C winter 2010

• Leach Section 3
  – Age 0 - 3 months
  – Double aeration pipes
  – Temperature 10 – 40 C
  – Ore charging on going

• Metals Recovery
  – Present PLS flow 800 m3/h
    • Ni 2 g/l 38 t/d
    • Zn 5 g/l 96 t/d
Zinc Leach Profiles

- Leach Section 1
  - Age 11-23 months
  - Aeration poor
  - Temperature 50 -> 20°C winter 2010

- Leach Section 2
  - Age 3-11 months
  - Partially double aeration pipes
  - Temperature 50 -> 34°C winter 2010

- Leach Section 3
  - Age 0 - 3 months
  - Double aeration pipes
  - Temperature 10 – 40°C
  - Ore charging on going

- Metals Recovery
  - Present PLS flow 800 m³/h
  - Ni 2 g/l 38 t/d
  - Zn 5 g/l 96 t/d
Bioheapleaching – secondary leaching

- Secondary heap areas to be developed during 2010-2011
Production Process
Process performance

Materials Handling - mothly crushing performance (t)

Production Target

Fine crushing modification

New tertiary crushers
METALS RECOVERY
Leif Rosenback
Chief Technology Officer
A versatile metals recovery plant

- Production line 1 in production
- Production line 2 commissioning scheduled for June 2010
- Second hydrogen plant to be commissioned in October 2010 allowing production expansion to 50,000 tpa of nickel
Metals Recovery Basic principles

• Heap Leaching
  – Metals are leached resulting in a metal solution containing Nickel Zinc and other components

• Metals Recovery
  – Valuable metals are recovered selectively as precipitate from the solution to enable refining into pure metals in respective refineries
Process Description

• The valuable metals are precipitated controlling two major parameters
  – PLS pH 2.3
  – Molar ratio H2S/Me
  – pH levels
    • Cu,Zn Low pH 1.5-2
    • NiCo pH 3-3-4
• H2SO4, Al and Fe precipitation
  – Iron is oxidized to Ferri iron
  – pH 5.5 using limestone
• Mn, Mg precipitation
  – pH 9,5 using slaked lime (Ca(OH)2)
  – Simultaneous effluent treatment
• Raffinate is returned back to heap leaching
  – Solutions in closed loop with heap
Process performance

- The process has been run close to design
  - 800 m³/h (900 m³/h design)
  - acceptable settling and filtration properties
- Sulphide precipitation selective for Zn and nickel
- Precipitate qualities close to or better compared to testwork experience
- Zn sulphide moisture 20 % (<40% expected)
  - Development project on going to reach TML requirements
- Ni sulphide moisture 17 % (<40% expected)
- Zn sulphide low in Nickel < 500 ppm
- NiCo precipitate
  - Target to improve quality as Nickel levels increase
- Development project for H2S scrubbing from vents
- Effluent quality acceptable