Developments in Hydrometallurgy Since Mintek 50

Michael J Nicol
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<td>5</td>
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<td>SX</td>
<td>3</td>
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<td>IX</td>
<td>5</td>
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<td>EW</td>
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Plenary – Mineral sulfide leaching
Separation processes

One paper on heap leaching
No papers on environmental issues
Developments since 1984

- CIP/CIL
- Leaching – Pressure, heap and bio-
- Mechanisms of sulfide leaching
- SX reagents, processes and equipment
- IX materials/RIP/NIMCIX
- Electrowinning of base metals
- Application of advanced mineralogical techniques
Hydrometallurgy

2 g/tonne in ore to 99.999% pure with >90% recovery
Carbon-in-Pulp Process
CIP and Declining Gold Grades

Source: Abare
Adoption of CIP Technology by Industry

- CIP technology rapidly adopted by industry
- Open exchange of technology permitted widespread application
- Advances made possible by large R&D investment throughout world
- The process is inherently simple and forgiving
Pressure Oxidation and Leaching
After many years of development, processes for the direct leaching of sulfides are becoming a commercial reality. The oxygen-H$_2$SO$_4$ pressure leaching of zinc concentrates has been demonstrated successfully at a commercial level, and the use of the technology is expanding.

J Dutrizac, Mintek 50
Development of Advanced Leaching Processes

1955 : First POX/hydrogen reduction process for Ni/Co, Sherritt Gordon, Canada

1959 : First PAL plant for laterites, Moa Bay, Cuba

1960 : Bacterial innoculation of stopes for U recovery, Gencor, RSA

1981 : First POX plant for Zn, Cominco, BMR at Rustenburg

1985 : First POX plant for Au, McLaughlin (CA, USA)

1986 : First full scale BIOX plant for Au, Fairview

2002 : Bio-leach plant for base metals, Kasese, Uganda
Barrick Goldstrike Pressure Oxidation
Laterite Processing

1%Ni, 0.02%Co

Pressure-acid leaching

Purification by SX/IX

Electrowinning/
H₂ reduction
Bacterial Oxidation and Leaching
• Bioleaching is on the Brink of Commercial Implementation for Treatment of Base Metal Sulphide Concentrates, Including Chalcopyrite

• To Improve the Competitiveness of Bioleaching, Development Work Should Focus on Reducing Residence Times and Improving Oxygen Transfer Rates to Lower Power Costs per Unit of Metal Produced

• Commercial Success is Dependent on the Speed of Development over Next Five Years and Realization of Process Economics Against Competitors
Impact of POX/BIOX on the Industry

- Largely driven by environmental pressures for Au
- Alternative to smelters for Ni/Co and now Cu(?)
- Alternative to roasting for Zn - acid disposal
- Major expansion of laterite Ni industry
- Heap leaching for sulfides (Cu, Ni/Co)
- Lower capital and operating costs than smelting/roasting
Adoption of Technology by Industry

- POX: Relatively slow adoption - Sherritt responsible for early implementation.
- BIOX: Assimilation by industry slow (ca 30yr) - increased gold price acted as catalyst
- Excess capacity and advances in smelter technology slowed implementation for both in the case of copper
- POX perceived as too high tech. and BIOX not robust
Competing Processes for Copper

- **Established Smelters**
- **Bio-Leaching Processes**
  - Mintek/Bactech, BHP Billiton
- **High Pressure Leaching**
  - Dynatech, CESL, Phelps Dodge/Placer, AARL
- **Low Pressure Leaching**
  - Activox, Mt Gordon
- **Atmospheric Leaching**
  - MIM, Rio Tinto
- **Intec, Nitrox(Cammp)**
Mechanisms of Leaching of Sulfide Minerals

Sulfur on Chalcopyrite after Leaching of Composite with Graphite

Wan, Miller and Simkovich, Mintek 50
MLA of chalcopyrite leach residue
Mechanisms of Chalcopyrite Dissolution

Oxidative Model

\[
\text{CuFeS}_2 + \text{Ox} = \text{Cu}^{2+} + \text{Fe}^{2+} + \text{S} + \text{Red}
\]

Non-Oxidative Model

\[
\text{CuFeS}_2 + 4\text{H}^+ \Leftrightarrow \text{Cu}^{2+} + \text{Fe}^{2+} + 2\text{H}_2\text{S}
\]

\[
\text{CuFeS}_2 + 2\text{H}^+ \Leftrightarrow \text{CuS} + \text{Fe}^{2+} + 2\text{H}_2\text{S}
\]

\[
2\text{H}_2\text{S} + \text{Ox} = 2\text{S} + \text{Red} + 4\text{H}^+
\]

Cpy at high E

Cpy at low E

Primary S

Secondary S

Red, Cu^{2+}, Fe^{2+}

H^+

Ox + H_2S

Ox

CuFeS_2

CuFeS_2
Heap Leaching SX/EW for Copper
Heap Leaching for Copper
Copper Metal Production Costs

Source: LME

Cost, US$/lb

% Production
Development of Selective Extractants for Copper

1960’s: First copper reagents developed
1968: First SX/EW plant Bluebird Mine (AZ)
1980: 10 plants in US, Zambia, Peru
1990’s: Improvements to reagents, SX contactors, EW technology
2008: 64 SX/EW plants for Cu world wide
Technological Impact on Production of Other Metals

- Development of selective reagents for other metals, e.g. Ni, Co, Zn, Precious metals
- Improvements and innovations in SX equipment, e.g. pulse columns
- Improvements and innovations in EW processes and equipment, e.g. ISA process, Co addition, Anodes
- Parallel development of selective ion exchange resins
- Provided incentive for heap leaching of others
Adoption of Technology by Industry

- Relatively slow implementation of SX/EW technology
- Rapid expansion after benefits fully demonstrated
- Open technology has permitted widespread adoption even for small operators
- Adoption of advanced SX/EW processes too rapid in some cases - Ni
Supported liquid membranes seem to be poised for commercialization .... The extension of the process to the processing of dump leach liquors, minewaters etc., cannot be ruled out. The use of supported liquid membranes might at last provide the answer to the problem of design of viable solvent-in-pulp systems.

D Flett, Mintek 50
Ion Exchange Processes
Multi-stage Continuous Ion Exchange

NIMCIX
The Penjom Process

1. Ore bin
2. Jaw crushe
3. Conveyor
4. Ball mill
5. Cyclone
6. Desliming
7. Knelson concentrator
8. Falcon separator (Tails)
9. Jig (Concentrate)
10. Spiral table (Concentrate)
11. Leaching reactor
12. Carbon stripping column
13. Resin-in-leach tanks
14. Final plant tailings
15. Cathode loaded with gold
16. Smelting
17. Gold bullion
18. Sulphide solid waste handled
19. Pregnant solution
20. barren solution
Application in Iron Removal
Adsorption of $\text{Au(S}_2\text{O}_3\text{)}_2^{3-}$ onto Anionic Resin

Gold Concentration on Resin (g/L) vs. Gold Concentration in Solution (mg/l)

- No Anions
- $\text{SO}_4^{2-}$
- $\text{S}_2\text{O}_3^{2-}$
- $\text{SO}_3^{2-}$
- $\text{S}_4\text{O}_6^{2-}$
- $\text{S}_3\text{O}_6^{2-}$
Permanent Stainless Steel Cathodes
Effect of Co on Anode Potentials
Pb-Ca-Sn Anode – 300A/m²

Time (sec)

Potential (V)

0 ppm
5 ppm
50 ppm
100 ppm
500 ppm
# LME Grade A Copper

<table>
<thead>
<tr>
<th>Element</th>
<th>Max. (ppm)</th>
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<tbody>
<tr>
<td>Se</td>
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<tr>
<td>Te</td>
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<tr>
<td>Bi</td>
<td>2</td>
</tr>
<tr>
<td>Sb</td>
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<tr>
<td>As</td>
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<tr>
<td>Pb</td>
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<tr>
<td>S</td>
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<tr>
<td>Sn</td>
<td>5</td>
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<tr>
<td>Ni</td>
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</tr>
<tr>
<td>Fe</td>
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<tr>
<td>Ag</td>
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[S] content and cathode porosity

[S]  3 ppm  5 ppm  11 ppm  24 ppm  56 ppm
SIMS Depth profile Analysis: Pb content of copper

- 1 g/L of PbO₂ in the absence of Galactosol
- 1 g/L of PbO₂ in the presence of galactosol (3.5 mg/L)
Anticipated Developments (1984)

- Expansion of CIP/CIL
- Leaching of base metal sulfide concentrates
- Applications of IX/RIP – Au, U, base metals

Developments not Anticipated

- Heap leaching/SX/EW
- PAL processes for Ni/Co
- Environmental pressures
- Energy as a major driver – U revisited
- Globalization and deterioration in education and R&D
Next 25 years?