Metallurgical Testwork to Support Development of the Kintyre Project

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ANSTO Minerals¹, Cameco²
ANSTO Minerals

• Studied processing of uranium ores for over 30 years;

• Extensive variety of deposits:
  • 6 operating mines in Australia (3 open, 3 closed)
  • 15 potential mines in Australia
  • 14 operating and potential mines outside Australia (mainly Southern Africa)

• Fundamental and diagnostic leach studies

• Detailed geometallurgical studies
• Discovered in 1985 by CRA (Rio Tinto)
• Acquired in 2008 by Cameco/Mitsubishi JV (70/30)
KINTYRE URANIUM DEPOSIT

• 55 Mlb $U_3O_8$ @ 0.58% average grade

• Uranium present mainly as:
  – Uraninite ($UO_2$)
  – Coffinite ($\{(USiO_4)_{1-x}(OH)_{4x}\}$) – lesser amounts

• High in carbonates
  – Ankerite ($Ca(Fe,Mg,Mn)(CO_3)_2$)
  – Dolomite ($CaMg(CO_3)_2$)
Metallurgical Testwork

History

• Acid Leach Pilot Plant operated at ANSTO in 1997
  – Ore upgraded to 2% U₃O₈ by radiometric sorting and gravity separation
  – 7 campaigns
  – Direct uranium precipitation yielded on-spec product

• Alkaline Leaching subsequently investigated by Cameco, but acid route selected
Metallurgical Testwork

Objectives of Work Discussed Today

- Optimisation of leach conditions
  - Maximise U extraction
  - Minimise acid and oxidant consumption

- Evaluate leaching of variability samples

- Effect of ore type and leach conditions on settling, filtration and rheology

- Neutralisation and radionuclide deportment in tailings

- Solvent Extraction Pilot Plant
  - Evaluation of ammonia and strong acid stripping
Automated – Computer controlled pH and ORP
Leach Optimisation Program

• Composite sample prepared to represent average of U and CO₃ in orebody

<table>
<thead>
<tr>
<th>Species</th>
<th>wt%</th>
<th>Species</th>
<th>wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₃</td>
<td>9.55</td>
<td>Mg</td>
<td>7.3</td>
</tr>
<tr>
<td>Ca</td>
<td>3.03</td>
<td>Si</td>
<td>25.6</td>
</tr>
<tr>
<td>Fe</td>
<td>8.2</td>
<td>U₃O₈</td>
<td>0.52</td>
</tr>
</tbody>
</table>

• Leach Testwork:
  – 50 wt% solids
  – 18 h leach time
  – NaMnO₄ as oxidant

• Variables investigated:
  – Temperature 35-65°C
  – pH 1.8-2.5
  – ORP 450-550 mV (vs. Ag/AgCl)
  – P₈₀ 250-710 μm
• U leached at varying rates, but final extractions similar
• 55°C selected as optimum temperature
• Final U extractions similar at all pHs except 2.5
• pH 2.2 selected as optimum
• 450 mV selected as optimum ORP
• U present mainly as Uraninite – leaching not driven by ORP as long as Fe$^{3+}$ concentration is sufficiently high
### Variability Samples Leaching

- Performed under optimum conditions determined:
  - pH 2.2
  - ORP 450 mV
  - $P_{80}$ 500 $\mu$m
  - 50 wt% Solids
  - 18 h Leach Time

<table>
<thead>
<tr>
<th>% U Extn.</th>
<th>Acid Addn. (kg/t)</th>
<th>Equiv. MnO$_2$ Addn. (kg/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max</td>
<td>99.2</td>
<td>432</td>
</tr>
<tr>
<td>Min</td>
<td>86.2</td>
<td>42</td>
</tr>
<tr>
<td>Avg.</td>
<td>95.5</td>
<td>187</td>
</tr>
</tbody>
</table>
Variability Samples Leach Results

The graph shows the relationship between calcium content in ore (%) and leach acid addition (kg/h). There is a positive correlation, indicating that as the calcium content increases, the leach acid addition also increases. The data points are scattered around a trend line, suggesting variability in the results.
Other Work from Leaches

• QEMScan on leach feeds and residues

• Effect of ore type and particle size on settling and filtration rate

• Effect of solids density on rheology for feed and residue slurries and neutralised slurries

• Tailings Neutralisation and radionuclide deportment
Bulk Leaching

- 2000 kg of ore leached over three campaigns
Solvent Extraction Testwork Objectives

To carry out equilibrium batch testwork and to operate solvent extraction mini-pilot plant:

- To compare the performance of the ammonia and acid options for uranium stripping;

- To further define the solvent extraction process unit operation for the Kintyre Uranium Project to obtain engineering design data for a DFS.

- Confirm/optimise operating conditions;

- Identify potential operational issues;

- To trace the deportment of impurities.
Uranium Solvent Extraction – General Process

Extraction → Scrub → Strip

- U PLS
- Scrub feed
- Strip feed
- Raffinate
- Spent scrub
- Loaded strip solution
- To product precipitation
Mini-Plant Continuous Operation

- Two separate continuous solvent extraction mini-plant trials operated for a total of 6 days;
- Total of ~1000 L of PLS was treated
- Alamine 336 (5 vol. %) + 2.5% iso-decanol in Shellsol 2046
- Stripping methods:
  - Ammonia stripping process \((\text{NH}_4\text{OH}/(\text{NH}_4)_2\text{SO}_4)\),
  - Acid stripping process \((\text{H}_2\text{SO}_4)\)
SX Mini-Plant Setup
Uranium Solvent Extraction - Ammonia Strip Process

- **Extraction**
  - U PLS
  - Raffinate

- **Scrub**
  - Spent scrub
  - H₂O

- **Strip**
  - U loaded strip
  - 1.5 M (NH₄)₂SO₄

- **Re-protonation**
  - Spent solution
  - H₂SO₄

- **ADU precipitation**
  - NH₄OH
Uranium Solvent Extraction - Acid Strip Process

Extraction
- E4
- U PLS
- H₂SO₄
- Raffinate

Wash
- Spent wash
- H₂O

Scrub
- Sc1
- Spent scrub
- H₂SO₄

Strip
- St5
- 4 M H₂SO₄
- U loaded strip

Diagram showing the flow of uranium in the solvent extraction process with acid strip.
<table>
<thead>
<tr>
<th></th>
<th>Feed Liquor</th>
<th></th>
<th>Feed Liquor</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g/L</td>
<td></td>
<td>g/L</td>
<td></td>
</tr>
<tr>
<td>U</td>
<td>2.7</td>
<td>As</td>
<td>0.002</td>
<td>Al</td>
</tr>
<tr>
<td>S</td>
<td>53</td>
<td>Mo</td>
<td>&lt;0.001</td>
<td>Ca</td>
</tr>
<tr>
<td>pH</td>
<td>1.8</td>
<td>Si</td>
<td>0.3</td>
<td>Cu</td>
</tr>
<tr>
<td>ORP (mV)</td>
<td>420</td>
<td>Zr</td>
<td>0.01</td>
<td>Mg</td>
</tr>
<tr>
<td></td>
<td></td>
<td>V</td>
<td>&lt;0.001</td>
<td>Mn</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fe</td>
<td>1.5</td>
<td>Na</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ni</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Zn</td>
</tr>
</tbody>
</table>
Extraction

- **Operating Conditions:**
  - pH 1.9-2.1 in E1 (loaded organic)
  - 1.6-1.8 in E4 (raffinate)
  - Temperature = 35-45°C
  - O/A = 0.65

- **Performance:**
  - U extraction = 99.7-99.96 %
  - \([U]_{\text{raffinate}} = 1-9 \text{ mg/L}\)
  - \([U]_{\text{loaded solvent}} = 4.2-4.3 \text{ g/L}\)
Phase Disengagement – Extraction

Organic Continuous

Aqueous Continuous
Scrub

Operating Conditions:

<table>
<thead>
<tr>
<th>Stage</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sc1 (spent scrub)</td>
<td>≥1.5</td>
</tr>
<tr>
<td>Sc3 (scrubbed organic)</td>
<td>≥2.5</td>
</tr>
<tr>
<td>Ammonia strip process</td>
<td>1.5</td>
</tr>
<tr>
<td>Acid strip process</td>
<td>1.7</td>
</tr>
</tbody>
</table>

Temperature 30-40°C O/A ~10

Performance:

- ≥ 50% of entrained Mg and Mn removal;
- Negligible scrubbing of As, Ca, Cu, Si and Zr;
- U scrubbing = 0.1-0.3%
Operating Conditions

Ammonia Strip:
- \[(NH_4)_2SO_4\] = 1.5 M
- pH gradient:
  - pH 3 in St1 (product stream)
  - pH 5 in St5 (stripped organic)
- Temperature = 30-40°C
- O/A = 5

Strong Acid Strip:
- \(H_2SO_4\) Concentration:
  - 390 g/L in St1 (product stream)
  - 400 g/L in St5 (stripped organic)
- Temperature = 30-40°C
- O/A = 10
## Mini-Plant Performance - Comparison

### Ammonia Strip:

<table>
<thead>
<tr>
<th>Element</th>
<th>$[M]_{\text{product stream}}$ g/L</th>
<th>$[M]_{\text{stripped solvent}}$ mg/L</th>
<th>Strip %</th>
</tr>
</thead>
<tbody>
<tr>
<td>U</td>
<td>18</td>
<td>30</td>
<td>99.3</td>
</tr>
<tr>
<td>S</td>
<td>54</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

### Strong Acid Strip:

<table>
<thead>
<tr>
<th>Element</th>
<th>$[M]_{\text{product stream}}$ g/L</th>
<th>$[M]_{\text{stripped solvent}}$ mg/L</th>
<th>Strip %</th>
</tr>
</thead>
<tbody>
<tr>
<td>U</td>
<td>41</td>
<td>15</td>
<td>99.6-99.8</td>
</tr>
<tr>
<td>S</td>
<td>126</td>
<td>3,700</td>
<td></td>
</tr>
</tbody>
</table>
## Mini-Plant Performance - Comparison

<table>
<thead>
<tr>
<th></th>
<th>To Raffinate</th>
<th>To Spent Scrub</th>
<th>To Loaded Strip</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ammonia Strip</strong></td>
<td>0.3</td>
<td>0.1</td>
<td>99.6</td>
</tr>
<tr>
<td><strong>Strong Acid Strip</strong></td>
<td>0.04-0.35</td>
<td>0.1-0.3</td>
<td>99.6-99.8</td>
</tr>
</tbody>
</table>
## Impurities in the Product Stream

<table>
<thead>
<tr>
<th></th>
<th>Ammonia strip</th>
<th>Acid strip</th>
<th>Max. U Concentrate Limit**</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of U</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>As</td>
<td>0.03</td>
<td>0.02</td>
<td>0.10</td>
</tr>
<tr>
<td>Ca</td>
<td>0.16</td>
<td>0.29</td>
<td>1.0</td>
</tr>
<tr>
<td>Fe</td>
<td>0.04</td>
<td>0.01</td>
<td>1.0</td>
</tr>
<tr>
<td>Mg</td>
<td>0.07</td>
<td>&lt; 0.002</td>
<td>0.50</td>
</tr>
<tr>
<td>Mo</td>
<td>&lt; 0.03</td>
<td>&lt; 0.01</td>
<td>0.30</td>
</tr>
<tr>
<td>Si</td>
<td>&lt; 0.03</td>
<td>&lt; 0.01</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>&lt; 0.03</td>
<td>&lt; 0.01</td>
<td>0.30</td>
</tr>
<tr>
<td>Zr</td>
<td>0.06</td>
<td><strong>0.15</strong></td>
<td>0.10</td>
</tr>
</tbody>
</table>

* Zr rejected by H₂O₂ precipitation

** Without rejection  (ASTM C967-13 Standard Specification for Uranium Ore Concentrate)
Acid vs. Ammonia Stripping Methods

- Both methods are equally effective, achieving > 99% stripping of U;
- The acid circuit is easier to control;
- Higher U concentration in the loaded acid strip solution;
- Acid route – more options for uranium final product;
- Environmental issues associated with ammonia;
- Use of corrosive reagent.
Conclusions

• Acid leaching has been identified as a robust process for Kintyre ores

• Testwork showed that optimum leach conditions for Kintyre are:
  – pH 2.2
  – ORP 450 mV
  – $P_{80}$ 500 µm
  – 18 h Residence time

• Average Uranium Extraction of 95.5% for Variability Samples
Conclusions

• Two fully integrated U SX mini-pilot plants were successfully operated for 6 days testing ammonium strip and acid strip processes;

• High U recoveries from feed to product stream were achieved:
  o [U]raffinate < 10 mg/L;
  o acid strip process: 99.8 %;
  o ammonia strip process: 99.6 %.

• Comparable stripping efficiency:
  o ammonia strip process: 99.3 %;
  o acid strip process: 99.6-99.8 %.

• Potential operational issue with ammonia strip – stable emulsion formation (extraction) and crud.