Gold and Silver Leaching in Alkaline Amino Acids Solutions

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Outline

- Introduction
- Target Properties of Lixiviants
- Amino Acids WHY?
- Advantages of Amino Acids
- Alkaline System WHY?
- Gold and Silver Leaching in Glycine Solutions
  - Effect of Amino Acids
  - Effect of Glycine Concentration
  - Effect of Silver Content
  - Effect of Temperature
  - Effect of pH
Outline

- Leaching at Low Glycine Concentration
  - Effect of Glycine Concentration
  - Effect of Temperature
  - Effect of Peroxide

- Gold and Silver adsorption onto activated carbon
Introduction

Different types of reagents have been used as lixivants in precious metals leaching:

- Cyanide
- Thiosulfate
- Thiocyanate
- Chloride
- Thiourea.

Of these, cyanide remains the only reagent that is applied on an industrial scale for gold and gold-silver ores. However, cyanide use poses a number of challenges:

- Toxicity
- Transport restrictions
- Restriction on use of cyanide in certain jurisdictions (e.g. Cadia in NSW, Montana & California, USA, Europe)
- Large increases in cyanide consumption with decreasing gold grades in ores
What is an Amino Acid?

- Building block of all proteins
- About 500 different types.
- Simpler amino acids are produced in bulk quantities and available at low prices.
- Glycine is simplest amino acid (amino acetic acid).
- Sweet tasting, non-toxic, occurs in human body.
- Glycine has the following structure:

Black: Carbon
White-grey: Hydrogen
Blue: Nitrogen
Red: Oxygen
What are the requirements for a good lixiviant?
Target properties of lixiviant

- Appropriate leach rate for mode of leaching.
- Toxicity and biodegradability.
- Cost, bulk availability and ease of production.
- Accessibility, including legal and regulatory constraints.
- Criticality of supply.
- Volatility of reagents.
- Ability to recover and recycle for reuse.
- Control and complexity of the leaching chemistry.
Target properties of lixiviants (continued)

- Solubility and stability of the lixiviant in water
- Solubility and stability subsequent metal-lixiviant complexes.
- Transportability by ship, rail or truck and transport restrictions and risk.
- Ability to destroy excess reagent or unwanted metal-lixiviant complexes in a controlled and cost-effective manner.
Do Amino Acids Fulfil These Requirements?
## Pros and cons of Amino acids system

<table>
<thead>
<tr>
<th>Pros/Materials of Construction</th>
<th>Cons/Heat Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-toxic</td>
<td>Operated under dilute and concentrated modes</td>
</tr>
<tr>
<td>Environmentally benign</td>
<td>Thermally stable and non-volatile</td>
</tr>
<tr>
<td>High affinity for Au, Ag and Cu</td>
<td>Application to various leaching modes</td>
</tr>
<tr>
<td>Simple chemistry</td>
<td>Materials of construction</td>
</tr>
<tr>
<td>Selective over non-sulfide gangue minerals</td>
<td>Recoverable using conventional technology</td>
</tr>
<tr>
<td>Leach rate</td>
<td>Heat requirement (Au) &amp; (Cu)</td>
</tr>
</tbody>
</table>
The alkaline-glycine system

- Glycine has a FOB price of $1,800-$2,400 per ton.
- \( \text{H}_2\text{O}_2, \) Oxygen and Cu(II) is already in use for many gold leaching operations.
- Lime is already in use.
- Glycine is readily available in bulk quantities: Food grade glycine of around 488,000 tonnes was produced in 2010.
- The gold glycinate complex is stable over a wide pH-Eh range.
Potential alkaline lixiviant systems

- **Ammoniacal-Cu-Thiosulfate**
  - pH ~ 9.5
  - Understanding of chemistry and mechanism still unclear.
  - High thiosulfate consumption.
  - Inability to reuse and recycle.
  - High ammonia concentration required to balance Cu in solution and prevent tenorite (CuO) precipitation.
  - Small stability range.
  - Polythiononates problematic.
  - Significant variation in gold recovery from various ores.
  - Need for ion exchange technology for Au recovery.
Gold Leaching
Amino Acids Type

0.5M amino acid, 1% H₂O₂, pH 11, at 60 °C
Effect of Glycine Concentration

<table>
<thead>
<tr>
<th>Glycine, M</th>
<th>Au, $10^3 \times \mu$mol/m².s</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.30</td>
<td>11.3</td>
</tr>
<tr>
<td>0.50</td>
<td>16.9</td>
</tr>
<tr>
<td>1.00</td>
<td>31.3</td>
</tr>
</tbody>
</table>

Glycine, 1% H₂O₂, pH 10, 60 °C
Effect of Silver

1M Glycine, 1% H₂O₂, pH 10, 60 °C

<table>
<thead>
<tr>
<th>Au, Ag Source</th>
<th>Au, 10³ x µmol/m².s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold from (pure gold sheet)</td>
<td>31.3</td>
</tr>
<tr>
<td>Gold (from 50% Au-50% Ag)</td>
<td>185</td>
</tr>
<tr>
<td>Silver (from 50% Au-50% Ag)</td>
<td>247</td>
</tr>
</tbody>
</table>
Effect of Temperature

1M Glycine, 1% H₂O₂, pH 10, 60 °C
Effect of pH

<table>
<thead>
<tr>
<th>Leach Time, hr</th>
<th>pH 5.8</th>
<th>pH 10</th>
<th>pH 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>8.11</td>
<td>0.59</td>
<td>352</td>
</tr>
<tr>
<td>29</td>
<td>8.75</td>
<td>1.30</td>
<td>367</td>
</tr>
<tr>
<td>48</td>
<td>5.13</td>
<td>11.47</td>
<td>322</td>
</tr>
<tr>
<td>119</td>
<td>4.19</td>
<td>14.34</td>
<td>174</td>
</tr>
<tr>
<td>167</td>
<td>3.02</td>
<td>16.93</td>
<td>142</td>
</tr>
</tbody>
</table>

0.5M glycine, 1% H₂O₂, pH, and 60 °C
Leaching at low Glycine concentrations

0.1M glycine, 1% H₂O₂, initial pH 11.5
Effect of glycine concentration in low concentration range on gold leaching

Glycine, 1% H$_2$O$_2$, pH 11, 60 °C
Effect of H$_2$O$_2$ concentration

0.1M glycine, different percentages of H$_2$O$_2$, pH 11.5, 60 ºC
Catalytic effect of cupric ions

0.1M glycine, 0.1% H$_2$O$_2$, pH 11, at 30 °C

0.1M glycine, 0.3% H$_2$O$_2$, 4 mM Cu$^{2+}$, pH 11.9 and 30 °C

0.1M glycine, 0.3% H$_2$O$_2$, 4 mM Cu$^{2+}$, pH 11.9 and 30 °C
Synergistic effect of amino acid mixtures

0.1M amino acid, 1% H$_2$O$_2$, pH 11, at 60 °C
Effect of pyrite on gold dissolution from glycine-peroxide solutions  

0.1M Glycine, 1% H$_2$O$_2$, pH 11, at 60 °C
Metal recovery: Adsorption of metal glycinates onto activated carbon

Plot of Log (\(\Delta [\text{Me}c/\text{[Me}s]\) against Log (t) for 4 hours (1 M Glycine; pH 10, T=25 °C; Activated Carbon 1.5 g/L) [13.2 kgAu/ton carbon in 4 hours]; [8.89 kgAg/ton carbon]

<table>
<thead>
<tr>
<th>Time min</th>
<th>[Au] mg/L</th>
<th>[Ag] mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>38.70</td>
<td>56.1</td>
</tr>
<tr>
<td>30</td>
<td>24.60</td>
<td>48.1</td>
</tr>
<tr>
<td>96</td>
<td>15.82</td>
<td>42.7</td>
</tr>
<tr>
<td>180</td>
<td>12.08</td>
<td>39.1</td>
</tr>
<tr>
<td>240</td>
<td>10.26</td>
<td>37.0</td>
</tr>
</tbody>
</table>

Plot of Log (\(\Delta [\text{Me}c/\text{[Me}s]\) against Log (t) for 4 hours (1 M Glycine; pH 10, T=25 °C; Activated Carbon 1.5 g/L) [13.2 kgAu/ton carbon in 4 hours]; [8.89 kgAg/ton carbon]
Metal recovery: Adsorption of metal glycinates onto activated carbon

Plot of Log (∆[Me]c/[Me]s) against Log (t) for 4 hours (0.5 M Glycine; pH 10, Temp=25 °C; Activated Carbon 1.02 g/L) [6.7 kgAu/ton carbon in 4 hours]
Conclusions

- Results show high potential for the use of alkaline amino acids at moderately elevated temperatures (40-60 °C) as alternative gold lixiviant.
- The presence of silver and Cu²⁺ ions enhance gold dissolution in the glycine-peroxide solutions.
- Gold leach rate from gold-silver (50% Ag) alloy is about 6 times higher than rate from pure gold.
- The silver leach rate (0.247 µmol/m².s) is an order of magnitude higher than gold (0.012 µmol/m².s).
Conclusions (Cont’d)

- Amino acids, or their salts, with a suitable oxidant ($O_2$, $H_2O_2$, Air) opens up a range of leaching options (ISL VL, HL) feasible at alkaline pH.

- Glycine, in particular, shows much promise due to bulk availability and low cost.

- Gold, silver and copper can be all be differentially leached using glycine, allowing sequential leaching with change in temperature and oxidant type/conc.

- Heating the leach solution between 40 and 60 °C was found to enhance the gold dissolution significantly in alkaline amino acid–peroxide solutions.
Conclusions (Cont’d)

- Gold dissolution increases by increasing amino acid concentration, peroxide and pH.
- The gold-glycinate complex was found to effectively load on activated carbon up to 13.2 g-Au/kg-carbon in 4 hours.
- Reagent suite is non-toxic (but leachate may not be).
- High stability of reagents and metal glycinate complexes.
Thank You!