NON AND REDUCED CYANIDE GOLD EXTRACTION SYSTEMS

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ABSTRACT

Mining and Process Solutions are the owner of several patents that use glycine to extract gold and other base metals from ores. These processes are in varying stages of development and vary from advanced pilot plant stage to experimental.

The most advanced process is our GlyCat™ technology that uses a glycine base under cyanide starved conditions. It requires the need for oxygen but works best with small amounts of copper, that seems to enhance the ability of both the cyanide and glycine to extract gold quicker under lower reagent concentrations.

Next advanced is our glycine alone process. Glycine is capable of slowly leaching gold at ambient temperatures but when the pH is made quite basic (pH >12.5) and the temperature increased, leaching rate are dramatically improved. MPS are evaluating this process for in situ and In Mine leaching purposes.

There are a number of chemicals that can be combined with glycine in basic solutions that do not use cyanide. The principal combination being studied is glycine combined with potassium or sodium ferricyanide. The ferricyanide salt is commonly used as a food additive. At very high concentrations ferricyanide is known to be able to leach gold by itself but when combined with glycine, it has proven to be able to leach gold at much lower concentrations. The second option is glycine combined with sodium or potassium permanganate. The chemistry is still not well defined, but there is enough empirical data that demonstrates good gold recovery from a number of different ores.

Lastly, there is our acidic G&T process which operates in an acid environment. It uses thiourea, which is a well-known lixiviant for gold. The typical thiourea leaching of gold operates in a reasonably acidic environment (pH 1-2) and uses ferric ion as an oxidant. However, the process suffers from high reagent consumption due to the ferric ion also oxidising and destroying the thiourea and this demands very high thiourea concentrations. When glycine and thiourea are used in combination in much lower concentrations at pH values between 2 to 6 it can be a very efficient process to extract gold from ores.

The last 4 glycine processes are still in experimental stage, but MPS/Curtin are expending a lot of effort in developing their capabilities. Glycine technology offers a means to not only extract the gold but also other base metals.

Keywords glycine, GlyCat™, potassium ferricyanide, potassium permanganate, thiourea
NON AND REDUCED CYANIDE GOLD EXTRACTION SYSTEMS- ALTA 2020
Frank Trask and Dr Elsayed Oraby
“Our mission is to deliver innovative thinking and technology solutions to the mining and processing of deposits”

“We believe smart chemistry and a deep understanding of mineralogy are key to unlocking untreatable and eco-sensitive opportunities”

• Strong patent position. 5 Patents being progressed. First two patents granted in over 20 countries to date;
• 15 Staff + Curtin Gold Technology Team;
• 6 Royalty based licenses with end-users executed;
• Over 250 test programs on different ores, wastes and slags carried out;
• 4 Continuous Pilot Plant programs in Perth with over 2000 hours of runtime and,
• >$8m spent to date in testing and piloting.
Definitions are as follows:

GlyLeach™ refers to leaching metals with glycine alone, including elevated temperature and pH values.

GT™ is a mixture of Glycine and Thiourea used to leach gold under acid conditions.

GlyCat™ refers to dual lixiviant systems, and second lixiviant can include cyanide, potassium ferricyanide (abbreviated KFC commercially), potassium permanganate, and other experimental oxidants.
Outline of Presentation

Introduction
A. Glycine leaching alone and with non-cyanide additives.
   • Glycine leaching - Elevated temperature & pH
   • Glycine-Permanganate
   • Glycine-Ferricyanide
   • Glycine-Thiourea (GT™)
B. Glycine leaching in Cyanide Starved Systems (GlyCat™)
Adding appropriate oxidants or catalysts with glycine has the following merits.

1) Accelerated leach rates of gold;
2) Establish a cyanide-free leaching system; and
3) Achieving high leach rates at ambient temperature.

Leaching gold by glycine at high pH can be represented by the following equation:

$$4Au + 8NH_2CH_2COOH + 4NaOH + O_2 \rightarrow 4Na[Au(NH_2CH_2COO)_2] + 6H_2O$$

Leaching gold by glycine in the presence of ferricyanide or permanganate can be represented by the following equations:

$$Au + Fe(CN)_6^{3-} + 2(NH_2CH_2COO)^- \rightarrow Fe(CN)_6^{4-} + Au(NH_2CH_2COO)_2^-$$

$$2MnO_4^- + 2(NH_2CH_2COO)^- + 1/2 O_2 \rightarrow 2MnO_2 \downarrow + 2C_2O_4^{2-} + 2NH_3 + H_2O$$

$$C_2O_4^{2-} \rightarrow 2CO_2 \uparrow + 2e^-$$
Glycine (\(\text{NH}_2\text{-CH}_2\text{-COOH}\)) is a stable amino acid that has various aqueous ionic forms.

Prior research indicated that using only alkaline glycine and air, in the absence of catalysts, leaching times for gold would be too long for conventional agitated tank leaching of ores.

The leach rate of gold with glycine is significantly slower than with cyanide, but still shows promise for heap, dump and in situ operations.

Some improvement has been reported with a combination of high temperature and high pH, as recently shown for a Western Australian paleochannel ore, but the rate is still less than cyanide.

In spite of these drawbacks, glycine has been shown as a promising alternative to cyanide.
Cyanide still remains the best process for the gold extraction because of its efficiency and simplicity.

However, there are a number of drawbacks associated with the cyanide use.

In order to overcome these drawbacks, intensive research has been made to find non-cyanide alternatives to cyanidation.

These alternatives include thiourea, glycine, thiosulfate, thiocyanate and halides.

Plant adaptability is difficult and expensive with most of these alternatives.
Outside Verification of GlyLeach™ Extraction of Gold

Pori Research Centre, Metso Outotec, Kuparitie 10, 28101 Pori, Finland


**Independent validation** of the basic work by Eksteen and Oraby at Curtin University.
Outside Verification of GlyLeach™ extraction of Gold (Altinkaya, et.al, 2020)

Pori Research Centre, Metso Outotec, Kuparitie 10, 28101 Pori, Finland

Graphic representation of the solubility of gold foil in glycine with variable pH and temperature.
Extraction of gold as a function of time in glycine leaching in comparison with conventional cyanidation. (Altinkaya, et.al.)

The time-dependent extraction of gold from the ore in glycine and cyanide media. Better performance by glycine is due to telluride minerals being more soluble in glycine than cyanide.
Cyanide-Free Glycine Leaching

Gold leaching of sample in cyanide-free permanganate -glycine systems

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Cyanide</th>
<th>Glycine+Reagent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glycine, g/l</td>
<td>0.0</td>
<td>7.5</td>
</tr>
<tr>
<td>Cyanide, ppm</td>
<td>50, 300</td>
<td>0.0</td>
</tr>
<tr>
<td>pH</td>
<td>10.5</td>
<td>10.5</td>
</tr>
<tr>
<td>KMnO4, g/l</td>
<td>0.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Gold leaching in glycine and permanganate
Cyanide-Free Glycine Leaching

Gold leaching of sample in cyanide-free permanganate - glycine systems

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Cyanide</th>
<th>Glycine + Reagent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glycine, g/l</td>
<td>0.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Cyanide, ppm</td>
<td>1000</td>
<td>0.0</td>
</tr>
<tr>
<td>pH</td>
<td>10.5</td>
<td>10.5</td>
</tr>
<tr>
<td>KMnO4, g/l</td>
<td>0.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Bottle Roll, Room Temperature, 30% Solids
GT™ (Glycine-Thiourea) Leaching of BiOx acid Product

Conditions

\[ \text{pH} = 1.5 \]

\[ \text{Glycine} = 6 \text{ GPL} \]

Gold is 140 GPT

Variable Thiourea and Ferric as noted.

24 hour leach

Leaching of Au under acid conditions
Copper will form complexes with cyanide or glycine

\[ 4 \text{Cu} + 12 \text{CN}^- + O_2 + 2 \text{H}_2\text{O} \rightarrow 4 \text{Cu(CN)}_2^- + 4 \text{OH}^- \]

\[ 4 \text{Cu} + 8 \text{NH}_2\text{CH}_2\text{COO}^- + O_2 + 2 \text{H}_2\text{O} \rightarrow 4 \text{Cu(NH}_2\text{CH}_2\text{COO)}_2^- + 4 \text{OH}^- \]

Exact leaching mechanism has not been determined but it likely copper cyanide will convert back to copper glycinate releasing cyanide for gold leaching

\[ \text{Cu(CN)}_2^- + 2 (\text{NH}_2\text{CH}_2\text{COO})^- \rightarrow \text{Cu(NH}_2\text{CH}_2\text{COO)}_2^- + 2 \text{CN}^- \]

\[ 2 \text{Cu(CN)}_3^- + 2 (\text{NH}_2\text{CH}_2\text{COO})^- \rightarrow \text{Cu(NH}_2\text{CH}_2\text{COO)}_2^- + \text{Cu(CN)}_2^- + 4 \text{CN}^- \]

So adding back copper cyanide and recycling is not a bad thing as still leaches gold

\[ 4 \text{Au} + 8 \text{Cu(CN)}_3^- + O_2 + 2 \text{H}_2\text{O} \rightarrow 4 \text{Au(CN)}_2^- + 8 \text{Cu(CN)}_2^- + 4 \text{OH}^- \]

\[ 2 \text{Au} + \text{Cu(NH}_2\text{CH}_2\text{COO)}_2^- + 4 \text{CN}^- + 0.5 \text{O}_2 + \text{H}_2\text{O} \rightarrow \text{Au(CN)}_2^- + \text{Au(NH}_2\text{CH}_2\text{COO)}_2^- + \text{Cu(CN)}_2^- + 2 \text{OH}^- \]

\[ \text{Au} + \text{Cu(NH}_2\text{CH}_2\text{COO)}_2^- + 2 \text{CN}^- + 0.25 \text{O}_2 + 0.5 \text{H}_2\text{O} \rightarrow \text{Au(NH}_2\text{CH}_2\text{COO)}_2^- + \text{Cu(CN)}_2^- + \text{OH}^- \]
• Gold is more stable complex with cyanide than glycine
  
  \[ \text{Au}^+ + 2 \text{(CN)}^- \rightarrow \text{Au(CN)}_2^- \quad \log K = 39.3 \]
  \[ \text{Au}^+ + 2 \text{(NH}_3\text{CH}_2\text{COO})^- \rightarrow \text{Au(NH}_2\text{CH}_2\text{COO})_2^- \quad \log K = 18.0 \]

• Exact leaching mechanism has not been determined but it is likely gold is complexed by cyanide and to a lesser extent glycine
  
  \[ 4 \text{Au} + 8 \text{CN}^- + O_2 + 2 \text{H}_2\text{O} \rightarrow 4 \text{Au(CN)}_2^- + 4 \text{OH}^- \]
  \[ 4 \text{Au} + 8 \text{NH}_2\text{CH}_2\text{COO}^- + O_2 + 2 \text{H}_2\text{O} \rightarrow 4 \text{Au(NH}_2\text{CH}_2\text{COO})_2^- + 4 \text{OH}^- \]

• It also possible under the low or no free cyanide environment gold cyanide is less stable so reverts to the more stable glycinate complex
  
  \[ \text{Au(CN)}_2^- + 2 \text{NH}_2\text{CH}_2\text{COO}^- \rightarrow \text{Au(NH}_2\text{CH}_2\text{COO})_2^- + 2 \text{CN}^- \]

• Due to the nature of glycine it is also possible to form a mixed complexation
  
  \[ 2 \text{Au} + \text{CN}^- + \text{NH}_2\text{CH}_2\text{COO}^- + 0.5 \text{O}_2 + \text{H}_2\text{O} \rightarrow \text{Au(CN)}\text{Au(NH}_2\text{CH}_2\text{COO}) + 2 \text{OH}^- \]
Gold ore:
- Au 2.36 g/t, Ag 0.80 g/t & 0.0128% Cu
- Cyanidation
  - Currently use 150-125 g/t NaCN
- GlyCat™
  - Currently testing at 50 g/t NaCN with 30 g/t glycine GlyCat™
Gold ore:

- Au 3.99 g/t, Ag 43.82 g/t & 0.004% Cu
- Cyanidation
  - 1.25 kg/t NaCN
- GlyCat™
  - 0.43 kg/t NaCN with 0.43 kg/t Gly
MPS Pilot Plant (8 kg/hour)
Au 20 g/t, Ag 30 g/t & 0.3% Cu
Target 88.5% cyanidation at 8 kg/t NaCN
GlyCat™ with 1.92 kg/t NaCN
Cyanide and Sulphur Speciation in tails

<table>
<thead>
<tr>
<th>Test</th>
<th>Cyanidation</th>
<th>GlyCat™</th>
<th>Reduction</th>
<th>International NaCN Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>[NaCN] kg/t</td>
<td>8.36</td>
<td>1.92</td>
<td>77.0%</td>
<td></td>
</tr>
<tr>
<td>Free CN</td>
<td>913</td>
<td>0</td>
<td>100.0%</td>
<td>1</td>
</tr>
<tr>
<td>OCN</td>
<td>90</td>
<td>80</td>
<td>11.1%</td>
<td>50</td>
</tr>
<tr>
<td>CN_WAD</td>
<td>2,500</td>
<td>1</td>
<td>100.0%</td>
<td>1</td>
</tr>
<tr>
<td>SCN</td>
<td>1,600</td>
<td>110</td>
<td>93.1%</td>
<td></td>
</tr>
<tr>
<td>S₂O₃</td>
<td>1,400</td>
<td>287</td>
<td>79.5%</td>
<td></td>
</tr>
<tr>
<td>SO₄</td>
<td>2,800</td>
<td>1,983</td>
<td>29.2%</td>
<td></td>
</tr>
<tr>
<td>S_Total</td>
<td>2,900</td>
<td>1,357</td>
<td>53.2%</td>
<td></td>
</tr>
</tbody>
</table>
Conclusions

- GlyCat™ is a dual lixiviant and oxidant process
- Able to reduce cyanide requirements by 50-80% depending on the ore
- Able to still recover the same or better gold extraction
- Able to recover copper as well as gold and silver
- Able to recover the leached gold onto activated carbon
- Able to reduce cyanide speciation in the tails so reduce or eliminate the requirement for detoxification
Conclusions

✓ Heated Glycine and hybrid lixiviant systems (such as glycine & non-cyanide additives) are emerging promising alternatives to cyanide;

✓ Our GlyCat™ process involving starved quantities of cyanide has been demonstrated at pilot scale to produce a tailings well below international cyanide management code recommendations without cyanide destruction.

  ✓ It also offers a substantial reagent savings demonstrated to be 20-80%.

  ✓ It applies to complex gold ores (with elevated base metals) as well as free milling ores;

  ✓ It is easily adapted to existing CIL/CIP plants with little/no capex and implementation risk.

✓ Our acidic GT™ (Glycine-Thiourea) process is under development as a potential method of treating pre-oxidation of refractory gold ores and acid leached copper oxide ores with residual gold values.
Glycine Leaching Technology Project

✓ Glycine Leaching Technology can be applied to:
  ✓ Free milling gold ores
  ✓ Complex gold ores and concentrates
    - Cyanide and oxygen consuming
  ✓ Refractory gold ores
  ✓ Gold tailings
✓ Can offer a cyanide free leaching option
✓ Currently seeking companies that want to invest in the gold mining industries future

Further information contact

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