3rd International Conference SDIMI

RECOVERY SILVER AND GOLD
BY DIRECT OXIDATIVE PRESSURE CYANIDATION

by

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CYANIDE PROCESS
The McArthur-Forrest Process (1887)

Is a metallurgical technique for extracting gold from low grade ore by converting the gold to water soluble aurocyanide metallic complex ions.

Leaching Time
42 - 72 hrs.
REFRACTING ORE
(Recovery less than 60 %)

IMPROVED TREATMENT PROCESSES:
- Fluid Bed Roasting
- Whole Ore Roasting
- Pressure Leaching
- Biological Oxidation
**Refractory Gold & Silver Ores**

- Oxidative Pretreatment
  - Whole Ore Roasting
    - Atmospheric Acid Leaching
  - Chemical Oxidation
  - Biological Oxidation
    - Acid Leaching High Pressure
    - Alkaline Cyanidation High Pressure

- Direct Leaching
  - Carbon in Leach
  - Alkaline Cyanidation & Oxygen High Pressure
  - Other Lixiviants Thiourea, Thiosulfate
Biological Oxidation

Pyrite particle before biooxidation with bacteria.

The sample pyrite particle after 30 days of biooxidation with bacteria. The bacteria are causing "corrosion" of the pyrite resulting in exposure of occluded gold.
Whole Ore Roasting
Pressure Oxidation of Refractory Gold Ores
Bulk Flotation → Grinding → Direct Oxidative Pressure Cyanidation 90 Minutes → Au(CN)₂⁻
### CHEMICAL AND MINERALOGICAL ANALYSIS

<table>
<thead>
<tr>
<th></th>
<th>Concentrate</th>
<th>Ore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au (g/ton)</td>
<td>87.09</td>
<td>4.12</td>
</tr>
<tr>
<td>Ag (g/ton)</td>
<td>12320</td>
<td>289</td>
</tr>
<tr>
<td>Pb (%)</td>
<td>2.6</td>
<td>0.5</td>
</tr>
<tr>
<td>Zn (%)</td>
<td>3.8</td>
<td>0.4</td>
</tr>
<tr>
<td>Cu (%)</td>
<td>0.5</td>
<td>0.04</td>
</tr>
<tr>
<td>Fe (%)</td>
<td>29.2</td>
<td>3.67</td>
</tr>
<tr>
<td>As (%)</td>
<td>0.15</td>
<td>0.1</td>
</tr>
<tr>
<td>S (%)</td>
<td>32</td>
<td>3.7</td>
</tr>
</tbody>
</table>

THE MINERALOGICAL ANALYSIS ARE:

- Silver Iron Sulfide
- Argentite, Pyrite
- Pyrrhotite, Arsenopyrite
- Chalcopyrite, Covellite
- Hematite and Magnetite
- Quartz and Calcite
Schematic mechanism of gold and silver leaching
60 minutes

Fe\(^{3+}\) → Zn\(^{2+}\) → CN\(^{-}\) → \(15O_2 + 2H_2O\) → \(2Fe(SO_4)_2 + 2H_2SO_4\) → \(2Ag(CN)_2\) → \(Au(CN)_2\) → \(GOLD\) → SPHALERITE → GALENA → PYRITE PARTICLE → ARGENTITE → Fe\(_2(SO_4)_3\) → \(O_2\)
The primary reactions are:

$$2\text{FeS}_2 + 7\text{O}_2 + 2\text{H}_2\text{O} = 2\text{Fe}^{2+} + 4\text{SO}_4^{2-} + 4\text{H}^+ \quad (1)$$

$$\text{FeS}_2 + 2\text{H}^+ = \text{Fe}^{2+} + \text{H}_2\text{S} + \text{S}^0 \quad (2)$$

Ferrous ions produced by reaction (1) and (2) are subsequently oxidized to ferric ions:

$$2\text{Fe}^{2+} + 1/2\text{O}_2 + 2\text{H}^+ = 2\text{Fe}^{3+} + \text{H}_2\text{O}$$
The ferric ions an also contribute to the oxidation of silver iron sulfide, argentite, pyrite, pyrrhotite, sphalerite and chalcopyrite:

\[
\text{AgFe}_2\text{S}_3 + \text{Fe}^{3+} = \text{Ag}^+ + 3 \text{Fe}^{2+} + 2\text{S}^{2-} + \text{S}^0
\]

\[
\text{Ag}_2\text{S} + 2\text{Fe}^{3+} = 2\text{Ag}^+ + 2\text{Fe}^{2+} + \text{S}^0
\]

\[
\text{ZnS} + 2\text{Fe}^{3+} = \text{Zn}^{2+} + 2\text{Fe}^{2+} + \text{S}^0
\]

\[
\text{CuFeS}_2 + 4\text{Fe}^{3+} = \text{Cu}^{2+} + 5\text{Fe}^{2+} + 2\text{S}^0
\]
Then, elemental sulfur may also be further oxidized to sulfate by oxygen or by ferric sulfate:

\[
2S^0 + 3O_2 + 2 = 4H^+ + 2SO_4^{2-}
\]

\[
S^0 + 6Fe^{3+} + 4H_2O = 6Fe^{2+} + 8H^+ + SO_4^{2-}
\]

This results in the formation of a porous, but nonprotective, elemental sulfur layer, thus allowing cyanide and dissolved oxygen to access the previously locked gold, silver and electrum.

\[
Ag_2S + 4CN^- = 2Ag(CN)_{2-} + S^{2-}
\]

\[
4Au + 8CN^- + O_2 + H_2O = 4Au(CN)_{2-} + 4OH^-
\]
Comparison of silver extraction at ambient conditions and high pressure

**CONDITIONS**
- %Solids = 20
- pH = 11.0
- Pressure = 80 psi
- rpm = 300
- Temp. = 80 °C

**Graph**
- SILVER 80 C (80 psi)
- SILVER (N.C.)
Comparison of gold extraction at ambient conditions and high pressure

![Graph showing comparison of gold extraction at different conditions](image)

- **GOLD 80 psi** at 80 °C
- **GOLD (1 atm)** at 25 °C
Effect of autoclave retention time on gold and silver extraction

<table>
<thead>
<tr>
<th>CONDITIONS</th>
<th>GOLD</th>
<th>SILVER</th>
</tr>
</thead>
<tbody>
<tr>
<td>%Solids = 20</td>
<td><img src="image" alt="Graph showing extraction percentage for gold and silver over time." /></td>
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</tr>
<tr>
<td>pH = 11.7</td>
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<tr>
<td>rpm = 300</td>
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</tr>
<tr>
<td>Temp. = 80°C</td>
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Effect of the cyanide concentration on gold and silver extraction

![Graph showing the effect of cyanide concentration on gold and silver extraction. The graph illustrates the percentage extraction of gold and silver against varying cyanide concentrations. The conditions for the experiment are specified as: 20% solids, pH = 11.7, Temp. = 80°C, Pressure = 80 psi, rpm = 300, and leach time = 60 min.]

- **Gold**
  - Extraction increases with cyanide concentration.

- **Silver**
  - Extraction increases sharply with cyanide concentration.

**Conditions**
- % Solids = 20
- pH = 11.7
- Temp. = 80°C
- Pressure = 80 psi
- rpm = 300
- Leach time = 60 min.
Effect of temperature on gold and silver extraction

Effect of temperature on gold and silver extraction

CONDITIONS
- % Solids = 20
- pH = 11.2
- Pressure = 80 psi
- rpm = 300
- leach time = 60 min.
Effect of pH on gold and silver extraction

**CONDITIONS**

- % Solids = 20
- Temp. = 80 °C
- Pressure = 80 psi
- rpm = 300
- NaCN = 1%
- Leach time = 60 min.

**RESULTS**

- Gold extraction
- Silver extraction
Effect of percent solids in the extraction of gold and silver

**CONDITIONS**
- Temp. = 80 °C
- pH = 1.2
- Pressure = 80 psi
- rpm = 300
- NaCN = 1%
- leach time = 60 min.

**Graph:**
- GOLD
- SILVER

**Y-axis:** Extraction, %
- 0 to 100

**X-axis:** % SOLIDS
- 0 to 35
Results of continuous plant operation
CONCLUSIONS

- The present study shows that, gold and silver values are associated with silver iron sulfide, argentite, pyrite, pyrrhotite, sphalerite and chalcopyrite in the Bacís concentrate.

- The dissolution of gold and silver are due to the strong complexing capabilities of cyanide anions combined with the oxidizing properties of the dissolved molecular oxygen.
The kinetics of the direct pressure oxidation/cyanidation was found to be strongly dependent on particle size, concentration of sodium cyanide, temperature and pH.

Single stage direct pressure oxidation/cyanidation, has proven to be effective in treating pyrite refractory gold and silver concentrates from Bacís mining, for both gold and silver it was found that the precious metals recovery exceeded 96%.
The relatively mild operating conditions of 80 °C and 80 psi oxygen pressure offer distinct advantages. For example, low cost materials of construction can be utilized for the autoclave.

Finally in this process, there is obviously lower gold and silver inventory.
Thank you for your attention

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10 nuevos proyectos mineros en operación en el período 2004-2009

- Proyecto El Chinate: Oro
- Proyecto Cerro Colorado: Oro
- Proyecto Lluvia de Oro: Oro
- Proyecto Milpillas: Cobre
- Proyecto Mariquita: Cobre
- Proyecto Bacadehuachi: Sulfato de Sodio
- Proyecto Mulatos: Oro
- Proyecto San Antonio: Oro, Cobre
- Proyecto Piedras Verdes: Cobre
- Proyecto Alamo Dorado: Plata