Lecture 20

Biotechnology For Gold – Biooxidation Of Refractory Sulfidic Concentrates

Keywords: Refractory Sulfides, Biooxidation, Bioreactors

Biotechnology could be effectively used to extract gold from the following unconventional and waste resources. [116-123]

a) Tailing dumps accumulated at the mine sites over a period of several years amounting to several millions of tonnes, which in few locations contain as high as 1 gram / tonne of gold
b) Lean grade sulfidic gold ores containing less than 1-2 gram/tonne of gold, which cannot be economically processed through conventional processes.
c) Refractory ores-sulphidic or carbonaceous, where finely disseminated gold particles are locked up, making them uneconomical for direct cyanidation

Gold occurs in nature in its native state in three different types of ores, namely, free milling, base metal and refractory. Free-milling ores are those from which the precious metal can be efficiently liberated from the host rock (quartz) through size reduction. Most of the gold-processing plants around the world utilize free milling ores to recover the metal through the cyanidation process. Base metal ores containing copper, lead, zinc and iron as their sulphides often contain gold which is recovered as a by-product metal. The third type, namely, refractory ores, is becoming commercially important as a potential primary source of gold. Among the refractory gold ore occurrences, two types are important, namely, sulphidic and carbonaceous. In sulfide deposits, the precious metal is finely disseminated within sulphide minerals such as pyrite and arsenopyrite and the encapsulated gold particles cannot be efficiently liberated even after fine grinding and direct cyanidation would be inefficient for metal recovery. In the case of
refractory gold bearing carbonaceous ores, gold particles are locked-up, making recovery by gravity or cyanidation methods unacceptably low. Another problem with carbonaceous materials is ‘preg-robbbing’ which means even if liberated gold particles are cyanided, they get reabsorbed onto carbon matter making recovery extremely difficult.

The use of mixed strains of bacteria containing *Acidithiobacillus ferrooxidans*, *Acidithiobacillus thiooxidans* and *Leptospirillum ferrooxidans* may prove to be more efficient in sulphide mineral oxidation due to synergistic mechanisms. The use of thermophilies such as *Sulfolobus* which have optimum activity at about 60-80°C would ensure enhanced leaching kinetics in gold liberation.

Biooxidation reactions to liberate gold entrapped in the sulfide matrix are given below:

\[
\begin{align*}
2\text{FeAsS} + 7\text{O}_2 + \text{H}_2\text{SO}_4 + 2\text{H}_2\text{O} & = 2\text{H}_3\text{AsO}_4 + \text{Fe}_2(\text{SO}_4)_3 \\
4\text{FeS}_2 + 15\text{O}_2 + 2\text{H}_2\text{O} & = 2\text{Fe}_2(\text{SO}_4)_3 + 2\text{H}_2\text{SO}_4 \\
4\text{FeS} + 9\text{O}_2 + 2\text{H}_2\text{O} & = 2\text{Fe}_2(\text{SO}_4)_3 + 2\text{H}_2\text{SO}_4 \\
\text{FeS}_2 + \text{Fe}_2(\text{SO}_4)_3 & = 3\text{FeSO}_4 + 2\text{S} \\
2\text{S} + 2\text{H}_2\text{O} + 3\text{O}_2 & = 2\text{H}_2\text{SO}_4 \\
4\text{FeSO}_4 + \text{O}_2 + 2\text{H}_2\text{SO}_4 & = 2\text{Fe}_2(\text{SO}_4)_3 + 2\text{H}_2\text{O}
\end{align*}
\]

Both direct and indirect biooxidation mechanisms may be operative. Bacteria require nutrients, O\(_2\) and CO\(_2\) for growth which are provided through aeration and supplementing growth media. The following substances can be toxic to bacterial growth.

- Cyanides and thiocyanates even in low levels
- Grease, oily matter
- Chlorides
- Dissolved arsenic [As (III) more toxic than As (V)], ferric ions, copper and other metals depending on concentrations.
It may be reiterated that biooxidation of sulphidic gold-bearing concentrates is essentially a pretreatment process for liberation of locked-up gold particles. The acid bioleached residues need be lime-treated before subsequent cyanidation. In the absence of prior biotreatment, even finer grinding of such refractory ores would result in very poor gold recoveries, even as little as 6-10% and at any rate never exceeds 30-40% even under optimum processing conditions. The improvement in gold and silver recovery after prior biooxidation would be significant, often exceeding 95%.

There is a direct relationship between the degree of sulphide bio-oxidation and percent gold recovery. Complete oxidation of sulphides is not always essential to achieve acceptable gold recovery. Depending on the sulphide entity, high gold recoveries can be obtained with even as low as 50% oxidation of the total sulphides. The entire biooxidation process is agitation leaching for the concentrates carried out in stirred bioreactors or Pachuca type reactors. The percent oxidation of sulfide biooxidation depends on the type of sulphide involved, whether pyrite or arsenopyrite.

Though gold bearing sulphides can be directly bioleached, it is often preferable to treat a flotation concentrate of the ore since it enables easy handling of a reduced tonnage of enriched material. The following variables need be closely controlled to achieve optimum efficiency.

- Appropriate preadapted bacterial culture (adapted to sulfide concentrates and arsenic)
- Particle size – finer size means faster oxidation
- Pulp density – 20-30% optimum
- Oxygen and carbon dioxide availability (aeration)
- Agitation and homogeneous mixing of pulp
- Temperature, 30°C to 45°C (use of moderately thermophilic strains)
- pH 1 to 2
• Residence period 2 – 7 days
• Eh 700-900 mV
• Availability of nutrients
• Removal of toxic and interfering reaction products

Large-scale industrial applications of biotechnology for refractory gold ores and concentrates have shown great promise.

There are several stages in the feed preparation for biooxidation in reactors.

• Thickening and remilling (if necessary of a flotation concentrate (pyrite, arsenopyrite or pyrite-arsenopyrite) – size about 70 - 80µm.

• Adjustment of pulp density at about 20% solids (pulp density can be optimized depending on the nature of concentrates).

• Nutrient addition

• Use of primary and secondary reactors (series or parallel arrangement).

• Typical residence period between 3-6 days.

• Oxygen requirement-supply of air and dispersal through mechanical agitators to ensure acceptable oxygen transfer.

• Impellers-different designs.

• Slurry temperature to be maintained 34° – 45°C – Due to exothermic reactions, slurry temperature can shoot up- Provision for cooling essential.

• pH maintained between 1 -2.

• Counter-current decantation before cyanidation of oxidized residues.

• Neutralization by lime (or CaCO₃). Removal of arsenic and iron from neutralized and alkaline slurry.
2H₃AsO₄ + Fe₂(SO₄)₃ + 3CaCO₃ = 2FeAsO₄ + 3CaSO₄ + CO₂ + H₂O

Fe₂(SO₄)₃ + 3CaCO₃ + 3H₂O = 2Fe(OH)₃ + 3CaSO₄ + 3CO₂

H₂SO₄ + CaO = CaSO₄ + H₂O (lime neutralization)

A list of industrial bioreactor operations for gold operations in different parts of the world is given in Table 20.1.

Typical industrial bioreactors for gold biooxidation and cyanidation are illustrated in Figs 20.1 and 20.2.

**Bioreactor engineering for refractory sulphidic gold concentrates: an Indian experience**

India is the largest consumer of gold in the world while in terms of production of the precious metal, India produces only about 4 tons of the metal per year. The Hutti Gold Mines Company Limited (HGML) in Karnataka is the only primary gold producer in the country today. Most of the ore is mined by underground mining and gold is extracted from free milling ores by cyanidation using carbon-in-pulp method. The typical grade of the ore is about 4-5 gm/ton.

In recent years, HGML has identified several newer deposits for extracting gold and silver. G.R.Halli and Anjanahalli deposits are sulphidic ore deposits containing about 3-4 gm of gold per ton of ore. As expected, extraction of gold from such ore or its flotation concentrate by conventional cyanidation has not been encouraging. The concentrate needs to be biooxidized before it is cyanided to enhance gold recovery. It is in this regard that HGML and Indian Institute of Science undertook a joint project to develop bioreactor technology for biooxidation of the refractory G.R.Halli concentrate with financial support from the Department of Biotechnology, Government of India during 1997–2002.
### Table 20.1: Gold Bioreactor operations

<table>
<thead>
<tr>
<th>Location</th>
<th>Bioreactor</th>
<th>Concentrate, tonnes/day</th>
</tr>
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<tbody>
<tr>
<td>Fairview, South Africa, 1986</td>
<td>Biox</td>
<td>65 - 80</td>
</tr>
<tr>
<td>Sao Bento, Brazil, 1991</td>
<td>Biox</td>
<td>380</td>
</tr>
<tr>
<td>Harbour Lights, Australia, 1991-94</td>
<td>Biox</td>
<td>40</td>
</tr>
<tr>
<td>Wiluna, W. Australia, 1993</td>
<td>Biox</td>
<td>158</td>
</tr>
<tr>
<td>Ashanti, Ghana, 1994</td>
<td>Biox</td>
<td>960</td>
</tr>
<tr>
<td>Yauanmi, W. Australia, 1994-98</td>
<td>BacTech</td>
<td>120</td>
</tr>
<tr>
<td>Tamborique, Peru, 1998</td>
<td>Biox</td>
<td>60</td>
</tr>
<tr>
<td>Beaconsfield, Tasmania, Australia, 2000</td>
<td>BacTech</td>
<td>~70</td>
</tr>
<tr>
<td>Laizhou, China, 2001</td>
<td>BacTech</td>
<td>~100</td>
</tr>
<tr>
<td>Olympiada, Krasnoyark, Russia, 2001</td>
<td></td>
<td>1000</td>
</tr>
<tr>
<td>Suzdal, Kazakhsan, 2005</td>
<td>Biox (Gold field)</td>
<td>196</td>
</tr>
<tr>
<td>Fosterville, Victoria, Australia, 2005</td>
<td>Biox (Gold field)</td>
<td>211</td>
</tr>
<tr>
<td>Bogoso, Ghana, 2006</td>
<td>Bac Tech - Bacox</td>
<td>750</td>
</tr>
<tr>
<td>Jinfeng, China, 2006</td>
<td>Biox</td>
<td>790</td>
</tr>
<tr>
<td>Kokpatas, Uzbekistan, 2008</td>
<td>Biox</td>
<td>1089</td>
</tr>
</tbody>
</table>


Fig. 20.1: Agitated Bioleach Reactors to Oxidise Refractory Gold Concentrate
(Kind courtesy from MINTEK, P.J. van Staden, manager, Biotechnology Divn.MINTEK)
(Permission from MINTEK thankfully acknowledged)

Fig. 20.2: Agitated Bioleach Reactors and Cyanidation Plant to treat Refractory Gold Concentrate
(Kind courtesy from MINTEK, P.J. van Staden, manager, Biotechnology Divn.MINTEK)
(Permission from MINTEK thankfully acknowledged)
Initial agitation leaching tests were carried in laboratory scale bioreactors using *At.ferrooxidans* preadapted to concentrates (fig. 20.3).

Flowsheet for pilot scale biooxidation and typical photographs of pilot bioreactors are shown in figs.20.4 and 20.5.
Gold and silver recovery data after biooxidation and cyanidation are given in fig. 20.6.
Biooxidation tests were carried out on a continuous mode, the reactor was first run in batch mode to bring the pulp density up to 10%. Initial experiments were carried out with 1% pulp density and the iron leached was estimated. When the iron leached out approximately attained the theoretical amount in the concentrate, more concentrate was added and such step leaching continued until the pulp density reached 10-15%. Further increase in pulp density did not enhance the leaching rate. The high iron and sulphur content in the concentrate introduced a lag period, slowing the leaching rate. The above method of step leaching is more effective than starting with 10% pulp density at the beginning itself. Most of the iron leached was in the form of ferric ions while very little ferrous was present. The leaching rate of iron was consistent with reported results for pyrite and arsenopyrite bearing gold ores. The reactor was then operated in a continuous mode with a feed rate of 1.5L/day and 4 days residence time. The slurry was pumped using a peristaltic pump. On an average, 90% of gold and 95% of silver could be extracted from biooxidised concentrate. The bioreactor was operated for about 15 days in this mode and it was observed that consistently good recoveries could be achieved over the period of study.
Biooxidation as a pretreatment can be used effectively for treating G. R. Halli sulphidic concentrate at the HGML.

After intensive laboratory testing for nearly a year, it was decided to test the technology on-site at HGML. For this purpose, a demonstration pilot facility was designed with a capacity to process 100Kg of concentrate per day. Three bioreactors with a total capacity of 6 m³ was used. The concentrate was fed from the feed tank to the first two bioreactors, which were in parallel, through peristaltic pumps. Outputs from reactors 1 and 2 were fed to reactor 3 from where the treated slurry was sent to a settling tank. The solids were drawn from the settling tank for cyanidation. The reactors were provided with water jackets for controlling the temperature. The start-up strategy was to get all the three bioreactors running in batch mode before the continuous operation started. The bacteria (At.ferrooxidans) were cultured in the bioreactors itself in the presence of the concentrate by the step leaching technique with all the necessary nutrients for bacterial growth without ferrous sulphate. The feed was acid stabilized in the feed tank before it was fed to the bioreactors. The important process variables such as Eh, pH, temperature pulp density, iron concentration and bacterial population were monitored at regular intervals.