**Bioleaching**

Bioleaching is the extraction of metals from their ores through the use of living organisms. This is much cleaner than the traditional leaching processes like heap leaching using cyanide or other chemicals. Bioleaching is one of the latest technologies used to recover many important metals like copper, zinc, lead, uranium, arsenic, antimony, nickel, molybdenum, gold, silver and cobalt from their ores.

**Evolution of Bioleaching**

- Bioleach technology first investigated in the mid of 1980’s at King's College, London, England for the elimination of sulphur from coal
- Technology, still in its infancy, migrates to Perth, Australia, in the late 1980s, where it is funded privately
- 1994: A public company, Gold Mines of Australia, builds the first BacTech bioleach plant at the Youanmi Mine in Western Australia. Bioleaching provides additional mine life of three years processing refractory arsenic gold concentrates from the mine. The mine was closed in 1997 due to low gold prices, but BacTech had its first successful commercial application.
- 1998: A public company, Allstate Mining, licenses and installs the 2nd BacTech bioleach plant to process refractory arsenic ore from the Beaconsfield Mine in Tasmanian (Australia). The mine is now in its 12th year of continuous operation.
- 2000: A Chinese company, Shandong Tarzan Biogold Co. Ltd. ("Biogold"), licenses and installs a bioleach plant capable of treating 100 tonnes of concentrate per day from mines both in China and abroad, demonstrating the diversity of the technology for treating non-homogenous feeds from various metallurgical backgrounds. Recently, the current owner, Sino Gold Mining Limited, doubled the capacity of the current plant to 200 tonnes per day.
- 2001: Industrias Peñoles S.A. de C.V. ("Peñoles"), the world's largest silver producer, contributed USD$5 million to build a demonstration plant in suburban Monterrey, Mexico, to test the technology's ability to treat dirty or complex base metal concentrates. The findings of the study proved the benefits of bioleaching with respect to (a) neutralizing deleterious elements in the concentrate, and (b) eliminating costly transportation of concentrates to smelters, thereby reducing the environmental footprint left by smelting and truck haulage usage.

- Nowadays, about 40 bioleaching plants are in industrial use for extraction of copper, gold, zinc, cobalt, uranium metals.

It should be noted that since 2001, research and development carried out by REBgold has led to many improvements to the technology, and what exists today is considerably different and advanced compared to what was used in the past.
Principle of Bioleaching:

Basic principle of bioleaching is the conversion of insoluble metal sulfides into water-soluble metal sulfates liberating metals using microorganisms. The bacteria oxidize ferrous ion (Fe\(^{2+}\)) and sulfur (S) in the ore to produce ferric ion (Fe\(^{3+}\)) and sulphate (SO\(_4^{2-}\)). The Fe\(^{3+}\) in turn reacts with the sulfide minerals to produce Fe\(^{2+}\) and S.

Bioleaching can involve numerous iron and sulfur oxidizing bacteria, including *Acidithiobacillus ferrooxidans* (formerly known as *Thiobacillus ferrooxidans*) and *Acidithiobacillus thiooxidans*. As a general principle, Fe\(^{3+}\) ions are used to oxidize the ore. This step is entirely independent of microbes. The role of the bacteria is the further oxidation of the ore, but also the regeneration of the chemical oxidant Fe\(^{3+}\) from Fe\(^{2+}\). For example, bacteria catalyze the breakdown of the mineral pyrite (FeS\(_2\)) by oxidizing the sulfur and metal (in this case ferrous ion Fe\(^{2+}\)) using oxygen. This yields soluble products that can be further purified and refined to yield the desired metal.

The microbial oxidation process occurs at the cell membrane of the bacteria. The electrons pass into the cells and are used in biochemical processes to produce energy for the bacteria while reducing oxygen to water. The critical reaction is the oxidation of sulfide by ferric ion. The main role of the bacterial step is the regeneration of this reactant.

The process for copper is very similar, but the efficiency and kinetics depend on the copper mineralogy. The most efficient minerals are chalcocite (Cu\(_2\)S) and covellite (CuS). The main copper mineral chalcopyrite (CuFeS\(_2\)) is not leached very efficiently, which is why the dominant copper-producing technology remains flotation, followed by smelting and refining. The leaching of CuFeS\(_2\) follows the two stages of being dissolved and then further oxidized with Cu\(^{2+}\) ions being left in solution.

Traces of precious metals such as gold may be left in the original solution. Treating the mixture with sodium cyanide in the presence of free oxygen dissolves the gold. The gold is removed from the solution by adsorbing (taking it up on the surface) to charcoal.

Reaction mechanisms:

The reaction mechanisms are of two types such as,

1- Direct bacterial leaching;

In this process, a physical contact exists between bacteria and ores and oxidation of minerals takes place though enzymatically catalysed steps. For example, pyrite is oxidised to ferric sulphate

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2\text{FeS}_2 + 7\text{O}_2 + 2\text{H}_2\text{O} \rightarrow 2\text{FeSO}_4 + 2\text{H}_2\text{SO}_4
\]
2- **Indirect bacterial leaching:**

In this process, the microbes are not in direct contact with minerals, but leaching agents are produced by these microbes which oxidize the ores.

**Bioleaching Processes:**

There are three commercial process used in bioleaching;

1. **Slope leaching:**

Here the ores are first ground to get fine pieces and then dumped into large leaching dump. Water containing inoculum of *Thiobacillus spp.* is continuously sprinkled over the ore. Water is collected from the bottom and used to extract metals and generate bacteria in an oxidation pond.

2. **Heap leaching:**

Here the ore is dumped into large heaps called leach heaps. Water containing inoculum of *Thiobacillus spp.* is continuously sprinkled over the ore. Water is collected from the bottom and used to extract metal.

3. **In situ leaching:**

In this process the ore remains in its original position in earth. Surface blasting of earth is done to increase the permeability of water. Water containing *Thiobacillus spp.* is pumped through drilled passages to the ores. Acidic water seeps through the rock and collects at bottom. Again, water is pumped from bottom. Mineral is extracted and water is reused.

**Important bacteria used for bioleaching:**

The most commonly used microorganisms in bioleaching are *Thiobacillus thiooxidans* and *Thiobacillus ferrooxidants*. Other microorganisms which may also be used are; *Bacillus Licheniformis, B. luteus, B. megaterium, B. leptospirillum ferrooxidans, Pseudomonas flavescense, Sulfolobus acidocaldarius*, etc;

Bacteria are classified according to temperature at which they are active such as:

- **Mesophiles** (30 - 42 °C)
- **Moderate thermophiles** (45 - 60 °C)
- **Extreme thermophiles** (65 - 85 °C)

**Bioleaching with fungi:**

Several species of fungi can be used for bioleaching. Fungi can be grown on many different substrates. Experiments have shown that two fungal strains (*Aspergillus niger* and *Penicillium simplicissimum*) were able to mobilize Cu and Sn by 65% and Al, Ni, Pb, and Zn by more than 95%.
Aspergillus niger can produce some organic acids such as citric acid. This form of leaching does not rely on microbial oxidation of metal but rather uses microbial metabolism as source of acids that directly dissolve the metal.

**Comparison with other techniques:**

Extractions by chemical methods involve many expensive steps such as roasting and smelting which require sufficient concentrations of elements in ores and are environmentally unfriendly. Low concentrations are not a problem for bacteria because they simply ignore the waste that surrounds the metals, attaining extraction yields of over 90% in some cases. These microorganisms actually gain energy by breaking down minerals into their constituent elements. The company simply collects the ions out of the solution after the bacteria have finished.

**Advantages of bioleaching:**

1-Environmental:
   - The process is more environmental friendly than traditional extraction methods.
   - The bacteria are naturally occurring and harmless to the environment and human health.
   - What is being treated is the actual source of acid generation and not the symptoms.
   - Prevention of future Acid Mine Drainage through sulphide neutralization.
   - Toxic heavy metals, like arsenic, are converted into stable, environmentally benign products.
   - No gaseous emissions (e.g. SO\textsubscript{2}, As\textsubscript{2}O\textsubscript{3}) so there is no need to control or limit the emissions of sulfur dioxide or other pollutants.
     - Efficient reuse of water from the process.
     - Reduction in use of mercury by artisanal miners.

2-Economic:
   - Bioleaching is in general simpler and cheaper to operate and maintain than traditional processes.
   - Remediation of tailings at no cost to government.
   - Revenues through the recovery of contained metals like gold, silver, copper, zinc, nickle, cobalt etc.
   - Local opportunities for work, training, development and the start of a new 'green' industry.
   - Lower cost than the alternatives (e.g. pressure oxidation) and requires less capital.
   - Easy to expand to accommodate tailings from many types of mines within a region.
3-Technical:

- The technology is already commercially proven
- Bioleaching can be used to extract metals from ores that are too poor for other technologies. It can be used to partially replace the extensive crushing and grinding that increase cost and energy consumption in a conventional process.
- It is a continuous process which is safe, easy to operate and flexible.
- Scalable in a short period of time and capable of processing a wide variety of low to high grade mine tailings

**Disadvantages of bioleaching:**

1-Economical: The bacterial leaching process is very slow as compared to traditional methods. This brings in less profit as well as introducing a significant delay in cash flow for new plants.

2-Environmental:

- Toxic chemicals are sometimes produced in the process. Sulfuric acid and H⁺ ions that have been formed can leak into the ground and surface water turning it acidic, causing environmental damage.
- Heavy ions such as iron, zinc and arsenic may leak during acid mine drainage and cause pollution.
- For these reasons, a setup of bioleaching must be carefully planned, since the process can lead to a biosafety failure.
- Unlike other methods, once started, bioleaching can’t be quickly stopped, because leaching would still continue with rain water and natural bacteria.

**Copper vs. gold bioleaching:**

At the current time, it is more economical to smelt copper ore rather than to use bioleaching, since the concentration of copper in its ore is in general quite high. The profit obtained from the speed and yield of smelting justifies its cost. At the largest copper mine of the world, Escondida in Chile the process seems to be favorable.

However, the concentration of gold in its ores is generally very low. In this case, the lower cost of bacterial leaching outweighs the time it takes to extract the metal. Economically it is also very expensive and many companies once started can’t keep up with the demand and end up in debt.