Bioleaching technology in minerals processing

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Bioleaching is a process that employs micro-organisms to dissolve (leach) sulphide minerals. It finds application in the extraction of metals from their ores.

Although bioleaching was used unknowingly by the ancients to extract metals (principally copper) from ores, the development of modern commercial bioleaching processes is relatively new. It began in the late 1940s, with the discovery of the role of bacteria in the formation of acid mine drainage. From there, research and development activities in the field flourished, and the earliest commercial applications of the process involved *in situ* leaching of uranium in Canada and dump leaching of copper in the United States.

Development of the technology advanced rapidly during the 1980s, leading to the commissioning of the first commercial tank bioleaching plant at the Fairview Gold Mine near Barberton in South Africa. This plant, which has been expanded several times in the intervening two decades, is still in operation today, processing refractory gold concentrates from several mines in the area. Tank bioleaching of refractory gold concentrates has since found widespread application in South America, Asia, Africa and Australia.

An industrial bioleaching plant for the treatment of a refractory gold concentrate. At the Beaconsfield Gold Mine in Tasmania, Australia, about 70 t per day of a refractory pyrite-arsenopyrite concentrate per day are processed through this plant, which comprises six mechanically-agitated reactors each with a volume of 380 m^3.

The implementation of copper heap bioleaching has been an evolutionary process, with existing acid heap leach operations converted into heap bioleaching processes as the orebodies changed from oxides to secondary sulphides. In recent times, research in this area has accelerated, and several significant programmes aimed at the heap bioleaching of primary copper sulphides are at an advanced stage of development.

The Girilambone heap bioleaching operation in Australia, which operated between 1993 and 2003, produced about 14,000 t of copper per annum from a chalcocite/chalcopyrite ore. The open pit mine is seen in the background, with the heap leach pads in the foreground, and the hydrometallurgical copper recovery plant situated to the right of the heaps.

The chemistry of the bioleaching process is relatively straightforward. The bioleach micro-organisms catalyse the oxidation of ferrous iron and sulphur, to produce ferric iron and sulphuric acid, according to:

$$Fe^{2+} + \tfrac{1}{4}O_2 + H^+ \rightarrow Fe^{3+} + \tfrac{1}{2}H_2O$$

$$S + \tfrac{3}{2}O_2 + H_2O \rightarrow H_2SO_4$$

The ferric iron reacts with mineral sulphides to produce ferrous iron and sulphur, according to the following general scheme of reaction:

$$MS + 2Fe^{3+} \rightarrow M^{2+} + 2Fe^{2+} + S$$

The micro-organisms applied in bioleaching comprise consortia that are characterised principally by their useful range of operating temperature. The *mesophiles*, which are bacteria that operate well between 30 and

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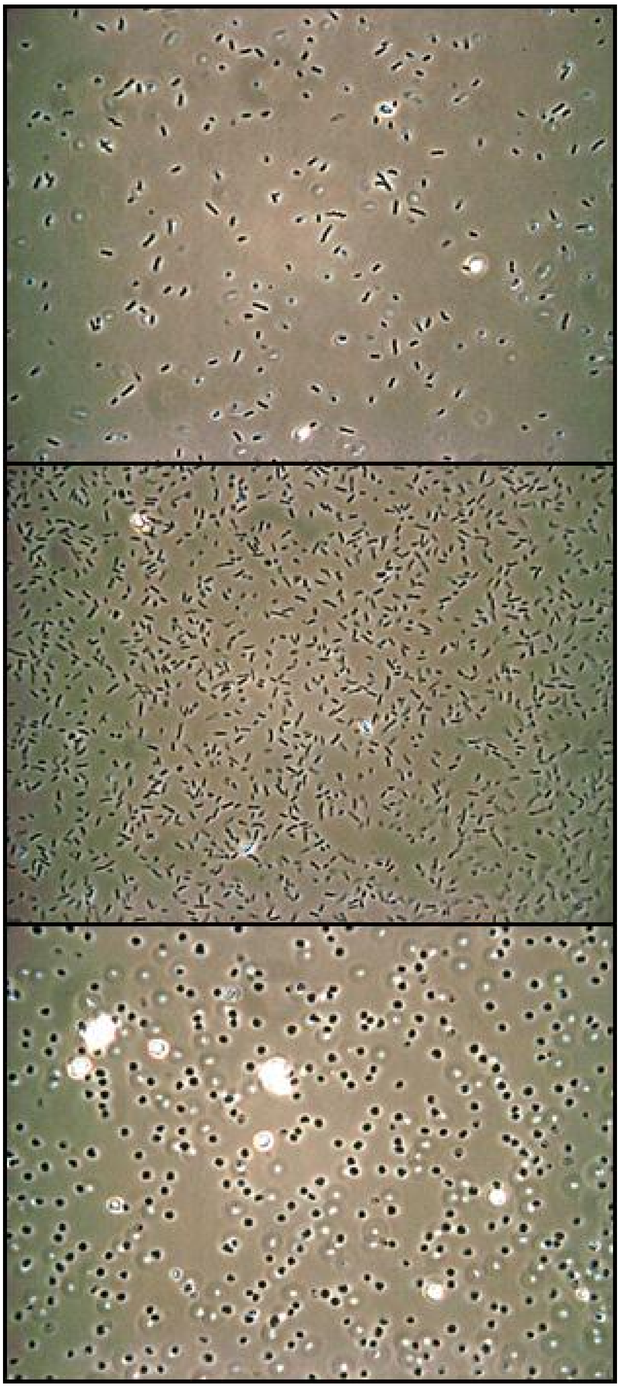
42 °C, include *Acidithiobacillus ferrooxidans*, *Acidithiobacillus caldus* and *Leptospirillum ferrooxidans*. Other *Acidithiobacillus* species also thrive in this temperature range. The *moderate thermophiles* are mostly bacteria that exist within a relatively narrow temperature range of 45 to 55 °C, and include several of the *Sulfobacillus*, *Acidimicrobium* and *Ferroplasma* species, as well as *Leptospirillum ferriphilum* and *Acidithiobacillus caldus*. The *extreme thermophiles*, which are dominated by archaea (as opposed to bacteria), and thrive at elevated temperatures of between 60 and 90 °C, include various species of *Sulfolobus*, *Acidianus* and *Metallosphaera*.

The extreme thermophiles used in bioleaching processes have been isolated from a variety of locations, such as the thermal springs that are found in the Yellowstone National Park in the United States (above), and the burning coal dumps located near Witbank in South Africa (below).

Most of these organisms are characterised as being *autotrophic*, which means they grow by fixing CO_2 from the atmosphere, and *acidophilic*, which means they can tolerate a low pH environment. Several of these organisms have the ability to oxidise both iron and sulphur, whereas some can only oxidise iron or sulphur. They also have the ability to tolerate remarkably high concentrations of a wide range of metal ions.



Bioleach bacteria are characterised by their optimal operating temperatures. *Mesophiles* (top) operate best between 30 and 42 °C, and are rod-shaped bacteria with dimensions of about 0.5 × 2.0 µm. *Moderate thermophiles* (middle) have a similar morphology to the mesophiles, and operate at 45 to 55 °C. The *extreme thermophiles* (bottom), which are often spherical and have a diameter of 1 to 2 µm, operate at elevated temperatures of between 60 and 90 °C.

Bioleaching applications are many and varied. In the case of refractory gold bioleaching, the process is used to leach sulphide minerals such as pyrite (FeS_2) and arsenopyrite (FeAsS), which encapsulate microscopic and submicroscopic gold particles. By dissolving these sulphide minerals, the gold particles are exposed and can be recovered by further treatment. Industrial-scale bioleaching of refractory gold concentrates has been practised in South Africa, Brazil, Australia, Ghana, Peru, China and Kazakhstan. A similar process for the treatment of cobaltiferous pyrite has been applied in Uganda. Currently, two large refractory gold projects are being implemented in Uzbekistan.

Bioleaching is also applied to a wide variety of base-metal sulphides, mainly in large-scale heap bioleaching operations located in Chile, Peru and Australia. In these operations, copper is extracted from ores containing minerals secondary copper sulphides such as covellite (CuS), chalcocite (Cu_2S) and bornite (Cu_5FeS_4), and the primary copper sulphide, chalcopyrite ($CuFeS_2$). Other base-metal sulphides that can be bioleached include pentlandite ($(Ni,Fe)_9S_8$), millerite (NiS), sphalerite (ZnS), and galena (PbS).

One of the attractions of bioleaching is that it presents an environmentally-friendly alternative to conventional metallurgical processing routes. Bioleaching has virtually replaced roasting of arsenic-rich refractory gold concentrates. In the roasting process, arsenic is converted to arsenic trioxide, a highly toxic form of arsenic that requires disposal in specialised waste facilities. In the bioleaching process, arsenic is co-precipitated with iron in a stable form, and can be safely disposed of at the treatment plant site.

Similarly, bioleaching is often useful for the treatment of 'complex' or 'dirty' base-metal concentrates, which are costly to treat in smelters. Complex polymetallic concentrates containing more than one metal value often cannot be separated efficiently during flotation. Bioleaching can treat the bulk concentrate, with the metals being recovered separately thereafter. Dirty base-metal concentrates are those which contain small quantities of smelter penalty elements such as arsenic or bismuth. Several large-scale bioleach demonstration plants treating these types of concentrates have been operated successfully in recent years, although none of these processes has yet proceeded to commercial implementation.

A large-scale, integrated demonstration plant for the bioleaching of a complex polymetallic sulphide concentrate, located in Monterrey, Mexico. The plant, which was designed, commissioned and operated by Mintek, BacTech and Industrias Peñoles SA de CV in 2001, successfully treated a concentrate contained chalcopyrite, sphalerite, galena and silver.

Ongoing developments, such as heap bioleaching of low-grade primary copper ores, will ensure that this modern and cost-effective technology gains wider application in the minerals industry in the years ahead.

Further reading

Many excellent reviews on bioleaching are available; what follows is a selection of a few recent ones.

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