Bugs banquet

The mining industry is investing heavily in bioleaching to extract metals but will it be enough to satisfy demand? **Richard Corfield** takes a closer look at the emerging technology

Far in the southwestern corner of Spain, in the heart of the Sierra Morena mountains of Andalucia, is a land where the streams run red as blood. These are the mines of Rio Tinto, rumoured to be the fabled mines that inspired H. Rider Haggard to write *King Solomon's Mines*. They are very ancient. Pliny the Elder, writing in the first century AD, describes how gold was extracted from the waters of the Rio Tinto and its tributaries. But gold is not the only mineral treasure in the Rio Tinto; copper too is important and its distinctive hues also tint the waters of the region.

The secret of Rio Tinto lies not in the quantity of its natural mineral reserves but rather in the fact that the minerals are economic to extract because of a strange suite of chemical processes that release the ores into solution. And the agents of this release are the humblest of all Earth's creatures – bacteria.

The process at the heart of the Rio Tinto's mineral fecundity is bioleaching, the extraction of metals from ores using microbes to convert insoluble minerals into soluble metals.

In recent years bioleaching and its complementary process, biooxidation, have come to prominence in a notoriously conservative mining industry as concerns about environmental contamination, the cost of conventional mineral extraction and the rising price of base metals, such as copper and zinc, have spiralled. But the emergence of bioleaching as an important new technology has not only been driven by the expanding industries of China and India.

Natural evolution

Murray Bath, managing director of Colorado-based Geobiotics makes the point clearly. 'The mining industry has always been very conservative and the project cycle time in the mining industry is ten to 15 years.' Thus the emergence of bioleaching is as much a natural evolution of changes in the way we view the environment, as it is a response to a business opportunity.

And yet, recent announcements from mining giants such as BHP Billiton suggest that they are looking at a future where microbial biotechnology features heavily. BHP Billiton and state-owned Chilean mining company Codelco have jointly invested almost $60m in a pilot bioleaching project at its Escondida, Chile, facility, over the past half a decade. The plant leaches low grade (0.3-0.7% copper) sulfide ores to produce 84 000t/year of copper. Compare this with Chile's total copper production in the late 1990s – a paltry 5m tonnes – and the emerging importance of bioleaching is easy to see.

In addition,

In brief

- **About 20% of copper produced worldwide is generated using bioleaching technology**
- **Developing countries are the focus for most bioleaching developments**
- **The biggest goal remains the bioleaching of copper from its richest ore, chalcopyrite**
- **Bioleaching is unlikely to replace completely conventional smelting**

'Recent announcements from mining giants suggest that they are looking at a future where microbial biotechnology features heavily'

Free lunch

Rio Tinto: the river runs as red as blood

'For developing countries with large ore deposits, bioleaching is relatively simple and, with a couple of exceptions, only requires low start-up costs'

Consolidated Minerals of Australia has recently bought Titan Resources, a major player in the development of commercial heap leaching.

Bioleaching and biooxidation are often used as interchangeable terms in the mining industry but in fact there is a subtle difference in emphasis. Bioleaching is the extraction of soluble metals from ores through the chemical action of micro-organisms and the subsequent collection of the leachate for processing and refining. Biooxidation is the dissolution and subsequent removal of ore components that are *not* required. This then leaves the residue amenable to conventional extraction techniques.

Bioleaching is a suitable process for copper, zinc, nickel and uranium extraction, while biooxidation is typically used in the gold mining industry. About 20% of copper produced worldwide is generated today using bioleaching technology. Chile – the so-called Saudi Arabia of Copper – produces over 10% of its copper via the process. Both these figures are certain to rise as the world price of copper continues to increase and environmental concerns intensify.

Developing countries

Developing countries are the focus for most bioleaching development for two reasons: they have large ore deposits and bioleaching is relatively simple and, with a couple of exceptions, only requires low start-up costs.

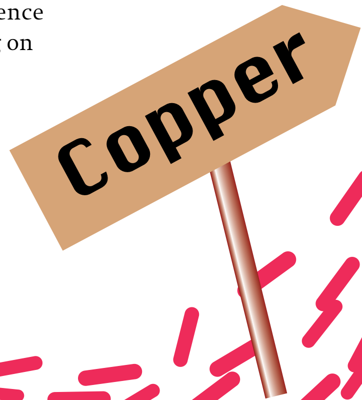
The simplest types of bioleaching process are so-called dump and heap leaching, while more complex versions are reactor and agitated reactor leaching. The latter two require significantly larger start-up costs because they focus on the need to keep the microbial miners in optimal conditions and therefore maximise ore throughput. The biggest difference between heap and dump leaching on the one hand and reactor leaching on the other is time. Reactor leaching is a five to six day process while heaps and dumps take between six to 12 months. This makes reactor leaching more cost-effective in the long term.

Dump leaching uses mesophilic or ambient temperature microorganisms: predominantly bacteria. Heap leaching of ore may involve mesophilic or thermophilic – high temperature – microorganisms: archaea, depending on the mineral species present and the physical chemistry of the leach environment. Leaching of chalcopyrite and concentrate leaching requires thermophilic microorganisms.

Choice of process

The choice of process depends on the grade of copper and ore-particle size. As a rule of thumb the cheapest processes of dump and heap leaching are appropriate with low grade ores (0-2%) while more costly reactor and agitated reactor leaching becomes worthwhile with ores of 2-5% purity and grain sizes of less than 10mm. Before the recent dramatic rise in price, reactor leaching tended to be used only on ores with of about 0.8% purity if extracted from open pit mines to 1.3% from underground mines. The recent rise in copper demand has meant that more dilute ores are now considered economic for reactor leaching. Indeed, it is the recent rise in copper and other ore prices that is responsible for the increased interest in the relatively costly reactor technologies.

The biggest goal remains the bioleaching extraction of copper from its richest ore, chalcopyrite, which is often hindered because a passivating coating builds up on the ore surface which eventually halts further oxidation by mesophilic bacteria. Three bioleaching processes though now show promise in solving this. Geobiotics' *Geocoat*



process; BHP Billiton's *BioCop* process and the *BacTech/Mintek* Process – all of which use thermophilic bacteria, which do not suffer from this problem. Experiments have also shown that adding silver to the leaching solution can dramatically improve yields.

In transition

BacTech Mining Corporation is a good example of how bioleaching is developing in the mining industry. It is a company that is in transition from a technology think tank to technology licensor to finally, technology user. It has licensed three gold plants over the past decade and is now looking to participate in a broader range of projects that need bioleaching in order to be viable. BacTech's proprietary technology can leach not only refractory gold but also copper and zinc sulphides.

In general, the capital cost of a bioleaching operation is about half that of a conventional smelting/refining operation. Quoted operating costs are between $0.07 and $0.09/kg of cathode copper, which is competitive with the unit costs of conventional smelting/refining. With further refinements using thermophilic archaea to increase reaction rates and shorten leaching times, and especially if plans to genetically modify them to improve yields bear fruit, costs should further decrease.

A research consortium, BioSigma, comprising Nippon Mining and Metals and the Chilean national mining company Codelco, was formed in Chile in 2002 to conduct and promote research on bioleaching. BioSigma's focus is on developing products ranging from simple technologies optimising current heap and dump bioleaching processes through better operational control, to more complex technologies, such as the identification, characterisation and subsequent cloning of proteins and bacteria used in biomining. Special emphasis is on environmentally sustainable technologies for low grade ores and for metals recycling.

Bacterial miners

Biomining organisms have several physiological features in common. They are all chemolithoautotrophic, which means that they are able to use ferrous iron or reduced inorganic sulphur sources, or both, as electron donors. The byproduct of these reactions is sulphuric acid, which means that all these organisms are all extremely acid tolerant and grow best in a pH range 1.5-2. Most biomining bacteria thrive in highly aerated aqueous solutions and require both oxygen and carbon dioxide.

Along with *Acidithiobacillus* species, other bacteria such as *Leptospirillum* are also important. An important feature of biomining is to tailor the bacterial cocktail to the type of ore that needs to be separated and to provide the biomining microbes with the necessary environment in which they are most efficient. Thus, a combination of *Leptospirillium* and *A. ferrooxidans* can degrade both pyrite and chalcopyrite ores, something that neither species can do alone.

Most biomining bacteria are mesophilic: they flourish in a temperature range of 20–50°C. Hyperthermophile biominers tend to be archaea, which can live at much higher temperatures up to 90°. They offer the advantage of vastly enhanced reaction speeds, with clear cost benefits to companies increasingly seeking to improve yields from low grade ores.

Efforts are under way to culture these and other more exotic archaea and sequence their genome to improve yields. To date, probably the strangest extremophile discovered is *Metallosphaera prunae*, which can live at temperatures above 80°C, and which was found in the slagheap of a uranium mine in Thüringen, Germany. About 30 naturally occurring strains of microorganisms have so far been screened and evaluated as being useful in bioleaching.

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Drawbacks

Finally, while bioleaching will undoubtedly contribute to progressively more ore extraction worldwide because of its ability to process run-of-the-mine low grade sulphide ores and its environmental friendliness, it is unlikely to replace completely conventional smelting. First, bioleaching does not recover the precious metals in the ore and these are often an important component in the profitability of an operation. Second, the requirement for large quantities of sulphuric acid makes it expensive to deliver in sufficient quantities to often remote locations. Third, some ore bodies are not sufficiently high in acid-consuming minerals to neutralise it all. In these cases any residual acid has to be neutralised externally, an expensive process.

Regardless of the drawbacks of bioleaching, the future for the various processes looks rosy. But the big question for the longer term is whether, with the gigantic economic growth of China and India, even the ancient technology of King Solomon will be sufficient to meet our demands.

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