Bio/hydro – different metallurgical options

BioHeap bacterial farm at Huogeqi copper mine, China

Bio and hydro processes, examined by **John Chadwick**, offer substantial improvements in metal production through increased recovery, reduced costs and reduced energy demands

Biometallurgy has the potential for a major technology breakthrough, and as a result great interest is evident from major international companies. BioMinE is a leader in this field, an integrated European project looking at innovative biotechnology based processes for recovery and/or removal of metals from primary materials (ores and concentrates), and secondary materials (mining wastes, metallurgical slags, metal bearing scrap, power plant ashes, etc.). It aims at "the production of tomorrow" and involves biotechnological research to provide "radical changes for cleaner, safer and more eco-efficient production". The objective of BioMinE is to develop sustainable solutions covering the whole life cycle of products and equipment. It is a four-year project to be completed in October 2008. Progress will be examined in ***IM*** September.

One BioMinE participant, Mintek, a leader in the field, describes bioleaching as "a robust and cost-effective technology." Mintek offers a full range of services to evaluate and implement bacterial leaching processes.

Leaching base metals

Many of the process issues associated with introducing bioleaching have already been resolved in the gold sector, and the knowledge gained in treating refractory gold concentrates is readily transferable to future bioleaching processes for the copper and other industries.

BioHeap, previously Pacific Ore Technology is developing and commercializing the innovative BioHeap™ process. Large scale trials have demonstrated high recoveries of nickel, copper and cobalt can be achieved using BioHeap's proprietary bacteria and patented processes, thereby indicating that the use of BioHeap technology can lead to a step change in capital and operating costs associated with the extraction of nickel and copper. The process is also applicable to other sulphide ores such as zinc, polymetallic and refractory gold ores.

Among the advantages of BioHeap are:

- Low capital and operating costs
- Low environmental impact
- Simple to operate
- Well suited to remote locations
- Produces high value products.

China is likely to become a leader in BioHeap use. The Western Mining Stockholding Co (WMSC) became a foreign-owned company limited by shares in 2004. Lead, zinc and copper are its focus.

WMSC owns mining rights to several mines throughout China, including China's second largest lead and zinc mine at Xitieshan Mountain, the Shaishatang copper mine in the Qinghai Province, and the Huogeqi copper mine, in Inner Mongolia. BioHeap has entered into a Joint Venture arrangement to determine the feasibility of treating low grade copper ore from Huogeqi, using BioHeap technology, and the Inner Mongolia Western BioHeap Co has been registered for this purpose. The ownership of the joint venture company is 50:50. After successful laboratory testing giving copper recoveries of up to 88%.

Construction commenced in September 2006 with the first phase completed in early December 2006. The works completed consist of earthworks, civil, structural and building works and piping, mechanical and electrical installations. Off site planning, procurement and manufacturing continued during the northern winter with construction re-commencing in March 2007. This should see the operation commence in early June 2007.

In February Australian Resources signed an Ore Leaching Agreement with BioHeap. This provides the required licence to access the BioHeap technology for the Sherlock Bay nickel project. The technology is particularly applicable in the harsh climate of north Western Australia, where Sherlock Bay is located. BioHeap commissioned a bacterial production facility to provide bacteria for Sherlock Bay in February 2005. The process involves the introduction of the hybrid BioHeap saline tolerant bacteria into the heaped ore to help oxidize the sulphides, which in turn will allow the irrigation system to leach metals from the heaps and into the process ponds. Several test programmes were commenced in 2005 to allow the development of process flow sheets, engineering design, cost estimates and financial models.

BioHeap's Technical Director, Colin Hunter, says that by this time next year "we will also have pilot operations running in Chile. Besides Chile and China we are also working on projects in Canada, Europe, Indonesia and of course Australia.

"We've been working on this technology for over ten years but right now attitudes are changing toward bacterial leaching for base metals, especially primary sulphides, and it seems that the industry is ready to embrace it. In another ten years everybody will be doing it. I suspect that aside from the current resources boom, a big driver behind this change is the current world focus on global warming and carbon footprints. That in turn is a part of the reason we chose to develop a heap leach while others have focused on concentrate leaching. By cutting out the energy intensive milling-flotation-ultrafine grinding step, our carbon footprint shrinks dramatically. Its also a little known fact that the bacteria we use actually consume carbon dioxide from the atmosphere."

Biogold Bioleaching Facility, Laizhou, Shandong Province, China. View from the top of a Bactech bioleach plant. Note circular cement pads for future expansion (it is about to go to 150,000 oz/y).

Leaching chalcopyrite

Paul Miller, Vice President Engineering of BacTech Mining believes "the next few years hold exciting prospects for the use of bioleaching in the copper industry for the treatment of chalcopyrite ores and concentrates. For many end-users, it may provide an economic and environmentally sound alternative to smelting and give their operations a greater flexibility and independence with on-site metal production."

"Bioleaching can be thought of as the acceleration of a natural environmental process using naturally occurring organisms that leach sulphide minerals. Programmes of process development are well advanced by BacTech for the future treatment of copper concentrates by bioleaching in agitated reactors.

"Over the last few years, advances in understanding the requirements for successful bioleaching of chalcopyrite concentrates have led to experimental campaigns using continuous laboratory scale bioleach plant, to show that high recoveries in an economic time frame are achievable. These findings for concentrate treatment were confirmed on a larger demonstration plant, suggesting that bioleach facilities for chalcopyrite concentrate may be a commercial reality within the not too distant future.

From an environmental perspective, many people also consider that bioleaching will become a preferred method of beneficiation of sulphide deposits as the natural process produces stable benign products for disposal and there are no noxious gases.

BacTech established a continuous small-scale, bioleach pilot plant to investigate the bioleaching of chalcopyrite concentrates in 1998 at Mt. Lyell in Tasmania. The plant was integrated with downstream SX-EW for copper recovery.

In 2001, the technology progressed to demonstration scale in BacTech and Mintek's joint technology partnership in conjunction with Peñoles in Mexico. The plant operated for a year with a capacity of 200 t/y copper cathode production using commercial equipment, and "demonstrated well the technical feasibility of a totally integrated process with high levels of copper recovery from a dirty concentrate blend," Miller reports. On completion of the demonstration trial, a feasibility study was conducted for a commercial bioleach plant currently envisaged as having an initial capacity of 25,000 t of copper with a contingency to increase the capacity in the future.

In this type of process to treat chalcopyrite concentrates, the material is ground finely and fed continuously into a series of agitated aerated temperature controlled reactors containing the bacteria. The residence time is four to six days, similar to bacterial processes in gold extraction. After separating the oxidized residue, copper is extracted from the liquor by conventional SX-EW technology. Iron (and if necessary arsenic) is rejected from the liquor by neutralization with limestone to give a stable solid of ferric or ferric arsenate for disposal, which meets the strictest environmental requirements.

Some more potential benefits for treating chalcopyrite concentrates are:

- Bioleaching provides independence for on-site metal production and is particularly attractive when the cost of concentrate transport to the smelter is high
- Bioleaching can be installed as an add-on to an existing SX-EW operation originally intended and used for earlier oxide ore treatment. This is highly applicable for projects in which oxide resources are exhausted and continuation of the mine is only achievable by the production and sale of sulphide concentrates to a smelter for which the existing SX-EW circuit is now redundant. The installation of a bioleach circuit can allow a more profitable overall operation by using much of the existing capital equipment such as SX/EW. Also the financial pipeline can be reduced by direct production of LME grade copper on-site from the sulphide resource
- Bioleaching can readily treat concentrates containing arsenic, as this is stabilized as a ferric arsenate precipitate, producing the arsenic as a product in a safe disposable form, which is environmentally benign meeting US EPA or equivalent requirements. This is clearly appropriate for the treatment of copper enargite concentrates or those, which are high in arsenopyrite mineralization

- High extraction of precious metals from residues is readily achieved
- Bioleaching can treat a lower grade of concentrate if required. This may often allow an increased recovery of a few percent in the production of the copper concentrate
- Further to the ability to treat dirty copper concentrates, some of the base metal elements penalized in copper smelting are solubilized in the bioleach process and can be recovered for sale to create additional revenue. Transport of copper metal from site is also lower in cost than transport of concentrate to a smelter
- Bioleaching can be used on both small or large projects for concentrate treatment
- Bioleaching is a relatively simple technology in terms of its equipment requirements and conditions of operation at ambient pressure and non-excessive temperatures close to ambient
- Bioleaching can accept a variety of feed types over a period of time and is a more forgiving process due to the longer residence time compared to other treatment methods.

Key project drivers in copper bioleaching technology include the requirement for acceptable or modest on-site power costs for both the leaching operation and for downstream SX-EW. A good source of low cost limestone is needed to neutralize and remove iron from the leaching solution. Also, a reasonable project life is required to justify the capital expenditure for the bioleach and copper recovery operation.

Hydrometallurgy developments

European Nickel explains that sulphuric acid heap leaching is common in the copper industry, but although nickel is worth considerably more than copper, the process has not yet been used on nickel ores. However, the geological formation that led to the company's Çaldag nickel laterite deposit in Western Turkey lends itself to heap leaching due to the low clay content of the ore. The nickel is present in the goethitic phase and is soluble in dilute sulphuric acid. The lack of clays in the laterite profile assists the percolation of the solutions through the heaps throughout the heap leach cycle, which in Çaldag's case is over a year. European Nickel has demonstrated the percolation and extraction of nickel on a large scale on three full height heaps, irrigated with dilute sulphuric acid. The nickel in the Çaldag deposit is predominantly in the goethitic mineral and explains the longer leach cycles required to extract the metal compared to other laterites that have been tested. The leach rates have been consistent with three phases of leaching being identified, a neutralizing leach, primary leach and secondary leach.

This leaching mechanism varies between the different laterites with the length of leaching under one particular mode varying depending on the mineralogical characteristics of the laterite under test. The mineral extraction of the first trial heap has reached 78% nickel and 82% cobalt after some 15 months of irrigation, 72% for both metals was used in the bankable feasibility study.

At Çaldag in Turkey, European Nickel has demonstrated the percolation and extraction of nickel on a large scale on three full height heaps, irrigated with dilute sulphuric acid.

European Nickel's current programme envisages nickel laterite heap leaching starting during the fourth quarter of 2007, nickel concentrate production early in 2008 and full production in early 2009. At full capacity the mine will produce some 20,400 t of nickel and 1,200 t of cobalt a year in a mixed hydroxide product. The total development cost of the project is $300 million.

Galvanox into action

Bateman Engineering has the exclusive rights, from the University of British Columbia (UBC), to market, in about 20 countries, its Galvanox technology, which offers several potential advantages over existing copper-leach processes. With this novel atmospheric leaching process, copper recoveries of 98% or greater can be achieved at 80°C under atmospheric conditions, thus obviating the need for high-cost pressure-leach autoclaves. With a residence time of as little as four hours, the processing capacity of the leaching circuit is also increased. The process is selective for chalcopyrite over pyrite, making it applicable to low grade or bulk concentrates, and thus offering a distinct recovery advantage over smelting. Furthermore, it generates near-quantitative levels of elemental sulphur in less than 24 hours, and is fully compatible with conventional SX-EW of pure copper.

Galvanox uses ferric sulphate to leach copper from concentrates containing a mixture of copper sulphides, but particularly those containing chalcopyrite ($CuFeS_2$). The process takes advantage of the galvanic couple between pyrite and chalcopyrite to ensure rapid oxidation of chalcopyrite under mild conditions in the acidic iron (ferric sulphate) solution, without the need for microbes, ultrafine grinding, or chemical additives such as chloride, nitrate or surfactants.

Normally the surface of the chalcopyrite becomes passive in ferric-sulphate solutions and this has limited its use in copper leaching circuits. The inventors of the technology, Dr David Dixon and Alain Tshilombo, however, found that this passivation may be overcome by the addition of a pyrite catalyst to the leach liquor so that near complete dissolution of the copper can be achieved many times faster than has been possible up to now.

The process offers several other potential advantages over existing processes including the fact that the leach liquor is a pure sulphate medium with a relatively low propensity to corrode the process vessels, equipment and piping. Elemental sulphur rather than sulphate is generated, facilitating waste treatment, and the process also operates below the melting point of sulphur and therefore requires no surfactants

As part of the programme to commercialize the technology, for which patents have been filed in several countries, Bateman Engineering commissioned pilot-plant studies on batches of chalcopyrite concentrate sourced from several of the existing producers of concentrate. These trials successfully demonstrated the technology on a continuous basis and the results are comparable with the equivalent batch results. The copper recoveries achieved will be competitive with smelting.

Under the terms of the marketing agreement, Bateman Engineering will prepare all the technology-supply packages for proposed projects and in each case will assist UBC and the end users to negotiate licenses for project-implementation services at end-user sites. ***IM***