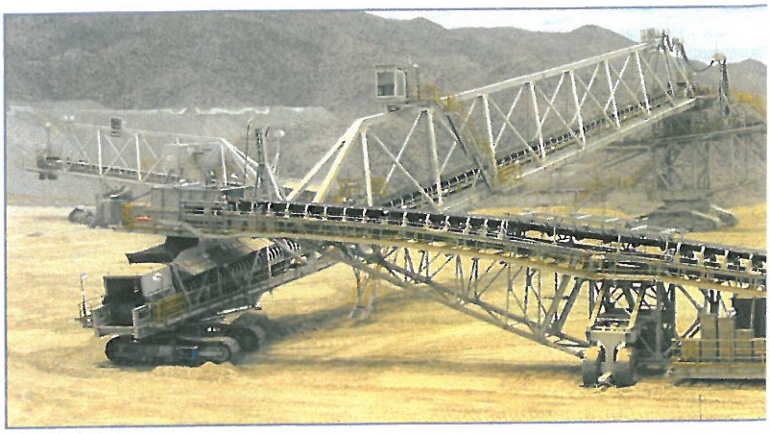
Top of the heap

Anna Hayes investigates developments in leaching equipment and process technology



Tenova TAKRAF spreaders and grasshoppers in operation at Toquepala, Peru

The use of a leaching solution to extract valuable minerals from ore is not new, and has been taking place, by accident and design, for many hundreds of years. However, advances in process technology and equipment are continuously improving efficiency, mineral recovery and quality, in keeping with rising costs and increasing complexity of ores.

Leaching of gold, silver and base metals such as copper, nickel, zinc and cobalt can be performed by various means, including tank leaching and heap leaching, and both of these can be performed either chemically or biologically in which case it is referred to as bioleaching.

"Advances in process technology and equipment are making this form of extraction more commercially viable"

- **Tank leaching:** involves the suspension of finely milled ore in water using large mixers, into which the agents necessary for the leaching reactions are added. The 'agents' may be just a simple dilute acid solution. This is the case when the ore is well-weathered and the valuable minerals occur in oxide form, because most oxide minerals react directly with dilute acid to yield the desired metals in solution. Tank leaching tends to be used for higher grade ores, where the cost of milling the rock to a fine powder can be afforded.

- **Heap leaching:** in the heap-leaching process, the ore is crushed to an aggregate then stacked into piles on an imperious pad of plastic or clay. These heaps are typically 3 to 10m high and can extend to 500m wide by more than 1km long. The heaps are irrigated with the leaching solution which is allowed to percolate through the ore and is drained from the bottom. On its way down, the reagents in the percolating solution react with the ore aggregate. The type of leaching medium used depends on the nature of the minerals. It is usually a dilute acid but, in some instances, for instance in the recovery of uranium, a dilute alkali solution can also be used as the leaching solution. Heap leaching is more viable for lower-grade ores.

- **Bioleaching:** Bioleaching is the extraction of metals from sulfidic ores and concentrates using microbiological technology. It is applied to enhance the extraction of gold and silver, and to the extraction of base metals. Heap bioleaching is used to extract copper or other base metals from sulphide ores on engineered pads. The solutions are usually acidic containing a mixture of iron in solution with the bacterial cultures. Air is blown into the mix to aerate the bacteria. The bacteria 'capture' the oxygen and iron and react them with one another to oxidise the iron from the ferrous-iron form to the ferric-iron form. The ferrous iron is an ion with 2+ charge, and the ferric iron is an ion with a 3+ charge. The 'charged-up' ferric-iron is sufficiently energetic to convert the sulphide minerals to sulphate minerals which do react with dilute acid, thus yielding the valuable minerals into solution.

METHOD CHOICE

Choosing the most suitable leaching method is key to ensuring the economics of a metals recovery project. The correct method is determined by considering the associated energy requirement, the extent of extraction achieved, the rate of extraction (the kinetics), the capital cost of the chosen reactor, and the running cost of the chosen leaching agent.

As previously discussed, heap leaching is more likely to be chosen over tank leaching where the ore deposit is of low grade. "Since existing mines are getting deeper, and unexploited ore deposits tend to be of lower grades, heap leaching is becoming an increasingly popular recovery method," explains Petrus van Staden, manager of the Biotechnology Division of Mintek, South Africa's national mineral research organisation.

"However, rising metal prices may in turn reduce the cut-off grade below which heap leaching becomes economically more favourable than tank leaching," he adds.

A major area of growth is in bioleaching/bio-oxidation, with the main players in this arena all reporting increased interest, as metal prices rise and ore quality falls.

Jan van Niekerk of Gold Fields BIOX operations reports increased interest in the BIOX gold bio-oxidation process, due to rising gold prices. He declared several project proposals under consideration for many years now becoming active again, including some pre-2008 projects. The company is seeing increased interest from Latin America, west Africa and CIS countries.

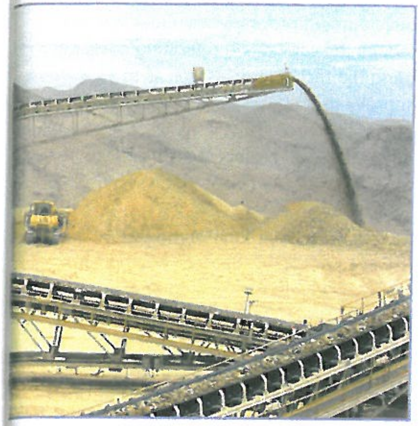
REBGold reports interest in bioleaching projects as coming from Australia, Asia and Africa, with South and North America being the last continents to consider the technology. Dr Paul Miller, REBgold vice president of technology and engineering says that in a typical plant, the capital cost of introducing bioleaching is half of that for more traditional methods and that operating costs are also much lower.

Mintek

Mintek is South Africa's national mineral research organisation, and offers expertise in leaching of all types. The company has developed both tank bioleaching and heap bioleaching technology.

According to Mr van Staden, the key to successful heap leaching is in good heap design and suitable treatment of the ore prior to stacking in the heaps. He suggests that a common problem in the heap is a failure to achieve effective contact between the percolating solution and the stacked ore aggregate, either because the solution was not evenly distributed, leaving part of the ore dry; or the permeability of the stacked ore was insufficient to allow percolation of solution and/or air at an economically feasible rate.

"It goes without saying that once the aggregate is stacked on a heap, there is no way of undoing the effects of poor pre-treatment conditions upstream, since stacked aggregate cannot be pumped around to undergo another cycle of pre-treatment as may still be possible in



tank leaching where one deals with a suspension of finely milled ore," he says.

"And if a certain combination of stacking height and irrigation rate that was set during the design stage is found wholly unsuitable after the plant has been constructed, it is no simple matter to change the layouts of pads, irrigation piping and other plant to suit a different combination."

Environmental and logistical considerations are also important. These of course differ from one location to another, since different challenges are posed by an arid location opposed to a rainy location. Furthermore, as more inventiveness is entering the design of heap leaching, the management of the associated intellectual property also warrants more attention, be it the protection of new inventions or the licensing of proprietary features.

Heap-leach design engineers have not been idle and the fundamental science governing the mechanics, hydrology and heat and mass transfer in heaps are coming to be understood, and are being incorporated into the procedures for approaching metallurgical test work and design principles for heap-leach plants.

Furthermore, much research has been conducted in the pre-treatment steps of the aggregate before stacking, so that novel means of crushing and mechanised ore sorting offer more possibilities for the optimising the heap-leaching process.

"There have been advances in ore sorting steps and ore upgrading, for instance in sorting large chunks of particles and in using less material of higher grade," says Mr van Staden.

Another important research area in heap leaching is that of high-temperature heap leaching. Mintek has conducted much research in this area and successfully demonstrated this technology in a pilot plant for leaching copper ores bearing chalcopyrite in Iran.

The company developed the SmartColumn, a novel testing apparatus for confirming that heaps being exposed to the outside environment will heat up as required and to develop a set of rules according to which the heaps need to be operated.

Mintek also developed HeapStar software to guide the daily operation of a multitude of heaps, according to the rules established using the SmartColumn. In-heap instrumentation was also developed for tracking the development of conditions at various depths below surface.

A summary of the BIOX operations

Mine	Concentrate treatment capacity (t/d)	Reactor size (m³)	Date of commissioning
Fairview, South Africa	62	340[a]	1986
Saõ Bento, Brazil[b]	150	550	1990
Harbour Lights, Australia[c]	40	160	1991
Wiluna, Australia	158	480	1993
Ashanti, Ghana	960	900	1994
Coricancha, Peru[d]	60	262	1998
Fosterville, Australia	211	900	2005
Suzdal, Kazakhstan	520	650	2005
Bogoso, Ghana	820	1,500	2007
Jinfeng, China	790	1,000	2007
Kokpatas, Uzbekistan	1,069	900	2008
Agnese, South Africa[e]	20	75	2010

a The volume of the two primary reactors at Fairview.
b,d Mines are under care and maintenance.
c Mining operations were completed in 1994 and the plant decommissioned.
e Demonstration plant.

ALTA Metallurgical Services

Alan Taylor of ALTA Metallurgical Services explains that both heap and tank bioleaching applications are increasing. He says tank bioleaching will still be applied to suitable refractory gold concentrates, but may eventually find limited application for suitable concentrates of copper and nickel sulphides. He also highlights possibilities for tank bioleaching of sulphidic uranium concentrates, particularly in South Africa, where uranium is often associated with pyrite.

Mr Taylor proposes that heap bioleaching is likely to develop further. He suggests that heap bioleaching of secondary copper sulphides will continue to be widely used but that this technique may also be applied to primary copper ores.

"Heap bioleaching of primary copper ores has a potentially large target area of application for low grade ores not suitable for processing by other means," he says.

"There is a big incentive, which is why a number of groups are active in development. Progress is being gradually made and there is likely to be an increasing number of applications."

Limited applications for heap bioleaching will also be available for refractory gold ores, nickel sulphides in low grade deposits and sulphidic low grade uranium ores.

One of Mintek's 6m heap-leach testing areas

Gold Fields

Gold Fields offers the BIOX process, which was developed for the pre-treatment of refractory gold concentrates and ores. Refractory concentrates and ores are defined as ores where the overall recovery from a direct leach of the sample yields a recovery of less than approximately 50 to 70% and a large percentage of the unrecoverable gold is associated and occluded by sulphide minerals, mainly pyrite, arsenopyrite and pyrrhotite.

The BIOX process destroys the sulphide minerals and exposes the gold for subsequent cyanidation, thereby increasing the overall gold recovery that can be achieved.

The process has been used commercially for 23 years. To date, eleven commercial BIOX plants and one demonstration plant have been commissioned, with nine plants currently in operation.

The process utilises a mixed population of bacteria to break down the sulphide mineral matrix, thereby, liberating the occluded gold for subsequent cyanidation. The process involves the continuous feeding of the flotation concentrate slurry to a series of stirred reactors.

"Limited applications for heap bioleaching will also be available for refractory gold ores"

The pulp residence time in the bio-oxidation reactors is typically four to six days depending on the oxidation rates achieved. The BIOX product contains high concentrations of dissolved ions and must be washed in a three stage Counter Current Decantation (CCD) circuit before cyanide leaching.

Recent projects include the Kokpatas mine, in Central Uzbekistan. The deposit is owned and operated by the Navoi Mining and Metallurgical Combinat, the largest gold producer in Uzbekistan. Ore will be supplied from various open pits, including the Daugystau deposit some 140km from Kokpatas. The design concentrate treatment capacity of Phase 1 of the project is 1,069t/d. During Phase 2 the plant capacity will be increased to 2,137t/d to incorporate flotation concentrate from the Daugystau deposit.

The Phase 1 BIOX plant consists of four modules, each has three primary reactors and three secondary reactors. The CCD thickeners were sized to accommodate the Phase 2 capacity of the plant. During Phase 2, four additional BIOX modules will be added and the neutralisation plant capacity increased.

"The pulp residence time in the bio-oxidation reactors is typically four to six days depending on the oxidation rates achieved"

Commissioning of Phase 1 commenced mid-2008 and was completed early 2009. Commissioning of Phase 2 started in April this year and is expected to be completed in early-2012.

In South Africa, the Agnese demonstration plant is in production. According to Mr van Niekerk, the plant will be scaled up to full commercial production at some point in the future.

The company is at an advanced stage with two further projects. The Metals Exploration's Runruno project in the Philippines is at the implementation stage and due to be commissioned next year. The project, 320km north of Manila, has a defined resource of 1.42Moz of gold, and 25.6Mlb of molybdenum, with 900,000oz gold reporting to the measured and indicated categories and 780,000oz gold within the mining proven and probable reserve category. It will have a production rate of 96,700oz/y of gold over a mine life of at least ten years.

The Angostura gold-silver project in Colombia, will exploit a total sulphide resource of approximately 12Moz. The production rate is currently under review, based on plans for a potential new underground mine. Sulphide production is to start in 2014 to 2015 (subject to a new underground mine plan).

The company has a number of development programmes under way to reduce the capital and operating costs for using the technology, as well as to improve the robustness and ease of operation of any BIOX installation. The most advanced project is the development of an alternative aeration system.

REBgold/BacTech Environmental

In December 2010, BacTech Mining Corp was divided into two new companies, REBgold Corp, a gold mine development company and BacTech Environmental Corp, an environmental remediation company. Both companies will utilise the proprietary BACOX technology.

REBgold will apply the BACOX bioleaching technology to recover gold and base metals in mining projects, while BacTech Environmental will apply it to the processing of toxic, arsenic-laden mine tailings.

The change in company structure reflects a new policy for the business, with REBgold now seeking to exchange its technology for equity in mining projects, rather than providing it under licence.

"It is an essential way forward. Being a public company, there is only a certain amount we can earn from licensing. The value comes from the mine itself," says Dr Paul Miller, REBgold vice president of technology and engineering.

Dr Miller claims this policy is receiving a good reception, explaining that he currently has enquires from some 50 projects. Although recognising that the technology might not be suitable for all, and so they will not all come to fruition, Dr Miller sees the outlook as promising.

"The future for bioleaching is extremely good. The technology is coming into its own and REBgold is one of the leaders in the field. Our technology is very difficult to copy and we also bring our knowledge base into any partnership," he says.

BACOX bioleaching is well proven. It evolved from a process originally developed by Kings College, London for use in coal desulphurisation. It is a tank leaching process in which bacteria cultures are used to oxidise sulphides

"REBgold will apply the BACOX bioleaching technology to recover gold and base metals"

Gold Field's Kokpatas BIOX plant

and metals from refractory gold ores.

The bacteria are provided with air, small amounts of simple fertililser-type nutrients and must be in good contact with the minerals to be oxidised. For this reason a series or chain of stirred aerated tanks are used. A ground pulp of the minerals (or a concentrate) is introduced into the first tank with the oxidised product withdrawn from the last tank. Oxidation of the sulphides occurs as the pulp passes through a cascade of tanks over a period typically of four to six days.

The overall process is exothermic (heat is generated), and the tanks must be cooled with water to maintain an optimum temperature at which the bacteria operates. This means the technology can be used in various hot and very cold climates, as the actual temperature of the process is well controlled.

The first project to use the BACOX process commercially was the Youanmi mine in Western Australia in 1994. This handled 100t/d of refractory gold, under licence, for three to four years.

BACOX technology was then incorporated into the sulphide treatment plant at the Beaconsfield gold mine in Tasmania in 1998. Originally designed to produce 50t/d of gold concentrate, the plant is currently operating at 80t/d.

In April 2000, REBgold signed a licensing agreement with the Laizhou Gold Metallurgy Plant (then renamed 'Tarzan Biogold') of Shandong Province, China. REBgold built a bioleach plant that was designed to treat multiple sources of concentrate, as its primary focus was to operate as a toll treatment facility.

The plant was officially commissioned in September 2001, with the initial output in excess of 65,000oz/y of gold and recoveries exceeding 97%. Since that time, production has risen to 75,000oz/y. Later this year, will see the opening of a plant expansion that will move total capacity to 150,000oz/y of gold.

According to Dr Miller, this plant demonstrates the flexibility and ease of operation of the technology, as well as its ability to handle lower grade ores over a wider spectrum.

"The plant is modular in design. It is easy to expand and to operate. There are no long lead times for the equipment and no need for intensive operator training," he declares.

The technology has also been proved for base-metal recovery from chalcopyrite concentrates. In 2001, a demo plant was operated at Peñoles of Mexico. The plant operated for a year with a capacity of 200t/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. The plant produced at least 96% copper from chalcopyrite concentrates, according to Dr Miller.

With environmental concerns having greater significance, bioleaching is "the way forward", according to Dr Miller, since it produces no noxious gases and all the bi-products of the process are benign and environmentally stable. "The value of this technology is its ability to make arsenic benign," he says.

The company is involved in two new projects, in Chile and Finland. REBgold is conducting bioleach test work on concentrates from Yamana Gold's Jeronimo gold project in northern Chile.

REBgold had previously conducted some initial bioleach test work for Yamana on its Jeronimo project and initial positive results indicated further test work was appropriate. In the event that results are satisfactory, Yamana will pay a 1% net smelter returns royalty to REBgold on gold production generated from REBgold technology at the project. In the event that REBgold can acquire an equity interest in the project, the royalty would be decreased to a 0.5% NSR and the fees for the test work would be reduced.

On March 24, REBgold announced that it had signed an agreement to joint venture with Belvedere Resources on a select number of Belvedere's gold projects in Finland. REBgold has agreed to spend US$6 million (US$1.5 million this year) on the properties over four years to earn a 50% interest. REBgold can increase its interest to 75% by sole-funding a feasibility study. What attracted the company to the projects was the refractory nature of the ore. Drilling has already commenced and positive results were released in May.

Dr Miller says: "REBGold is working on this project in the early stages as we see it as a good user of our technology. We see good potential in the project."

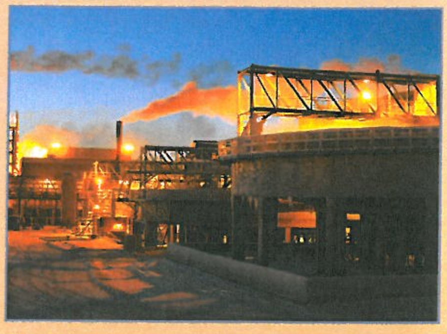
"REBgold recently signed an agreement to joint venture with Belvedere Resources on a select number of Belvedere's gold projects in Finland"

Geobiotics

GeoBiotics developed and patented technologies for bio-oxidising or bioleaching sulphide ores and concentrates in an engineered heap environment. The two principal technologies are GEOCOAT and GEOLEACH. Both technologies incorporate the patented HotHeap control philosophy to ensure optimum biological performance.

GEOCOAT is applicable to treatment of refractory sulphide gold concentrates,

Case Study: Talvivaara



The Talvivaara metals recovery plant

Built on one of the largest known sulphide nickel resources in Europe, Talvivaara is the first mining company to use bio-heap leaching for the extraction of nickel. The process uses naturally-occurring bacteria in the local rock to extract metals, a cost-effective method which uses air, water and microbes to leach metals from the ore. Bioleaching is a cleaner, less energy-intensive and more environmentally-friendly process which requires lower capex and opex than traditional smelting and refining.

The rock is extracted from the open pit at Talvivaara, crushed and stacked in 8m-high, 400 x1,200m heaps. The heaps are then aerated with fans and irrigated with a water-based solution. The water, air and bacteria trigger a chemical oxidation reaction which releases metal sulphides, including nickel, into the solution. When enough metal sulphides have built up in the solution, they are precipitated and recovered in a processing plant.

Construction at the Talvivaara mine began in April 2007. Like every new mining project, Talvivaara experienced some teething problems. These difficulties related mainly to the primary crushing system and the metals recovery plant. The full optimisation of the process continues with Talvivaara ramping up towards achieving full production in 2012.

In full production, the mine will produce: 50,000t/y of nickel; 90,000t/y of zinc; 15,000t/y of copper; and 1,800t/y of cobalt.

An infill drilling campaign at the Kolmisoppi deposit between September 2009 and June 2010 resulted in a 270% increase in total resources at the deposit from 178Mt to 660Mt. Mineral resources, as defined by the JORC code, increased by 54% to 1,550Mt from the total of 1,004Mt announced in December 2008.

Measured and indicated resources increased by 75% to 1,121Mt. The increased resources contain 3.4Mt of nickel and 7.6Mt of zinc, up from 2.2Mt and 5Mt in 2008, respectively. Following this, Talvivaara announced plans to expand its production beyond 50,000t/y and a scoping study into the expansion is ongoing.

In addition, Talvivaara has signed an agreement with Cameco for its planned uranium production, obtained as a by-product of other metals in the form of yellow cake, while manganese recovery is also being considered.

and to copper, nickel, cobalt, zinc, and polymetallic base metal concentrates. It is particularly suited to the treatment of 'dirty' and low-grade concentrates.

The sulphide flotation or gravity concentrate is coated onto crushed and sized medium to support the concentrate during the bio-oxidation cycle. This medium, known as 'support rock', can be barren or may contain sulphide or oxide mineral values. The coated material is stacked on a lined pad. Low-pressure air is blown up through the heap. The heap is irrigated with recycled effluent solution that carries bacteria, ferric iron and nutrients for the bacteria. The oxidised concentrate and/or the pregnant leach solution is further processed by conventional means for metal recovery.

The relatively uniform size of the support rock particles results in large interstitial spaces within the heap, which provide low resistance to air and solution flows. Low-pressure fans supply air through a system of perforated pipes placed under the heap.

"At Union Reefs Gold, Australia, GeoBiotics completed the design of a commercial-scale GEOCOAT plant in 2007"

The large interstitial spaces, combined with the thin concentrate layer, create ideal conditions for bio-oxidation. Oxidation is typically complete within 45 to 120 days, depending on the mineralogy. After bio-oxidation, the heap is reclaimed and the concentrate is separated from the support rock by wet screening. The washed support rock is recycled for re-coating with fresh concentrate.

GEOLEACH is a proprietary whole-ore heap bioleaching technology used to recover copper and other base metals from primary and secondary sulphide ores. Operating a GEOLEACH heap is similar to conventional whole-ore acid heap-leaching systems, but with the addition of a system to maintain biological activity and maximise heat conservation. GEOLEACH optimises the sulphide leaching kinetics by maximising and maintaining high temperatures within the heap.

The pad is loaded with agglomerated ore in individual panels. Irrigation with a barren leach solution is started in the first panel to achieve the desired pH, and then the panel is inoculated with a microbial culture in solution to begin the bio-oxidation process. Agglomerated ore continues to be placed in adjacent panels, with the conditions in each panel monitored separately and the operating parameters adjusted accordingly.

Once the pre-determined oxidation level is reached within the first panel, the leached ore is transported to a tailings containment area, and the panel is re-loaded. The overall result is a 'moving slot' within the heap where reclaiming and reloading takes place. Pregnant leach solution, containing the base metal, is collected in ponds, and then sent for downstream metal recovery.

Geobiotics' HotHeap process controls management system allows aeration and irrigation rates to be varied to maintain elevated temperatures within the heap, which results in faster leaching rates and higher metal recoveries.

Projects include the Quebrada Blanca copper demonstration plant in Chile. The operation mines approximately 10Mt/y of ore from an open pit and leaches the ore to produce copper cathodes via conventional solvent extraction and electrowinning processes. In 2007, GeoBiotics began a laboratory and field testwork programme on the Quebrada Blanca ore and, in 2009, a 47m x 66m section of the existing pad was isolated for construction of a test pad to bio-oxidise approximately 40,000t of ore.

At Union Reefs Gold, Australia, GeoBiotics completed the design of a commercial-scale GEOCOAT plant in 2007. This treats refractory concentrate from the Maud Creek mine in Northern Territory, Australia at the owner's Union Reef processing site. Maud Creek and Union Reefs were owned by GBS Gold until the company went into receivership in late 2008 and the assets were sold to Crocodile Mining in 2009.

The GEOCOAT process design was completed based on extensive testwork and considered treatment of 40,000t/y of high-grade flotation concentrate, with allowance for expansion to 70,000t/y.

Improved heap efficiency

Mining Magazine speaks to manufacturers about equipment updates

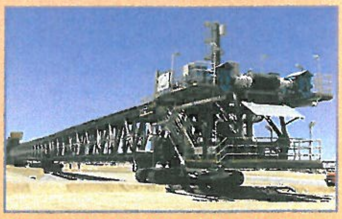
Tenova TAKRAF provides for the design, supply and installation of material handling equipment for heap and bioleaching. It offers conveyors, agglomeration drums, mobile bridges, grasshoppers, stackers, reclaimers and equipment for residue dumps.

It also offers equipment for use in on-off pads used for bioleaching and has supplied equipment to Freeport McMoran's El Abra project, Chile; Codelco's Radomiro Tomic and Gaby mines in Chile; and PTMP's Chuquicamata project.

In 2006, Tenova TAKRAF launched the Mobile Bridge for the on-off-leach pad of the Gaby Project. This concept was also utilised for a client in Mauritania, which ordered two mobile stacking bridges at the end of last year. The company focuses mainly on high availability and low maintenance costs.

Tenova TAKRAF mobile stacking and reclaiming bridges have unusually long bridge segments and therefore provide fewer mechanical parts for the crawlers and levelling mechanisms. Also the crawlers and the associated connecting elements are of rugged design with a minimum of sensors.

For permanent leach, Tenova TAKRAF introduced a new grasshopper design providing a minimum of transfer points. This results in higher availability and less wear.


Tenova TAKRAF mobile stacking bridge

Advances in emitter design are helping address problems relating to poor solution distribution over the heap. Often, the leach solution delivered by sprinklers can channel through the heap, leaving dry pockets in the ore with low to no metal extracted.

The use of drip emitters to deliver leach solution to the heap have improved metal extraction but uneven solution distribution caused by emitter plugging, remains an issue.

New drip emitter technology from Oremax aims to solve this problem. Designed specifically for the mining industry, the Max-Emitter offers a 330° screened inlet that is very difficult to plug. It also has a longer flowpath to improve flow consistency from each emitter, even with pressure variations. All these features together add up to improved solution distribution over the heap and improved metal extraction.


Tenova TAKRAF leachpad reclaimer