

The advantages that Gold Fields' BIOX offers are very project-specific, but the company says that it has seen improved rates of gold recovery

# Recovering refractory resources

Refractory gold ore needs pre-treatment for cyanidation to be effective in gold recovery. Ailbhe Goodbody looks at the advantages and disadvantages of the most common pre-treatment options, and speaks to some companies that offer or use the processes



**“In the past two to three decades, gold recovery from refractory ores has received an increased amount of attention”**

**A** refractory gold ore is gold-containing ore that is resistant to recovery by direct cyanidation and carbon adsorption processes. More specifically, it is an ore that has a gold recovery rate of less than 80% when direct cyanidation is applied to it.

Dr Chris Fleming, senior metallurgical consultant at SGS Minerals, says: “In the past two to three decades, gold recovery from refractory ores has received an increased amount of attention due to a higher number of orebodies failing to respond adequately.”

Refractoriness (the degree of resistance to standard recovery methods) is generally due to total encapsulation of extremely fine gold particles by a host mineral that is impervious to the cyanide leach solution. As a result, refractory ores require physical or chemical pre-treatment for adequate gold recovery to be achieved through traditional cyanidation and carbon adsorption processes. Pyrite and arsenopyrite are the most common host minerals in refractory gold deposits.

“Recent introduction of hydrometallurgical pre-treatment processes, such as pressure oxidation and bacterial leaching (bio-oxidation), has given mining companies more options for treating refractory ores,” says Dr Fleming. “In many cases, these new technologies have found favour over traditional roasting practices.”

*A sample of vein gold from Timmins Ontario mining camp*



There are four common pre-treatment options for refractory gold ores: roasting; pressure oxidation; bio-oxidation; and ultra-fine grinding.

In roasting, pressure oxidation and bio-oxidation, the iron sulphide minerals are oxidised to create sulphur dioxide (SO<sub>2</sub>) gas in the case of roasting, or sulphate ions in pressure oxidation and bio-oxidation. The iron component is oxidised to the trivalent state and forms solid compounds such as haematite (roasting), basic iron sulphate or jarosite (pressure oxidation and bio-oxidation) and soluble compounds such as ferric sulphate (pressure oxidation and bio-oxidation). Ultra-fine grinding is a strictly physical process and there is no chemical change to minerals in the feed.

Mineral concentration steps, such as sulphide flotation, often precede the pre-treatment processes. By reducing the volume of ore going in to the pre-treatment process, the size of the equipment needed is also decreased.

“The infrastructure needed for refractory gold processing varies depending on the method chosen,” says Rachel Bridge, metallurgist at Hatch. “The process steps common to each method are crushing, grinding, gravity concentration, intensive cyanidation of the gravity concentrate and all refinery processes downstream of carbon-in-leach (CIL).”

Dr Fleming comments: “It is important to note that no single pre-treatment process provides the best economic and environmental outcome for all cases. Each process has strengths and weaknesses. Often at SGS we evaluate all four pre-treatment options during feasibility studies to ensure the customer gets an economically viable solution.”

The decision on which method of refractory gold recovery to choose is usually based on the economics of

investment and operating costs (OPEX). These processes are all expensive and economic considerations have traditionally weighed heavily on the final process decision. Marcus Runkel, senior process engineer at Outotec, says: “The economics are driven by the gold recovery rate. The pre-treatment of refractory gold ore should increase the gold recovery rate in the cyanide leach process by 30-40% in order to be economical”

“Large operations tend to choose roasting or pressure oxidation, while smaller operations tend to select bacterial leaching,” says Dr Fleming. “Other factors, such as gold and silver recovery rates and environmental regulations, also determine which process will be used.”

However, environmental regulations can sometimes outweigh cost and gold recovery. “It is very difficult or even impossible to get a permit to build a roaster in some countries,” adds Dr Fleming. “Other countries will not allow arsenic to be handled in any way other than pressure oxidation. While there isn't one set procedure for refractory gold ore processing, SGS looks at every situation separately, to evaluate which option is the best fit.”

## ROASTING

Roasting is generally applied to sulphide minerals and refractory ores. It involves a thermal gas-solid reaction during which sulphides and sometimes organic carbon are oxidised to SO<sub>2</sub> and carbon dioxide (CO<sub>2</sub>) at temperatures between 500°C and 700°C. Mr Runkel of Outotec says: “Roasting plants can be designed with a throughput up to 5,000t/d or higher per line, depending on the ore composition.”

Dr Fleming says: “Prior to the 1970s, roasting was the only process available to metallurgists for treatment of refractory gold ores and it was applied in most of ▶

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**SGS autoclave set-up for gold processing** ▶ the gold-producing regions of the world.”

The reactor types are: bubbling fluidised bed (FB) or circulating fluidised bed (CFB). A FB roaster operates at relatively low gas velocities, with the particles kept in balance against their own gravity. Ms Bridge says: “A CFB roaster operates at higher gas velocities, and is used to evaporate residual moisture and roast the flotation concentrate, oxidising 98% of the sulphide and 65% of the carbon.”

**“While gold recovery by roasting is high, the higher CAPEX and OPEX have caused roasting to be less attractive in some regions”**

Gold ores are typically pre-concentrated through a flotation process prior to roasting. For ores that do not respond well to flotation, recent technical innovations in roasting have made it possible to treat whole ores. This has also allowed for the re-evaluation of deposits previously thought uneconomical for exploitation, such as those found in the southwestern US.

Mr Runkel adds: “The removal of impurities such as arsenic and mercury in particular can be done very effectively in a roasting step, which is always designed in compliance with the environmental regulations. Another factor is the production of sulphuric acid and heat recovery in the form of high-pressure steam, which in special applications can improve the economic model.”

The advantages of roasting include



high gold recovery and the potential for a slight capital cost (CAPEX) advantage over alternative methods of treating refractory gold ore. “The roasting oxidant can be air or pure oxygen, so there may no need for a dedicated oxygen plant, which will lower the overall CAPEX,” explains Dr Fleming. “If air is used, the SO<sub>2</sub> that is generated is generally too dilute to make acid, so it is scrubbed from the gas phase and neutralised with limestone. If the plant is going to produce sulphuric acid as a saleable by-product,

then it will generally have to use oxygen as the oxidant and the CAPEX will be higher. This can be offset by acid sales.”

However, roasting will not provide large savings if an oxygen plant, in combination with comprehensive scrubbing of the gases, is required to meet stringent modern standards for discharge of toxic elements in the gas phase. Roasters also have to recover arsenic trioxide (As<sub>2</sub>O<sub>3</sub>) and SO<sub>2</sub> from the gas very efficiently to meet environmental standards and the CAPEX of gas capture can be expensive.

Ms Bridge says: “While the gold recovery by roasting is high, the higher CAPEX and OPEX requirements needed to comply with environmental standards have caused roasting to be less economically attractive in some regions.” Concerns over the potential for environmental damage have made it difficult to obtain an operating permit for a roaster in a number of countries.

Another product of the roasting process is haematite (Fe<sub>2</sub>O<sub>3</sub>), which is made by converting the iron in pyrite and arsenopyrite. This is a desirable product for thickening, filtering and storing in tailings as it is dense and compact. It is also chemically inert, eliminating the possibility of release of acid or heavy metals into the environment. However, when the feed ▶



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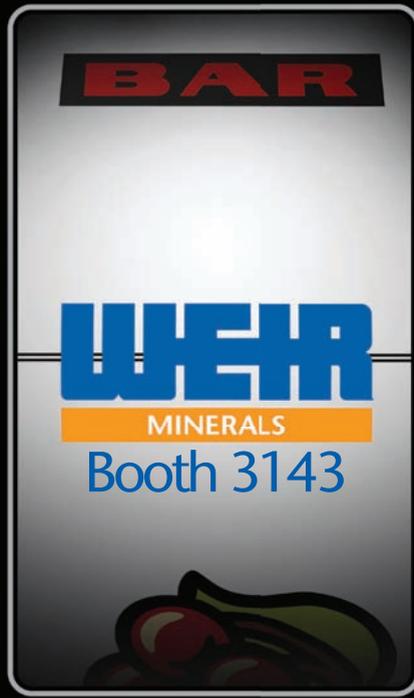
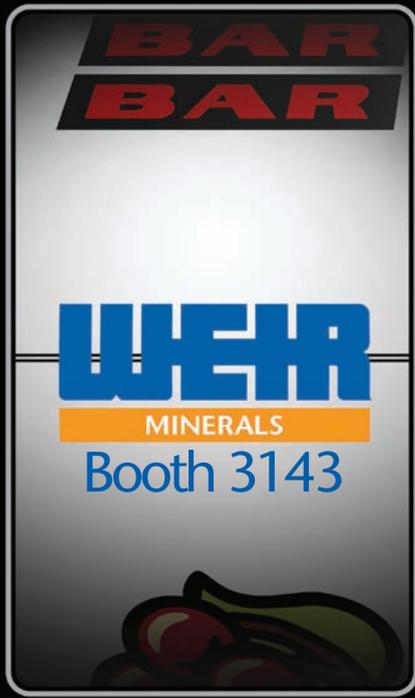


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► contains arsenopyrite, the process can become quite complex, as the roasters have to be operated in two stages.

When implementing a roasting plant, the longest period is typically in the concept stage. Mr Runkel explains: "Roasting test work and finalising the design basis should be done within a year. For a lump sum turnkey roasting project including the roasting, gas cleaning and sulphuric acid unit, the timeframe from start of the contract to mechanical completion and start-up of the plant can take 2-3 years."

### PRESSURE OXIDATION

Pressure oxidation, or autoclaving, was originally developed for processing base metal concentrates. In the last 30 years, it has been adapted for processing refractory gold ores and concentrates where gold is trapped in sulphide minerals, such as pyrite or arsenopyrite.

During this process, the sulphides are oxidised by pure oxygen at an elevated temperature and pressure in an aqueous slurry. This breaks the sulphides down to a solution phase consisting of metal sulphate compounds and sulphuric acid. The gold locked in the original sulphide mineral is completely liberated, allowing very high gold recovery to be achieved when the product is treated with cyanidation.

The use of pressure oxidation has become common in the past 20 years as a result of better gold recovery efficiency when compared to roasting, and an inability of first-generation roasting plants to meet increasingly strict environmental controls on sulphur and arsenic discharge.

Advantages of pressure oxidation include: high gold recovery; and sulphide minerals break down completely into solution, allowing the gold locked in the sulphides to be fully liberated. Pressure oxidation is also capable of handling a range of feed rates. Dr Fleming says: "Pressure oxidation gold recovery rates are a minimum of 10% better than those of roasting."

Toxic elements such as arsenic and sulphuric acid are produced in solution, rather than in the gas phase as in roasting. These by-products are much easier to contain and stabilise as environmentally benign products when in solution. Arsenic is converted to ferric arsenate (scorodite) in the autoclave, which is as stable as the original arsenic sulphide mineral and can be disposed of to the process tailings without further treatment. The acid is converted to gypsum, a stable and environmentally benign compound.

However, the technology has some disadvantages as well: it has a higher throughput and requires larger equip-

ment, such as an oxygen plant, making the overall CAPEX typically higher than bio-oxidation or roasting. Also, a workforce with technical expertise is required to operate high-pressure vessels.

Pressure oxidation is not well suited for feed materials with high levels of silver, as the silver often reacts with iron in the autoclave to form a silver jarosite compound that is resistant to cyanide leaching. Expensive measures have to be adopted to liberate and recover the silver.

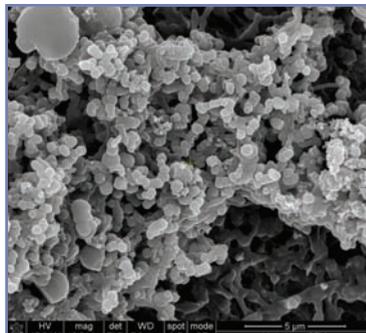
There are some environmental concerns about the technology. Traditionally, only a small percentage of the iron in pyrite and arsenopyrite is converted to haematite during pressure oxidation, and the majority ends up as jarosite or basic iron sulphate. These compounds can cause metallurgical challenges in downstream precious metal recovery and both have the potential to release acid and heavy metals to the environment.

To meet environmental regulations in most gold-producing nations, the tailings from a pressure oxidation plant may have to be deposited in a lined tailings pond. Creating a tailings pond will result in an increased CAPEX for the project.

### BIO-OXIDATION

In bio-oxidation, certain strains of bacteria are used to accelerate the natural process of sulphide oxidation. These bacteria metabolise energy from the oxidation of ferrous ions and sulphides. The by-products then report to the aqueous phase as metal sulphate compounds and sulphuric acid (similar to what happens in the pressure oxidation process). Gold recovery is very high and is similar to what is achievable using pressure oxidation. Bio-oxidation is a reasonably well-established technology with several plants operating globally.

The largest interest in bio-oxidation is focused on high-grade concentrates by treatment of finely milled solids in stirred tank reactors. Dr Fleming adds: "An important characteristic of bacterial leaching reactions is that the bacteria are autocatalytic; ie, the bacteria, which are the catalyst for the reaction, are also



beneficiaries of the reaction, allowing them to multiply."

Bio-oxidation enjoys lower CAPEX than roasting and pressure oxidation, and has a slightly lower net present value (NPV) than pressure oxidation, so it often produces the best overall economics for smaller-scale operations. The process uses air to oxidise the sulphides, so no oxygen plant is needed. The process is simple to operate with limited expertise required, so operators can be sourced from local communities and trained.

"For the bio-oxidation option, alternatives in various design details can be investigated to reduce CAPEX and OPEX," says Ms Bridge. "Also, bio-oxidation designs are exceptionally well suited for incremental expansion to accommodate a mine plan calling for a production ramp-up over time."

Bio-oxidation has a lower environmental impact than some other technologies. Toxic elements such as arsenic and acid are generated in solution and are easier to contain and stabilise as environmentally benign by-products. The sulphide minerals break down completely into solution. However, arsenic is converted to an amorphous ferric arsenate compound in the tailings, which is not as stable as scorodite. Amorphous ferric arsenate could create issues when attempting to meet environmental regulations in some regions.

Bio-oxidation is best suited for smaller-scale operations due to the long residence time required for oxidation of the sulphides. Dr Fleming explains: "Residence time for bio-oxidation processes is typically 4-5 days, compared with roughly 1h for pressure oxidation and less than 30 minutes for roasting. The plant footprint will, therefore, be much larger for bio-oxidation than the other alternatives for a given ore throughput capacity. This becomes an issue if space is limited."

Cyanide consumption can also be a problem. Cyanide consumption is typically 10-20kg/t, versus a maximum of 1-2 kg/t ►

*Gold Fields' BIOX technology is in use at Eldorado Gold's Jinfeng plant in China*

**"Bio-oxidation designs are exceptionally well suited for incremental expansion to accommodate a mine plan calling for a production ramp-up over time"**

*Gold Fields' BIOX uses a mixed population of bacteria to break down the sulphide mineral matrix*

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► after pressure oxidation or roasting. The high cost of new cyanide purchases, as well as the cost of cyanide detoxification in the tailings, can negate any benefits gained due to the lower cost of oxidation by air. As a result, OPEX in bio-oxidation can be the highest of the three processes.

Minor metal impurities may poison the bio-organisms. The main consumer of cyanide is the reaction between cyanide ions and sulphur, which is a by-product of the bacterial oxidation of sulphides. This reaction produces thiocyanate in solution. Thiocyanate is very toxic to the bacteria used in the bio-oxidation processes, so great care must be taken to avoid recycling tailings water containing thiocyanate back to the bio-oxidation part of the process.

### Gold Fields

Gold Fields owns the BIOX biological process, which uses a mixed population of bacterial cultures to break down the sulphide mineral matrix and liberate the occluded gold for subsequent cyanidation.

BIOX development started in the late 1970s and early 1980s at Gencor's Process Research Facility (now Billiton Process Research). At that stage, Gencor owned the Fairview gold mine in the Barberton area of South Africa and it needed a low-cost technology to treat a concentrate stock pile in parallel with the Edwards roasters it was operating. The first 10t/d plant was commissioned in 1986 to treat the refractory concentrate.

The performance of the process was such that Gencor continued to operate BIOX in parallel with the roasters, feeding fresh concentrate after depletion of the stockpile. The roasters were nearing the end of their life at that stage, and in 1991 the decision was taken to switch to BIOX treating 100% of the feed concentrate. The decision was based on the improved process performance and lower OPEX of BIOX over the roasters. Importantly, BIOX was more environmentally friendly than the roasters, as it was able to fix the arsenic in the ore in a stable precipitate that could be discharged to the tailings dam.

In 1997, the gold assets from Gencor merged with those of Gold Fields South Africa to form Gold Fields. The Fairview mine and the ownership of the BIOX technology transferred to Gold Fields at the same time. Gold Fields sold the Fairview mine shortly after but retained the BIOX technology.

The advantages that BIOX offers over alternative processes for refractory gold recovery are very project-specific, but the company says that, in general, it has seen improved rates of gold recovery,

### ASTER

In addition to BIOX, Gold Fields also offers its Activated Sludge Tailing Effluent Remediation (ASTER) technology. This is a fully commercial process that focuses on the destruction of biological cyanide and thiocyanate, which are by-products of BIOX. The first operation has been running for over 18 months and the company says it has been giving consistently good results, so it would be of interest to any mine evaluating options for cyanide and/or thiocyanate destruction.



Gold Fields' ASTER technology focuses on the destruction of biological cyanide and thiocyanate

significantly lower CAPEX, lower running cost, more robust technology that is suited to remote locations, lower levels of skills required for operation, low impact on the environment and on-going process development and improvement.

The technology is also backed by 25 years of operating experience, and Gold Fields says the fact that it is owned by a major gold mining company ensures technical support into the future. The company says that approximately 1.5Moz of gold was produced from BIOX in 2011, with the cumulative gold production from BIOX estimated at around 16Moz to date.

"Although CAPEX and OPEX structures are project-specific, we have seen an increased focus on the 'non-financial' advantages," says Jan van Niekerk, senior manager for BIOX at Gold Fields. "The availability of skilled people and the ability to use local semi- or unskilled operators on the plant become important considerations when operating a mine in remote locations. With increasing variability in ore grade and quality in most new projects, we are seeing factors such as the flexibility of the technology, turndown capacity and ease of expansion also becoming important factors during the selection of the technology. This is again where BIOX offers significant advantages over processes such as roasting and pressure oxidation."

Another advantage of BIOX is the treatment of arsenic-containing concentrates. Arsenic is dissolved in the BIOX process, and afterwards is fixed as a ferric arsenate during neutralisation. BIOX puts the arsenic into a stable form that can be safely deposited onto a tailings dam. Test work on the old tailings dams at Pan African Resources' Fairview mine in South Africa confirmed that, after 25 years, the arsenic precipitates are still stable.

Gold Fields is working on the fourth generation (Generation IV) of BIOX, and

hopes to have it available by the end of 2013.

For more information on the BIOX and ASTER processes, see the May 2012 issue of *MM* for an exclusive interview with Jan van Niekerk.

### REBgold

REBgold owns a bacterial oxidation technology called BACOX, which uses naturally occurring bacteria to separate out the gold. The technology provides a suitable environment for the bacteria within tanks, creating what the company calls a 'Garden of Eden' for them to live in.

Originally, a group from King's College London, UK, isolated the bacteria that could make the iron, arsenic and sulphide minerals associated with refractory gold ores soluble and cultivated them in the laboratory. Studies were then conducted to evaluate the bacterial requirements, such as nutrients, temperature and acidity, to create agitated aerated reactors that provide the ideal environment for bacterial growth and division, as well as for the solubilisation of refractory gold ores.

BacTech was formed to commercialise this technology in the early 1990s, and it discovered how to scale up the process and make it work on a continuous basis to treat refractory gold ores as part of a normal gold processing operation. The technology was also developed further for treating complex base metal concentrates, allowing the production of on-site metals from polymetallic ores that are difficult to treat.

The first application of the technology was in Western Australia in 1994, where the company was originally based before obtaining a listing in Canada. The technology was then applied in Tasmania and in China. The plant in China treats a variety of different concentrate types, and was so successful that it was doubled in capacity a few years ago. ►

**"BIOX was more environmentally friendly than the roasters, as it was able to fix the arsenic in the ore in a stable precipitate"**



**A REBGOLD BACOX plant in operation**

**Thermophilic bacteria used in REBGOLD's BACOX process**



REBGOLD says that the separation technology achieves in six days what would take 20 years to occur in nature. It also says that the tailings created are benign and there is no risk of environmental damage. The typical gold recovery rate is 90-95%.

The BACOX process can work at a variety of scales. Concentrate treatment rates vary from 30t/d to 1,000t/d of concentrate, which is generally equivalent to between 200t/d to 5,000t/d of ore. The company's largest installation processes 200t/d of concentrate, which is roughly equivalent to 1,000t/d of ore. The process is modular, making expansion at a later date very easy.

The process can treat a variety of ore types through the life of a project, from transition ores to fully refractory ores.

REBGOLD says that for many operations, bioleaching technologies are now the treatment method of choice, due to the lower costs and environmentally responsible practices associated with the process. BACOX is well suited to a variety of locations, even those in remote areas.

A reasonable quality of water is required together with a good source of local limestone, which the company says are usually readily available. REBGOLD has built a plant in a desert region where the water was mildly saline, and says that it works well. The process maximises water re-use to minimise discharge requirements.

The timeframe for implementing the BACOX process is project-specific. However, REBGOLD says that getting permits for projects is often easier with BACOX processing due to the products being environmentally benign, and that lead times can be shorter than with other technologies, as no specialised equipment is required.

Test work protocols are well established for taking projects from a conceptual basis through to commercialisation, so it can take as little as one year from test work to engineering, design, construction and commissioning, depending on permitting.

The capital investment is also very

project-specific, but the company says that it is generally half of that required for pressure oxidation.

REBGOLD says that the technology is very good at managing toxic elements. The company says that it handles arsenic and iron as part of the ore composition in many projects; the bacteria make the arsenic and iron soluble, and a benign stable waste is produced by neutralisation of this solution with limestone. The precipitate produced as part of the process binds the arsenic very strongly into a matrix, meeting US Environmental Protection Agency (EPA) or equivalent regulations for safe disposal.

REBGOLD is currently examining a number of projects for the possible application of BACOX in a variety of countries. It is active in Finland, where there is a mixture of prospects from conventional non-refractory gold resources through to sulphides where use of the technology may become appropriate.

The company believes that there are more projects in Europe and South America where the technology could provide an advantage, as well as an entry to projects by economic participation, as REBGOLD not only provides the technology but also help to secure funding for the right project. ▶

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**Case study: AngloGold Ashanti****MINERAÇÃO**

AngloGold Ashanti has a number of mines that feature refractory gold. For example, the Mineração mining complex in Minas Gerais, southeastern Brazil, uses the roasting process to treat its refractory ore.

The company says that the roasting process was chosen because it is the best match to the type of ore at the mine; the choice was made based on the process that would provide the best metallurgical efficiency. The roasting process promotes the release of the gold contained in the ore concentrate, and thus increases the metallurgical recovery of the gold treatment process. It also allows the production of another value-added product – sulphuric acid. This way, AngloGold Ashanti can maximise the mineral resource mined at its mines.

The roasting process used at AngloGold Ashanti is the single-stage FB type. In this process, the pulp concentrate at a typical particle size (80% passing through 400-mesh, or 38 microns) is fed by 12 compressed air ‘feed guns’. The slurry inside the roaster reacts with the air blown from the bottom of the furnace, which has a dual function: it fluidises solids and provides the oxygen required for the various sulphide oxidation reactions.

The ore is processed at the Queiroz and Cuiabá plants. The Queiroz plant roasting process can treat 848t/d of concentrate, which is equivalent to 5,000t/d of ore, bearing an average gold content of 7.5g/t. Therefore, the Cuiabá metallurgical plant has the capacity to treat 37.5kg/d of gold (13.7t/y or 440,000oz/y).

Infrastructure required included a power supply, water and a site to build the processing plant and tailings dams. It took 3-4 years to proceed from initial test works, studies, and assessment of metallurgical processes alternatives to implementation and plant start-up. The capital invested in the roasting plant and sulphuric acid plant was US\$35 million.

**CÓRREGO DO SÍTIO**

The ore from the company’s Córrego do Sítio mine, also in the Minas Gerais region of Brazil, is highly refractory, and therefore requires a more intense oxidation process to achieve high recovery. In this case, after metallurgical tests were carried out, pressure oxidation was chosen. It works at 230°C and 36bar pressure by injecting oxygen to attain oxidation. This plant began operation early this year, and is currently in the stabilisation phase. No by-product is produced in this particular process. The investment made in the pressure oxidation system was US\$25 million.

The process for treating SO<sub>2</sub> uses double oxidation and double absorption. The process comprises three steps:

- gas drying – removal of all moisture (water vapour) from the gas. It is accomplished by recirculating the 96% sulphuric acid stream in counter-current in the drying tower;

- conversion of SO<sub>2</sub> to sulphur trioxide (SO<sub>3</sub>) – once dry, the SO<sub>2</sub> contained in the gas needs to be converted to SO<sub>3</sub> with the aid of a catalyst to enable the absorption of the reaction to become thermodynamically feasible in such operating conditions; and
- absorption of SO<sub>3</sub> – the SO<sub>3</sub> produced in the previous step is absorbed by dilution water contained in the sulphuric acid circulating in the interpass and final absorption towers, which leads to the production of additional sulphuric acid (H<sub>2</sub>SO<sub>4</sub>) molecules.



*Anglogold Ashanti uses bio-oxidation at Obuasi*

**OBUASI**

Gold Fields’ BIOX process is used at the Obuasi plant in Ghana. Different treatment routes were evaluated in 1991, and the choices were narrowed down to pressure oxidation and bio-oxidation. The company says that it chose bio-oxidation for the following reasons:

- there was the need to move away from roasting, which had caused environmental pollution through emission of arsenic trioxide;
- bio-oxidation was perceived to provide a cleaner operating environment, as arsenic compounds are safely neutralised and impounded to conform to EPA requirements;
- the relative simplicity of operation and control for bio-oxidation when compared with pressure oxidation; and
- the low CAPEX and OPEX.

The BIOX plant at Obuasi is made up of four modules; each contains six stainless steel reactors that are each 895m<sup>3</sup> in volume. There is also a 25th reactor that is common to all of the modules. The plant also has four counter current decantation (CCD) thickeners, a neutralisation circuit made up of six tanks, and ancillaries such as a cooling tower, blowers and a nutrient mixing dosing facility.

It took two years to conduct the pilot test work, design and construct the plant, and it was commissioned in 1994 with a capital investment of US\$25 million.

The BIOX plant was initially designed to treat 720t/d of concentrate, and the capacity was increased to 1,050t/d with the addition of extra reactors in 1998.

The waste stream from the process, which contains soluble arsenic, is precipitated as insoluble ferric arsenate, which is considered stable, and then disposed of on the tailings storage facility.

**ULTRA-FINE GRINDING**

Ultra-fine grinding is when grinding is used to reduce the particle size of the host mineral so that part of the gold surface is exposed, allowing contact with cyanide solution. A benefit of this technique is that the host mineral is not destroyed in an oxidative chemical reaction, which avoids the resulting problems of how to treat the reaction products.

However, such fine grinding is increasingly energy-intensive with each size reduction step. Dr Fleming explains: “Gold particles in refractory deposits are generally less than 0.1micron in size and it is impractical, if not impossible, to grind sulphides to a fine enough state to liberate the gold particles.”

He continues: “Ultra-fine grinding, if successful at liberating gold, provides the lowest CAPEX and OPEX of the four processes. Unfortunately, it is very seldom effective as a technique. However, because of the favourable economics, ultra-fine grinding should always be tested and evaluated during project feasibility studies for the rare occasion that it proves to be beneficial.”

**Maelgwyn Mineral Services**

Maelgwyn owns the Leachox process, which was developed by combining its experience in gold processing with its flotation technologies to modify the Imhoflot pneumatic flotation aerator. This allowed it to be used as a highly efficient mass-transfer device to introduce oxygen into slurry, which is combined with ultra-fine grinding of a flotation concentrate.

The concentrate is then fed to Maelgwyn’s Aachen reactors to provide low-pressure partial oxidation of sulphides combined with high shear to remove passivation of gold surfaces often associated with other oxidative leaching processes. The shear action facilitates the thinning of the diffusion or boundary layer around the mineral particles, while also enhancing kinetics and reduced cyanide consumption. The typical recovery rate is a function of the ore mineralogy, but can often be in excess of 90% compared with 30-60% without Leachox.

“The Leachox process is very flexible and so the circuit can be modified to handle any required tonnage,” says Steve Flatman, general manager at Maelgwyn. “While Leachox and other competitor processes are generally associated with refractory gold treatment, the Aachen reactors themselves, which are the core part of the Leachox process, are increasingly being used on run-of-mine (ROM) circuits to accelerate leach kinetics, or in a pre-oxidation mode where a light pre-oxidation is required.” ▶

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The efficiency of Leachox is not a function of grade, so it is not limited to just high-grade flotation concentrates. This can enable mines to increase their flotation mass pull, albeit at a lower grade to enhance flotation metal recovery.

**“Leachox is generally significantly more cost-effective than other refractory processes from both a CAPEX and OPEX viewpoint”**

Maelgwyn says there are a number of advantages to using Leachox. Mr Flatman explains: “Firstly, Leachox is generally significantly more cost-effective than other refractory processes from both a CAPEX and OPEX viewpoint. This is essentially because the process is flexible and is able to combine a number of Maelgwyn’s core technologies to formulate a bespoke solution for a specific orebody, rather than trying to make the orebody fit the process.

“Secondly, the flexibility also extends to recovery, where the number of passes through the Aachen reactor can be tailored to achieve an economic recovery, as opposed to maximum recovery.”

The only ‘chemical’ that Leachox uses is oxygen, so the process is very environmentally friendly. Leachox also reduces cyanide consumption, particularly when ultra-fine grinding is required. While not strictly part of Leachox, Maelgwyn can also incorporate its cyanide destruction process, which reduces residual cyanide levels to below international cyanide



guidelines, again through using its Aachen reactors.

An oxygen supply is the major requirement for Leachox. For remote plants this would typically be a pressure swing adsorption or vacuum swing adsorption (PSA/VSA) plant. Imhoflot pneumatic flotation cells would then normally be used to produce a flotation concentrate. Depending on the mineralogy, ultra-fine grinding may be necessary, requiring an ultra-fine grinding mill. Historically, Maelgwyn has used vendor mills for this, but has also developed its

own in-house ultra-fine grinding mill.

Thereafter, the Aachen reactor contains no moving parts, with the flow through the reactor provided by a feed/recirculation pump. Mr Flatman concludes: “Due to its inherent simplicity, the Leachox process is ideally suited to remote locations.”

Maelgwyn has extensive laboratory facilities in South Africa, through its subsidiary Maelgwyn Mineral Services Africa. “The amount of test work and the timeframe required is a function of how much test work the client has already done,” says Mr Flatman. “Normally, scouting work would be needed to narrow down the process options, followed by more detailed confirmatory work. A timeframe of six months is typical. Thereafter, another six months for manufacture and installation/commissioning should be allowed.”

The Leachox process has been used commercially at both the Galaxy Gold Mining’s Agnes mine near Barberton and Transvaal Gold Mining Estates’ operation near Pilgrim’s Rest, both in South Africa. A Leachox circuit is also being installed at a west African gold producer’s mine. Additionally, several mining companies have committed to incorporating the process into their planned operations pending funding finalisation. ▼

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