

Leveraging the lixivants



The extraction of gold has become increasingly complex over the last few decades, leading to the development of several new technologies able to effectively recover gold while, at the same time, meeting the needs for more environmentally friendly processing options. Dan Gleeson profiles some of these

Gold may dominate when it comes to the number of mines currently in operation across the globe, but, if analysts are correct, we could soon hit a mine supply peak.

There is a simple explanation for this: one, the easy-to-find deposits in favourable jurisdictions have been discovered and exploited, meaning development costs for new mines can be high; two, and related, the complexity associated with processing gold orebodies has significantly increased.

Brian Howlett, CEO of **Dundee Sustainable Technologies** (DST), a company that has devised alternative gold processing methods to aid mining companies faced with metallurgy, recovery and environmental challenges, is all too aware of this.

"Most of the 'easy gold' in the world has been found; we are seeing a lot more complex concentrates in the market, whether that be arsenopyrite-types, or copper with gold," he said.

David Kratochvil, President and CEO of **BQE Water**, says his company, which helps miners avoid the negative interference of base metals in the extraction of precious metals through

processes such as sulphidisation, acidification, recycling and thickening (SART), concurs.

"There seems to be fewer and fewer 'clean gold' deposits of any significance discovered," he told *IM*. "Consequently, the ounces of gold produced are increasingly being replaced by ounces from more complex gold deposits that feature a mix of gold and base metals."

It is not only metallurgy and gold being 'locked up' in, for example, refractory orebodies that is reducing the amount of yellow metal likely to be produced in the future. Environmental regulations and the negative perceptions associated with existing gold processing technology is holding back the development of various gold deposits.

The use – or potential use – of cyanide has had a negative effect on permitting at, for example, the Rosia Montana gold-silver deposit in Romania; an open-pit development that has the potential to be Europe's biggest gold producer, but remains on hold awaiting a parliamentary decision on the potential use of the controversial lixiviant.

"Cyanide is becoming more of an issue every day," Howlett said, explaining places such as

Commercialisation of the 'Going for Gold' process technology occurred in June, not too long after the thiosulphate process devised by CSIRO had produced Australia's first gold using a non-toxic chemical process

China, Eastern Europe and the US have either implemented, or plan to implement, bans on its use.

The perceived risk of continuing to operate mines that use cyanide into the future is also leading some companies to reassess existing process routes, according to Howlett.

"We have spoken to major miners that tell us – and they are looking five-to-10 years ahead – if cyanide were to be banned overnight for some unknown reason (I'm not saying that is likely), they could lose the ability to operate the majority of their mines," Howlett said.

It is these considerations shaping the way gold miners, developers and explorers continue to do business in the gold space.

Cyanide alternatives

Alternatives to cyanide in the gold processing flowsheet have received much attention in recent years largely driven by the health, safety and environmental risks associated with its use.

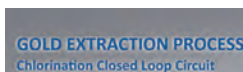
Professor Jacques Eksteen Director, Gold Technology Group and Chair, Extractive Metallurgy Western Australia School of Mines, Curtin University, Australia, summed up the situation nicely in an abstract to his 'Fit-for-purpose precious metals leach systems:

He said: “The gold industry has been supporting research into alternative lixiviants over a number of decades. However, it may sometimes appear to the casual observer that the industry is no closer now than it was 20 years ago to implementing a feasible solution at multiple sites.”

DST believes it has devised a new technology, the CLEVR Process™, that can have wide-scale appeal. The cyanide alternative produces no toxic liquid or gaseous effluents, and generates solid residues that are inert, stable and non-acid generating, according to the company.

DST has opened the number of applications suitable for CLEVR by introducing, depending on the nature of the mineral, a pre-treatment step prior to gold extraction.

Originally commissioned in 2015, a first demonstration campaign, completed in early



Thiosulphate leaching is another route often highlighted in the discussion of processing



ENGINEERING DOBERSEK®

MEET US!

ROASTING DEVICE

COMPLETE PLANT LAYOUT

**MINING
METALS
CENTRAL
ASIA
18-20
SEPTEMBER
2019
ALMATY
KAZAKHSTAN**

dobersek.com

Au
196.96

CIL TAILINGS OXIDISING ROASTING

PILOT PLANT TESTS • ENGINEERING • PROCUREMENT • CONSTRUCTION • SERVICE

double refractory ores without the use of cyanide. This technology was first commercialised in 2014 when Barrick Gold, in partnership with Australia's CSIRO, started up its thiosulphate plant at the Goldstrike mine (Nevada, US).

As part of the thiosulphate process at Goldstrike, gold-bearing, sulphur-based ore is heated as a thick slurry of ore, air, water and limestone in large pressure chambers or autoclaves and then pumped into the 'resin-in-leach' circuit that takes place inside large stainless steel tanks, according to CSIRO. Within the tanks, the slurry interacts with thiosulphate and a fine, bead-like material called resin that collects the gold.

Barrick says the plant has allowed Goldstrike to process 4 Moz of double-refractory ore that would otherwise have been processed at the end of the mine's lifecycle many years from now.

Despite the success achieved at Goldstrike, the leach reagent system the mine adopted has not yet found widespread appeal.

CSIRO, however, separately developed a thiosulphate-based reagent system for gold leaching that, according to the organisation, has excellent stability and shown broad applicability in the laboratory.

"The reagent system is an alternative to cyanide and has particular application where cyanide cannot be used and to unlock stranded high-grade deposits," CSIRO said.

CSIRO, in collaboration with Eco Minerals Research Limited, commenced a project in July 2017 to undertake a demonstration at scale in the field using the CSIRO reagent system. The mobile demonstration plant setup on the Menzies stamp battery site (in Western Australia) used a low capital expenditure vat leach process to recover gold from ores, having good gold liberation at a p80 greater than 300 microns, CSIRO said.

In under 10 months, the demonstration project took a laboratory developed concept and transformed it into a demonstration plant involving design, build and commissioning through to successfully producing gold doré bars. The demo plant has since processed up to 30 t/d of ore by vat leaching and has operated successfully for more than six months to validate the reagent performance and stability. The leach reagent consumption for the optimised demonstration process was 1.6 kg/t, the majority of this being entrained loss with the tails.

According to a paper presented at the ALTA 2019 conference, authored by CSIRO's Paul Breuer, Michael Jackson, Marlene Engelbrecht, Amy Evans and Lauren Bourke, and Eco Minerals Research/Clean Mining Ltd's Jeff McCulloch, the demonstration process was initially designed to treat tailings from the gravity plant at Menzies

(less than 10 mm material with only 20-30% passing 850 micron).

This coarse particle size distribution allowed the adoption of the low capital cost vat leach process, according to the authors.

To facilitate the short procurement and construction time, the modular and mobile plant design was also adopted. Additional advantages of this design were the flowsheet could be easily modified to treat different ores and the mobility allowed easy relocation, if required, as opposed to trucking in ore.

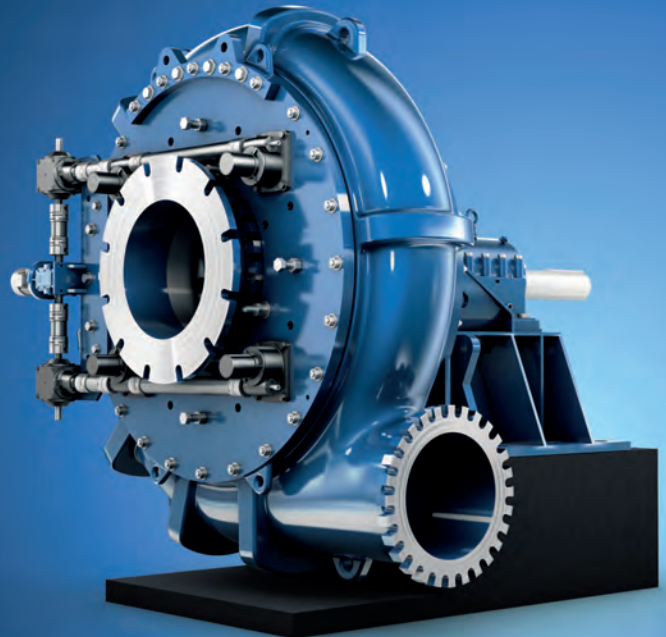
The plant treated old battery sands available on the Menzies site, according to the authors, who explained that this stockpiled material was a conglomerate of many small parcels of ore from the local area that had previously been treated

through the battery.

"The battery sands had variable mineralogy and gold grade, and also contained significant fines and clay materials, which were largely removed using a 12 in cyclone (p80 of cyclone overflow was 25-30 microns). The mill was used to slurry the battery sands and remove any plus-2 mm particles before being fed to the cyclone. The cyclone underflow material was placed in the vats and leached to recover the gold."

The flowsheet for this process saw the dissolved gold thiosulphate complex recovered from the pregnant leach solution in the leach solution processing plant using ion exchange resins. This was subsequently eluted from the resin under ambient conditions and a gold-containing product obtained from the eluate.

NO TIME IS A GOOD TIME FOR DOWNTIME.



Don't let downtime cost you. Choose GIW's RAMSL technology to extend your pump's wear life with just the push of a button.

Learn more at www.giwminerals.com.

GIW® Minerals



“No pre-elution of copper or regeneration of the resin was undertaken which significantly simplified the resin elution process,” the authors said. “This gold product was retorted to recover mercury (some of the mercury entrained with the ore when it was previously treated in the battery is dissolved and recovered along with the gold) and then smelted to produce gold doré.”

The barren leach solution (BLS) was recycled back into the leach process with reagent top-up as needed to replace that consumed or lost in the process. The leach tails were rinsed with process water to reduce the loss of any residual gold and reagents in the solution exiting the process with the solids, the authors said.

The recovery and recycling of BLS to minimise gold and reagent losses, and maintain the resultant water balance, is a vital aspect to the application of this technology as the efficiency of

this stage influences the overall process economics, according to the authors. “Hence, this was a major focus of the demonstration.”

The authors concluded the technology package, over the test period, successfully demonstrated:

- A stable/reusable non-toxic leach reagent having similar gold recovery rates to cyanide;
- Proven gold recovery plant and processes that enable gold doré bar production on site;
- Feasible and simple processing plant enabling small scale miners to recover fine gold without toll treatment or the need to use cyanide;
- A mobile leaching plant that has a significantly cheaper entry level cost compared with a carbon-in-pulp/carbon-in-leach plant;
- A mobile modular plant design that is the precursor to in-situ, heap, vat or tank leach plant designs;

- An option for countries that have banned the use of cyanide to recommence gold mining, and;
- An option for countries that tolerate the use of cyanide through lack of alternative, to transition to a non-toxic leach process.

“The successful validation in the field at scale of the leach reagent and technology has paved the way for commercialisation,” the authors said.

Commercialisation of the ‘Going for Gold’ process technology occurred in June, not too long after the thiosulphate process devised by CSIRO had produced Australia’s first gold using a non-toxic chemical process.

Clean Mining will deliver the new technology solution to a global market of gold producers, offering technology products and licences as well as turn-key processing plant options, plus equipment and product support throughout the

Earlier this year, FLSmidth looked to broaden its gold processing offering with the addition of Barrick Gold’s AuTec Innovative Extractive Solutions. Dan Gleeson put some questions to Wayne Douglas, Director of the FLSmidth Minerals Testing Center, to find out more about the rationale for the acquisition.

IM: How will the acquisition of AuTec enable FLSmidth to cope with the increasing complexity of gold-bearing orebodies?

WD: With AuTec as an integrated part of FLSmidth, we will continue to work quickly and in an agile way to respond to each challenge as it is presented by the industry. This will happen through using our advanced mineralogical characterisation tools to develop the needed appropriate metallurgical process. I believe we will continue to see an increase in the refractory nature of new deposits. The AuTec acquisition brought over 100 years of experience pertaining to development and selection of the optimum oxidation processes and downstream treatments required for these complex gold ores.

More importantly, personnel have seen these processes from benchtop test work, piloting, demonstration plants, through to commissioning and optimisation of some of the largest refractory gold process plants. Adding this expertise to the existing world-class flotation, leaching, separation, comminution, and ore characterisation team allows FLSmidth to provide practical solutions for any simple or complex gold ore.

This development comes at the same time as the game-changing Rapid Oxidative Leach process (ROL) is reaching the milestone of a demonstration-scale plant. ROL, in short, makes it possible to develop mineral deposits containing arsenic for recovery of copper, gold, and silver, while complying with stringent environmental regulations. ROL also allows for recovery from waste streams, and piles containing arsenic can be processed on site. This makes it possible to avoid potentially toxic emissions to soils, air and water. In combination with the new expertise from AuTec, this gives FLSmidth an unrivalled offering towards gold customers.

IM: What technology/processes within AuTec will, for example, allow you to provide advice or engineering on how to process sulphide-bearing orebodies, or preg-robbing ores?

WD: The AuTec acquisition provides both the equipment and proven expertise in full flowsheet development of both single and double

refractory gold orebodies. Capabilities include a pilot autoclave, benchtop autoclaves, benchtop roasting, as well as downstream treatment and leaching to maximise metals recovery in even the most complex orebodies or novel flowsheets. Additional analytical instrumentation and methods were obtained to provide the necessary support. Coupled with existing FLSmidth Mineral Testing and Research Center capabilities, we can provide full ore characterisation with metallurgical testing and plant support from comminution through tailings.

IM: The use of cyanide within the gold processing field has become a hot topic in the past decade or so, with many companies developing alternative lixivants or ways to recycle/reduce cyanide consumption: How will AuTec help facilitate the move towards using less cyanide?

WD: There are various mineralogical and process conditions that create a high cyanide consumption that require special attention to achieve required efficient metal extractions. AuTec has utilised and helped develop a few of these technologies to minimise cyanide usage. The technical experts that have joined FLSmidth from AuTec have brought the skillset to optimise current processes or develop new technologies to address this issue.

It should also be noted that the AuTec group helped to develop, pilot, and commission the thiosulphate leaching process being utilised by Barrick Gold’s Goldstrike mine. Personnel have been involved with examining alternate lixivants for the last three decades. We look forward to continuing to work with our customers as they look to meet their challenges.

IM: How will the combination of AuTec and the existing gold extraction capabilities of FLSmidth differentiate you from your peers?

WD: The combination of strengths will give customers a one-stop shop for all their ore processing needs.

The addition of the AuTec team gives FLSmidth an unrivalled depth of expertise in the gold and precious metals sectors. It allows us to provide processing solutions to even the most challenging gold orebody, making us partner of choice in providing solutions to the gold industry. Whether undertaking test work to develop a new deposit, selecting the appropriate equipment to meet production challenges, through to maximising productivity of an operating site, FLSmidth has every base covered.



As part of the thiosulphate process at Goldstrike, gold-bearing, sulphur-based ore is heated as a thick slurry of ore, air, water and limestone in large pressure chambers or autoclaves and then pumped into the 'resin-in-leach' circuit that takes place inside large stainless steel tanks, according to CSIRO

mine life, according to CSIRO.

"This new technology literally delivers a new gold standard for the global gold industry," CSIRO said.

Clean Mining is currently in negotiations with ICA Mining Services, in the Northern Territory of Australia, to commission the first commercial plant to process gold using this technology, and with Nu-Fortune Gold to commission a plant, in

the Goldfields of Western Australia.

EnviroLeach Technologies believes its own patent-pending process can provide a more environmentally friendly and safe alternative to the 66,000 t/y of cyanide used in the mining industry and has recently carried out testing to prove how it can compete with the lixiviant from a recovery perspective.

The company's patent-pending process sees material prepared using separation, grinding and classification before the ground material is dissolved in the lixiviant for a pre-specified time. The metals are then recovered from the solution using ion exchange, carbon absorption,

electrowinning or precipitation. Following this, the precipitate, carbon or electrodes are refined to recover "999 gold", plus other strategic metals.

The company claims it owns the "only cost-effective alternative to cyanide", which has a broad applicability in most ores, offers fast leach kinetics, and is environmentally friendly and sustainable.

In recent studies carried out by the company and SGS on two separate samples of high-grade ore that compared the EnviroLeach process with cyanide, EnviroLeach outperformed cyanide on both overall recoveries and leach kinetics, according to the company.

Twenty-four-hour leach tests were performed as part of a continued strategic collaboration between the company and several gold producers. The tests were conducted on high-grade ore and flotation concentrates using the EnviroLeach formula compared with a high-grade 5 g/l cyanide solution. SGS was contracted to conduct the cyanide leach tests for the comparison.

The tests on the high-grade ore sample, with an assayed gold head grade of 675 g/t, showed the most favourable results with the EnviroLeach formula attaining gold recoveries of over 99% in under six hours, with cyanide attaining recoveries of 94% in 24 hours.

Testing of flotation concentrate with an assayed gold head grade of 55.1 g/t showed high gold recoveries of over 90% by EnviroLeach in six



Join the [R]evolution

Vancouver, Canada. September 22-26, 2019

<https://www.sagconference.com/>



NETWORK. EDUCATE. SHARE.

The premier global event for Semi-autogenous and High Pressure Grinding Technology.

The SAG Conference event brings together all those engaged in the field of autogenous, semi-autogenous and HPGR grinding in the industrial and metalliferous mineral industries. SAG 2019 conference theme (R)EVOLUTION reflects incremental and step change improvements in SAG and HPGR technology.

MEI Conferences

Flotation '19

Cape Town, South Africa, November 11-14, 2019

Sponsored by: Magotteaux, Maelgwyn Mineral Services, FLSmidth, Axis House, Promet101, Metso, Glencore Technology, Eriez, Outotec, BASF, Clariant, Kemtec, ZEISS, Senmin, Hudbay Minerals, Nouryon, Solvay, Festo, Minerals, International Mining & Imformed

Comminution '20

Cape Town, South Africa, April 27-30, 2020

Sponsored by: King's Ceramics & Chemicals, Russell Mineral Equipment, Keramas, Grinding Solutions, Glencore Technology, Starkey & Associates, ME Elecmetal, Derrick Corp., ZEISS, Hudbay Minerals, Magotteaux, FLSmidth, Outotec, CEEC, International Mining & Imformed

Biomining '20

Falmouth, Cornwall, UK, June 8-9, 2020

Sponsored by: International Mining

Sustainable Minerals '20

Falmouth, Cornwall, UK, June 10-11, 2020

Sponsored by: FLSmidth, International Mining & CEEC

Hi-Tech Metals '20

Cape Town, South Africa, October 12-13, 2020

Sponsored by: Zeiss & International Mining

Process Mineralogy '20

Cape Town, South Africa, October 14-16, 2020

Sponsored by: Zeiss, FLSmidth & International Mining

www.min-eng.com/conferences/
E: bwills@min-eng.com



hours, with cyanide providing similar recoveries in 30 hours, EnviroLeach said

The company currently estimates its process is applicable to over 80% of mining/extraction methods, yet it is working on a new in-situ leaching application that could expand this further.

Kell progress

In this same feature two years ago, we reported on developments of **Kell Process'** hydrometallurgical process, a treatment option for the recovery of platinum group metals (PGMs), gold, silver and base metals from flotation concentrates to refined products on site.

Since then, the process, which is cyanide-free and can eliminate emissions of sulphur dioxide, arsenic trioxide and other toxic elements often emitted by smelters and roasters, has been demonstrated in a nine-week pilot program at Simulus Laboratories in Perth, Australia.

This 1:1,000 scale campaign supported a bankable feasibility study for a 110,000 t/y plant treating a UG2 Meresky concentrate at the Pilanesberg platinum mine, owned by Sedibelo Platinum. Sedibelo, along with the South African Industrial Development Corp, are investors in Kell Process.

At the same time as this, Zimbabwean Mining Development Corp has signed an agreement with the company for a centralised PGM concentrate processing plant.

Kell is a patented four step process involving aqueous pressure oxidation, atmospheric leaching, heat treatment and atmospheric oxidative leaching. It typically recovers a higher percentage of value metals (around 94-99% for platinum, palladium, rhodium, gold, nickel, cobalt and copper) than smelter refining or cyanide leaching, according to the company.

In addition to the two agreements Kell Process has in place, further test work and engineering studies for Kell applications at several other producers and development projects are being progressed, according to the company. This is for a range of concentrates, including PGMs, refractory gold and silver, copper-gold and polymetallic.

Efficient cyanide use

While there are several trends pushing miners away from the use of cyanide, there is still a reluctance to completely move away from using the lixiviant.

Still, whether it be for financial or environmental reasons, all companies using cyanide are keen to reduce the amount they are using: a tricky proposition considering the gold-bearing ores coming into the market are increasing in complexity.

The presence of cyanide-soluble base metals such as copper and zinc in gold concentrates are becoming much more commonplace, according to BQE Water. These metals form weak acid dissociable (WAD) complexes with the cyanide and preferentially compete for cyanide, the company said. This typically means that, in order to effectively extract gold from the concentrate, more cyanide must be added to the solution – bringing about financial and environmental costs.

BQE Water has taken the SART process, developed and commercialised by Lakefield Research (now SGS Canada), and is applying it to mining projects suffering such problems.

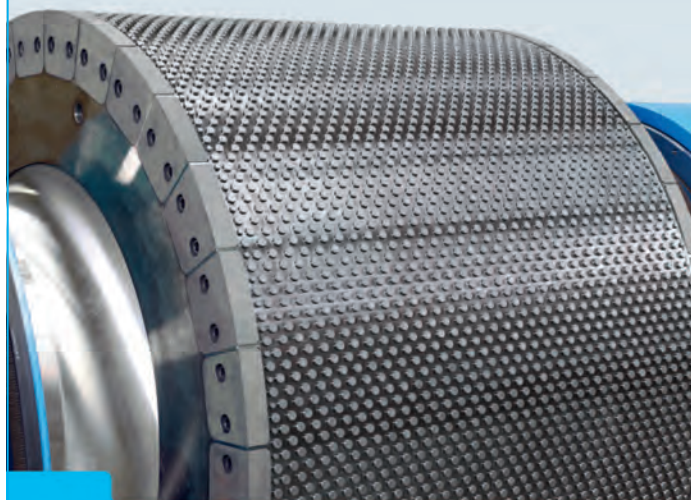
As Kratochvil explains, "SART comes in because it avoids the negative interference of base metals in the extraction of precious metals."

SART, specifically, breaks the base metal bond from the WAD complex and precipitates the metal as a commercial-grade concentrate. The cyanide is regenerated as free cyanide and recycled to the gold extraction circuit.

Kratochvil provided two examples that best displayed the results of BQE's SART work to date:

"The SART at the Mastra mine, in Turkey, where the process permitted gold production from the part of the orebody, which helped access cleaner gold mineralisation while achieving a payback of less than six months on the SART plant investment.

Köppern



Grind down your maintenance costs



Köppern roller presses have been proven successful throughout the world in plants specializing in the cost-saving high pressure comminution of various ores like iron, copper, gold, diamond, molybdenum and lithium ore. The Köppern Hybridur® tires feature an extremely wear-resistant surface that provides enhanced roller protection when grinding abrasive ores.

Köppern – Quality made in Germany.

- » State of the art HPGRs and wear protection
- » Process technology know-how
- » High plant availability
- » Low maintenance cost

Pilot HPGR testing capabilities in Australia, Canada, Germany and Russia

For further information please contact
sales@koeppern.de

www.koeppern.de

As gold-bearing orebodies continue to become increasingly complex, processing technologies such as bioleaching are, again, being looked at to solve processing problems. BIOX is a process that has been around for more than 30 years, over that time establishing itself as a proven technology that can aid gold recovery through the pre-treatment of sulphide-based refractory orebodies. Since 2015, the process has been further developed by Outotec, a global leader in minerals and metals processing.

Dan Gleeson spoke with Jan van Niekerk, Senior Manager, BIOX, Outotec, to find out a little more about the technology and how it has helped produce over 22 Moz of gold since its launch in 1986.

IM: What are the main reasons customers are currently looking to incorporate Outotec's BIOX process into their flowsheet? Is it purely to improve gold recovery?

JvN: If you have a refractory orebody, you need a pre-treatment process to destroy the sulphides and liberate the gold. Otherwise you are not going to get the required gold recovery.

Outotec is in a unique position in that it has all three of the main oxidative pre-treatment processes as part of its offering – BIOX, pressure oxidation (POX) and roasting. We can offer all three and evaluate them for the client in an objective manner. This is one of the reasons Outotec is becoming a leader in the treatment of refractory orebodies.

BIOX, specifically, offers some real advantages to clients, especially for small to medium-sized projects, or projects in remote locations. That isn't to say BIOX cannot compete with other technologies for bigger projects, but those are not in the sweet spot.

This is because BIOX offers lower capital costs than POX and roasting due to its relative simplicity; it has less process controls and uses standard atmospheric tanks operating at 40°C. It is also a simpler process to operate and maintain for the same reason. For remote locations, it means your spares holdings are lower and you can use local labour for plant operation. The process is also safer as you are operating at lower temperatures and pressures.

Mostly, BIOX is also environmentally favourable; it produces a stable arsenic precipitate that can be deposited onto a tailings dam. We've proven that over the past 30 years of operation. For example, at Fairview, in South Africa, they are reprocessing an old tailings dam. They have checked the stability of the old precipitates and proven that it's as, or more, stable than what was originally deposited onto the tailings dam. I think the arsenic question has been answered in that respect.

IM: Out of the 13 BIOX plants successfully commissioned worldwide, which one has seen the biggest improvement in terms of recoveries, cost, consistency, etc? What do you put these results down to?

JvN: Plants like Fosterville, in Australia, and Fairview, in South Africa, have dedicated metallurgical teams that are constantly looking at process improvements. At those plants, you can really see the benefit of this – not only in the BIOX process, but for the full plant flowsheet – in terms of recovery and stability improvements.



The Runruno plant, in the Philippines, was the first BIOX plant based on the generation three design, Jan van Niekerk says

At most of the BIOX plants, you do see improvements over the years as operators get to know the process and get a better understanding of how to manage it.

We very often get asked the question, especially in the North American markets, if BIOX bioleaching can operate in cold climates. We have a reference – the Suzdal BIOX plant in Kazakhstan – that has been in successful operation for almost 15 years. This proves that the process generates enough heat, and, in fact, you still need to cool the BIOX tanks during winter and when the tanks are located outside of the building. The bacteria themselves are not exposed to the ambient conditions; they operate in the BIOX reactors where the temperature is controlled at 40°C. But it is important to understand the energy balance and ensure that it is working out in your favour. We design the plant for potential power failures where, in such extreme conditions, the pipelines or even the tanks may freeze over.

IM: As high-grade, easy-to-treat ores continue to fall in volume, are you finding more potential BIOX customers?

JvN: I think the gold price showing stability over the last few years at a reasonable level is probably a bigger push for the industry. The bulk of existing and new projects are still oxide projects – these are easier and cheaper to develop – but, there are a lot of projects looking at treating refractory orebodies and there are quite a few looking at going from an existing oxide deposit to the sulphide orebody below. At a lower gold price, they were not really looking at such developments.

IM: How has the technology and process evolved in the more than 30 years since BIOX was introduced to the market?

JvN: We're now on our fourth generation BIOX design.

The first generation was from the start of the technology, in 1986, up until to about 1995. In that period, we commissioned five plants and were still developing the technology. The focus was on understanding the



"SART comes in because it avoids the negative interference of base metals in the extraction of precious metals," BQE Water's David Kratochvil says

"Second, is the plant at Lluvia de Oro, which stood idle in the Sonora desert (Mexico) for almost a decade exposed to elements and was subsequently re-started with only a minor capital expense. This plant moved the goal post by demonstrating profitable SART operation at copper concentrations much lower than what the gold industry would think of as the cutoff for SART applicability."

BQE Water is on a mission to educate the wider community about SART's applicability in the mining sector, with Kratochvil saying, historically, SART would only be considered in situations when cyanide-soluble base metals such as copper and zinc are present at levels of around 10 kg/t of ore.

"What we see is that people underestimate the increased costs of not

process and bacteria, and what equipment and design to use. The generation one plants really proved the technical and economic viability of the process. The success of the Obuasi plant in Ghana – a large 1,000 t/d plant in a remote location – really established the process.

After 1995, the gold price fell and, over that period to the early-2000s, we only commissioned one plant. It took until around 2003 for the market to come back to life, when we started the design for two plants – Fosterville and Suzdal – both commissioned in 2005. The generation two plants were typically able to cope with higher sulphur levels and tonnages than their predecessors. Our basic design had been established at this point, so it was about finetuning the process. During that period to 2010, we commissioned six plants.

We then reviewed the commissioning and operating experience gained from those six plants to take what we learned into our generation three plants. As we knew the technology basis and the design and selection of equipment, we focused on operational issues to achieve ease of operation and improve maintainability. For example, we addressed ore variability in our design – very few plants operate at the design point for any period of time. We looked at the robustness of some of the equipment and developed our service offering to extend the life of the equipment. In the 20 years since we introduced BIOX, the industry, including the way engineering companies execute projects, had changed and we needed to adapt the way we worked with them accordingly.

Simultaneously, we started the development of our generation four design to achieve a major reduction in the capital and operating costs associated with the implementation and operation of the BIOX process. We focused on the main capital cost items; blowers, BIOX agitators and the construction materials of BIOX tanks. Regarding the operating costs, we wanted to reduce power required for agitation and aeration and cyanide consumption. This led to the development of a new agitation system that provides about a 20% reduction in power through optimal aeration and oxygen supply. We also developed our MesoTherm process that combines mesophile and thermophile bacteria to get lower overall cyanide consumption.

IM: Are there any generation four plants now running?

JvN: The Runruno plant, in the Philippines, was the first plant based on the generation three design. Although not commercialised at that time, the project team wanted to take advantage of the generation four agitation system and the potential savings achievable and decided to include that into the design of the plant. Fosterville has also replaced their older generation BIOX agitators with the new generation four units to achieve power savings.

IM: Has the industry requirements around cyanide changed and made you adapt your offering over the past 30, or so, years?

JvN: Yes, certainly the pressure for plants to manage their water balance has increased significantly. Part of our generation four developments – reducing cyanide consumption – is focused on that, but we have also

developed the ASTER process for this, which offers biological thiocyanate destruction to address the water balance and allow plants to recycle the water to be used in a BIOX plant. BIOX bacteria are very sensitive to cyanide and thiocyanate toxicity, but, whereas cyanide is relatively easy to destroy chemically, thiocyanate is not. We had to come up with a process to address that.

ASTER was developed as a biological means to do that. It is very efficient at destroying thiocyanate down to less than 1 ppm at a very low cost. There are three ASTER plants currently in operation, with a fourth one due to be commissioned soon. Fairview has the first ASTER plant, and the second one was installed for Suzdal; both of these plants treat tailings dam return solutions. Suzdal has tested up to 4,500 ppm thiocyanate in the feed to the ASTER plant that breaks that down to less than 1 ppm. The third plant is at Runruno where we are detoxifying the CIL tailings (destroying the thiocyanate) before it goes into the tailings dam to meet their water licence requirements. Fosterville has also selected the ASTER process to improve their water balance.

IM: How do you anticipate the process/technology continuing to evolve in the next decade?

JvN: I think it is all about being able to react to the complexity of the orebodies. Twenty years ago, a standard pyrite/arsenopyrite refractory orebody was considered difficult to treat. Nowadays, if we get a standard pyrite/arsenopyrite refractory orebody, we are very happy! Most of the orebodies coming to us have got organic carbon, so are double refractory, or has antimony, copper or other base metals within it. Orebodies are also more and more variable, and you need to be able to adapt your process to handle that.

Although usually outside our scope of delivery, we are investigating alternatives to cyanide. I believe cyanide is probably going to be around for a long time; it's just so efficient and easy to use and, let's be honest, relatively safe compared with some of the alternatives. But, as a lot of our customers are now asking for alternatives, a lot of our work will go into that.

The HITECC process that is used to mitigate preg-robbing and gold loss when treating double refractory orebodies, originally developed by Fosterville, is now in the Outotec business portfolio. We see more and more need for that type of process where you combine BIOX and HITECC to address preg-robbing when treating double refractory orebodies.

A new focus area for Outotec is to supply BIOX-tailored equipment. Historically, when BIOX was still part of Gold Fields and Biomin, we were only able to supply the technology. As part of Outotec, we can now supply the equipment as well. This can provide advantages for clients, such as a single point of contact for the full package and, in house, we can build our 30-plus years of experience into the design of the equipment, as well as the technology 'island'. I think there is a need for that on smaller projects – where clients are capital sensitive and don't have the money for large engineering companies – and equipment suppliers can provide a full technology package for the entire plant, or part of the plant.

having SART as part of the extraction process, even when base metal levels are lower, and choose to live with reduced margins rather than adopt SART," he said.

"You do have significant costs with tolerating the levels of cyanide in your process. It causes you to incur incremental costs, but people don't add these up and compare with the cost to implement SART."

The Mexico project – Lluvia de Ore – is a case he points to: "They are making money at levels that people did not think possible."

BQE Water could soon have another plant to add to its reference list, with GoGold Resources having recently contracted the company to build a SART plant at its Parral silver-gold tailings operation in Chihuahua, Mexico.

Construction is expected to be completed by the end of 2019 and, once the plant is commissioned, BQE Water will provide operations support services for a monthly fee for a period of three years.

Kratochvil concluded: "Hopefully, as more SART plants are built, the upside of SART becomes better quantified. Unless there are benchmarks, people can't really perform apples-to-apples comparisons or holistic lifecycle costs analysis for projects with and without SART, respectively."

We featured **GreenGold Engineering's** ReCYN™ process earlier in the year (*IM March 2019*), a process that, through an innovative resin-bead absorbent, reduces cyanide consumption by 50%, capturing free cyanide and recycling it back into the leach circuit, according to the company.

GreenGold CEO, Malcolm Paterson, was talking about applications in Indonesia back then, but at *ALTA 2019* he highlighted an Australia case study where the ReCYN process may lead to the re-start of a historic mine.

The Mt Morgan mine was an operation that, at the turn of the last century, was the largest gold and copper producer in the country, according to GreenGold.

"The legacy is the usual hole in the ground containing very low pH waters, which are also contaminated with copper and other metals," Paterson said. These waters require continuous detoxification before river discharge, at significant ongoing cost to the Queensland Government, he explained.

In 2018, Carbine Resources proposed a re-treatment program for the tailings that would solve the environmental problem and be economically positive, according to Paterson. The project, which incorporated the ReCYN process, failed to attract funding, partly due to excessive royalty obligation, he said.

Paterson says the rest of the flowsheet on this project was not optimised to take "full advantage" of the ReCYN Plant, resulting in high capital and operating costs.

"GreenGold has reassessed the process flowsheet and proposed a simplified version (without a flotation circuit, for example), optimising the use of the ReCYN process," Paterson told delegates. This saw costs drop and a different royalty arrangement – one that makes the project more financially attractive – proposed.

The project, which could produce 23,000 oz/y of gold over a 20-year life according to studies, is now undergoing a due diligence process, according to GreenGold.

Arsenic penalties

The processing of gold-bearing sulphides is also leading to the increased need to address the arsenic that comes with extracting the gold from these concentrates.

These sulphides contain arsenic in the form of arsenopyrite and other complex arsenic sulphide minerals, with the various forms released during processing. This arsenic is potentially dangerous to the environment and, in certain quantities, viewed as 'deleterious elements' by smelters.

DST says it has a different patented process that can address this problem: the GlassLock Process™.

"The penalty charged by smelters for taking high arsenic concentrate is very expensive," Howlett explained. "Our GlassLock Process comes in at a fraction of that price, so, if we can give the miner a 'value-add' by selectively removing and dealing with the arsenic, then it's a win-win for everyone."

DST's GlassLock Process deals with the arsenic by integrating it, in various forms, in a

vitrification mixture of commonly available reagents, such as silica or recycled glass and a source of iron, such as hematite, according to DST. "The mixture is then vitrified producing a meta-stable oxide system of which can hold up to 20% arsenic, depending on the form or arsenic being vitrified."

Briquetting is used to control the dust from the mixed product going into the glass making furnace. The briquettes also help to keep the surface contacts between the arsenic product and ingredients, after mixing, to create a homogeneous glass product, DST said.

"Any arsenic that may happen to volatilise can be recirculated in the system," the company added.

By using DST's GlassLock Process, arsenical compounds can be successfully and permanently stabilised from "their amorphous states", providing greater process control latitude, DST said. "The stability of glass offers a sequestration solution for arsenic that will hold over geological times, removing the need for waste disposal site monitoring, ad infinitum."

This has led to the arsenic content in the concentrate being reduced at >95%, according to DST, which, as Howlett said, can positively affect the price companies receive for their product from smelters and reduce their long-term environmental burdens.

DST has put this process to the test having, in 2016, constructed an industrial GlassLock Plant and demonstrated its technology on arsenic trioxide flue dust wastes produced in a copper smelting operation.

"During the tests, DST reached optimal processing conditions for the successful vitrification of arsenical material. The program demonstrated the stability of the produced glass, containing up to 20.4% arsenic while exceeding the US EPA's TCLP (toxicity characterisation leaching procedure) guidelines," DST said.

Since then, DST's arsenic vitrification program has continued to develop and reached the detailed engineering phase, in 2017, before, in March 2019, a 3,000 t/y plant was commissioned at a miner's processing facility in Africa.

"It's running every day, 24 h/d," Howlett said. "This plant was meant to handle 10% of their annual arsenic production needs. It was a proof of concept but is working within the smelter."

The plant has been performing well judging by the fact DST is expected to begin engineering of a full-scale installation by the end of the year, according to Howlett.

Fine gold recovery

AuStar Gold has been looking to breathe new life into some historic gold operations in Victoria, Australia, recently re-commencing gold processing at its Morning Star process plant.

At the same time as this, the company signed

an agreement with **Gekko Systems** to acquire a custom-made intense leach reactor for the processing of residual sulphide/gold concentrate. This pact with Gekko should enable increased overall gold recoveries from the process plant, and was the last remaining processing hurdle for AuStar, given the small component of non-free milling gold present in its ore, to maximise commercial gold recoveries, the company said.

The process plant at the Morning Star mine site uses standard gravity methods (enhanced by the recent investment in a high-speed centrifugal concentrator) to recover gold from the Morning Star and Rose of Denmark ores. "Through the gravity process, the gold room captures approximately 65% to 75% of the gold directly to bullion, with an additional 15% of fine free gold residing in the middlings as concentrate and up to 10% of fine free gold in the gold room table rejects," AuStar said.

The material containing the fine free gold (concentrate) not captured directly into bullion at the Morning Star plant is to be treated by Gekko Systems offsite, with expected recoveries in these two fractions of approximately 95% of the contained gold, the company said. This is expected to lift total gold recovered and sold from ore supplied to the mill to better than 90%, AuStar added.

A custom-made intense leach reactor made at Gekko's Ballarat facility and designed to suit Morning Star concentrate, went into operation earlier this year, with the company delivering 820 kg of concentrate for processing at the reactor as of June 11.

Gekko's line of intense leach reactors, branded the InLine Leach Reactor (ILR), came to prominence in 1997, with the introduction of the world's first intensive leach production unit, Gekko says.

The ILR is designed to optimise the recovery of gold and silver from high-grade gravity and flotation concentrate streams, with the company claiming the ILR has the highest unit recoveries of any concentrate treatment option available.

"The heart of the ILR's effectiveness is the horizontal rolling drum. This high shear mixing zone has been specifically designed to remove the attrition layer from the gold by speeding up cyanide access to the gold surface," Gekko says, adding that continuous removal of the diffusion layer significantly improves leach kinetics. "The Gekko ILR is the only intensive leach unit which attritions this layer."

Gekko continues: "The enriched oxygen zone ensures optimum dissolved oxygen levels are sustained, thus maintaining a high surface area for the solution/oxygen interface. Finally, the solution solid mixing zone allows for the most efficient chemical reaction." 