The Bacterial Oxidation (BACOX) Plant at Laizhou, Shandong Province, China
- The First Three Years of Operation

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ABSTRACT

By the year 2000, China was the sixth largest gold producer in the world, with about one-quarter of total production being derived from refractory or semi-refractory deposits. Although bacterial oxidation plants had been previously tried in China using unproven local technology, these plants had not been particularly efficient or effective. The Laizhou Gold Enterprise (Tarzan BioGold Co Ltd) located in Shandong Province, undertook to modernize their gold processing facility in 2000 with the introduction of Bacterial Oxidation Technology. In 1997 BacTech Australia and Mintek of South Africa had formed a technology partnership, combining forces in the provision of bioleach technology. Under a cooperation agreement, BacTech/Mintek were chosen as the preferred technology providers for this first application of commercially proven Bacterial Oxidation technology within China. The paper describes the successful operation of this plant over the last three years. The events of project implementation are described, from the metallurgical testing of concentrate; through to the commissioning at the design throughput of 100 tonnes per day. Process aspects of the operation over the last three years are discussed which illustrate the robustness of the operation. The success of the bioleach facility has led to an advancement of plans to double plant capacity and some of the innovations, which may be employed in this expansion phase, are discussed.

Introduction

Environmental regulations proposed within the Chinese gold industry suggest that the future use of roasting will be a less viable option for treatment of refractory gold ores (Worldbank 2003). China's current growth and quest for the introduction of new technologies for metallurgical processing has resulted in a re examination of techniques to increase gold production. For many years Bacterial Oxidation has been of significant interest in China as an alternative to roasting (Zhang 1992) and was previously trialed at semi commercial scale but with only partial success. These trials used local expertise to supply and implement the technique of bacterial oxidation with the aim of producing installations similar to bacterial oxidation facilities in other areas of the World.

Shandong Province has been one of China's leading gold producers for many centuries, initially from primary mining and treatment operations and more recently from secondary toll treatment of sulphide concentrates from all over China. In 1998 The Laizhou Gold Enterprise in Shandong Province, (now known as Tarzan Biogold Co Ltd), made the decision to introduce bacterial oxidation technology to its operations as a means of modernising its operation and introducing a competitive advantage to the enterprise. Without the use of oxidation pre-treatment, gold recoveries from some ores in the region is typically limited to about 20 percent recovery using cyanidation. In order to ensure the success of the Laizhou operation it was considered critical that the plant was designed in the West, utilising a proven technology and imported all of the latest equipment and technology, which was unavailable in China.

In 1997 BacTech and Mintek of South Africa had joined forces as a technology supplier of bacterial-oxidation processes for the treatment of sulphide ores. BacTech had earlier implemented the refractory gold process at the Youanmi Gold Mine in Western Australia (Bell 1997) and during 1998, BacTech/Mintek bacterial oxidation technology was incorporated into the Sulphide Treatment Plant at the Beaconsfield Gold Mine in Tasmania, Australia (Pinches 2000). The BacTech/Mintek partnership was appointed by Laizhou in 1998 to be the supplier of bacterial oxidation technology to the Laizhou Gold Operation with overall responsibility for technical aspects of the project from the metallurgical testwork through to assistance in plant start-up and achieving design throughput. This paper summarises the details of technology implementation and subsequent operation of the bacterial oxidation facility at Laizhou, which has been the first commercial use of proven bacterial oxidation technology in Asia.

Project Location & Background

The Laizhou Gold Enterprise of Tarzan Bio-gold Co Ltd is located in Shandong Province approximately 150km North of Qingdao and some 100km from the coastal town of Yantai. The area is well served by a road network with major roads being close to the proximity of the site, which is only a few kilometers from the coast. The site complex consists of an underground mine, a cyanide leach treatment plant, the Bactech/Mintek bacterial oxidation plant, and a gold refinery. Before the bacterial oxidation plant, the complex was treating about 120,000 ounces of gold per annum with 30,000 of these ounces being derived from its own underground mine and a further 90,000 ounces from toll treating other non refractory or semi refractory concentrates from all over China using direct cyanidation followed by refining. The objective for the bacterial oxidation facility was to produce an additional 80,000 ounces per annum from the toll treatment of highly refractory gold concentrates from around the region, to give a total site production of about 200,000 ounces per annum.

The climate at Laizhou is quite dry with only modest seasonal rainfall giving the need for more careful consideration of water usage than would be needed for other projects. Also the coastal location meant that more careful attention was needed to restrict the salinity content of process water to be used. In the last decade, the daily minimum temperature in January at Laizhou was recorded at between -8^{o}c to -12^{o}c with winds creating a chill factor, which reduce these temperatures further. In August the daily maximum temperatures noted over the same period have been between 32^{o}c to 36^{o}c combined with a high humidity due to seasonal rainfall.

The bacterial oxidation facility was to be integrated into the existing downstream gold recovery operations which consisted of cyanidation followed by zinc precipitation, with this being the traditional method of gold recovery in China as opposed to the use of Carbon in leach.

Metallurgical Testwork

Conducting metallurgical testwork is instrumental in providing plant design criteria, but the Laizhou plant was envisaged as a toll treatment facility in which the plant should be capable of treating future concentrates of undetermined composition. In April 1999 Bactech Australia Pty Ltd carried out testwork on two blended concentrate samples provided by Laizhou. These concentrates represented the most typical refractory concentrate blends to be treated in the short term by the plant and were derived from stockpiles available at this time. They were envisaged at this time as representing the “envelope” for design. One of the concentrates designated as sample “A” had modest arsenic content while the other designated as sample “B” had lower arsenic content. A summary of the composition of the concentrates is given in table 1 below:

Table 1 - Summary of Composition of Concentrates used for Metallurgical Testwork

Specification	Concentrate “A”	Concentrate “B”
Iron (%)	25.0	19.7
Arsenic (%)	6.7	3.8
Carbon Inorganic (%)	0.95	2.1
Carbon Organic (%)	0.15	0.35
Sulphide Sulphur (%)	24.6	19.7
Gold (g/t)	67	55
Calcium %	1.27	1.45
Magnesium (ppm)	3380	5200
Copper (ppm)	3010	982
Nickel (ppm)	310	235
Zinc (ppm)	1410	3800
Lead (ppm)	830	3450
Mercury (ppm)	6	60
Antimony (ppm)	415	125

Due to the limited knowledge of future concentrate compositions it was considered to be of limited value to conduct continuous piloting testwork to obtain design criteria specific to these concentrate types. The metallurgical investigation was therefore limited to conducting batch testwork. The objective of the work was to search for fatal flaws in the amenability of the samples to commercial bacterial oxidation processing and subsequent gold recovery. This was to be achieved by the interpretation of the physical; chemical; mineralogical characteristics and response to bacterial oxidation of the samples, using BacTech/Mintek’s previous experience gained from testing a large number of refractory gold concentrates over the previous 18 years.

The major findings of this programme of work were as follows:

- Both concentrates responded well to bacterial oxidation with gold extractions of 98% and 97% occurring on cyanidation of oxidised residues.
- The rates of oxidation noted during batch testwork were similar to other results noted from batch and continuous testing of other concentrates by BacTech/Mintek over the years, which had been translated into successful plant designs.
- A significant coarse fraction (>120um) was present in both concentrate types and regrinding of this fraction was required to ensure bacterial oxidation within an acceptable residence time.
- Although high gold recoveries occurred as a result of partial oxidation, a full oxidation was recommended to maximise gold recovery for these concentrate types
- Small amounts of organic carbon present in the samples were found not to be “preg-robbing” and suitable for gold recovery by cyanidation and zinc precipitation
- Minimal acid consumption would be required for continuous bacterial oxidation treatment of these concentrate types due to low carbonate values, but the carbonate present would be sufficient to supply carbon dioxide for bacterial growth in the primary reactors.

- Neutralisation tests on liquor showed that iron and arsenic were removed to negligible levels and precipitates subjected to TCLP testing passed equivalent US EPA requirements with respect to stability. Commercial Limestone consumption for liquor neutralisation was between 470kg/tonne and 400kg/tonne of concentrate dependent upon concentrate type.
- The presence of mercury was noted at levels of 60ppm in one concentrate blend but was shown as being benign during bacterial oxidation and not mobilised into the liquor.
- Low reagent consumptions for downstream gold recovery were noted with lime additions less than 5kg/tonne and cyanide consumption at 2kg/tonne of concentrate.
- A modest weight loss of about one-third to one half would occur during bacterial oxidation. Although this would reduce the size of downstream equipment this was not factored into the design.

Subsequent to the testing of these two concentrate blends, a sample of blended concentrate with higher arsenic content was also subjected to batch testwork and similar results were recorded as those on the previous two samples detailed above.

Design Criteria

The design envelope was for a plant with a nominal treatment capacity of at least 100 tonnes per day of concentrate. In January 2000, Minproc Engineers of Perth together with BacTech/Mintek were appointed to design a bacterial oxidation plant in which the technology would be supplied under a license agreement. The design would allow for later duplication of the bacterial oxidation tankage in order to expand plant capacity to at least 200 tonnes per day. The major design criteria used for this first phase of the project are given below in table 2

Table 2 - Major Design Criteria for Bacterial oxidation Plant

Data Specification	Units	Value
Concentrate feed	t conc./h	4.2
Received size analysis	$-F_{80}$ microns	75
Regrind product size analysis	$-P_{100}$ microns	103
	$-P_{80}$ microns	45
Bacterial oxidation Residence Time	H	144
Number of reactor stages		4
Number of primaries in parallel		3
Number of secondaries in series		3
Material of construction		SAF 2205
Average feed solids concentration	%w/w	16.3
Sulphide oxidation in primaries	%	65.5
Overall sulphide oxidation	%	95
pH range		0.9-1.4
Expected limestone addition	kg/t conc.	0
Average heat load per primary	KW	1524
Average oxygen take-up per primary	kg/h	409
Discharge soluble iron concentration	g/L	40.0

Average weight loss through oxidation	%	46.5
Average solids in discharge	t residue/h	2.2
CCD Circuit no of stages		3
Target Iron in washed slurry	g/L	0.5
Neutralisation no of stages		4
Limestone addition rate 80% purity	t/h	3.1
Cyanide consumption range	kg/t conc.	2 – 3

Project Implementation

As mentioned in the introduction, in order to ensure the success of the project, it was considered essential that the major items of equipment and specialised materials of construction were sourced from outside of China. An Australian company was responsible for much of this procurement, with the longest lead-time for delivery being the blowers required for aeration of reactors. Other key items comprised the SAF 2205 stainless steel required for the bacterial oxidation reactors and other tankage, agitators, the PLC and MCC, all piping and electric cabling, instrumentation; cooling tubes; launders; ancillary pumps; nutrient mixers and safety equipment. Procurement of these items began in June 2000 with sourcing by competitive tender from international suppliers.

Using the detailed design package supplied by Minproc, Shandong Tarzan Bio-gold managed the entire construction of the project using local contractors. Construction began in November 2000 with much of the construction therefore being undertaken in the winter months. Specialised contractors were used for specific areas of the plant such as the welding of the SAF 2205 steel and acid proofing of bund areas. Implementing an exceptional standard of high quality control and safety was a major feature during construction and was successfully managed by Shandong Tarzan Bio-gold personnel.

Inoculum growth on site began in February 2001 using one of the liquor neutralisation tanks of 80^3 m capacity, which had been completed early in the construction schedule for this specific purpose. The “first fill” of one of the primary reactors began in mid April and a continuous feed to the plant was started in early June. An incremental Ramp-up to full design capacity was initiated and completed by the end of August reaching the specified throughput of 100tonnes per day of concentrate treatment without any major difficulty.

Process Description

Concentrate Storage Washing and Regrinding

Concentrates are delivered by road to the main complex and weighed and assayed at the point of delivery before being designated an area for storage on a concrete pad. Quantities of concentrates are selectively reclaimed from this storage area according to their composition in order to create a suitable blend for the bacterial oxidation plant. Concentrate is fed by front-end loader into a hopper and is conveyed by screw feeder at a steady rate into a repulper. The repulped slurry is fed to a bank of cyclones with the cyclone underflow (material greater than 100um) being fed to the regrind mill. The regrind mill discharge reports to the cyclones, and cyclone overflow is washed and thickened. The washing operation was considered an important unit operation as no control could be exercised over flotation reagents used to produce off-site concentrates and provided effective removal of any unknown residual reagents before bacterial oxidation. The reground washed and thickened slurry is stored in an agitated feed tank of 24hours capacity at a minimum 50% wt/wt density for feeding at a controlled rate to the primary reactors.

Bacterial Oxidation

In line dilution with process water is made prior to the feed reaching a feed box for splitting between the primary reactors. Pulp density and flow rate is recorded for mass balance purposes. The final feed pulp density to bacterial oxidation is usually controlled at between 16%wt/wt and 20%wt/wt depending upon the concentrate feed blend. Concentrate blends of higher arsenic, iron and sulphide content are fed at a lower pulp density. The feedbox consists of a four-way splitter for distribution between primary reactors. There are six reactors with three acting as parallel primary reactors and the other three as secondary reactors in series to give a four-stage system. The four-way splitter allows feed to be directed such that three out of four reactors can feature as primary reactors at any time allowing for maintenance schedules when any one reactor is removed from service. The feed slurry is directed through a flexible hose to each of the discharge compartments of the splitter box by timer-actuated position. The time for which the flow is directed to each compartment can be set such that if necessary primary reactors can receive different rates of feed. The ability to feed primary reactors at different rates is considered a desirable feature and has not always been available on previous plant. Nutrient additions and any acid requirements (dependent upon feed) are made to the splitter box simultaneously. The slurry temperature within the reactors is normally maintained at between 40^0c to 45^0c by banks of cooling coils located in each tank. Cooling water is supplied to each set of cooling coils from a single header feed from the main feed line. The cooling coils also acts as baffles in each tank and are supported by brackets off the tank walls. Each reactor has a nominal working volume of approximately $700m^3$ and Lightnin agitators are used on all reactors with 185kw motors on primary reactors and 132kw and 90 kW motors on the last two secondary reactors. Two blowers are available to feed air through a central header pipe with off takes to each reactor for sparging. Partially oxidised slurry is transferred between the stages of oxidation by deep launders as opposed to airlifts as the launders are able to cope better with foam. Slurry from the final oxidation reactor flows to the counter current decantation (CCD) circuit

Downstream Processing

A three-stage CCD circuit is used with the objective of reducing the soluble iron to below 0.5g/l in the thickened slurry proceeding to gold extraction. All underflow pumps are peristaltic pumps fitted with variable speed drives. A mass flow meter is used to monitor the underflow residue tonnage leaving the CCD bacterial oxidation circuit for mass balance purposes. Flocculent addition is automatically metered to promote settling with overflow from the first CCD thickener reporting to liquor neutralisation. Liquor neutralisation is conducted in a series of four agitated and aerated reactors to precipitate iron and arsenic using local limestone slurry to achieve a final pH of 6.5 over a 6-hour period. An unusual feature of the Laizhou plant is that the resulting iron arsenic precipitate is then filtered in order to recycle the maximum amount of water back to the process and minimise the volume of precipitate reporting to tails disposal. Two plate and frame filter presses are used for this duty, operating in alternative cycles of loading and discharging with filter cake precipitate being handled by a front end loader for disposal to the tails area by trucks. In a similar fashion, the thickener underflow of oxidised residue from the CCD circuit also reports to plate and frame filter presses prior to cyanidation. This dual action of using both a CCD circuit combined with filtration is a possible aid to reducing cyanide consumption by minimising carry-over of soluble components which can act as cyanicides and also maximises water for re-use within the washing and liquor neutralisation circuit. Antifoam additions are necessary in cyanidation to prevent excessive foaming, which is a phenomenon often noted in the treatment of bacterial oxidation residues. As mentioned previously gold is recovered using zinc powder as the traditional method used in China. The cyanide tails are also filtered to produce a cake for disposal, which once again allows maximum retention of water within the cyanide circuit.

Plant Operation

Training

High caliber graduates with experience of the existing Laizhou operation had been specially selected by Shandong Tarzan BioGold as operators for the bacterial oxidation plant in which a three-shift system was envisaged. Daily training began early in the project, at the start of inoculum development, in order to familiarise future operators with the sampling and monitoring techniques that would be required on the bacterial oxidation plant. Comprehensive training manuals were provided by BacTech/Mintek and daily tuition classes held with operators through the progression of commissioning. Tarzan BioGold had constructed an extensive laboratory facility on-site with state of the art analytical equipment as part of the capital investment for the bacterial oxidation project. High quality graduates also manned the laboratory with experience in microbiology and chemical analytical techniques. This resulted in a very comprehensive on-site analytical capability during commissioning and for routine plant monitoring. Importantly the laboratory has the capability for testing the amenability of new potential concentrates for treatment by the bacterial oxidation facility.

Process Operation

The challenges, which arose during commissioning and during the last three years for which the plant has now been operating, have been relatively minor. A greater attention to the blending process of different feed types prior to treatment in order to minimize short term feed fluctuations was found very beneficial in increasing the stability of plant operation. More recently this has been found to be of particular importance when treating concentrates, which have high arsenic content in order to maintain a high plant throughput. The initial 12hour concentrate stock tank storage was found to be inadequate for downtime maintenance on the regrind circuit and additional storage tank of equal capacity was installed to give a 24-hour storage capacity. Foaming in the primary bacterial oxidation reactors was an issue during plant start-up and occurred when additions of feed were made during fed batch mode and and when increases were made to the feed rate to reach design throughput. However during a steady state condition of operation foam formation is relatively minor and adequately handled by the launders used for transfer of pulp between reactors. While the use of bacterial tolerant antifoam was found very effective during commissioning, it was also uneconomic to use in the quantities required to manage the foam effectively. An innovative system of low volume water sprays in strategic locations within the reactors in combination with the launders was found to be an effective solution to manage foam formation during commissioning.

No major mechanical issues have arisen on the project. One of the agitators on the secondary reactors was found to have an unusually high power draw, but a small correction in the speed of the agitator rectified this problem without impairing the oxidation performance of the reactor. The reactors are enclosed in an acid proof bunded area designed to withhold any spillage from reactors. The successful management of foam during commissioning has minimised spillage but short periods of very high rainfall can result in a high volume of water reporting to the bund area. The original design made provision for discharging the contents of the bund into one of the secondary reactors. However this can result in considerable dilution of the bacterial oxidation pulp and effective loss of useful oxidation capacity. To avoid this situation this water was directed into the CCD circuit to be used as wash water and avoid unnecessary dilution of the pulp in the reactors.

Although a clear overflow was obtained from the CCD circuit, a locally sourced flocculent was used which was common to other areas of the Laizhou plant. High flocculent consumptions were a feature of the operation and resulted in a decision to change to an international brand of flocculent, which consequently reduced flocculent usage and gave a more consistent quality to the oxidised solids both in terms of settling and filtration qualities prior to cyanidation.

In the initial start-up of the liquor neutralisation section, sedimentation of solids was noted resulting in solids accumulation in the last two stages. Although relatively small agitator motors are used on these tanks they were sized correctly for the duty of liquor neutralization and suspension of the resulting iron arsenic precipitate. The quality of the limestone being used in neutralisation was investigated and found to contain quantities of coarse grit, which the agitation was unable to suspend. A change in the type of limestone used corrected this problem of solids accumulation

Future Developments

The bacterial oxidation plant at Laizhou is one of only a few established facilities, which have the capability to treat refractory gold concentrates within China. As a result more mines are now examining the potential to produce arsenical pyritic concentrates from areas, which have not been previously exploited due to limited means for processing these ore types. The success of the Laizhou operation has led to a decision to accelerate the original plans for expansion. Already construction is well advanced to provide additional reactors, which would result in a 200 tonne per day bacterial oxidation treatment facility.

Many of the Chinese concentrates are particularly high in arsenic and advancements made by Bactech in treating such concentrates may be incorporated in a future facility. The use of inter-stage thickening between reactor stages in order to remove bioleach liquor and replace with fresh process water has been found to be effective in increasing oxidation rate particularly when treating these types of concentrates. A finer grind size has also been found effective at improving oxidation rate at minimal cost and is a further development, which may be incorporated into the expansion. The low cyanide consumption is a notable feature of this project in comparison to many previous bacterial oxidation plant and although this is somewhat dependent on the type of feed used, aspects of the design which contribute towards a lower cyanide consumption will also be used in future plant.

Changes are also occurring to the structure of the Tarzan BioGold Enterprise in which BacTech Mining Corporation will now take an equity interest in the venture through Sydney based Michelago Ltd. The strong relationships developed over the last four years in China combined with operational experience gained has resulted in an alliance between BacTech and Tarzan BioGold to joint venture new projects in China amenable to Bacterial oxidation treatment.

Acknowledgements

The authors wish to thank all of the persons of Tarzan BioGold who contributed towards the success of the project and in particular the Director Mr. Zhang An Kang. The input of Mr. Peter Secker of Michelago Limited and Moya Zhang is also acknowledged for ensuring the success of the bioleach project. Acknowledgment is also made to Minproc Engineers in Perth Australia for their plant design work.

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