THE ASTER PROCESS : TECHNOLOGY DEVELOPMENT THROUGH TO PILOTING, DEMONSTRATION AND COMMERCIALIZATION

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Abstract

Environmental legislation associated with the land disposal of cyanidation tailings and water discharge is becoming increasingly stringent world-wide, thus enforcing the treatment or recycling of contaminated water streams.

Micro organisms used in the bioleaching of sulphide minerals in particular, have a low tolerance to thiocyanate and cyanide species making the recycle of contaminated process water to the BIOX® plant impossible.

Laboratory and pilot scale testing of the ASTER process on 0.08, 6 and 25m^3 scale reactors at Fairview and Segala Gold plants yielded > 98% SCN^- removal. Based on the success and process robustness demonstrated during the various pilot runs, Barberton Mines decided during 2009 to go ahead with a full scale ASTER plant to treat contaminated water at the Consort Plant.

As part of commercialisation of the ASTER technology, a detailed Technology Mind Map was developed to ensure a comprehensive product package that develops a fundamental understanding on the process, a competent and flexible process design and also pathways for continual improvement of the technology. To facilitate the fundamental process aspects, a development program between Gold Fields and the University of Cape Town (UCT) was initiated which draws on advanced microbiological analyses and sequencing techniques. The first phase focuses on optimising the process conditions and effects of heavy metals and cyanide, and a second more fundamental phase involves modelling and characterisation of the microbial consortium.

The Consort ASTER Commercial Plant has a full capacity of 320 m^3/d tailings solution and a retention time of 12.5 hours. The plant is designed for SCN^- and CN^- concentrations of 120 ppm and 20 ppm respectively. An average minimum feed temperature of 12.5 ^oC and the reactor operating temperature of 24^oC was designed for. This plant was commissioned in September 2010.

The success of the Consort ASTER Plant and the outcome from the UCT test program will render an ASTER Generation 1 process commercially ready.

Introduction

Environmental legislation around process water disposal as well as fresh water availability for usage is becoming increasingly stringent forcing mining operations to be more prudent around their process water mass balances and upstream recycling. For bio-oxidation plants in particular, the restrictions are more severe as any possible recycled process water needs to be free of thiocyanate, cyanide and other toxic metals.

Various processes exist for treating cyanide; and to a lesser extent the usually accompanying thiocyanate; and may be categorised as a recovery process, or a destruction process. The latter processes typically involve the breaking of the carbon nitrogen bonds thereby destroying the cyanide species producing less toxic species.

Some of the more familiar and well established chemical cyanide destruction processes are summarised below :

Process	
Inco Sulphur Dioxide Reaction Description	 $SO_2 + O_2 + H_2O + CN^- = OCN^- + SO_4^{2-} + 2H^+$ Relatively high reagent consumption (SO_2, lime and Cu) Careful pH control is required. Poor removal efficiency for SCN^- (20 %).
Hydrogen Peroxide Reaction Description	 $H_2O_2 + CN^- = OCN^- + H_2O$ Relatively high reagent costs due to H_2O_2 consumption. No thiocyanate removal.
Caro's Acid Reaction Description	 $H_2SO_5 + CN^- = OCN^- + 2H^+$ The acid decomposes very quickly and typically needs to be produced on site using sulphuric acid and hydrogen peroxide. Acid produced is typically neutralised with lime. Some thiocyanate removal is possible and occurs.
Alkaline Chlorination Reactions Description	$Cl_2 + CN- = CNCl + Cl$ $CNCl + H_2O = OCN^- + Cl^- + 2H^+$ $4Cl_2 + SCN^- + 5H_2O = SO_4^{2-} + OCN^- + 8Cl^- + 10H^+$ This process is very effective at removing cyanide to quite low levels but is seen as being expensive owing to the high reagent consumptions. Oxidation of thiocyanate is also possible when excess chlorine is present but leads to very high consumptions of chlorine. The reactions occur typically at a pH greater than 10 to ensure cyanogen chloride is completely hydrolysed and the process yields low levels of cyanide.
Ozonation Reactions Description	 $CN^- + O_{3(aq)} = OCN^- + O_{2(aq)}$ $3CN^- + O_{3(aq)} = 3OCN^-$ The advent of using ozone for the destruction of cyanide is becoming frequently examined, as ozone generators become increasingly more simple and available. Ozone is a more effective oxidant than oxygen and reacts with cyanide to produce cyanate Oxidation of thiocyanate is also possible.

Biological degradation of cyanide using various species of bacteria, fungi and algae are also known to enzymatically oxidise cyanide. Homestake Mining in the late 1990's demonstrated an efficient biological treatment step for the removal of thiocyanate, cyanide and cyanate.

Of the aforementioned processes, quite established treatment stages for the degradation of cyanide are described, and to a lesser extent - if at all possible, degrees of thiocyanate oxidation have been demonstrated. Those that do show a suitability to remove thiocyanate, such as the alkaline chlorination process, is however complex, reagent intensive and may concomitantly introduce chlorine disposal as an additional process consideration.

In the case of certain bioleach effluent streams, the reaction of cyanide with reactive sulphide and partially oxidised sulphur surfaces inadvertently produces more thiocyanate and lower residual cyanide making most of these processes technically unsuitable, and those that are, economically unfavourable. Moreover, the degrees to which thiocyanate is produced is significant, ranging anywhere from 20 ppm to 5 g/l.

To this end, Gold Fields (together with BHP Billiton) has developed an activated sludge process called ASTER (Activated Sludge Tailings Effluent Remediation), which has shown to effectively degrade these concentrations of thiocyanate. No other biological treatment process is published to work at such high concentrations. The reaction pathways that are believed to occur are initially the hydrolysis of thiocyanate:

$$SCN^- + H_2O \ = HCNO + HS^-$$

Thereafter, the hydrolysis of cyanate and the oxidation of sulphide follows :

$$HCNO + 2H_2O \ = NH_4 + HCO_3^-$$

$$HS^- \ + 2O_2 \ = SO_4^{2-} \ + H^+$$

The overall reaction can be expressed as :

$$SCN^- \ + \ 3\,H_2O + 2O_2 \ = HCO_3^- \ + NH_4 + \ \ SO_4^{2-} + H^+$$

This paper describes the development testwork, some piloting results and the recent demonstration plant commissioned as the first large scale up of the ASTER technology.

Dominant Microbial Species Of The ASTER Consortium

The microbial culture for the ASTER process was isolated at the Barberton Mines, Fairview Plant and is constituted as a number of composites of organisms drawn from the tailings dam during the 1990's.

These organisms were cultivated internally and the dominant species identified over the last decade is shown in Table 1 below.

Table 1 : ASTER organisms

Microbial Culture	**Identified by**	**Reference**
Fusarium oxysporium	GFL	du Plessis et al., 2001
Ralstonia eutropha	GFL	du Plessis et al., 2001
Bosea thiooxidans	GFL	du Plessis et al., 2001
Sphingomonas paucimobilis	GFL, Homestake	
Pseudomonas stutzeri isolate OC-10		Watanabe et al., 1998
Pseudomonas alcaligenes strain HPC 1032		

Spumella-like flagellate		
Microbacterium schleiferi strain 118	UCT	
Acinetobacter sp. ST-01 or Acinetobacter venetianus strain L17	UCT	Barberio and Fani, 1998; Vaneechouette et al., 1999).
Pseudomonas fluorescens strain KDK8		
Candida humulis or Kazachstania sp.		

Fusarium oxysporium is a fungus and has previously been shown to degrade cyanide. The pathogenicity of this fungus was reviewed and tested by the Agricultural Research Council, Biosystematics Division and Plant Pathology Division and was found to be non pathogenic for all plants tested.

The three thiocyanate degrading bacteria were positively identified *as Ralstonia eutrophia, Bosea thioxidans* and *Sphingomonas paucimobilis* (du Plessis et al., 2001). *Sphingomonas paucimobilis* has been identified as the organism responsible for the degradation of cyanide in the Homestake process (Patent Number 4 461 834).

P. stutzeri has been confirmed to contain a nitrilase enzyme capable of the direct conversion of cyanide to ammonia and formate (Watanabe et al., 1998). Also, more recent analyses have identified organisms, particularly from the genus *Pseudomonas* which have been confirmed as cyanide degraders.

Members of the *Acinetobacter* genus have been isolated from varied habitats, ranging from seawater to activated sludge reactors in sewage treatment plants. They have been extensively studied for their ability to degrade a wide range of environmental pollutants, particularly petrochemicals, analine and a range of phenolic and halogentated phenolics (Barberio and Fani, 1998; Vaneechouette et al., 1999).

The presence of the *Microbacterium*, flagellate protozoan and yeast (*Candida or Kazachstania*) species in the samples are not directly related to the presence of cyanide or thiocyanate, but are likely to be facilitated by the addition of molasses. Protozoans were detected in previous analysis of ASTER samples and are likely to exist in environments with high bacterial populations. Neither the yeast species nor the *Microbacterium* has been recorded in literature as degrading cyanide species.

Technology Development

Testwork development commenced using two aerobic approaches; viz., an attached microbial growth system as well as a reactor based activated sludge system. The former concept was shown to be less effective and less robust and development work was discontinued.

Initial work was aimed at screening the ASTER culture through a series of thiocyanate concentrations which were synthetically prepared. This developmental work was conducted in a small laboratory glass test unit consisting of an air suspension reactor with a volume of 4 litres which cascaded into a clarifier which served to settle the sludge which could be purged and / or returned to the reactor. Figure 1 shows a depiction of the test unit alongside the actual unit.

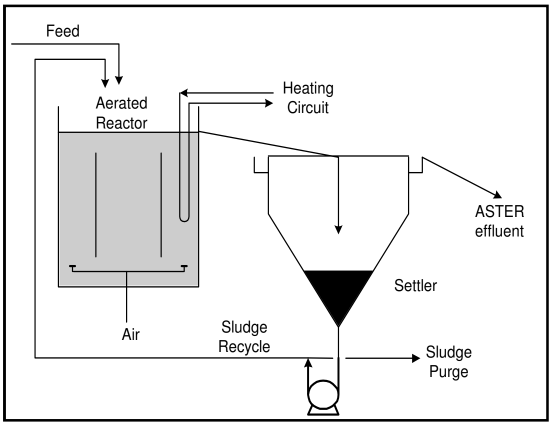

Figure 1 : Schematic and Actual Developmental Scale Unit

The clarifier acts as a static settler and separates the degraded solution into a clear product overflow and a thickened sludge which is circulated back to the reactor to ensure an active bacterial culture. Owing to the presence of residual cations in some solutions, the settler underflow was designed to allow for the purging of concentrated sludge to avoid any heavy metal accumulation once adsorbed onto the sludge.

The reactor was equipped with a heating coil to maintain the sludge at temperatures above ambient if required. Compressed air is injected into the reactor and the airflow was controlled at a certain level to maintain adequate sludge suspension. The results of the thiocyanate screening tests are shown in Figure 2. The graph also shows the biomass concentrations, measured as dried biomass per litre.

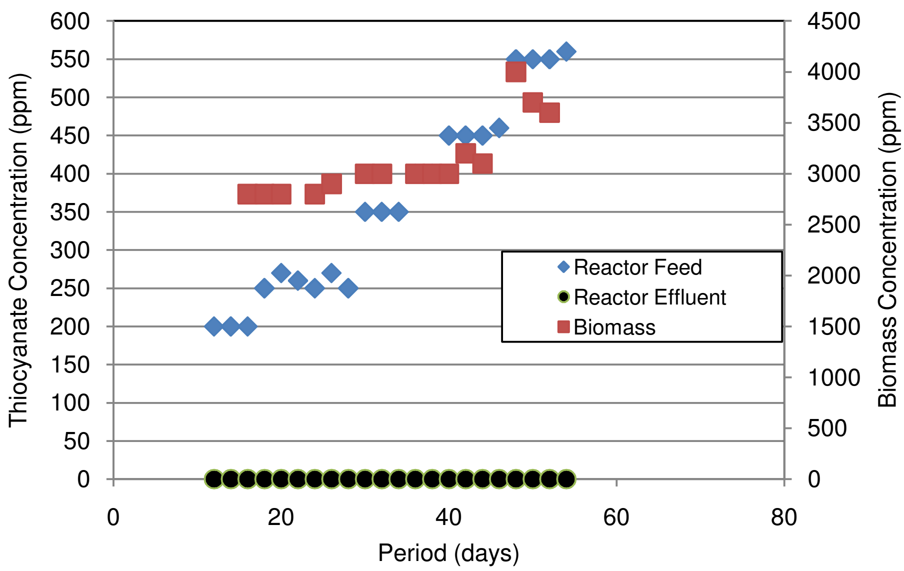

Figure 2 : ASTER Thiocyanate Screening And Biomass

Figure 2 shows virtually complete thiocyanate degradation for feed concentrations ranging from 200 ppm to 550 ppm. Also shown is the biomass concentrations which were measured in the reactor and show some tendency to increase as the substrate increases. The thiocyanate concentration entering the clarifier was < 1 ppm and hence it can be deduced that no degradation occurred in the clarifier. Reworking the data and normalising the biomass concentration to the reactor feed concentrations, an empirical correlation was proposed by du Plessis and co-workers (du Plessis et al., 2001).

This correlation is graphically shown in Figure 3 and considers the steady state data where the clarifier overflow thiocyanate concentration is < 1 ppm, in the ranges tested viz., 250 ppm < feed SCN < 550 ppm.

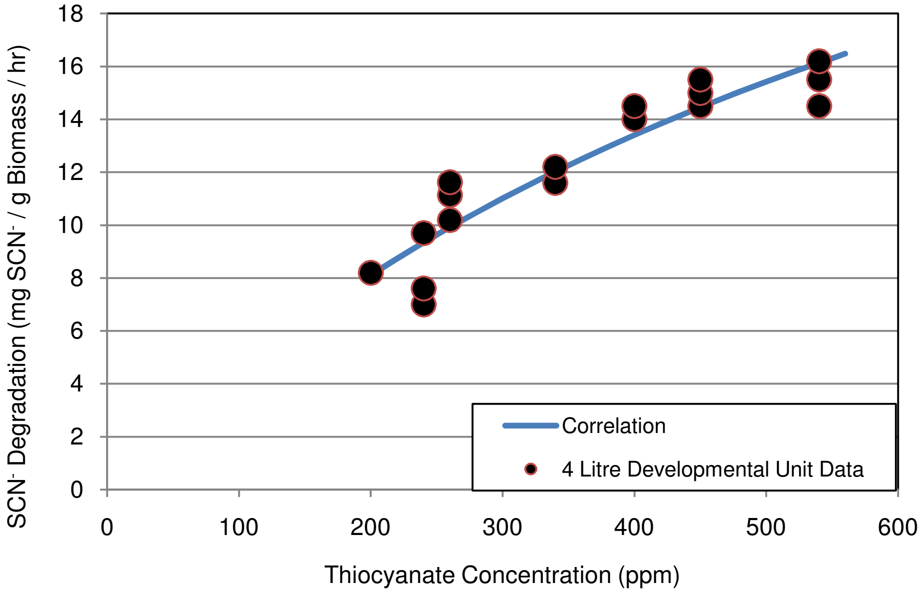

Figure 3 : Thiocyanate Degradation Rate As A Function Of Feed

The correlation proposed shows an acceptable fit to the data and also relies on the assumption that the low prevailing concentrations have no impact on kinetics (viz., a purely empirical relation). The biomass concentration is also assumed to have no mechanistic influence on microbial kinetics.

The correlation was a suitable and an acceptable first pass prediction for the ASTER thiocyanate degradation rates as a function of reactor feed concentrations when a suitable biomass and steady state conditions can be maintained within the assumptions listed.

Technology Piloting Trials

Continuous and larger scale testing was undertaken on real tailings dam process solutions to determine the effect of other dissolved species that may impact the degradation rate of the ASTER organisms that are not inherent to synthetically prepared solutions. Tailings solution from the Barberton Mines, Fairview Plant was the first to be piloted and the tests were undertaken in a larger scale test unit. Figure 4 shows the next scale up unit.

Figure 4 : ASTER 80 Litre Scale Test Unit

Testwork was done on various solutions from the leach and CIP circuits. The details of the testwork are shown in Table 2.

Table 2 : Results Of 80 Litre Pilot Unit On Fairview Solutions

Solution Treated	Feed		Overflow		Sludge		% SCN^- Removed
	SCN^- (ppm)	CN(T) (ppm)	SCN^- (ppm)	CN(T) (ppm)	Au (g/t)	As (g/t)	
BIOX® CIP Solution	965	n.d	0.7	n.d.	n.d	n.d	99.9
BIOX® Leach Solution	184	2	1.4	<0.7	114	35	99.2
BIOX® Tailings Dam Return Water	405	<5	0.3	<0.02	107	465	99.9

Results from these tests showed that very high removals of thiocyanate can be maintained over a wide feed concentration. Importantly, residual anions and cations from the process solution did not seem to inhibit or destabilise the microbial consortium. A typical analysis of one of the feed samples and the ASTER overflow sample is shown in Table 3.

Table 3 : Major Species Determined For Typical Fairview Solutions

Species	Concentration (ppm)	
	Feed	Overflow
Li	<0.05	<0.05
Be	<0.05	<0.05
Mg	3040	2950
Al	<0.05	<0.05
Si	27	35
Ca	1030	1100
Ti	<0.05	<0.05
V	<0.05	<0.05
Cr	<0.05	<0.05
Mn	81	80
Fe	<0.05	3.0
Co	9.0	9.4
Ni	60	68
Cu	0.15	0.28
Zn	<0.05	<0.05
Ag	<0.05	<0.05
Cd	<0.05	<0.05
Pb	1.1	1.3

During certain trials, dried samples of activated sludge (dried biomass) were analysed for heavy metal accumulation.The results indicated that an amount of heavy metal accumulation (e.g. gold, copper, arsenic, etc) on the biomass, even though these solutions only contained trace amounts of these particular metals.

Following onto these initial Fairview tests, additional testwork was undertaken in the 80 Litre reactor unit, all on real solutions. This pilot plant trial was conducted on tailings dam water from a CIL plant retreating flotation tailings from old tailings dams, still in the Barberton area. The plant experienced water balancing problems, especially during the wet season when tailings dam water had to be discharged into the environment. The tailings dam water did not always comply with South African standards, especially in terms of the heavy metal concentrations. The solution also contained some thiocyanate.

The pilot plant operated consistently for a period of one month. The cyanide, copper and nickel concentrations in the overflow from the settler were less than 1 ppm cyanide, 2 ppm copper and 5 ppm nickel throughout the run. These results are summarised in Table 4.

Table 4 : Thiocyanate Degradation Of Old CIL Tailings Samples

Solution Treated	Feed SCN^- (ppm)	Overflow SCN^- (ppm)	% SCN^- Removed
Tailings A	36.7	0.5	98.6
Tailings B	26.8	0.7	97.4

Successful degradation of the samples implied that no inhibition was experienced by the cultures. Further testwork carried out on CIL solution produced on the bioleaching of a Greek concentrate also showed high thiocyanate removals. As with many mining projects, its successful implementation depended on its ability to re-use process water and /or discard the process water into the environment. Table 5 and 6 show these testwork results. For the Greek project, the operating envelope was characterised by the ASTER performance over selected residence times as well.

Table 5 : Thiocyanate Degradation Of A Greek CIL Sample

RT (hours)	Feed SCN^- (ppm)	Overflow SCN^- (ppm)	% SCN^- Removed
8	9.3	<0.2	97.8
6	6.1	<0.2	96.7
5	10.6	<0.2	98.1
4	10.1	<1.0	90.0
3	8.4	<1.0	88.1

Again, successful degradation of the solution implied that no inhibition was experienced by the cultures, however below residence times of 4 hrs there seemed to be a drop in the degradation rate. Also evident from Table 6 is the reduction of the heavy metal concentration in the overflow indicating adsorption onto the biomass.

Table 6 : Major Species Determined For The Greek CIL Sample

Species	Concentration (ppm)	
	Feed	Overflow
NH_4^+	10	230
SO_4^{2-}	2228	891
Al	67	<0.15
As	6.7	<0.25
Ca	1461	68
Cu	19	<0.05
Fe	33	<0.05
Na	3536	92
N	1.4	<0.13
PO_4^{3-}	26	61
S	3618	338

During 2008 a $6m^3$ continuous pilot plant was constructed at the Barberton Mine Fairview Plant from redundant equipment available on site to validate the previous results achieved on the 80 Litre unit and also to assist with scale up and further optimisation testwork. This unit is shown in Figure 5.

Figure 5 : ASTER $6m^3$ Scale Test Unit

The size and scale of this unit also made it possible to determine parameter changes such as residence times, nutrient changes and underflow recycle rates and its subsequent effect on process robustness. The operation of the $6m^3$ pilot unit commenced with tailings solution from Fairview Plant. Tailings solution from the dam was controlled in a feed stock tank to deliver 300 ppm and this was accomplished using the ASTER pilot unit overflow. As per the 4 litre and 80 litre pilot units, the underflow sludge was recycled back to the primary reactor to deliver active microorganisms. The hydraulic retention time was varied on this unit to determine the degradation rate and also to provide an indication of the operating envelope achievable at this feed concentration. Figure 6 shows these results as well as that obtained for the Greek trial.

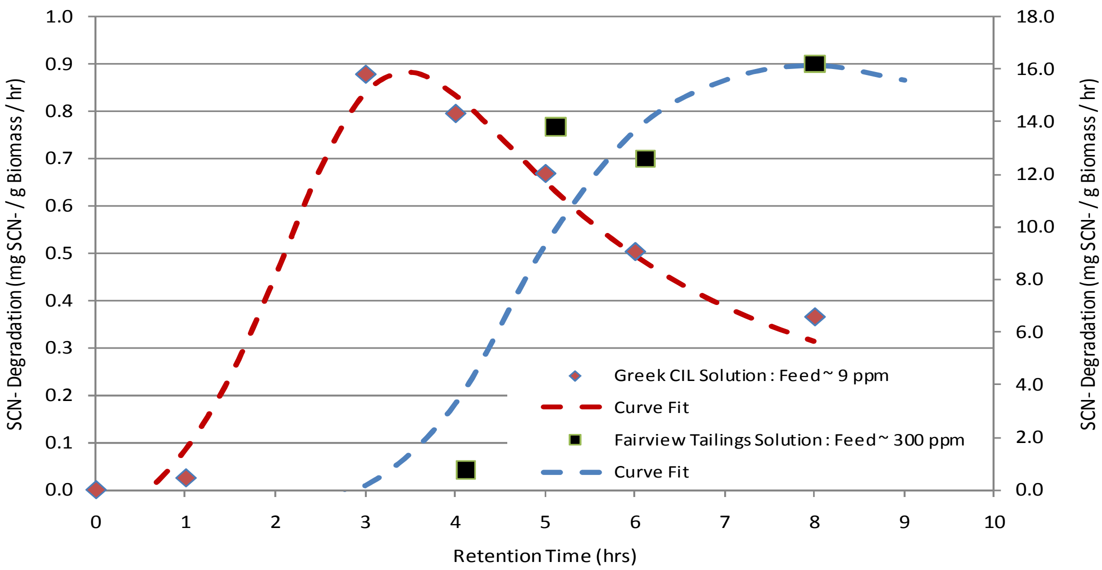

Figure 6 : Thiocyanate Degradation Rate As A Function Residence Time

Apparent from Figure 6 is that low thiocyanate feed concentrations have their maximum degradation rates at retentions ranging between 2 – 3 hrs, while a higher feed thiocyanate concentration requires a residence time of between 6 – 8 hrs. These plots therefore can give some indication of the operating envelope of the ASTER process based on a feed thiocyanate criterion.

Technology Demonstration

With the success of the testwork and pilot stages, it was decided to demonstrate the ASTER process at a larger scale. A 25 m^3 industrial sewage plant was acquired for this purpose. The demonstration plant was installed at another tailings dam treatment facility in the Barberton area. This plant also experienced water balance problems during the wet season. The thiocyanate and heavy metal concentrations in the tailings dam water from this site tended to be higher than at the pilot plant site, making it an ideal location for demonstrating the efficiency of the process on larger scale.

Figure 7 shows the demonstration plant.

Figure 7 : 25 m^3 Demonstration Plant

Table 7 shows the demonstration plant results achieved.

Table 7 : 25 m^3 Demonstration Plant Results

Species	Solution		Sludge	
	Feed (ppm)	Overflow (ppm)	Units	Assay
SCN^-	111.3	0.13	-	-
CN^-	7.9	2.69	-	-
CN(T)	119.11	2.82	-	-
As	<1.0	<1.0	g/t	770
Au	0.02	0.01	g/t	1.5
Cu	3.0	<0.2	%	2.3
Ni	7.1	3.7	%	1.9
Co	<0.2	<0.2	%	0.2
P	3.4	13.5	%	5.4

The solution analyses from the thickener overflow indicated that thiocyanate was effectively removed from the solution yielding approximately 99.9% removal.

Operation of the 25m^3 plant was successful in demonstrating the ASTER technology. Successful trialling on a 4 litre development unit, an 80 litre pilot unit, a 6m^3 pilot unit and a 25m^3 demonstration plant showed the process to be quite robust and effective in thiocyanate removal. The results derived at these scales were also replotted to determine the validity of the empirical correlation derived from the 4 litre developmental work, and its suitability as a first pass design screening tool. These results are shown in Figure 8.

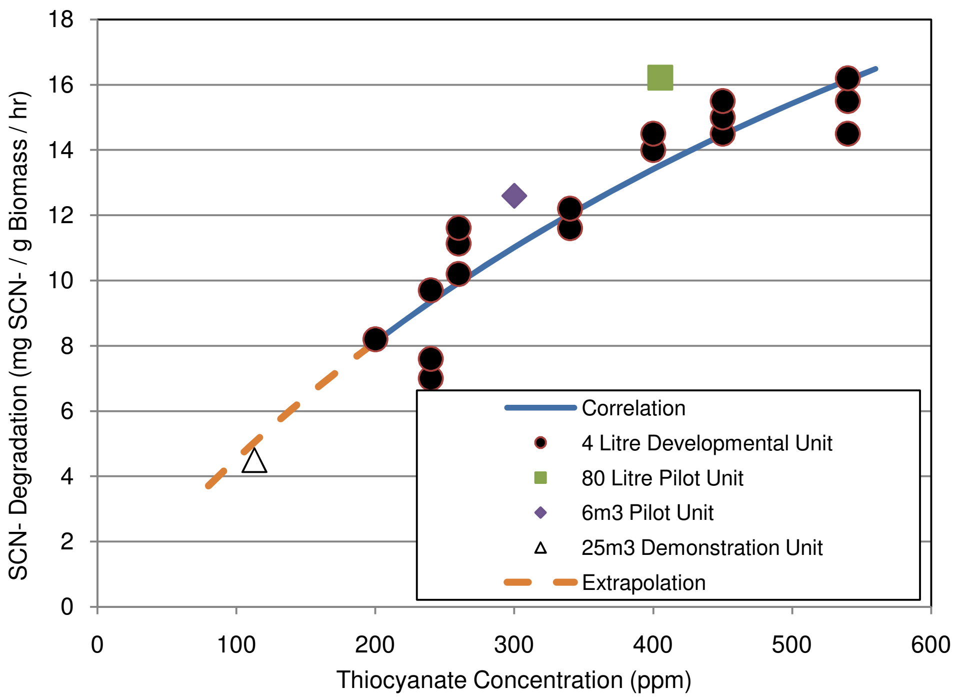

Figure 8 : Thiocyanate Degradation Rates Achieved On Developmental, Pilot And Demonstration Unit

The figure shows the degradation rates achieved at the different thiocyanate feed concentrations, as well as that achieved at the different process scales, viz., 4 litres, 80 litres, 6 m^3 and 25 m^3. Seemingly apparent is that the large scale data does follow the empirical correlation, but at this scale and the higher feed concentrations the correlation is more conservative in its prediction of the degradation rate. This could suggest that at the higher feed thiocyanate concentrations and larger scales, the kinetics of the degradation rate is being influenced on a more fundamental and kinetic level, which could be related to the concentrations and microbial growth rates. Extrapolation of the empirical model outside of the ranges it was derived for does show quite good correlation to the degradation rate of the 25m^3 plant. This may perhaps be expected owing to the lower feed concentration, around 113 ppm, which may suggest the rate is less dependent on the concentration and more on the sludge volume. This fundamental expression is currently being reviewed, but what is demonstrated by Figure 8 is a first pass design tool available for scale up of the ASTER technology.

From the consistency and good reproducibility of the ASTER technology trials, it is possible to formulate a set of parameters which characterise the operating principles. This is shown in Table 8 below.

Table 8 : Broad Conditions Suitable For ASTER Process

Parameter	Unit	Consort Plant	Current window
Feed : SCN^-	ppm	120	300
Feed : Free CN^-	ppm	20	≤50
Tailings Solution pH		As is	As Is
Dissolved Oxygen	ppm	8	≥1
Temperature	^oC	24	20
Nutrients : Molasses	kg/m^3	0.15	0.02
Nutrients : Phosphorous	kg/m^3	0.13	0.13
Reactor Sludge	% v/v	20-30	20-30

No pH control is currently employed on the ASTER process which makes the process versatile over a wider pH range than some of the existing technologies. Typically tailings solutions in the pH range 7.5 to 9.5 have been successfully treated.

The aforementioned conditions are broadly prescribed and it should be noted that setting the process design criteria for an ASTER application is project specific. A typical process flowsheet is shown below and as an example and therefore it is shown integrated to an existing BIOX® plant. Substantial synergies can be achieved in such cases owing to available (and free) air and heating. Figure 9 shows this typical flowsheet integration and Figure 10 the actual Barberton Mine, Consort ASTER Plant currently installed as a standalone treatment plant.

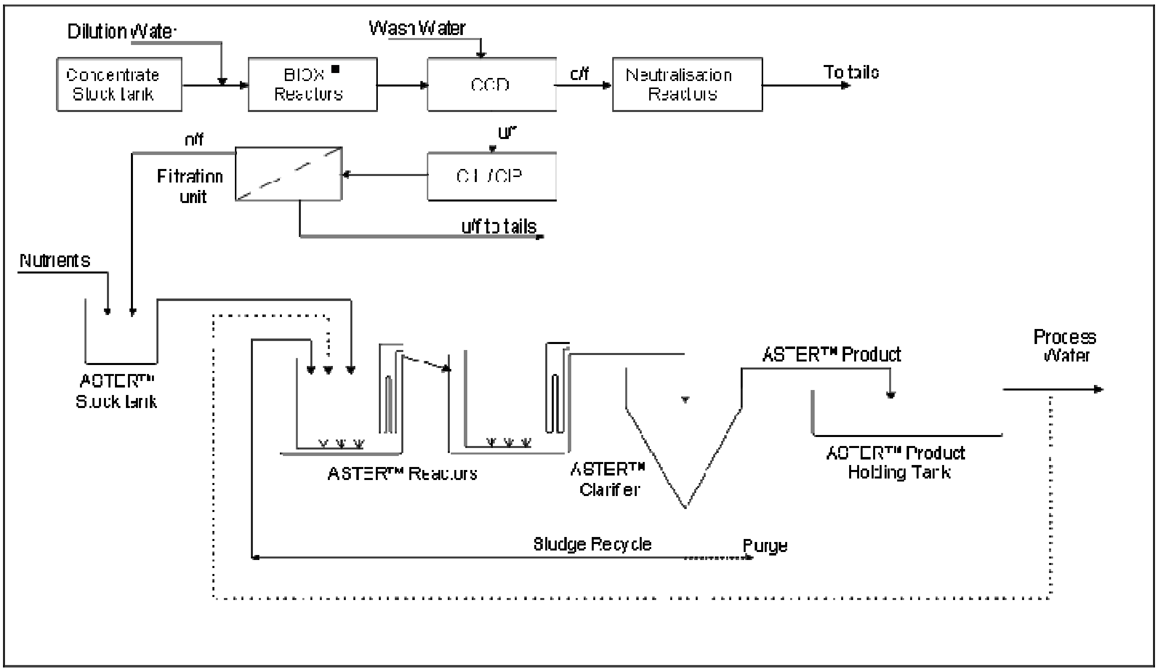

Figure 9 : ASTER Schematic Integration To Current BIOX® Plant

Figure 10 : Actual ASTER Operating Plant (320 m^3/d) At Consort Mine

The Barberton Mine, Consort ASTER Plant is designed to treat 320 m^3/d of tailings dam solution containing a thiocyanate feed range of 100 to 120 ppm, and a free cyanide concentration of 10 to 20 ppm. A typical BIOX® reactor configuration – four primary reactors in parallel and four secondary reactors in series - was adapted. The plant has a residence time of 6 hrs across four primary reactors in which 80% of the degradation occurs. An excess of reactor volume is supplied through the availability of four additional secondary reactors, which cascade into a clarifier that returns thickened sludge to the primary reactors. The clarifier overflow delivers a final thiocyanate concentration of < 1 ppm and can be discharged to the natural waterways or used as process water in the main plant. All residual free cyanide is also removed to trace values.

Construction of the Consort ASTER plant commenced April 2010. The objective was to construct the plant at minimal cost hence the use of off the shelf 20m^3 PVC agricultural (Jojo) tanks. The tanks are fitted with heaters installed from the top of the tank and sparge rings installed at the bottom of the tank. All the construction work was conducted in-house by Consort Plant engineering.

The capital cost distribution for the Consort ASTER Plant is shown in Figure 11.

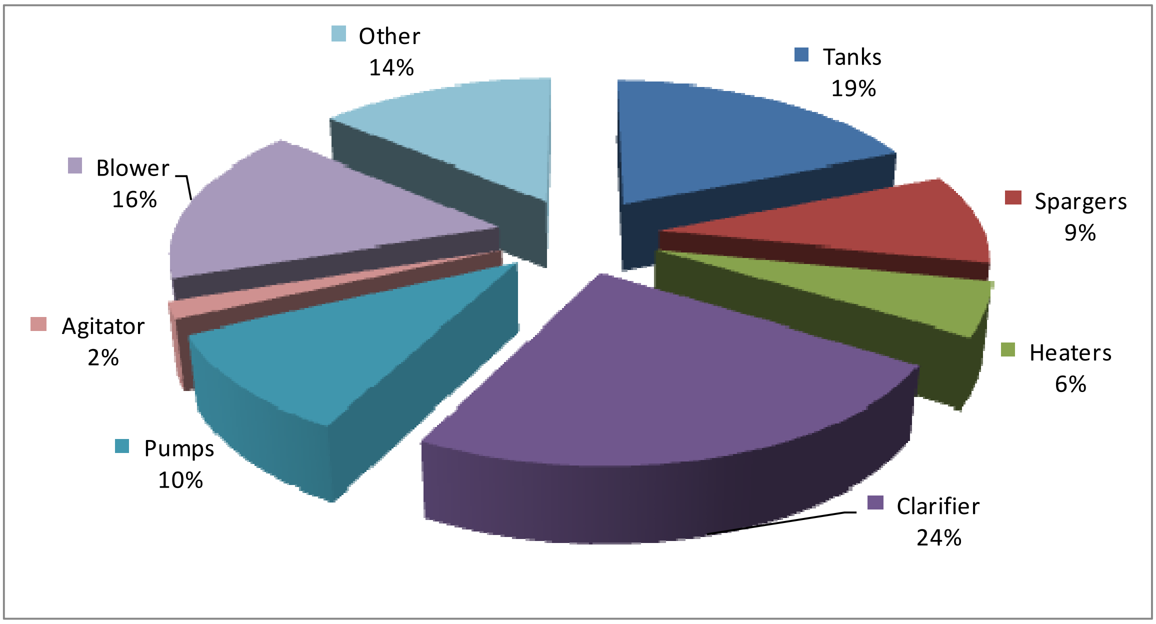

Figure 11 : Capital cost breakdown of Consort ASTER Plant

As indicated from the figure the main cost drivers for the Consort ASTER plant were the clarifier, the tanks and the blower in that order. The other costs were insignificant.

Commissioning of the Consort ASTER plant commenced on 06 September 2010. No major problems were encountered during commissioning however a lot of lessons learnt for future plants. The bacteria remained active during solution movement and 99 % SCN^- degradations were achieved consistently. This validated the robustness of the technology.

What Next

Figure 12 shows the trajectory of the ASTER commercialisation pathway, and is benchmarked against the BIOX® process, another Gold Fields Limited technology supplied to the mining industry in the early 1990's.

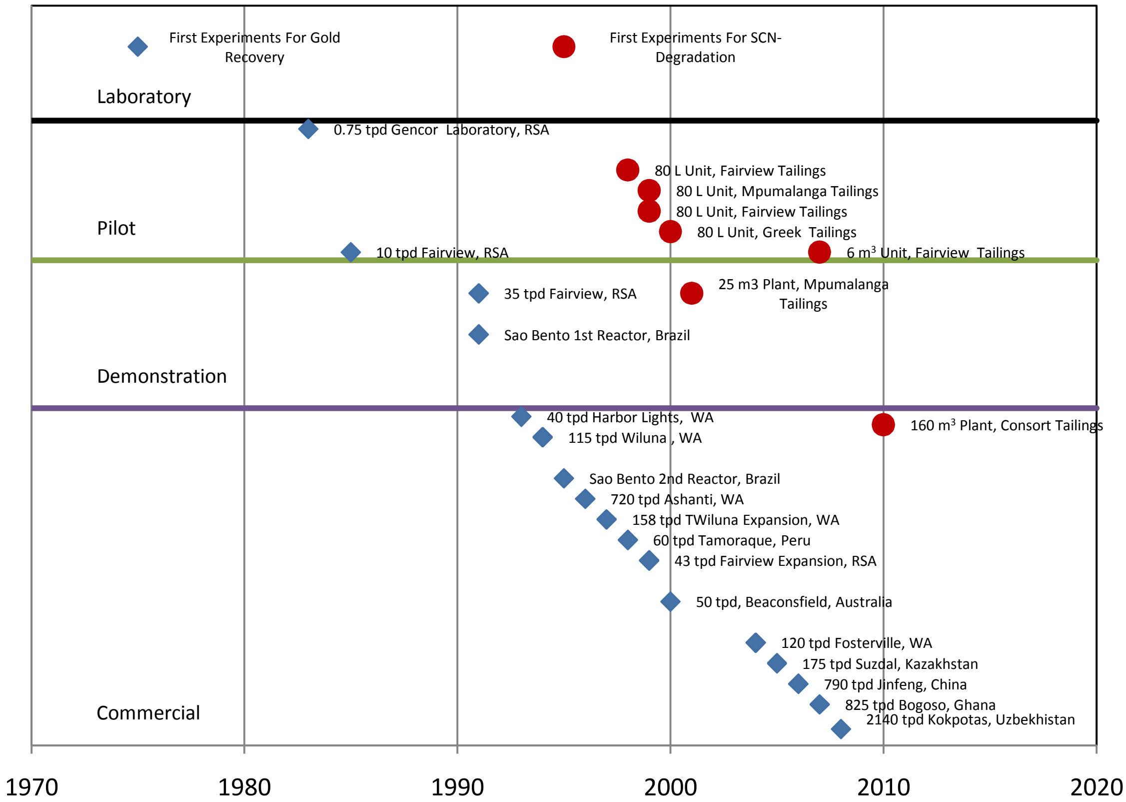

Figure 12 : Current ASTER Pathway To Commercialization

Apparent from the figure is that the technology is waiting for a larger scale implementation. The successful demonstration in early 2000 and the Consort Commercial scale in 2010 has shown the process to be robust and effective as a biological means of degrading thiocyanate and cyanide.

Also evident from the figure is a technology development slow down period between 2001 and 2005. This was due to the merger Gencor (now BHP Billiton) and Gold Fields Limited which resulted in the following:

- There was people constraints within the Gold Fields Group where the technology was transferred;
- The company focus shifted as resources were re-shuffled;
- Know-how and test equipment not all transferred to Gold Fields Group.

This resulted is the need to review all the data in a pilot scale unit. Hence the shifts from a demonstration scale to a 6m^3 pilot scale in 2008.

Learnings from these large scale plants as well as the smaller test units have also shown considerable potential exists to optimise the process. These initiatives and learnings have been wrapped up into additional Gold Fields Limited internal developmental programs currently being pursued at the Consort Mine site, and a more fundamental program being driven at the University Of Cape Town (UCT).

The program from UCT is looking to deliver and support a more fundamental and enhanced process by delivering an ASTER Generation 2 process which again will follow the standard internal tollgate stages shown broadly in Table 9 below.

Table 9 : Generic Process Development

Item	Description
Concept and Opportunity	During this stage the focus is mainly on fundamental and applied research, Legal and IP protection and Market research. There is a significant market potential under current and future BIOX® users with the option to later focus more on the cyanide specific market (typical Wits ores). A project management plan that provides a basis for resources needed to achieve the deliverables was developed.
TOLLGATE	
Feasibility	During this stage a basic cost benefit analysis and risk management plan was developed.
TOLLGATE	
Detailed Design and Development	This stage will comprises of transforming the process requirements into detailed documents focusing on delivering the required functionality. The documents are then converted into test databases, test procedures and reviews.
TOLLGATE	
Implementation	This stage involves implementation of the process into production environment.
TECHNOLOGY COMMERCIALLY READY	
Maintain & Improve	During this stage the technology supplier will support, maintain and improve the technology through operational support and ongoing R&D and product improvement.

Some of the fundamental work conducted by UCT is:

- Determining the envelope of thiocyanate and cyanide degradation on a quantifiable microbial species;
- Investigating the impact of temperature on microbial growth rates and hence thiocyanate and free cyanide degradation;
- Determining individual microbial species present and respective growth rates to enhance the consortium;
- Mapping the kinetic growth rates to kinetic constants with the intention of providing a fundamental model to support the currently held empirical correlation;
- Providing a detailed characterisation of the microbial consortium and its pathogenicity to compliment the currently held Gold Fields Limited patent, and also to support exporting of the ASTER culture for international mining projects.

Some of the internal Gold Fields work is aimed at:

- Higher degradation rates leading to smaller reactors;
- More effective biomass management leading to lower biomass recycling;
- Improved clarifier design leading to reduced total cost.

With the ongoing work, it is expected that a revised cost breakdown structure shown in Figure 11 above can be achieved, and a more robust and competitive process design criteria shown in Table 10 below can be delivered.

Table 10 : ASTER Generation 2 Future Window

Parameter	Unit	Future window
Feed : SCN^-	ppm	≥1000
Feed : Free CN^-	ppm	≤50
Tailings Solution pH		As Is
Dissolved Oxygen	ppm	≥1
Temperature	^oC	20
Nutrients : Molasses	kg/m^3	0.02
Nutrients : Phosphorous	kg/m^3	0.13
Reactor Sludge	% v/v	20-30

Conclusion

The Gold Fields Limited ASTER technology has proven to be a cost effective biological treatment process for the degradation of thiocyanate and free cyanide (<50ppm).

The process has been successfully validated at a developmental, piloting and demonstration stage over a wide range of real mine tailings dam solutions.

Construction and commissioning of the first commercial scale, 320 m^3/d ASTER Generation 1 treatment plant at the Barberton Mines, Consort Plant was a success.

ASTER Generation 1 technology is now available and ready to be expanded.

Additional large scale piloting and more fundamental testwork and modelling is currently underway to produce the next generation of ASTER treatment plants.

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References

C.A du Plessis, P. Barnard, R.M. Mulbauer and K. Naldrett. (2001) Empirical model for the autotrophic biodegradation of thiocyanate in an activated sludge reactor. The Society for Applied Microbiology, *Letters in Applied Microbiology*, **32**, 103-107.

M.A Botz, (May 2001) Overview of Cyanide Treatment Methods. Mining Environmental Management, Mining Journal Ltd., London, UK, pp. 28-30.