MINTEK'S IGOLI™PROCESS. HISTORY, PILOTING AND TECHNO ECONOMICS.

By

Elmar Muller and Sazini Makamu

Mintek
200 Malibongwe Drive
Randburg
South Africa

Presenter and Corresponding Author

Elmar Muller
elmarm@mintek.co.za

ABSTRACT

South Africa has an extensive abandoned mine problem, with the country having more than 6000 abandoned mines according to Statistics SA. Although the SA Mine legislation (MPRDA s.43(1)) requires mining operators to make financial provision for mine closure and rehabilitation, it is not effectively enforced. This has lead to extensive illegal mining and the rise of criminal enterprises.

The South African government has identified artisanal mining as an initiative to help to alleviate unemployment, but the criminality and safe use of cyanide and mercury have severely curtailed this initiative.

The iGoli™ project, which started at Mintek more than 20 years ago with its main purpose as an alternative technology to using mercury for gold recovery, has come a long way and its scope and applicability has increased.

The project has expanded and now covers:

- Alternative process to using mercury in gold recovery,
- Treatment of mine tailings,
- New life for abandoned mines,
- Assisting artisanal miners,
- Linking other Mintek technologies and
- Initiating down stream processes.

This paper will discuss the latest developments in the iGoli™ process as it applies to piloting for the treatment of mine tailings, techno economic evaluation as well as other Mintek's offerings to assist in addressing the abandoned mine problem together with socio-economic upliftment of disadvantaged communities.

The benefits to the community includes job creation and the freeing of previously locked land for use while the SA government benefits through the reduction of the following adverse effects of abandoned mines and dumps:

- Environmental impact from dumps,
- Illegal mining,
- AMD,
- Locking of land and
- Loss of revenue
- Unemployment (Due to mine closure).

Keywords: iGoli™, illegal mining, artisanal mining, abandoned mines, socio-economic.

INTRODUCTION

South Africa has a rich mining history that started in 1852 when the first mine, a copper project, was constructed in what is today the town of Springbok, in the Northern Cape province[1].

This was followed by the boom in the diamond industry when 15-year-old Erasmus Stephanus Jacobs discovered South Africa's first diamond, the Eureka, in Hopetown in 1867 and kickstarted what historians call the Mineral Revolution[1].

Although small gold alluvial deposits were found near Pilgrim's Rest and Barberton in 1873, these were only precursors to the biggest discovery of all, the Main Reef on Gerhardus Oosthuizen's farm Langlaagte, Portion C, in 1886. This led to the Witwatersrand Gold Rush with mining starting in Ferreirasdorp in the same year which led to the establishment of Johannesburg.

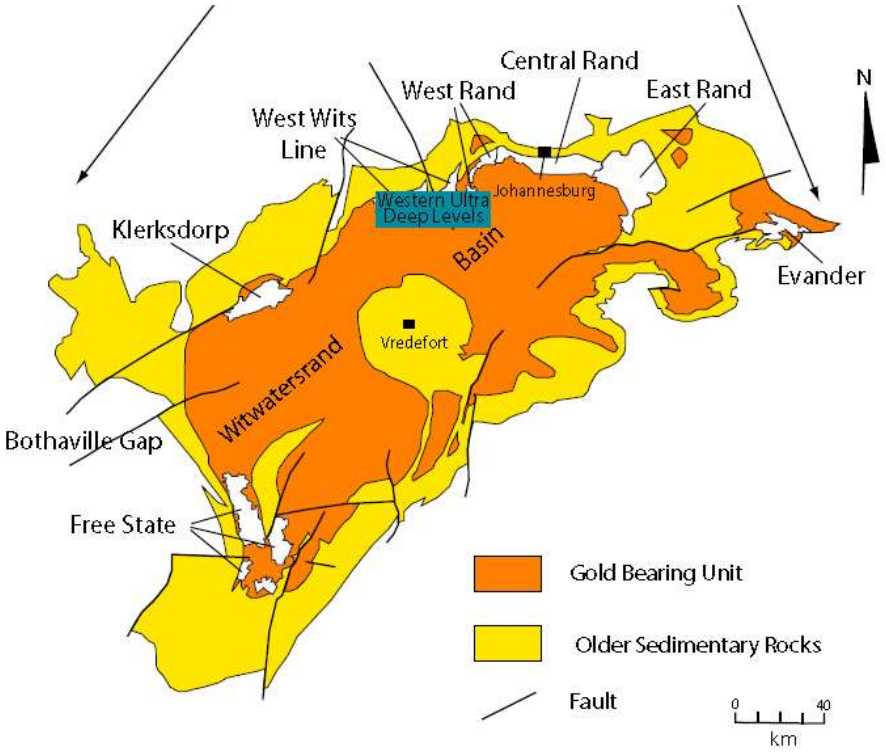

Figure 1: Map of the Witwatersrand basin[2].

Today, the mining industry remains one of the biggest contributors to South Africa's economy with an estimated yearly sales exceeding R850 Billion[3]. It is the world's fifth largest mining sector in terms of gross domestic product (GDP), contributing eight percent to South Africa's GDP.

According to the South African Council for GeoScience, there are more than six thousand (6000) abandoned mines in South Africa[4].

Planning for mine closure has been a requirement in South African legislation since the Minerals Act of 1991 came into effect, which required that an environmental management programme (EMP) be drafted, rehabilitation be undertaken, financial provision made, and an application submitted for a closure certificate.

Under the current regime, the granting of mining authorizations, regulation for operations and the issuing of closure certificates are all governed by the Department of Mineral Resources and Energy (DMRE), This is predominantly managed through 3 pieces of legislation, namely the Mineral and Petroleum Resources Development Act (MPRDA, Act 28 of 2002),the National Environmental Management Act (NEMA, Act 107 of 1998 and various updates), the National Environmental Management: Waste Act (NEMWA, Act 59 of 2008). Other government departments (most notably Environmental Affairs and Water and Sanitation) and various other pieces of legislation have lessor roles to play but also come into play.

The MPRDA, the main source of rehabilitation obligations, "……requires rights holders to 'as far as reasonably practicable' rehabilitate the land affected by the operation 'to its natural or predetermined state, or to a land use which conforms to the generally accepted principle of sustainable development' (Section 38 (1) (d))…….".

Regulation 62 of the MDPRA regulation of 2004 require the submission of closure plan and objectives as part of the draft Environmental Management Programme (EMP) / Environmental Management Programme Report (EMPR) and which must contain '…the key objectives for mine closure to guide the project design, development and management of environmental impacts'; future land use objectives for the site, and the costs of closure...'(Reg 61 (1)).

Unfortunately, implementation and execution of these EMPs and submissions of the EMPRs are not effectively being enforced.

ISSUES

The South African Government inaction and large scale unemployment in the country have lead to a parallel mining industry in the country where illegal, artisanal and small scale miners (ASMs) are working these abandoned mines.

The South African Institute of Security Studies estimates that, only in the Gold industry, about 30 000 illegal miners produce R14-billion of gold a year. From the state's perspective this is "lost production".

The illegal miners live and mine under extremely hazardous conditions and stay for weeks underground fearing rock falls, government/police interventions and other highly armed gangs, while the masterminds and king-pins live in luxury (Figure 9). These miners still use cyanide and mercury-based technologies to recover the gold with extremely primitive equipment (Figures 6 – 8).

The United Arab Emirates and Switzerland have been identified as the primary export destinations.

Figure 2: Entrance to an abandoned mine.

Figure 3: Entering an abandoned mine[5].

Figure 4: Preparing meals underground.

Figure 5: Living conditions underground.

Figure 6: Gold bearing ore[5].

Figure 7: Gold processing in an informal settlement[6].

Figure 8: Gold processing in an informal settlement continued[6].

Figure 9: Suspected illegal mining kingpin[7].

Although Mining has and will continue to make a significant contribution to South Africa's economy and livelihoods, it is also associated with various other negative impacts. One such impact is acid mine drainage (AMD) caused by effluents from waste rocks and tailings.

AMD occurs when sulphide rich minerals, in the presence of catalysing bacteria such as Thiobacillus ferroxidases are exposed to air and water and are oxidized to form sulfuric acid. The sulfuric acid, which is generated easily dissolves metals such as iron, copper, aluminium and lead. This problem is more common in mine dumps where proper mine closure and reclamation procedures did not take place, as discussed above. The Witwatersrand and Greenstone belts host one of the largest gold deposits in the world and by far, the most gold that has been mined in South Africa is from the Witwatersrand goldfields.

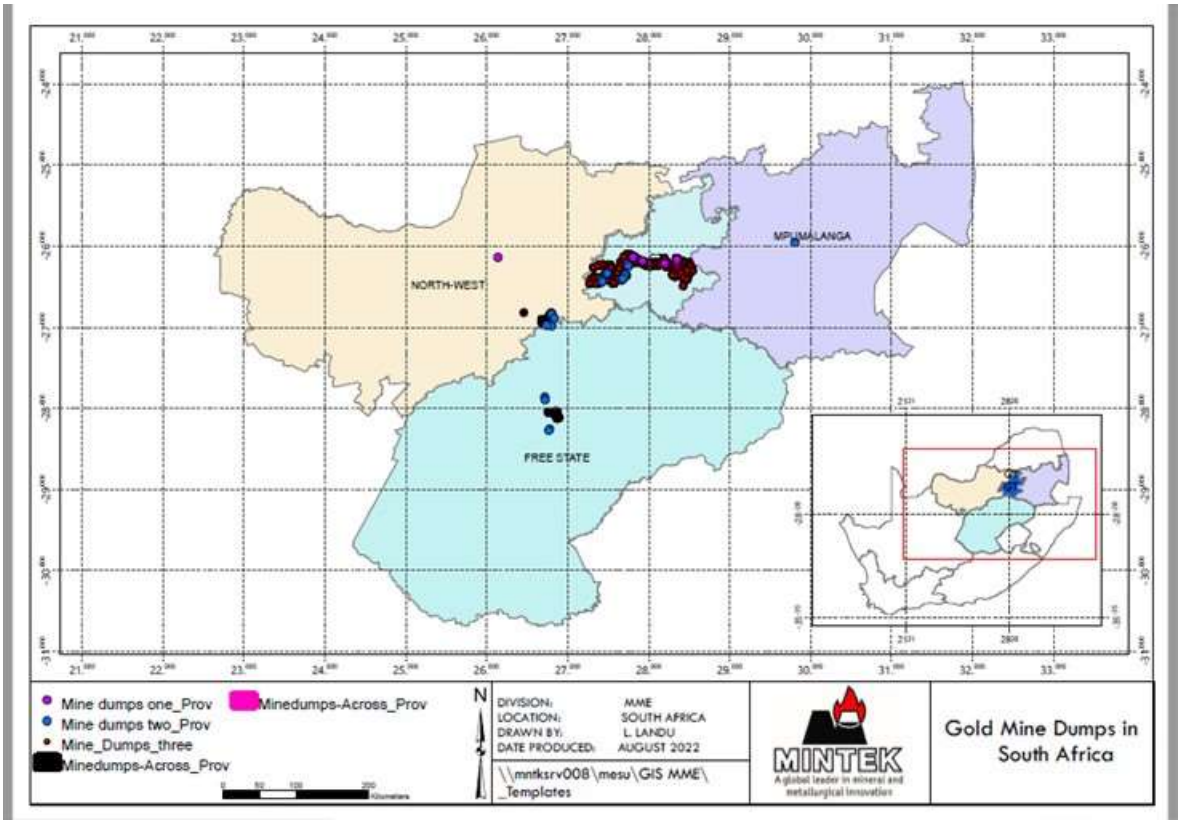

Figure 10: Location of the largest historic ownerless dumps in South Africa.

In a first step to understand the extent of the problem, the DMRE has embarked on a process of mapping the ownerless and derelict mines including mine dumps.

A further strategy that was put forward by the SA Minerals Council to the the DMRE to reduce illegal mining in these areas (Figure 10), is to formally register co-operatives of miners (ASMs) and incorporate them into the existing mine work force. Working together with the Government, the idea is that some large scale mining (LSM) operations, can enter into agreements with the ASM operators for the latter to process tailings within the mine facilities. Using technologies like iGoli™, the ASM are afforded an opportunity to process not only historical tailings but also those continually produced through current LSM activity and sell back the concentrates to the LSM.

This approach is under investigation by the DMRE but again progress is slow.

TECHNOLOGY DESCRIPTIONS

The iGoli™ Technology package (the Package) now includes three technologies developed by Mintek to provide an integrated solution for rehabilitation of urban mined waste. The current piloting will also benchmark the Package against recovery data from local ASMs to illustrate the value of the Package for the treatment of abandoned mines and dumps.

Various pilot campaigns are planned, and the information obtained from the demonstration campaigns will aid in determining the most feasible method for processing the tailings and/or assisting the ASMs where abandoned mines are being reworked. Depending on the ore/tailings composition, it may be possible to create mobile plants using iGoli™ or all three technologies in the Package.

An added complication is that the abandoned mines and dumps in South Africa have varying gold, sulphide, and uranium concentrations. In addition, there is no assurance that these waste streams will react similarly to the treatment procedure. Consequently, process mineralogy is also important and Mintek is offering assistance to legal ASMs.

iGoli™

As far back as 2001, Mintek started the development of hydrochloric and chlorine gas-based technology to recover gold. Although the original focused development on gold recovery from concentrate, this was expanded into the iGoli project to remove the use of cyanide and mercury in the recovery of gold as applied by ASMs.

The iGoli™ technique involves leaching gold concentration with diluted hydrochloric acid and bleach. The gold and base metals in the leach liquor are then reduced through precipitation to generate a metallic base metal and relatively pure gold powder. The reasonably pure metallic gold powder is created by reducing the gold in the leaching fluid with sodium meta-bisulphite.

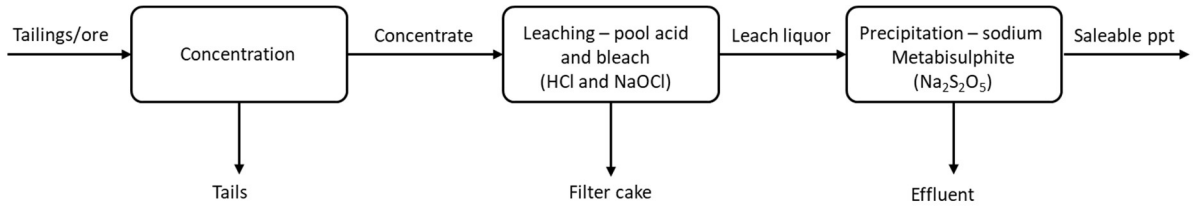

Figure 11: Simplified overview of the process flow.

Mintek sees iGoli™ is a sustainable process that could contribute to the global greening of the ASM gold sector.

There are various reasons why the acceptance of the technology into the informal/small scale mining sector has been slow. As discussed above, Government impassiveness is a huge frustration but there is also a huge overall distrust in Government from the ASMs. Mintek also has to carry part of the blame as Mintek previously failed to provide adequate training and technology support and did not efficiently engage the local communities. Finding a local partner with local knowledge and being trusted by the local community proved key in going forward.

Mintek also refocused their effort and over the last five years improved the process, made the process work with the simplest and cheapest materials of construction and decreased the operating costs. This enhancement of the iGoli process was performed in collaboration with BGRIMM and two South African universities as part of a larger research project that was initiated in 2018. South Africa and the People's Republic of China launched the South Africa-China Joint Research Centre for the Development and Utilisation of Mineral Resources (JRC-MR). This is an extensive program for the treatment of gold mine tailings to recover value and covers various aspects including communition, flotation, leaching and tailings stabilization.

The objective of the current pilot demonstration is to overcome the barriers of acceptance by demonstrating the technology to potential users and industry partners. This demonstration was scheduled for 2021 but due to the Covid pandemic, it was delayed by more than 2 years.

ReFlAut™

This technology provide a feasible processing technique to process the mine tailings but also to address the environmental impacts of the tailings. The ReFlAut™ process developed by Mintek offers a feasible solution to address AMD in mine tailings while also promoting recovery of economic valuable minerals. The process comprises of re-processing of the gold mine dump material through a flotation circuit and producing uranium, sulphide and gold containing concentrates.

CloSURE™

Mintek's water programme is focused on developing both incremental and transformative technologies, products, processes and services to address the ecological challenges of water usage, water treatment and waste management in the minerals sector as well as to find their application in other industrial and resource-intensive sectors. The legacy of AMD in South Africa has caused widespread contamination of river catchments. The AMD is typically characterized by high sulphate concentrations, in excess of 3 g/L, with relatively low concentrations of metals.

Biological treatment of mining effluents using sulphate reducing bacteria offers a cost-effective and sustainable alternative to conventional technologies for the treatment of effluents produced by the gold and coal mining industries. Mintek developed CloSURE™, a technology which employs biological processes to treat mine impacted water. The aim was to produce water that is fit for re-use in irrigated agriculture. CloSURE™ is suitable for small point sources in remote locations that lack services and infrastructure, such as legacy mines and mines after closure. The process consists of two stages, namely a biological sulphate reduction step followed by an oxidation step for sulphide removal and bio-sulphur production.

INTEGRATED PACKAGE

The flowsheet described in **Error! Reference source not found.**2 is a depiction of the entire process flow for the iGoli™ Technology package for the rehabilitation of abandoned mines and dumps. Apart from the recoverable gold, silver and base metals, the abandoned mines and dumps also contain a substantial amounts of AMD water. A further consequence of these dumps is that they lock-up soil and large portions of land. Through the combination of the Mintek technologies listed above these waste streams can be rehabilitated, recycled and reused.

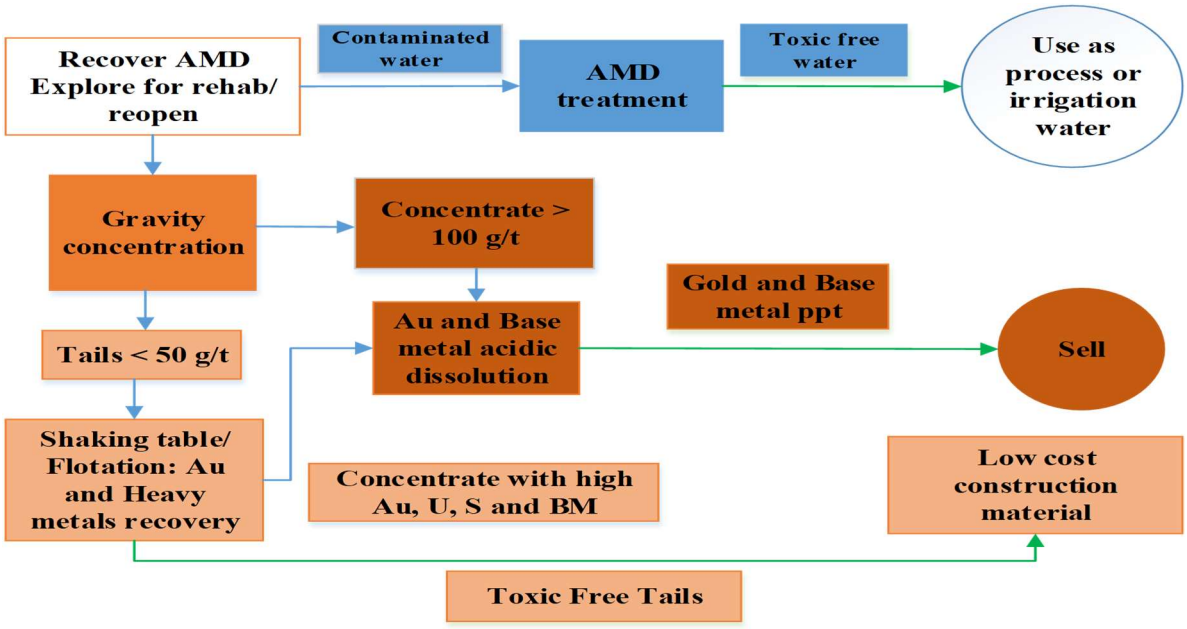

Figure 12: Flowsheet for the integrated package.

The current demonstration is based on the gold and base metal extraction process using iGoli™ for the concentrate and the ReFlAut™ flotation process of recovering gold, silver, uranium, sulphides and heavy metals from the tailings as shown in Figure 12. The final toxic free tailings will be collected and will be tested for stability and the manufacturing of a construction material via the JRC-MR collaboration. Laboratory testing has shown that this is a viable option for the treatment of the tailings waste.

The figure below is an updated plant design for the iGoli™ process and depicts the equipment that is being piloted.

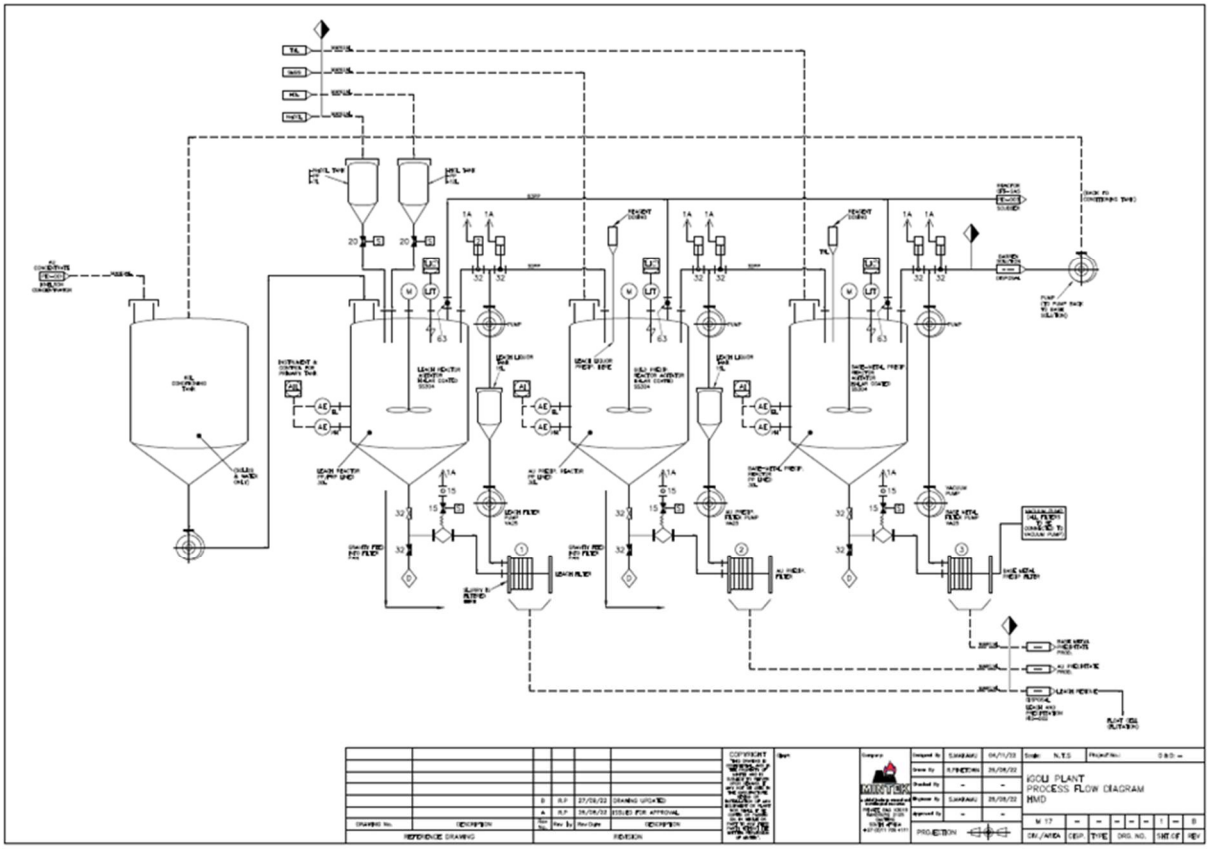

Figure 13: Improved iGoli™ plant design.

PILOTING

Mintek is currently running a demonstration pilot campaign on-site in Barberton Mpumalanga, including commission and de-commissioning of the plant.

Although fairly remote, this site was chosen as the owners have a DMRE license to work the abandoned mine but also to rework the huge legacy mine dumps. In its heyday this area around Barberton was a key part of gold production in South Africa but has since fallen into hard times with many illegal mining operations.

The distrust between ASMs and the South African Government continues to cause issues as all government supported initiatives are viewed by suspicion. The stakes are very high in the illegal mining business and the ASMs are ready to protect their income at all costs.

Due the security concerns, the owners of the mine/dumps have approached the South African Police Service and the South Africa National Defense Force to assist in providing security.

Figure 14: Mintek project leader in discussion with the representatives from the SAPS and SANDF.

The objective of the demonstration plant is to produce gold salt and tailings as per the scheme in Figure 13. The intellectual property of iGoli™ will remain vested in Mintek, but the demonstration partner will have the right to use and implement the results from the report at the agreed technology licensing fee as will be determined in an official agreement between Mintek and the demonstration partner.

Below is a list of equipment that was installed for the pilot campaign:

- Leach reactor
- Leach residue filter and tank
- Gold precipitation reactor
- Gold precipitation filter and tank
- Gold precipitation reactor
- Gold precipitation filter and tank
- Peristalsis pumps for each reactor

- One vacuum pump with manifold for filtration attached to each filter pan
- Scrubber with manifold attached to each reactor
- pH/Eh meters for various stages
- Various motor and agitator for various tanks

Figures 15 to 18 below show the equipment being delivered and the plant being installed. As the various process steps are done at ambient conditions, plastic hardware can be used for most unit operations.

Figure 15: Equipment being delivered before installation.

Figure 16: “Tank farm” built by the demonstration partner.

Figure 17: Plant being installed.

Figure 18: Gold precipitation reactor in action.

Results and Techno Economics

The results reported below is for a pilot plant that is currently in operation at a site in Barberton Mpumalanga South Africa.

Although a small ReFlAut™ plant is on site to make the concentrate for the iGoli™ plant, the results reported here are for the iGoli plant only and the feed comes from the old gold tailings dumps.

The current cost of reagents and consumptions are presented in Table 1. The gold concentrate feed into the iGoli™ plant is the product from the ReFlAut™ process where gold tailings were fed into the plant and upgraded to an average 120g/t concentrate.

The size of the plant is 20kg/hour but it is only being operated at 3kg/hour of concentrate for the first three months to establish the optimum operating parameters.

Table 1: Reagent Price and consumption per kilogram of a gold concentrate.

Plant flow)	Per hour	Per day	Cost/kg	Cost/day
	kg	kg	ZAR	
Solids	3	72		0.0
Water	17	408		0.0
HCl 15%	12.51	300.24	1.5	464.6
NaOCl 5%	36.00	864	1.5	1294.8
SMBS dry	0.11	2.592	13.0	33.7
NaOH dry	6.00	144	11.9	1717.6
Total cost of chemicals				**3510.8**

Table 2 below gives a summary of the first 4 campaigns specifically for the gold accountability. As expected, these gold recovery numbers show a very high gold recovery from the concentrate produced by ReFlAut™. The results indicate that the technology can be scaled from the laboratory to pilot plant.

As with all pilot campaigns the first three months had its fair share of breakdowns, equipment failures, clogging of sensors, etc. The issues were not unexpected and the remote area of also hampered bulk chemical delivery and logistics.

Table 2: Basic mass balance showing the Au “accountability”.

#	Mass balance							
	IN Head	OUT Filtrate	OUT Precipitate	Au Ext by solution	Accountability	HCl	NaClO	Calculated Head
	Au	Au	Au	Au	Au	Based on feed		Au
	mg	mg	mg	%	%	L/kg	L/kg	g/t
1	46.80	45.0	0.3	96.2	95.6	0.067	0.120	5.2
2	46.80	45.7	0.4	97.7	96.9	0.227	0.133	5.2
3	46.80	45.7	0.4	97.7	96.9	0.067	0.120	5.2
4	46.80	55.4	1.8	118	114	0.267	0.200	5.2

Table 3 shows the estimated project income using the numbers for this pilot campaign The finances presented only show the income possible from a 3 kg/hr iGoli™ leaching plant using gold price and ZAR/dollar exchange averaged for April 2023. Although simplified, this income estimate does clearly show that the process flowsheet and size of equipment are economically feasible options as the breakeven point is reached after 10 months of continuous operation.

Table 3: Techno economics for the current pilot campaign.

Expected Gold grade concentrate		120	g/t
Gold recovery		95	%
Gold price		$ 60	per gram
Gold revenue		$ 492	per day
Exchange rate ZAR USD		$ 18	
Gold revenue		R 8,865	per day

CAPEX		R 749,694	
OPEX Labour		R 547,500	per year
OPEX chemicals		R 1,281,441	per year
Total upfront costs		R 2,578,635	
Mintek costs		R 571,512	
Gold revenue		R 3,235,594	12 months
Time required to breakeven (pay back period)		10	months

CONCLUSIONS

One of the most important goals of this pilot plant demonstration of the previously developed iGoli™ was to introduce the process to a new market in Barberton Mpumalanga. The demonstration has enabled Mintek to demonstrate the possibility of extending the life of gold mines as the pilot plant is running at an abandoned mine that was recently saved from illegal miners by local entrepreneurs.

Mintek is currently running this pilot plant to demonstrate the amenability of the plant but to also establish the design criteria for a larger medium-scale plant to provide a cost-effective metallurgical solution for the rehabilitation of abandoned mines and tailings dumps.

Although the construction and demonstration are continuing, the outcomes of the pilot plant demonstrations have already showed other local entrepreneurs that this initiative is worth their support.

The large scale unemployment and constant influx of illegal immigrants from all over Africa is putting a huge strain on the infrastructure in areas like Barberton and causing extensive sosio-economic unrest. Using this technology from Mintek and working with local entrepreneurs is leading to new enterprise development which will create jobs and business opportunities through urban mining and artisan processing of previously locked resources.

Mintek is also working with the DMRE to urgently speed up attempts to formalise artisanal mining as a livelihood strategy. The department is in discussions with the mining industry and civil society in this process to support entrepreneurs to license the mining of these abandoned mines and also to rework old tailing dumps to achieve the benefits as discussed in the Abstract.

Although progress is slow, a coordinated transnational effort to break the strangle-hold of the criminal syndicates must continue.

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