IsaMills™ at Kalgoorlie Consolidated Gold Mines – from the M3000 to the M10 000 and Replacement of the Roasters at Gidji Processing Plant

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ABSTRACT

The IsaMill™ was originally developed to address liberation issues at Mount Isa Mines (now Glencore) operations, McArthur River and Mount Isa in the early 1990s. Following on from the industrial success at those operations, the IsaMill™ was commercialised. In the year 2000, Kalgoorlie Consolidated Gold Mines (KCGM) became the first external user of the technology with a 1.1 MW M3000 IsaMill™ installed to supplement the roaster capacity at its Gidji Processing Plant. The IsaMill™ was used to ultra-fine grind about 10 t/h of pyrite flotation concentrate to 10–12 μm prior to gold cyanide leaching. Based on the success of the Gidji installation, another was installed at the processing plant at KCGM's Fimiston operation in 2002 in a similar duty.

In 2014, a 3 MW M10 000 IsaMill™ was selected to replace the roasters at Gidji as part of the A$98 M emissions reduction project. The mill was commissioned in April 2015 at the design 30 t/h, allowing the immediate shutdown of the two roasters. Replacement of roasting with ultra-fine grinding completely eliminated air emissions at Gidji while maintaining overall plant production rates.

This paper details the history of the IsaMill™ at KCGM from the original M3000 to the latest M10 000. It covers the basis of the process selection, circuit design, operating and maintenance data.

INTRODUCTION

The IsaMill™ was originally developed by Mount Isa Mines (MIM, now a Glencore Company), in conjunction with Netzsch Feinmahltechnik, to address key liberation issues at the McArthur River project and within MIM's lead/zinc Mount Isa concentrator, which both required regrind sizes as low as 80 per cent passing seven microns. The first 1.1 MW IsaMill™ using inert media was commissioned at Mt Isa in 1994 and four 1.1 MW IsaMills™ became the enabling technology for the McArthur River project in 1995. The early development and implementation of the IsaMill™ is well described by a number of authors including Enderle *et al* (1997), Johnson *et al* (1998) and Harbort *et al* (1999). Modern internal operation of the IsaMill™ has been described by numerous authors including Anderson and Burford (2006).

By 1998 there were five IsaMills™ in operation at McArthur River, two in the lead/zinc concentrator at Mt Isa with a further six mills on order as part of the George Fisher project. The IsaMill™ program had been an outstanding success, allowing both the development of the McArthur River project and significant improvements in the grade-recovery performance of the Mt Isa lead/zinc concentrator, including a ten per cent gain in recovery and two per cent increase in zinc grade after the commissioning of the six mills. This was achieved through improved liberation and clean mineral surfaces due to the inert grinding environment (Pease *et al*, 2006).

The IsaMill™ technology was commercialised in December 1998 and made available to the general mining industry as a means to economically grind with inert media to ultra-fine sizes.

Kalgoorlie Consolidated Gold Mines (KCGM) is a 50/50 joint venture between Barrick and Newmont. It currently produces 700 000 up to 800 000 oz of gold annually and was formed in 1989 through the amalgamation of many individual leases and underground mines in an area known as The Golden Mile. A large-scale open cut mine, the Fimiston open pit, now popularly known as 'The Super Pit', was developed in place of the original underground operations, with the ore treated through the new Fimiston processing plant to produce a pyritic gold concentrate. The concentrator tailings were subject to cyanide leach at Fimiston while the concentrate was roasted to calcine and cyanide leached at the Gidji Processing Plant, 20 km north of Kalgoorlie-Boulder.

Due to a change in the mined areas in 1999, sulfur grades in the mined ore increased, resulting in a significant increase in the tonnage of flotation concentrate produced which exceeded Gidji Plant's roaster capacity (Ellis and Gao, 2002). Alternative treatment methods were investigated and evaluated, resulting in KCGM becoming the first external user of the IsaMill™ and

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the first gold application through the installation of an ultra-fine grinding and leach circuit at Gidji in 2001.

An additional 1.1 MW IsaMill™ was installed at Fimiston in 2002. The IsaMill™ was successfully scaled up to 3 MW in 2003 (Curry, Clark and Rule, 2005) and to date 115 IsaMills™ ranging from 75 kW to 3 MW have been installed across the world in lead/zinc, gold, platinum, copper, nickel, magnetite and molybdenum grinding duties.

This paper discusses the history and performance of the IsaMills™ at KCGM – from the first M3000 installation at Gidji Processing Plant to the latest M10 000 installation, which has allowed the two roasters at Gidji to be decommissioned.

THE GOLD PROCESS AT KALGOORLIE CONSOLIDATED GOLD MINES

The Gidji Roaster's flow sheet, shown in Figure 1, illustrates the process path for the Fimiston pyritic concentrates prior to leaching. The roasters were constructed in 1989 to process the sulfide concentrate from the Fimiston mill and was the first commercial application of a circulating fluid bed roaster in the gold industry. Filtered flotation concentrate at 33–38 per cent sulfur grade was trucked to the Gidji Plant where it was repulped to 60–65 per cent solids by weight and transferred into holding tanks. The slurried concentrate was pumped at around 18–27 t/h into one of two Lurgi circulating fluidised bed roasters operating at around 650°C maintained through the following exothermic roasting reactions:

$$4FeS_2 + 11O_2 \rightarrow 2Fe_2O_3 + 8SO_2$$

$$3FeS_2 + 8O_2 \rightarrow Fe_3O_4 + 6SO_2$$

$$FeS_2 + 3O_2 \rightarrow FeSO_4 + SO_2$$

The roasting process oxidised the pyritic concentrate particles to iron oxides (calcine), breaking down the particles and allowing the encapsulated gold to be accessed in the subsequent cyanide leaching process. The leached gold was processed through an eight-stage carbon adsorption circuit and the loaded carbon trucked back to the Fimiston Plant for elution and carbon regeneration. Gold recoveries generally achieved via the roasting, cyanide leaching route were 93–95 per cent.

As part of the roasting reaction, the sulfide sulfur was released as sulfur dioxide along with quantities of mercury and arsenic. The off-gas was processed through the electrostatic precipitator and then the gas released via the 180 m high stack.

The most dominant constraint for the roasters was the strict requirements for air quality control (AQC) to meet enforced environmental limits. This necessitated shutting down of the roasters whenever the prevailing atmospheric conditions required. AQC constraints included surrounding atmospheric sulfur dioxide levels – these limits were originally as high as 2000 μg/m^3, reduced down to 1400 in 1997, 700 in 2005 and just prior to closure was down to 400 μg/m^3.

In a typical week each roaster might be down for 50+ hours or over 30 per cent of available time. The stopping and starting created both operational and production issues. If the AQC was prolonged there was often a chance of having to reheat with the auxiliary diesel burner to regain adequate temperature. The time required to restore temperature was as much as 116 hours from cold and as much as 44 hours from 375°C. This led to a considerable loss of production. Table 1 shows a typical period (quarter) in 2014 clearly demonstrating the level of downtime experienced by the roasters. Corresponding data from the IsaMill™ M3000 ultra-fine grinding (UFG) circuit (UFGA), which was not impacted by AQC requirements, is included for comparison.

THE NEED FOR ULTRA-FINE GRINDING

During 1999, there was a significant shift in the areas being mined within the open pit operation such that the sulfur head grade of the ore increased by around 75 per cent from 0.8 per cent to 1.4 per cent (Ellis and Gao, 2002). As a result there was a significant increase in the amount of concentrate produced from the Fimiston concentrator, which exceeded the treatment capacity and availability of the roasters at Gidji. It was identified that additional processing capacity was required to supplement the roasters. A number of alternative treatment routes were technically and economically reviewed, including

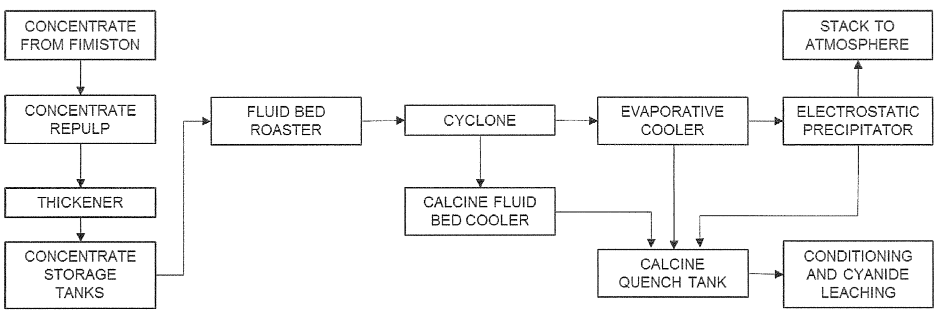

FIG 1 – Gidji Roaster flow sheet for treating Fimiston concentrates.

TABLE 1

Quarterly data from 2014 – Gidji Plant Roasters (R1, R2) and ultra-fine grinding circuit IsaMill™ operating.

Month	Run hours R1	Run hours R2	Run hours ultra-fine grinding circuit	Utilisation R1 (%)	Utilisation R2 (%)	Utilisation ultra-fine grinding circuit (%)
1	506	380	715	68.0	51.5	96.1
2	400	551	705	55.5	76.6	98.0
3	608	595	730	81.7	80.0	97.8
Averages	505	509	717	68.4	69.4	97.3

addition of an acid plant, pressure oxidation, bacterial oxidation and UFG. Based on net present value calculations, UFG followed by direct cyanide leaching was identified as the best alternative to the roasting process, warranting further investigation. A large body of work had been completed on this option over preceding years demonstrating that gold recoveries of up to 92 per cent could be achieved after grinding to a P_{80} of 10 microns (Ellis, 2003). Further laboratory and then pilot test work was carried out by KCGM and is summarised by Ellis (2003).

TECHNOLOGY SELECTION

During the laboratory test work phase, KCGM concentrate samples had been sent to a number of stirred mill providers in order for them to provide estimates of the specific energy requirements to grind to a ten micron product. As reported by Ellis and Gao (2002), due to a wide and differing variety of operating parameters employed by the different manufacturers, it was not possible to make any conclusive comparisons other than that all samples tested indicated that the energy consumption was high to grind below 20 microns.

Following the pilot scale test work there was still uncertainty within KCGM as to which fine grinding technology to select for the process, partly due to the fact that stirred milling to ultra-fine sizes was still a relatively new concept in the minerals industry at that time. A site team made a number of visits to operating sites examining all aspects of the technologies. As a result, the technology choice was narrowed down to the IsaMill™ and the Svedala Detritor (now the Metso SMD (Stirred Media Detritor)). To try and distinguish between the two mills, a head to head on-site pilot mill demonstration was conducted. After working through different media types, grind targets and other performance parameters, KCGM's conclusion was that there was no significant difference in the metallurgical performance of the alternative mills (Ellis and Gao, 2002).

One of the key final selection requirements for KCGM was that only a single mill with proven operational and maintenance performance could be installed for the duty as part of a risk reduction and capital cost minimisation process. As a result of the IsaMill™ having a proven operational and maintenance record at 1.1 MW scale, whereas the SMD was only available at 355 kW, the IsaMill™ became the selected technology.

GIDJI INSTALLATION AND PERFORMANCE

The Gidji 1.1 MW M3000 IsaMill™ circuit, was designed on the back of the laboratory, pilot and demonstration plant data to treat 12 t/h at an F_{80} of 120 microns to a product size of ten microns. It was commissioned in early 2001. Commissioning performance of the Gidji IsaMill™ circuit has been described by Ellis and Gao (2002).

Commissioned circuit

Figure 2 shows the feed preparation and commissioned UFG flow sheet at Gidji. The new IsaMill™ UFGA operated in parallel with the existing roaster circuit. The ground concentrate product from the IsaMill™ was thickened and processed through a three-stage cyanide leach circuit before joining with the leached calcine from the roaster circuit for combined processing through the eight-stage carbon absorption circuit.

Due to the internal product separator arrangement (described by Anderson and Burford, 2006), most current IsaMills™ operate in open circuit configuration with feed generally being prepared by a precyclone to both increase

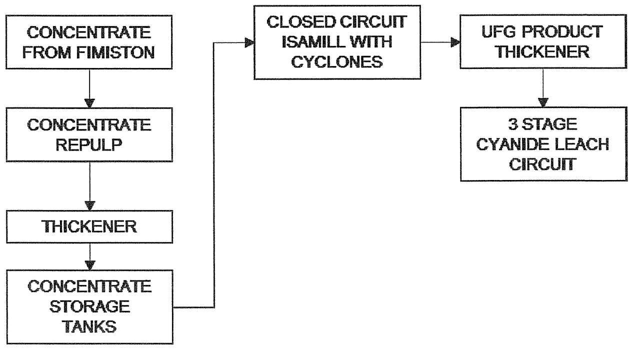

FIG 2 – Gidji ultra-fine grinding circuit after addition of IsaMill™ M3000 circuit.

operating density and allow bypass of material already at the target product size. The KCGM IsaMill™ was designed in closed circuit arrangement. Due to the high specific energy input required, open circuit arrangement would have created temperature issues within the IsaMill™, which is limited to a maximum 70°C to protect the internal rubber components. An additional benefit was the preference for high specific gravity (SG) pyrite (containing the gold) to report to the cyclone underflow at equivalent sizes where the lower SG gangue minerals reported to the cyclone overflow (Ellis, 2003). This essentially resulted in the pyrite being preferentially ground to a finer size than the gangue minerals, leading to a more efficient application of the grinding power to the target minerals rather than grinding gangue finer than necessary.

Grinding media

Grinding media selection for optimised energy efficiency must consider both the slurry feed size distribution and the required product size target. Primarily, the selected media must be large enough to ensure adequate top size breakage and prevent mill bogging. Build-up of unbroken coarse material in the IsaMill™ is characterised by a drop in drawn power due to locking of the charge, allowing one or more discs to rotate freely without engaging the media/slurry mixture. This was observed several times in the KCGM pilot plant operation and has also been observed in other full scale IsaMill™ installations where inadequate media size has been used, one example being during the coarse grinding development work at McArthur River (Anderson, Smith and Strohmayr, 2011).

The coarse media required to deal with the top size was not the optimal size to grind efficiently to the fine target product size. Therefore, the desire to make the size reduction at KCGM in a single step ensured that a penalty in grinding efficiency would be incurred due to the need for a compromised media size selection. At the time of the original installation, sand media was the only identified viable economic option (Ellis, 2003) and a 6 mm top size sand media was employed.

In the years since the KCGM installation, there has been a rapid uptake of both IsaMill™ and alternative stirred mill technology – IsaMill™, for example, grew from an installed base of 17 MW at the time of the Gidji installation to over 200 MW by 2013. This growth resulted in ceramic grinding media becoming a much more cost-effective option with many suppliers now vying for a share of the market, driving prices down. Over 90 per cent of all IsaMills™ installed now use ceramic media. Ceramic media provides significant advantages over sand due to its higher density, high hardness, smoother surface characteristics and lower consumption rates, leading to benefits in grinding efficiency and mill component wear (Curry and Clermont, 2006). Critically, it is manufactured and so can provide a much more stable and consistent product compared to sand, which is subject to natural variations that can impact on quality, consumption and therefore on mill performance in terms of both efficiency and wear characteristics.

KCGM started to investigate ceramic media use in 2006 and eventually changed both mills to operate on ceramic media by 2011. The higher density of the ceramic at SG 3.7 allows a smaller size media to be used and still generate the same breakage stress intensity inside the IsaMill™. The ceramic media also has a much smoother surface profile compared to the sand. These two factors assist to reduce the wear rate of the internal mill components, which lead to improved availability and reduced spare parts costs. Test work reported from a two month trial at the Fimiston M3000 IsaMill™ (Blake, Gianatti and Clermont, 2012) identified a 20 per cent reduction in specific energy, a 50 per cent increase in maintenance interval and a 25 per cent improvement in plant throughput for the same target grind size. Historical consumption rates of the sand at Gidji were around 17 kg/t of concentrate, whereas the current 3.5 mm Magotteaux Keramax ceramic media has a measured consumption rate of 1.30 kg/t, which is about 15 g/kWh. It is noted that the Fimiston UFG mill, also an M3000, uses a 2.5 mm Keramax ceramic media.

Wear performance

One of the main issues post commissioning was the initially high wear rates of discs at the feed end of the IsaMill™, which required mill shutdowns approximately every ten days for disc maintenance. The performance was significantly worse compared to the Mt Isa or McArthur River mills and was a direct outcome of the coarse and hard pyrite feed material coupled with the coarse sand media in use (Ellis and Gao, 2002). Shell liner wear was also higher than the other sites. Through a concerted development effort between KCGM and Glencore Technology (GT), significant improvements were made in the wear performance during the initial operating period.

There have been a number of changes to mill configuration, material development and media use since then. Currently, the M3000 IsaMill™ operates on a four to five weekly shutdown cycle, consuming approximately 14 discs and two shell liners per annum.

Smaller diameter disc configuration

In late 2014, the Gidji mill was configured with smaller diameter discs (SDD), which had been developed by GT to address wear issues at other sites experiencing higher than average wear rates as a result of processing coarse, hard feed material (Rule and deWaal, 2011). A total of two SDD were ultimately installed at the first two disc positions in the Gidji mill leading to further improvements in the mill operational stability. Long-term benefits from the SDD included measured reductions in shell liner wear rates of 50 per cent and a ten per cent increase in mill throughput at the same grind size target. Shutdown frequencies were increased from a typical 18 days to 33 days.

FIMISTON INSTALLATION

A second M3000 IsaMill™ in a similar duty was installed and commissioned at the Fimiston concentrator in 2002 to process additional excess concentrate as result of higher concentrator throughput rates and increased sulfur grades. The IsaMill™ was selected for the UFG duty on the basis of the successful Gidji installation. Based on learnings from the Gidji circuit, several changes were made to the Fimiston circuit including cyclones and pumping discussed by Ellis and Gao (2002).

EMISSIONS REDUCTION PROJECT

The emissions reduction project (ERP) commenced in 2012 with the aim of eliminating sulfur dioxide and mercury emissions from the Gidji Processing Plant. The A$98 M project included the installation of the new M10 000 IsaMill™ at Gidji with associated flow sheet equipment, additional leaching tanks, decommissioning of the roasters and installation of an additional carbon regeneration kiln and new mercury scrubbing and capture system at Fimiston for the carbon regeneration process.

SELECTION, DESIGN AND COMMISSIONING OF THE GIDJI M10 000 ISAMILL™

A number of signature plot tests were completed by ALS Ammtec in Perth under various conditions resulting in a 3 MW M10 000 IsaMill™ being confirmed as the selected mill for the project to treat 29.5 t/h of fresh feed to a product size of P_{80} 12 microns. GT was contracted to supply its standard IsaMill™ package, which included the basic IsaMill™ supply (including drivetrain and associated lubrication/cooling systems) together with feed and discharge pump boxes and pumps, media collection bin and media charging system, instrumentation, associated piping, platforms and structure.

The mill circuit design was based on a two-stage closed circuit arrangement. Repulped feed from the existing concentrate holding tanks is fed into the IsaMill™ feed hopper from where it is pumped into the IsaMill™ with grinding media, as required. Discharge from the IsaMill™ enters the primary cyclone feed hopper from where it is pumped to the primary cyclones (32 Warman CVX 100 mm) with the underflow stream gravitating to the secondary cyclone feed hopper. Underflow from the secondary cyclones (also 32 Warman CVX 100 mm) is returned by gravity to the IsaMill™ feed hopper to combine with the fresh feed.

Both cyclone overflow streams report to a new 18 m diameter thickener. The thickener underflow is pumped to the existing cyanide leach circuit with thickener overflow reporting to a dedicated process water tank for use in the new circuit. The overall Gidji flow sheet utilising the two IsaMills™ and no roasters is shown in Figure 3.

A late change to the project was the inclusion of a variable speed drive (VSD) and Toshiba motor in order to prevent potential penalties associated with power flicker issues on the local reticulated power supply. Typically the large-scale IsaMills™ operate with a fixed speed motor to reduce the capital costs – a wound rotor motor and liquid resistance starter (LRS) combination can be less than half the cost of a squirrel cage motor with VSD. However, inclusion of a VSD can provide the operator with additional control variables with which to optimise grinding and component wear performance. To date, the IsaMill™ has only been operated at its design speed but there does exist an option to investigate the impact of mill speed in the future.

Figure 4 shows an overview of the new M10 000 IsaMill™ installation. Installation of the IsaMill™ and surrounding equipment was largely completed by mid-March 2015 and initial commissioning of the IsaMill™ commenced from 9 March. IsaMill™ commissioning follows a basic standard plan and checklist which ensures all items are correctly commissioned in the correct order. Within the main plan there is flexibility with the order, depending on the daily site conditions and priorities.

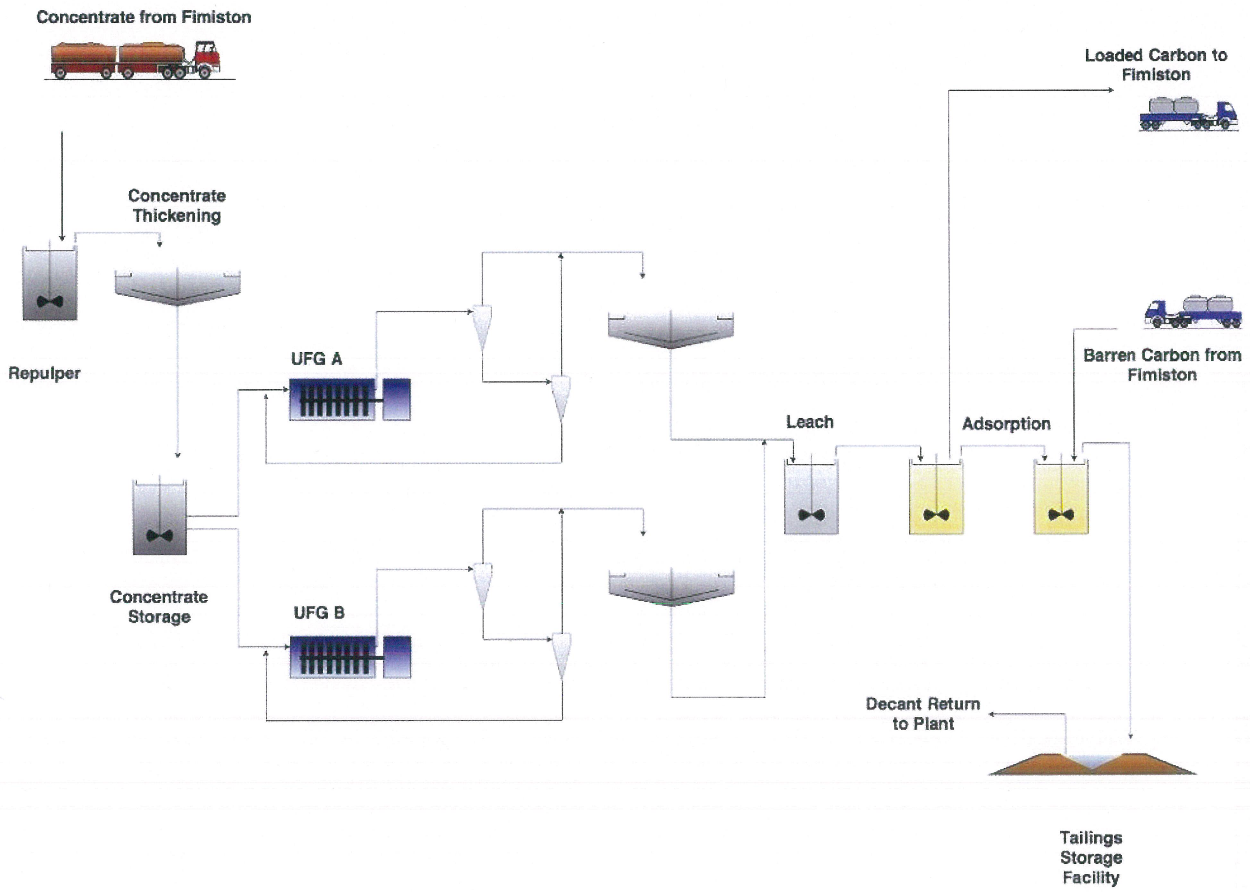

FIG 3 – Gidji – all ultra-fine grinding flow sheet.

FIG 4 – Kalgoorlie Consolidated Gold Mines' M10 000 IsaMill™ installation.

The initial priority was to prepare the necessary equipment to enable the uncoupled run of the IsaMill™ motor when it was available. This involved standard instrumentation/electrical and interlock checks through to the plant distributed control system (DCS) and flushing/commissioning of the mill motor bearing lubrication system. Availability of the motor for commissioning was delayed several days due to technical issues with the VSD. These were resolved and uncoupled motor testing was able to commence on 21 March. In parallel, commissioning of the IsaMill™ and surrounding equipment progressed. This included:

- standard instrumentation/electrical/interlock checks on each system through to the DCS
- operational testing of all valves
- flushing of all lines and tanks
- flushing and commissioning of the IsaMill™ bearing and gearbox lubrication systems
- flushing and commissioning of the IsaMill™ gland system
- water commissioning of the IsaMill™ media charging system (IsaCharger)
- water commissioning of IsaMill™ feed tank and pumps
- water commissioning of IsaMill™ discharge tank, pumps and cyclones
- control sequence logic (start-up, shutdown, media addition) simulation testing at the DCS.

The final step involved pumping water through the mill and actual testing of the start/stop sequences, without the motor coupled. Upon satisfactory completion of those tests, the motor was coupled to the gearbox and IsaMill™ for the final stage of water commissioning, which involved simulating slurry conditions, adding an initial charge of media into the mill and running final checks on the sequencing logic. In this testing the IsaMill™ was operated with both sets of cyclones in operation. Water testing was completed by 27 of March; however, due to other circuit issues, slurry remained unavailable to the IsaMill™ circuit and GT departed site, returning on 8 April to commence slurry commissioning.

The roaster suffered a significant failure on 5 April and the decision was made to not repair, which hastened the slurry commissioning in order to maintain site gold production. The IsaMill™ commenced treating slurry on 8 April and was quickly ramped up to the design target of 30 t/h at 2200 kW with measured thickener underflow circuit product distributions in the 11–13 micron range. As per standard commissioning practice, the IsaMill™ was shut down for an initial inspection on 12 April after 83 operating hours. The inspection highlighted no abnormal wear conditions in the mill, so the mill was closed and operation continued.

The IsaMill™ internal configuration was changed from three small diameter discs to two small diameter discs on the second inspection, which occurred on 21 April, to permit better distribution of the grinding media within the IsaMill™.

GIDJI M10 000 PERFORMANCE

Maintenance

Since commissioning, the M10 000 has operated at 96.3 per cent availability with shutdowns occurring approximately once every four to five weeks. The current data suggests about 11 discs and less than two shell liner change outs will be required per annum. The most recent shell liner lasted 285 days.

For the M10 000, the most significant maintenance issue since commissioning has been the drive end bearing failure, which was traced to an issue related to an extended period between the mill installation and the commissioning process.

Grinding media

The same 3.5 mm Magotteaux Keramax media is used in the M10 000 as the M3000. Consumption rate is now approximately 1.25 kg/t of dry concentrate processed.

Current grinding circuit performance – Comparing the M3000 and M10 000 IsaMills™

Table 2 compares the operational parameters between the two IsaMills™ at Gidji. The M10 000 is currently operating at more than ten per cent above the original design throughput of 29.5 t/h and achieving the grind targets set by the plant metallurgists.

Leaching performance

When head grade variation is taken into account, overall gold recovery at Gidji is assessed as being currently around 0.5 per cent lower than the modelled recovery and four per cent lower than the previous recovery obtained via the roasting process. The roasting process produces very porous particles once the sulfides are oxidised – essentially destroying the pyrite host. The high degree of porosity enhances the dissolution of gold by allowing access to a high percentage of the gold particles by the cyanide solution. The UFG route breaks the particles down to a fine size and induces stress into the mineral lattice allowing a high percentage of the gold to be accessed by the cyanide. Finer grinds promote further exposure; however, eventually this can introduce the formation of some surface coatings, which limit the extraction. A comprehensive study is underway to re-examine the full gold deportment and determine methods to improve the gold recovery by a minimum of two per cent to approach the same recoveries achieved under the roaster operation.

TABLE 2
M3000 and M10 000 operational parameters.

Parameter	Units	M3000	M10 000
Solids new feed	t/h	9.9	32.9
Recirculating load	wt%	497	435
New feed pulp density	wt%	52.5	50.0
Specific energy consumption	kWh/t	85	71.1
Media consumption	g/kWh	15	18
IsaMill™ circuit feed F_{80}	µm	125	125
IsaMill™ circuit product P_{80}	µm	12.1	12.8
Cyclone feed pulp density	wt%	30.6	22.0
Solids split to cyclone overflow	wt%	16.8	11.9
Water split to cyclone overflow	wt%	80.0	74.2
Cyclone underflow pulp density	wt%	51.7	62.9

Ultra-fine grinding versus roasting costs

Table 3 summarises the maintenance and operating costs for the Gidji Processing Plant comparing the last 12 months of roaster operation with the M3000 circuit to the ten months up until March 2016 of the all grinding/leaching circuit (roaster decommissioned) comprising the M3000 and the M10 000. Operating cost has reduced by 8.5 per cent and maintenance cost by 23.4 per cent for an overall combined reduction of 11 per cent or nearly \$13/t. On an annual basis this represents a A\$4.5 M saving in operating and maintenance costs.

Emissions reduction

The reduction of atmospheric stack emissions associated with the operation of the roasters at Gidji has been a long-term focus of KCGM and its joint venture owners, Newmont and Barrick. Following the formation of KCGM in 1989, the establishment of the Gidji Processing Plant resulted in the decommissioning of the remaining three in-town roasters. This resulted in a significant reduction in sulfur dioxide (SO_2) levels in the City of Kalgoorlie-Boulder. With the decommissioning of the roasters at Gidji Processing Plant, KCGM has eliminated 170 000 t of sulfur dioxide from entering the atmosphere annually. Gidji was previously listed in the National Pollutant Inventory (NPI) top two highest mercury and sulfur dioxide sources. Replacement of the roasters with the UFG circuit means that air emissions have now been totally eliminated from the site.

GIDJI M10 000 ACOUSTIC MONITORING

Typically, a skilled IsaMill™ operator can determine changes and diagnose the mills performance based on listening to the sound on the IsaMill™ shell with their ear pressed directly onto the shell. However, this is a difficult skill to learn and is subject to individual differences and interpretations. In conjunction with the CSIRO, GT has developed an acoustic analyser for the IsaMill™ to allow quantitative measurement and optimisation of the media charge position within the mill. Stress waves, generated by the impact of grinding media with the internal mill shell liner, are detected by broadband accelerometers and processed into an acoustic emission mean signal power to allow comparison at various points along the length of the mill shell including the product separator compartment. The unit itself has been well described by Jackson *et al* (2014). Two of these units were originally installed as part of the acoustic development program. One of the acoustically equipped IsaMills™ was idled during 2014, so the opportunity was taken to shift the analyser to the KCGM M10 000 site for the commissioning process. It has proved very useful in both assisting the

TABLE 3
Ultra-fine grinding and roasting cost comparison.

	Operating cost saving	Maintenance cost saving	Total cost saving
Change	-8.5%	-23.4%	-11.0%

operators to understand the condition and operation of the mill and in diagnosing several issues.

Media in the product separator

The product separator is located at the discharge end of the IsaMill™ and essentially allows ground slurry to exit the mill while retaining the grinding media in the mill through its centrifugal pumping action (Anderson and Burford, 2006). Under ideal operating conditions, the product separator area is free of media; however, certain conditions can cause media to enter the product separator. This can reduce the performance of the product separator, eventually leading to more media in the area, loss of media from the mill, wear of the rotor and unstable power draw.

After a mill shutdown on 5 May 2015, the mill was charged to a higher power draw set point than intended due to an issue with the control system around the media charger. This immediately resulted in an unstable power draw situation with a corresponding distinct change in the acoustic reading in the product separator area. This reading indicated the presence of media in the product separator, which could be confirmed by direct listening to the mill shell and suggested that the mill had been overcharged with media. Due to the closed circuit configuration, any media lost from the mill was ultimately returned back via the cyclone underflow so the actual media load could not be reduced without draining media from the mill back into the media hopper.

Higher flow rates can push media into the product separator area as the pumping action of the rotor is overcome. Reducing the flow rate can change the hydraulic balance back in favour of the product separator, allowing media to clear the area and compress more towards the feed end of the mill. Reductions were made to the flow rate in this case with minimal effect suggesting that the media was in the rotor because the mill was full of media rather than as a direct result of any specific process condition. Another observation was that the mill density was operating around 46–48 per cent solids by weight. The density/viscosity can have a significant impact on the overall mill power draw and grinding efficiency.

The mill was shut down for inspection on 26 May, the only changes being an end-to-end rotation of the shell liner. Some additional wear was observed on the product separator related to the presence of media. Prior to the shutdown the media bin was run as empty as possible so that the media volume dumped from the mill could be inspected and monitored during the recharge procedure.

It was recommended to restart the mill at a 50 per cent solids target as this should allow a higher power draw for a given volume of grinding media in the mill. Upon restart, the only process change was the increase in density and the mill was able to reach the target power draw set point of 2430 kW with no significant acoustic measurement detected in the rotor area. The before and after trends are shown in Figure 5. From observation of the charge level in the media bin, it was estimated that once the mill had reached the power draw set point, there were at least 4 t of media still remaining in the bin that had previously been in the mill (an M10 000 operating at full capacity would normally hold around 20 t of media). This confirmed that the mill had been overcharged with media. By remaining at the 50 per cent solids target, the mill was able to be operated successfully without any noise in the rotor area. Figure 5 also demonstrates the response of the acoustics to the variations in the mill power draw.

Shell liner wear

A disposable rubber shell liner supported in a 6 mm steel backer is mounted between the two outer shell halves and the end flanges. During an internal maintenance inspection,

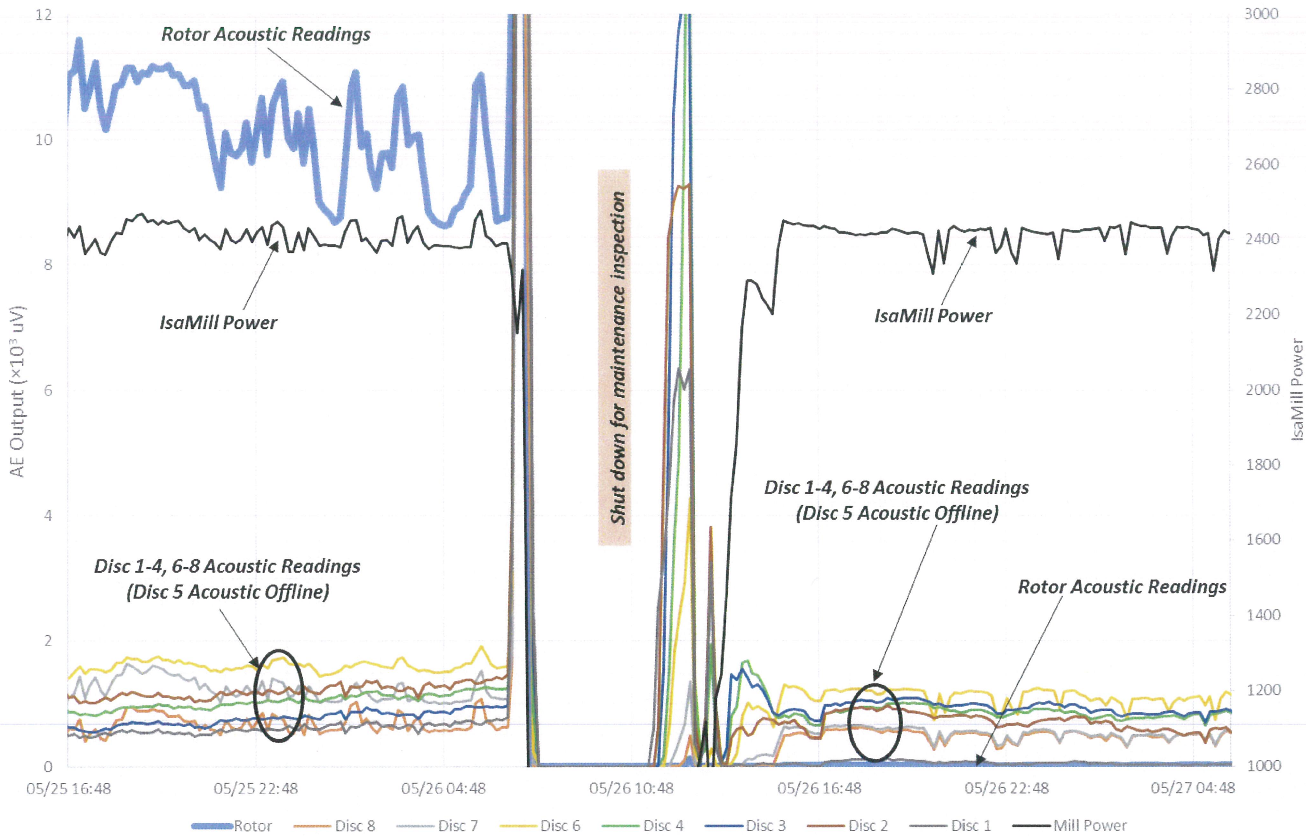

FIG 5 – IsaMill™ acoustic readings before and after shutdown.

the shell liner is rotatable about its own axis and end-to-end to allow the overall life of the liner to be maximised. The liner wears at different rates along its length and diameter dependant on the slurry/media characteristics and process conditions within the mill.

Due to the over-charging incident in May (referred to previously) there was an abnormal wear pattern on the shell liner. On 26 May shutdown directly after the over-charging period, the shell liner was rotated end-to-end and 180 degrees about its axis. Unfortunately this placed a more worn area of the liner into a section of the mill that was subject to higher wear under the normal operating conditions. As the run hours progressed during June, it was apparent that the acoustic reading at the disc four area steadily increased, in relation to the other acoustic channels, up until the afternoon of 9 June when it started to increase rapidly as shown in Figure 6. It is believed that the rapid increase corresponded with the last of the rubber wearing away and the media then starting to wear into firstly the shell liner steel backer and then into the actual mill shell, culminating in the leakage of slurry from the shell.

The acoustic system was not set up with any alarms at the time; however, on reviewing the acoustic data after the event, a series of alarms were implemented to warn of such an issue in the future. These alarms are now linked to the mobile phones of key plant personnel. This event demonstrated the ability of the acoustic system to pick up abnormal conditions within the mill and act as an early warning system, allowing potential issues to be addressed before they become problems.

SERIES GRINDING

The KCGM grind is a very arduous duty with a significant size reduction in a single step. Typical size reductions for the IsaMill™ are in the order of five to six times, whereas KCGM is around ten times. Previous test work by GT has demonstrated significant energy efficiency improvements through the use of series grinding, particularly where reduction ratios are greater than eight times and the product is ultra-fine.

Series grinding initially utilises a larger media to reduce the top size of the incoming feed down to a point where a smaller, more efficient media can complete the energy intensive grind to the final product target. At ultra-fine product targets, energy efficiency is dependent on media size. However, the media size must still be adequate to break the coarsest particles in the feed to prevent build-up and potential bogging of the mill.

The 3.5 mm ceramic media, employed in each of the parallel IsaMill™ circuits at Gidji, was a compromise between being large enough to break the coarse particles in the feed and having enough fine media present to enable production of sufficient sub 12 micron material. A 4–5 mm media was considered more ideal for breaking the top size of the incoming feed material but would simply not be efficient to grind all the way to 12 microns. A 2 mm media is much more suited to efficiently grinding to the 12 micron target; however, it would not provide adequate breakage of the coarse end of the incoming feed.

Considering that two IsaMills™ (the new M10000 and the existing M3000) would be on the Gidji site, investigations were conducted into possible energy efficiency improvements through series grinding. Based on the power available in each of the mills it was established that the M3000 would be used to do the initial grind of the coarse feed using larger media to produce a suitable transfer size for the more energy intensive finer grind in the M10000 using the smaller media. This represented about a 25/75 power split between the two mills.

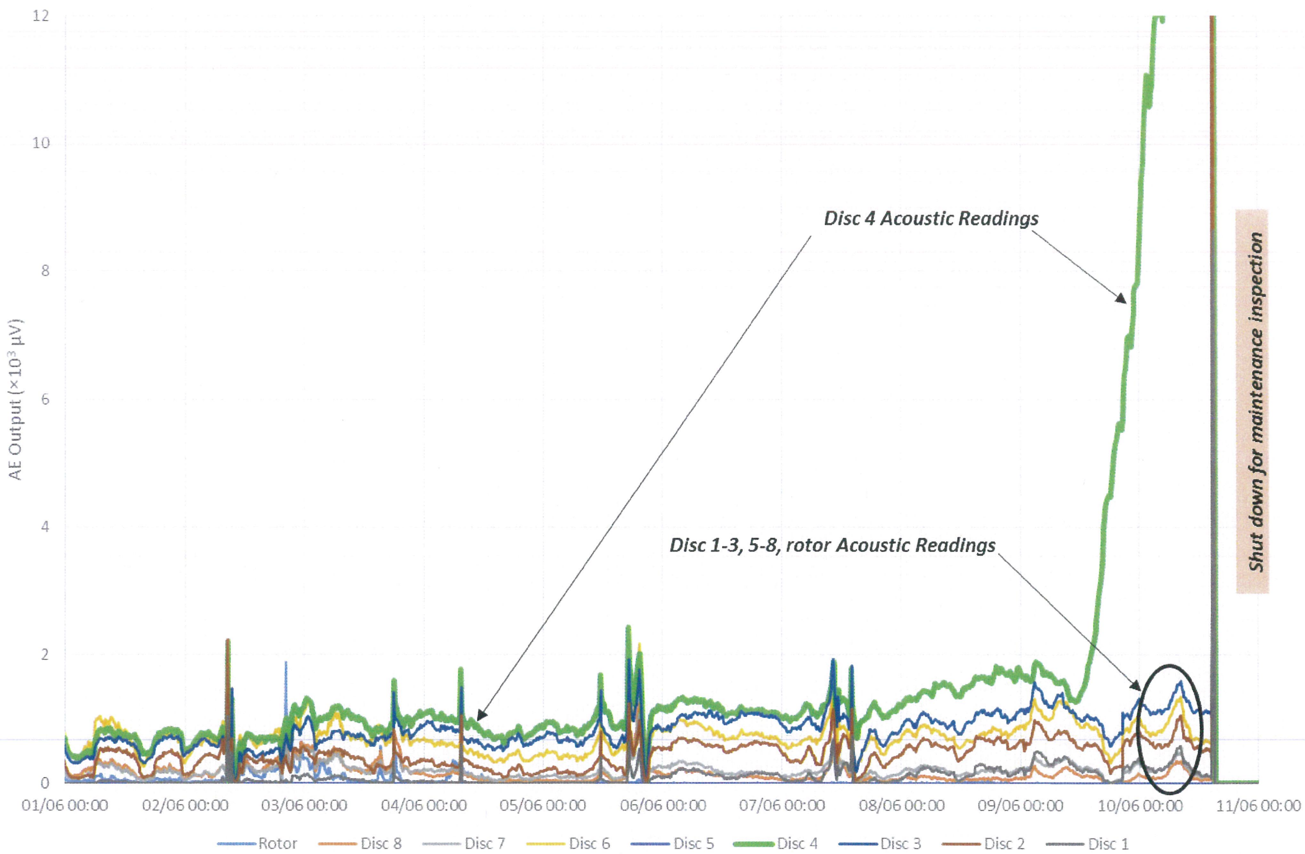

FIG 6 – IsaMill™ acoustic reading prior to shell liner holing.

Samples of KCGM regrind circuit feed were sent to ALS in Perth where they were prepared for standard IsaMill™ signature plot test work – ensuring that the samples for each test were identical. Analysis of the feed indicated a P_{80} of 117 microns. A single-stage test was conducted using the standard graded 3.5 mm media and resulted in a specific energy of 60 kWh/t to grind to a P_{80} of 12 microns. A two-stage grinding test was then completed whereby a graded 4–5 mm media was used as the first stage consuming 13.8 kWh/t to produce a P_{80} of 42 microns. The first-stage product became the feed to the second-stage grind using a graded 2 mm media, which consumed a further 35.7 kWh/t to reach the P_{80} 12 micron final grind target. The two stages combined consumed a total specific energy of 49.5 kWh/t to the P_{80} 12 micron target. This represents a 17 per cent reduction in specific energy compared to the single-stage grind using the 3.5 mm media and a potential substantial energy saving for KCGM. The P_{98} was maintained at 24.3 microns for both the single-stage and two-stage grinds where the P_{80} of 12 microns was achieved. Figure 7 shows the signature plots of both the P_{80} and P_{98} data for the single-stage and series grinds. The equations are shown for the P_{80} curves and the decrease in exponent (line slope) indicates the change in efficiency. The difference in total energy requirement at the 12 micron P_{80} target, and in the corresponding P_{98} curves, can be clearly seen and highlights the improved breakage rates of the two-stage grind.

To maintain the existing combined plant tonnage, overall throughput would be 45 t/h. The M3000 IsaMill™ would operate with 4–5 mm media and be configured with SDD to increase the disc-shell gap. Power draw would be limited to around 750 kW or about 16 kWh/t. The M10000 would operate with 2 mm media in conventional configuration and be able to input up to 60 kWh/t. If the predicted efficiency gains are realised, then there is also opportunity for overall plant tonnage to be increased.

In addition to improved efficiency, maintenance benefits may also arise. Observations by GT over many years have established that coarser feed distributions result in higher IsaMill™ internal component wear rates. The coarsest feed particles would be broken down more rapidly in the M3000 by the use of the 4–5 mm media (compared to the 3.5 mm media) in the M3000. The M10000 will not see any coarse particles due to it receiving the product from the M3000 and will only use fine 2 mm media. Both of these configuration changes will likely result in reduced wear compared to the current configurations using 3.5 mm media. Operationally, the 4–5 mm media will have a wider operating window to handle coarse material compared to the 3.5 mm media. This should result in the two-stage grind being better positioned to handle variations in feed size and hardness into the plant.

Ultimately the new M10000 circuit was installed in parallel to the existing M3000 circuit in order to simplify the commissioning process and develop operational and maintenance understanding of the new IsaMill™ at the plant. Plans are currently in place to investigate the options to transition to the series circuit.

CONCLUSION

Gold was traditionally produced at KCGM through roasting of the refractory concentrate followed by cyanide leaching. Since 2001, KCGM has operated the M3000 IsaMill™ technology, initially to provide additional gold output alongside the roaster at Gidji followed by a second unit at Fimiston. In 2015, with the installation and successful commissioning of an M10000 IsaMill™, the roasters were shut down with all gold production via the UFG route. This enabled atmospheric contamination by sulfur dioxide (170 000 t/a) to be eliminated. As a result of the operation no longer being constrained by AQC, March 2016 saw the highest monthly production tonnage at Gidji since 2002.

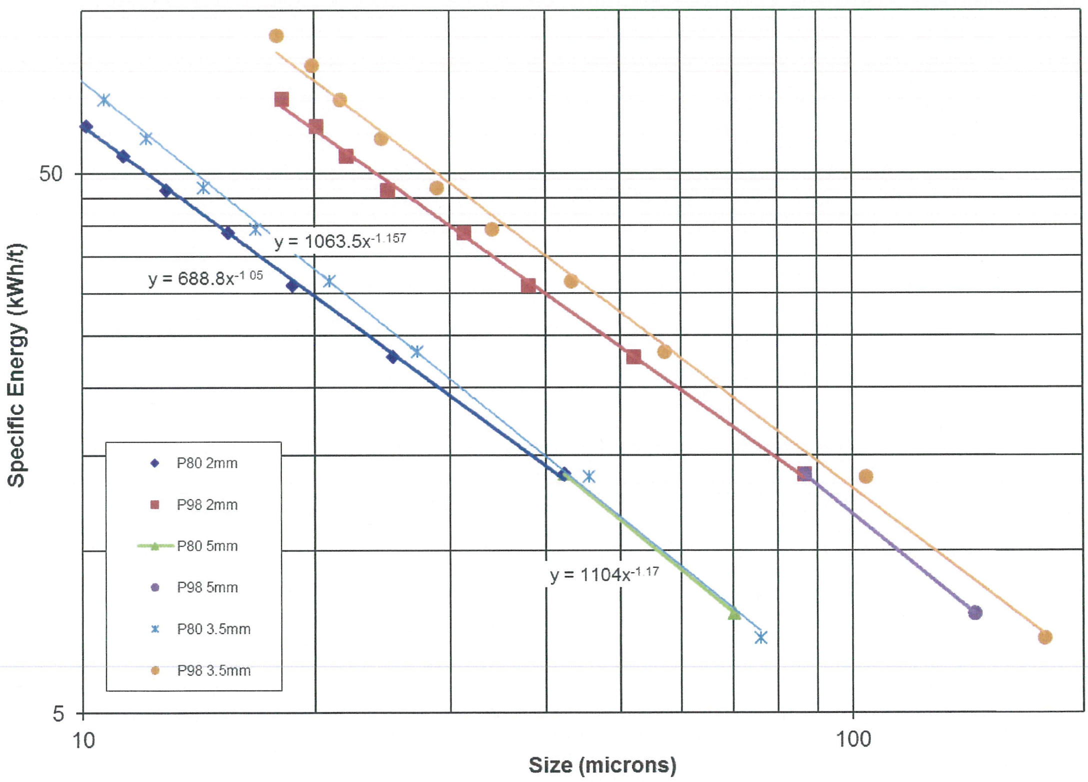

FIG 7 – Kalgoorlie Consolidated Gold Mines' signature plots for single stage (3.5 mm) and two stage (5 mm and 2 mm).

Site operating and maintenance costs were reduced by 11 per cent or A$4.5 M/a. Projects are currently underway to investigate increasing gold recovery.

A new acoustic monitoring system was added to the M10 000 IsaMill™, which has proved invaluable in assisting the plant operators to better diagnose issues within the mill. There now exists opportunities at Gidji to further improve the efficiency of the UFG circuit by combining both mills into a series grinding configuration.

ACKNOWLEDGEMENTS

The authors wish to thank the KCGM Mineral Processing and Assets Maintenance staff for their ongoing support. The authors further acknowledge and appreciate the management of Kalgoorlie Consolidated Gold Mines and Glencore Technology for permission to publish this information. The authors thank and acknowledge KCGM's joint venture owners Barrick Australia Pacific and Newmont Australia Pty Ltd for their support of the Emissions Reduction Project.

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