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Energy considerations in the current PGM processing flowsheet utilizing new technologies

C.M. RULE

Anglo Platinum Management Services

Energy efficiency is currently a significant area of interest due to the Eskom power situation, which led to severe power impacts to the PGM, and indeed whole SA primary industries, in early 2008.

Anglo Platinum has focused on energy efficiency for a number of years, especially in the concentrator operational area. New comminution technologies have been aggressively developed, which have shown real metallurgical efficiency gains as well as significant energy efficiency and saving potential for Anglo Platinum's total electrical consumption as the company expands into a growing PGM demand market. This paper illustrates this programme activities, potential and considerable achievements to date.

Introduction

Energy efficiency in the mineral processing industry is an area currently much in focus in South Africa. The recent major power cuts in January 2008 brought home to the population how precarious the Eskom supply-demand equation actually is. The mining industry is a major power consumer and Anglo Platinum is one of the largest mining industry consumers. It is imperative that Eskom customers deal with this situation as a matter of priority.

It is not expected that this tenuous power availability situation will be changed for the better for a number of years due to the long lead times in the installation of primary, large capacity, thermal power generation. Medupi and Kusile power plants are scheduled for full commissioning in 2016 and 2017 respectively. Unfortunately this situation has coincided with unique resources demand for the minerals industry in South Africa – driven by the behemoth of Chinese economic growth.

Anglo Platinum has invested significant time and resources in defining potential energy efficient comminution technology and indeed has taken a holistic look at the demands of becoming more energy efficient in the processing route for optimal PGM extraction in its processing flowsheets.

Concentrator circuit design and operation

The PGM industry has, relative to the other base metal processing operations, typically, a complex concentrator circuit design with usually multi-stage and fine grinding and flotation. This has arisen due to the inherent high metal prices for the precious metals contained in the ores mined and drives the pursuit of better metallurgical extraction efficiency. Thus it has made good business sense to spend money both on capital and at an operating level to maximize metals recovery.

Typically, depending on their vintage, the comminution technologies employed have been gyratory, jaw and cone crushing and tumbling mills, ball mills and semi-

autogenous or 'SAG', and less often, fully autogenous, 'FAG' milling. In recent years mills have become larger and larger following worldwide mining industry trends for realizing economy of scale benefits in unit equipment. The size of PGM industry concentrators has dictated that few very large mills have been installed – mining practice in the industry is manually intensive underground operations so throughputs required in related concentrators have been constrained.

The mineralogy of platinum group metals has dictated fine grinds to optimally liberate and hence make available the valuable components for recovery by froth flotation. The circuits have over time become more complex – current practice is for so called MF2 circuits, with regrinding after an initial milling and flotation stage, (Rule and Anyimadu, 2006). The circuit that arose from the low recoveries obtained on more complex and fine grained silicate associated ores became more and more prevalent. Typically the majority of Platreef and UG2 ores and altered Merensky ores show a higher tendency in these 'poor metallurgical response' characteristics. This is graphically illustrated in Figure 1 showing typical PGM speciation in plant tailings of a Western Bushveld UG2 concentrator (various AR mineralogy reports).

The increasingly complex and fine grained mineralogy and the pursuit of higher metals extractions not only naturally leads to more complex concentrator circuits and finer grinds, it logically leads to impacts on the quality of the flotation final product produced. In order to obtain reasonably high metallurgical recoveries, the final product grade is necessarily lower. The concentrator products dispatched to the next stage of the process, smelting, are typically low grade when the proportions of metal sulphides and value metals are compared to the silicate gangue minerals. This is one consequence of the pursuit of metals recovery. Hence a relatively large proportion of the overall energy employed in the PGM industry is consumed in the combined concentrating and smelting operations. Logically then this represents an ideal opportunity to become more energy efficient.

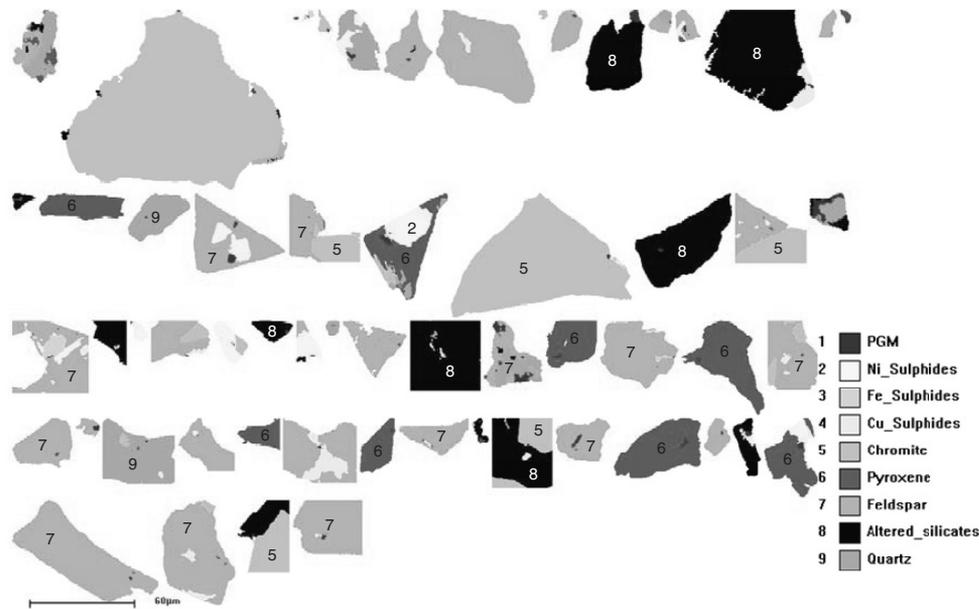


Figure 1. Photomicrographs sourced from an MLA investigation report on tailings from a Western Bushveld UG2 tailings sample showing the complexity of the liberation challenge; note that each particle shown has a PGM phase shown in red. These ‘attached’, ‘middlings’ and ‘locked’ composite particles are all sub 100 micron

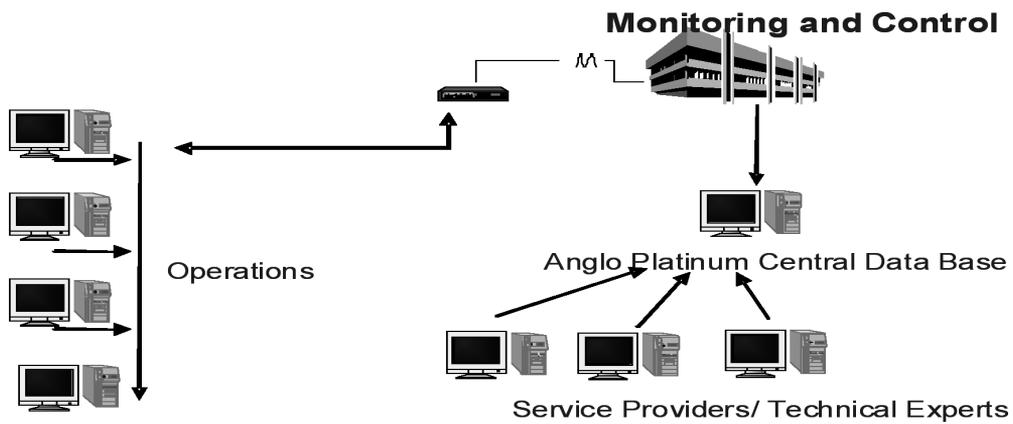


Figure 2. Schematic of the architecture for process monitoring at Anglo Platinum concentrators

Installed power—comminution and smelting

Comminution has been estimated to consume directly around three per cent of all world electrical power. In resource rich countries such as Australia, Peru, Chile and South Africa the minerals processing industry consumes much higher proportions of overall energy use.

Anglo Platinum currently has installed some 1 GV_a of Eskom power capacity. This should be seen in the light of a total installed Eskom power capacity of roughly 38 GV_a. A major portion of this power is installed to drive the unit equipment for the processes of comminution and smelting. Comminution is the process of rock size reduction, i.e. crushing and grinding. This size reduction is necessary to liberate the value minerals that naturally occur together in the run of mine ore. After liberation, froth flotation provides the primary separation process. Typically a mass reduction to 1–5% of the original ore feed to the concentrators is achieved in this step.

Smelting is the second major separation process in the PGM industry—it is carried out in electric furnaces; the

feedstock is the concentrator’s product flotation concentrate. Currently, of this total installed electrical power within Anglo Platinum, tumbling mills and IsaMill equipment represents 195 MW ‘nameplate capacity’ and furnaces at the smelters some 185 MW ‘nameplate capacity’. This represents some 380 MV_a of the installed 1 GV_a (or 1 000 MV_a) – i.e. nearly 40% of Anglo Platinum’s total Eskom consumer load.

Flowsheet and technology optimization as an energy usage optimization route

The pursuit of more optimal processing efficiency has gathered pace in recent years. Anglo Platinum is in a period of significant mining and processing capacity expansion, related to meeting an ever growing PGM market demand. A trend over this period has been the ever increasing exploitation of the UG2 reef horizon and the development of the Eastern Bushveld PGM operations.

The more complex PGM mineralogy and the chromite spinel content of the UG2 reef has introduced a level of processing complexity that was not required when PGMs operations were mainly Merensky focused. The key to more energy efficient and better extraction metallurgy lies in exploiting the mineralogical properties of the ores.

The plethora of new expansion and replacement mining projects and the arising need to understand the geology, metallurgy and mineralogy has been addressed by the establishment of state-of-the-art mineralogical and metallurgical analyses and pilot plant facilities within Anglo Platinum and at the supporting Anglo American Research facilities. This has led to a better than ever understanding of the ore characteristics and hence the extraction processes required and the development of a number of new strategies in flowsheet design and technology application. A feature of this has been the opportunity to install both greenfield and brownfield capacity utilizing modern large-scale plant equipment and new technology.

The IsaMill™ installation programme is one of the two major comminution initiatives that have been pursued aggressively over the last 5 to 7 years; the other has been in the utilization of high pressure grinding rolls, HPGR, crushers. (Rule, Smit, Cope and Humphries 2008).

This has occurred within an overall focus on process control and stability enhancement of the concentrator flowsheets for these new comminution technologies. This has also led to the development of some unique circuits where improved PGM and base metal recovery and improved final product grades and specification have been targeted.

Stability and the ability to run concentrator plants at fixed throughputs for long periods have been defined as a prerequisite for optimum plant performance and to ensure the full benefits of the new technology introduction are achieved. This remains a challenge—especially at sites with insufficient ore storage between mine and plant.

This expansion process at Anglo Platinum has seen a number of fundamental benefits:

- A modernization and rationalization of the concentrator capacity employed. This can be seen in the trend in recent years of older and smaller plant being made redundant and replaced by new plant with larger and fewer units of process equipment and flowsheet modification.
 - In the last two years some 47 old and small tumbling mills have been replaced with newer larger mills and 5 new mainstream, 3 MW IsaMills for regrinding duty,
 - A further 22 old and small tumbling mills will be replaced in the next five years.
 - 22 IsaMills in both ‘mainstream inert grinding’ applications or MIG and concentrate regrind, the industry referred, ultra fine grinding application or UFG, will be operational by the middle of 2010—both for new throughput at finer grinds and to replace less efficient secondary stage regrind ball mills
 - Old plants at Klipfontein, Frank and the Waterval Merensky comminution section have been shut down with a concurrent replacement of hundreds of small flotation cells, pumps and other associated equipment.
- Concentrator processing capacity measured as annual tonnes milled has increased from 22 million tpa in 1998 to the 41–44 million tpa levels achieved in 2005–2007.
- This is despite an increasing proportion of the more metallurgical difficult to process ores – UG2 and Platreef; due to their mineralogy, these both require finer grinding and more complex circuits to achieve required extractions and product grades for smelting.
 - UG2 has increased to 59% of ore milled from 19% in 1998.

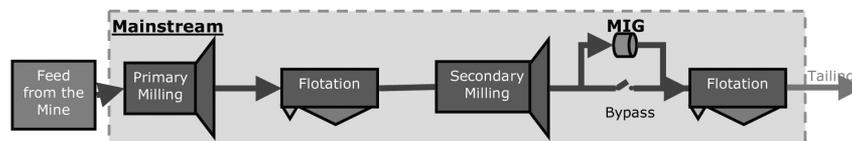


Figure 3. Schematic of the generic mainstream inert grinding, or MIG flowsheet for an MF2 PGM concentrator processing circuit

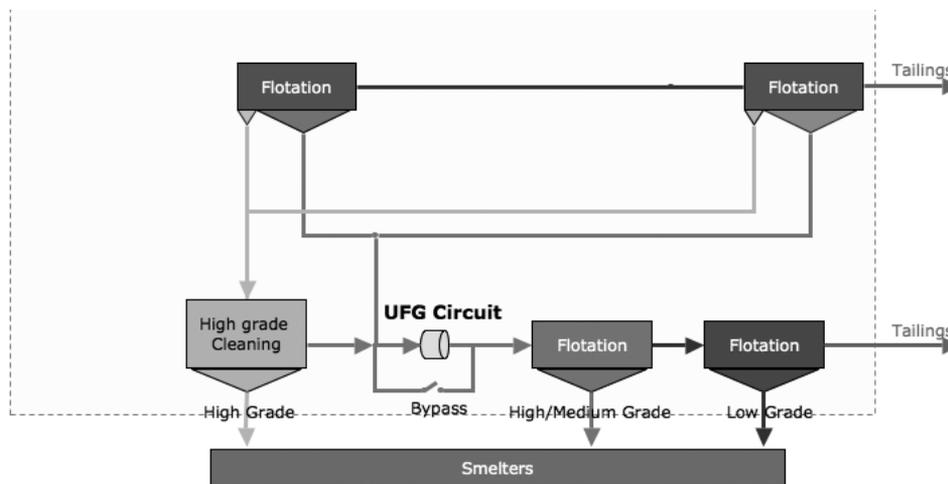


Figure 4. Schematic of the generic ultra fine grinding or UFG intermediate flotation concentrate regrind circuit as applied to a PGM MF2 circuit

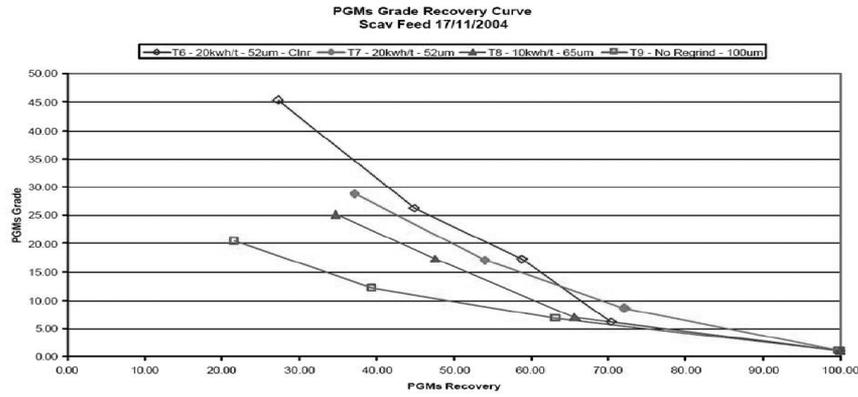


Figure 5. Graph of typical response curves for flotation of a typical scavenger feed stream with UFG IsaMilling applied showing the significant shift in the grade/recovery relationships, excerpt from an on site testwork analysis (AP internal DML report, 2007)

- Platreef will grow to >12 million tpa milled in 2009; the plant capacity was 4.5–4.6 million tpa prior to the commissioning of the plant at Mogalakwena North in the first quarter of 2008.
- Both these ores have higher proportions of fine grained PGMs associated with gangue minerals, for example, typical PGM grain size in UG2 is <10 microns; flotation efficiency is affected if the value minerals are only partially liberated and cannot be floated if completely enclosed in gangue silicates.

Inherently, both these technologies have major energy efficiency benefits; expressed as both KWhr per tonne mined and processed and also as KWhr per unit of metal recovered; when compared to historically conventional Concentrator process flow sheets developed for the PGM industry.

Table I
Comparison of various parameters—ball mills-IsaMills
(sourced from Xstrata Technology)

| | Ball mill | Isamill |
|-------------------------------------|-----------|---------|
| Total foot print (m ²) | 436 | 236 |
| Installed power (kW) | 3 250 | 3 000 |
| Power intensity (kWm ²) | 7.5 | 12.7 |
| Relative area requirement | 100% | 59% |

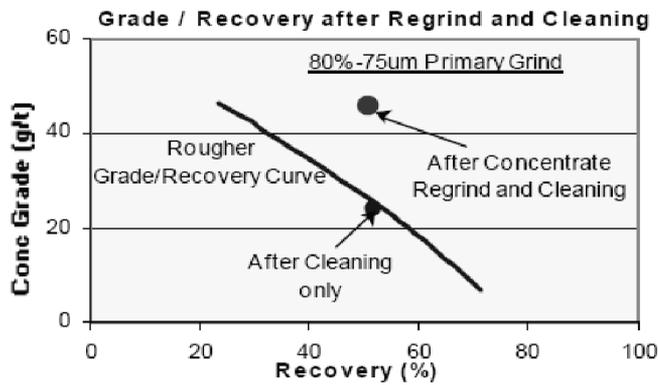


Figure 6. Graph showing impact on grade recovery for IsaMilling mainstream flotation concentrates; data extracted from the pilot work conducted for the Western Limb tailings retreatment project



Figure 7a and 7b. These two photographs, printed at approximately the same scale, show the relative sizes of a 3 MW IsaMill relative to a 1 MW tower mill, typically employed in the copper industry for concentrate regrind in larger scale copper-sulphide flotation plants; the unit size impact of high intensity grinding for an IsaMill is clearly seen. (extracted from Xstrata Technology presentation given at the IIR Comminution seminar, Perth September 2007)

IsaMill™ technology

The IsaMill™ technology roll-out comprises two separate programmes—MIG or mainstream inert grinding and the UFG, ultra fine grinding of intermediate concentrates. Both have significant energy efficiency benefits to the PGM processing route.

The extensive current and future use of IsaMilling technology by Anglo Platinum is due to number of overwhelming reasons (Gao *et al.* 2002, Pease *et al.* 2005 and 2006, Rule *et al.* 2008 and Walstra *et al.* 2008):

- The energy efficient grinding capacity of the stirred horizontal mill compared to ball milling and tower milling,
- Inert grinding environment and its downstream flotation beneficial impacts in comparison to the steel media generally employed in ball mills and tower mills,
- Relatively large unit size compared to alternative fine grinding technologies, typically vertical stirred milling, e.g. SMD™; Deswik (Lichter *et al.* 2002).
- Comparatively advantageous capital costs for installation—especially on brownfield sites and its small footprint and maintenance and operating user friendliness.

To facilitate the utilization of IsaMill technology in mainstream applications Anglo Platinum pioneered the largest milling unit—the M10000 IsaMill, with 10 000 litres of mill volume and a 2.6 MW variable speed drive

unit was development jointly with the technology providers and manufacturers. It was installed to fine grind intermediate mainstream flotation concentrates using inert silica sand media for the Western Limb tailings retreatment project which was commissioned in 2003 in the Rustenburg district.

Anglo Platinum has installed a further 5 mills subsequently, all in MIG duty at Mogalakwena South and Waterval UG2 concentrators. Further installations of MIG and UFG IsaMill units are in project execution phase at Mogalakwena North, Waterval Retrofit, Amandelbult and BRPM concentrator sites currently. At the conclusion of this roll-out programme there will be 22 operating IsaMills in the group.

Figure 8 shows the relatively simple circuit for an MIG IsaMilling installation, typically treating secondary ball mill product and producing a grind of 80% -50 microns or finer. Figure 9 shows the two units installed at Waterval UG2 concentrator and commissioned in the fourth quarter of 2007. The cyclone cluster is used to produce the required operating in-mill slurry densities and mill feed volumes.

One of the most significant benefits in the application of IsaMilling is the inert grinding environment. Figure 10 shows the relative flotation performance in a galena-lead ore system of various media; the advantage of ceramic media is clearly evident. Dissolution of iron when steel media is used is a well—documented phenomenon, which effects flotation performance negatively for many ores.

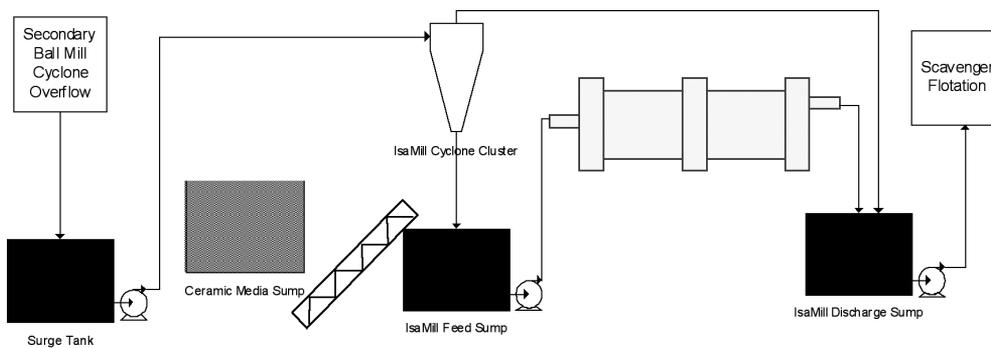


Figure 8. Schematic of typical MIG IsaMill circuit employed in tertiary regrind application

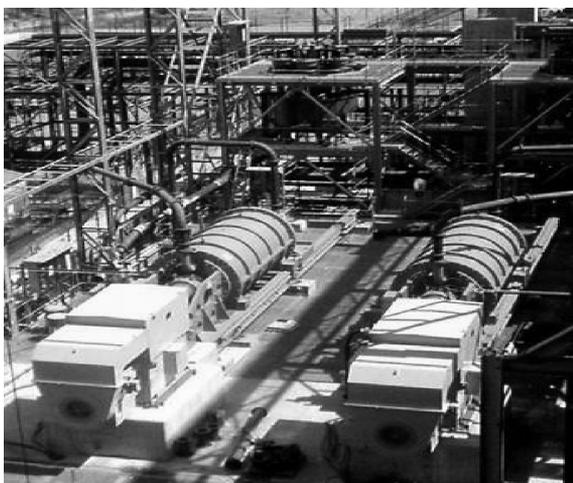


Figure 9. Waterval UG2 MIG IsaMilling circuit layout, showing two 3 MW units and associated feed cyclone clusters

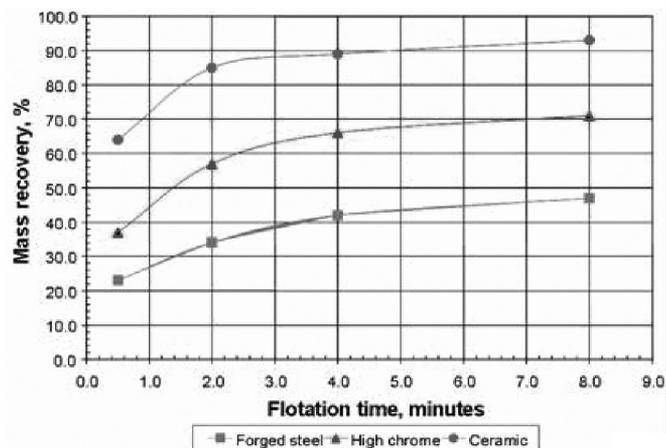


Figure 10. Metallurgical recovery as a function of grinding media type, galena ore (Walstra, 2008)



Figure 11. Photograph of the pilot facility at Mogalakwena South

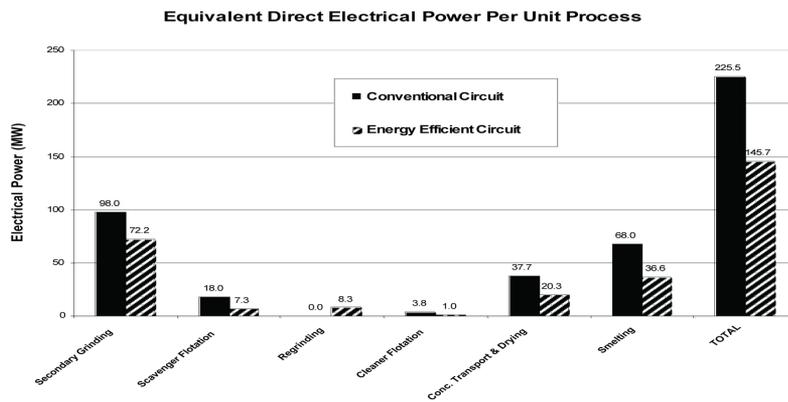


Figure 12. Graph illustrating reductions in relative power requirements for a conventional circuit flowsheet versus a circuit fully utilizing the benefits of IsaMilling with major impacts due to reduction in final product mass (Walstra, 2008)

Table II
Summary of the JKMRM work carried out on Platreef samples illustrating the quantum of energy saving achieved using HPGR technology compared to the conventional crushing route (Shi, 2004 and 2005; Smit 2005)

| | | | | | |
|---|------|------|------|------|------|
| Target grind size (µm) | 300 | 150 | 106 | 75 | 45 |
| Stage 1—HPGR energy (kWh/t) | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 |
| Ball milling of HPGR product (kWh/t) | 16.2 | 25.6 | 32.8 | 57.7 | 53.7 |
| Total HPGR route energy (kWh/t) | 19.5 | 28.9 | 36.1 | 61.0 | 56.9 |
| Stage 1—Jaw crushing energy (kWh/t) | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 |
| Stage 2—Rolls crushing energy (kWh/t) | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| Jaw + rolls crushing energy (kWh/t) | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 |
| Ball milling for conventional product (kWh/t) | 23.6 | 33.7 | 40.0 | 63.0 | 70.0 |
| Total conventional route energy (kWh/t) | 26.9 | 37.0 | 43.3 | 66.3 | 73.3 |
| Net energy saving HPGR route (kWh/t) | 7.4 | 8.1 | 7.2 | 5.3 | 16.4 |
| Energy saving (%) | 27.6 | 22.0 | 16.7 | 8.0 | 22.3 |
| Average energy saving (%) | | | 19 | | |

This has a potential performance impact combined with better liberation and the high intensity attritioning environment inside the mill in both MIG and UFG applications. There is better recovery and at better grades of final product.

The energy impact is very significant as the better selectivity leads to much reduced mass pull to final product for the same PGM recovery. Thus the energy requirement for smelting is much reduced when expressed as kWh per tonne milled. Another potential benefit when new UFG circuits are installed to brownfield plants is the opportunity to open the closed cleaner circuits, i.e. remove the recycle of cleaner tails to the mainstream which will naturally mean an enhanced flotation residence time and fewer flotation

cells and their drives. All these factors can translate into a much reduced footprint and a smaller number of unit equipment in the circuits, flotation cells, pumps, etc.

The relative quantification of the energy footprint such as can be illustrated in a flowsheet taking advantage of the IsaMill benefits described previously in the paper. This graphically shows the very significant potential savings. (Figure 12.)

High pressure grinding roll technology

This technology has been used extensively in the cement industry and later in the diamond industry. Applications in the hard rock mining industry have only recently become

commonplace. Mogalakwena North installed a 5.6 MW unit after a successful large scale trial in 2005 was completed (Rule, *et al.* 2008).

The use of the HPGR technology at Mogalakwena was driven by a number of critical issues:

- The finer particle size distribution, psd, relative to tertiary cone crushing allowed the circuit to be designed for the required tonnage as a single module with two gearless drive, 17.5 MW ball mills in the standard PGM industry MF2 configuration; the alternative was four twin—drive ball mills
- The energy requirement for the overall circuit has been reduced due to the HPGR inclusion taking advantage of the energy benefits in finer primary ball mill feed and micro cracking benefits for downstream primary ball milling.

Work is in progress to define the quantum of energy efficiency achieved in the full—scale operations at Mogalakwena by comparing the energy usage at Mogalakwena South and North plants. Early indications are that a definite energy benefit exists (Ayers, 2008).

The HPGR unit at Mogalakwena North has already shown the benefit of enhancing downstream circuit stability in the early operational period. The comminution circuit provides a very steady particle size distribution despite variations in ore quality coming into the plant.

Extensive work has and is being carried out at the JKMRC in Australia, and at Anglo Research to determine the energy benefits of HPGR technology on various ore types. (Shi 2004, Smit, Pelo, Van Drunick, Tsotetsi, Cassim, Wolmarens and Daniel 2005 and Shi and Daniel 2005). It is clear that HPGR is an energy efficient technology for specific characteristic hard rock ore processing.

Conclusions

By applying the technologies of IsaMilling and HPGR significant energy savings and other circuit benefits can be brought to account. The key to applying these technologies is the understanding of the mineralogical character of the ores and based on this designing a circuit, which can maximize the benefits of the technology to optimize energy usage.

Anglo Platinum has an aggressive roll-out of the IsaMill MIG and UFG technologies and it is expected that within five years significant change will have occurred in the overall metallurgical optimization and also a very real improvement in energy usage expressed as kWh per tonne milled and kWh per ounce PGM will be realized.

Other applications of HPGR technology are being investigated—an attractive option is the precrush of existing primary ore receipts, which has the potential to reduce ball milling power requirements or increase circuit capacity significantly.

Improved energy efficiency by more optimally controlled and stable plant operation will support these technology interventions into the PGM concentrator flowsheets in the future.

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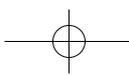
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Chris Rule

Head of Concentrator Technology, Anglo Platinum

28 years in the PGM industry in Southern Africa.

Held senior positions in operations, project execution, technical support and process and technology development for various companies including Impala Platinum, Genmin, BHP and Anglo Platinum.

Currently, Head of Concentrator Technology at Anglo Platinum; responsible for the technical support to operations, technology development and process engineering functions for the group Concentrators. Director of Masa Chrome.

