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The smelting operations of Anglo American's platinum business: an update

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Abstract – Anglo Platinum Ltd is the largest primary platinum producer in the world and operates three smelters in South Africa: Waterval, Mortimer and Polokwane. The operational details of the smelters are covered in previous reviews, thus only unit operations that have been upgraded are discussed. The most significant of the upgrades include the installation of a second ACP converter at Waterval Smelter in 2006 and the anticipated upgrade of Mortimer Smelter to 38MW in 2011.

Several advances have been made in the smelting operations to improve the furnace stability and longevity. Control of the chromium input to each of the smelters has substantially allowed continued operations at levels below the spinel saturation point in slag, which results in lowered matte and slag temperatures. Mogalakwena concentrate, arising from the Platreef ore, is used to dilute high chromium-containing concentrates. In addition, furnace controls have improved in terms of crucible temperature and condition monitoring, improved feeding control, management of alarms and trips and having the quality of instrumentation and operational rigour required to support this.

Advances have been made on the ACP converter in terms of good converter matte quality, and increased intensity and efficiency of operation. Combined with improvements to both the conventional and tower sulfuric acid plants, the emissions from Waterval Smelter have been reduced substantially since the introduction of the ACP. This is in spite of increasing metal throughput.

The Anglo Platinum Ltd smelting operations have made significant progress since 2006 and further advances are envisaged to further improve on safety, reduce costs, increase efficiencies and throughput, while reducing emissions.

INTRODUCTION

Anglo Platinum Ltd is the largest primary platinum producer in the world. The company operates three smelters in South Africa, namely, Waterval, Mortimer and Polokwane smelters. Waterval and Mortimer smelters are located on the western limb of the Bushveld Complex, and Polokwane Smelter is located on the eastern limb, as indicated in Figure 1.

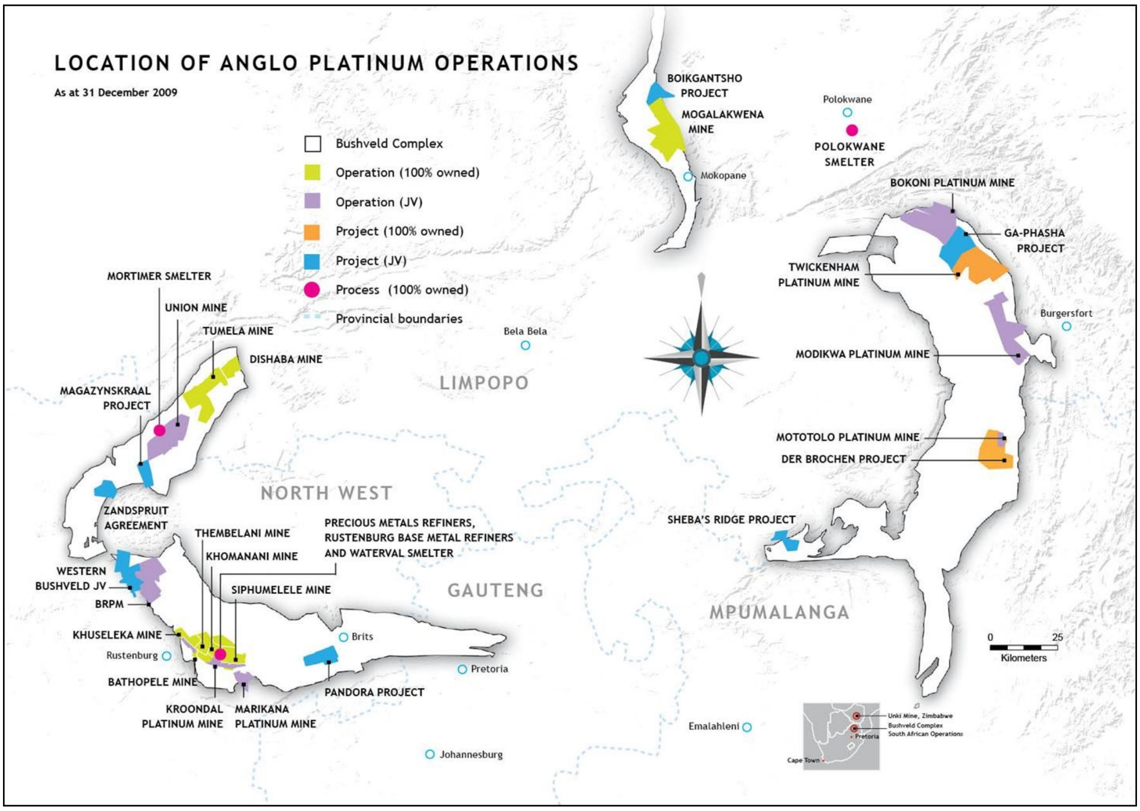

Figure 1: Location of the Anglo Platinum Ltd smelters[1]

Detailed descriptions and brief histories of each of the smelters were provided in 2006.[2,3,4] Further descriptions and data for the three smelters are provided in reviews of the PGM smelting industry[5] and the sulfidic nickel smelting industry.[6] The intention of this paper is to provide an update on the previous reviews and elaborate on several advances made at the smelters in the last 4 to 5 years.

UPDATED SMELTER INFORMATION

Flowsheet

For ease of reference, the Anglo Platinum Ltd smelter process flow is described and a schematic of the Waterval Smelter flowsheet is provided in Figure 2. The Mortimer and Polokwane Smelter flowsheets are simpler and comprise the drying, primary furnace, offgas, slag and matte handling unit operations.

The smelters receive the majority of their concentrates from nearby concentrators; however, there is some transportation of concentrate between regions for strategic reasons. The wet concentrate is dried in flash dryers at each of the smelters. Thereafter the dry concentrate is fed into the primary furnaces. The furnace matte is tapped and then granulated (Waterval) or cast and crushed (Mortimer and Polokwane). The furnace slag is milled and floated to generate a concentrate recycle (Mortimer and partially at Waterval) or stockpiled directly if essentially barren of pay metals (Polokwane, Waterval).

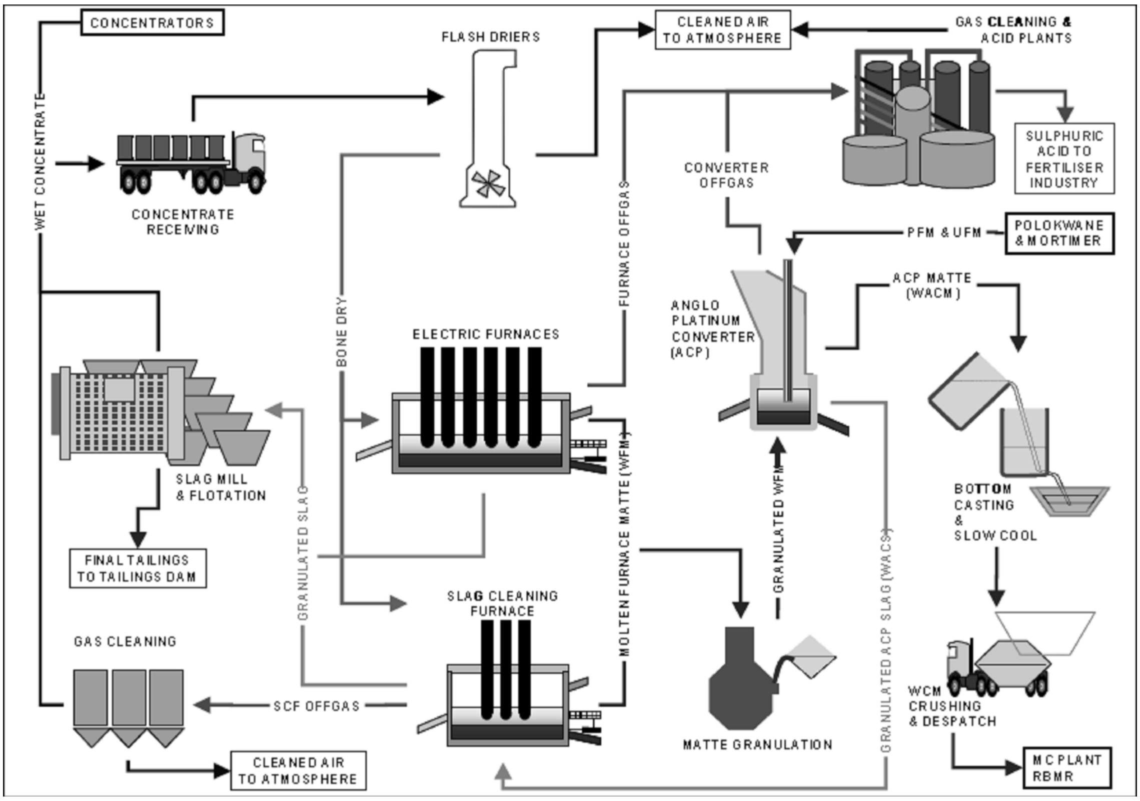

Figure 2: Schematic of process flow at Waterval Smelter (after Jacobs[2])

The furnace matte from all the smelters is then fed to the Anglo Platinum Converting Process (ACP) where the matte is upgraded through removal of the iron (and sulfur) to form Waterval Converter Matte (WCM). The WCM is bottom cast, slow cooled over several days, then crushed and forms the final product from the smelters. The converter matte is transported to the Rustenburg Base Metals Refinery (RBMR) for further processing.

The converter slag is granulated and recycled to a Slag Cleaning Furnace (SCF) at Waterval for recovery of the base and precious metals. The SCF matte is recycled to the ACP, while the SCF slag is milled and floated to produce a concentrate recycle.

Off-gases from the various furnaces are handled slightly differently. Mortimer makes use of dry electrostatic precipitators, while Polokwane has a high-temperature baghouse. The gas from the Waterval primary furnaces is treated with ceramic filters, a wet cleaning system and thereafter in a low-strength acid plant (tower plant). The ACP off-gas passes through wet cleaning and is then treated in a double-contact, double-absorption acid plant for production of 98% sulfuric acid. The 70–76% acid from the tower plant is used for dilution in the absorption circuit in the contact plant. The SCF off-gas is treated in a wet venturi scrubber.

Operational information

The 2007 review[6] of the Anglo Platinum Ltd smelters provides comprehensive details of the operations. Since the previous review several changes have been implemented, the more significant of which include upgrading of Mortimer Smelter and a second converter at Waterval Smelter.

Mortimer Smelter Upgrade

Mortimer Smelter was to be upgraded in two phases, with Phase 1 being carried out in 2008 and Phase 2 planned for 2009. Given global economic conditions towards the end of 2008, Phase 2 was delayed, however; it is now being executed during 2011. The changes implemented in Phase 1 of the upgrade included the following:

- Installation of copper plate coolers in the matte and slag endwalls

  Prior to 2008, the Mortimer furnace was a full refractory furnace, with the only furnace crucible, water-cooled, copper elements being matte and slag tapblocks. The refractory-only lining provided sufficient furnace longevity owing to the low power intensity (19 MW, 110 kW/m^2 hearth power density). However, in light of the intended upgrade of the furnace to 38 MW (51 MVA) upon completion of Phase 2, it was decided to install water-cooled copper plate coolers in the matte and the slag endwalls in Phase 1. The rationale for this was that the endwalls are subject to faster wear and hence to more frequent repair cycles than the sidewalls.
- Upgrade of the crucible binding system and dimensions to allow for future upgrade of power

  Given the inclusion of the copper plate coolers in the matte and slag walls, and the intention to install plate coolers in the sidewalls in Phase 2, the binding system on the furnace was upgraded to ensure sufficient binding load. The furnace dimensions changed slightly from those previously mentioned[6] and are now 25.8 m × 7.9 m.
- Central, remote control room in combination with upgraded instrumentation

  Sufficient instrumentation to monitor the condition of the water cooling circuits and the copper temperatures is essential for operating a furnace with water-cooled copper components. The instrumentation and PLCs were upgraded and the opportunity was taken to move the control room to a remote, safer location than its previous position adjacent to the furnace roof. A central control room was established, from which the entire plant is now controlled.

The second phase of the Mortimer Smelter upgrade is planned for later in 2011 and entails the following enhancements:

- Upgrade of furnace power to 38 MW (51 MVA)

  The power of the Mortimer furnace is to be doubled from 19 to 38MW in order to provide sufficient future concentrate smelting capacity for Anglo Platinum Ltd. Three 17-MVA transformers will supply the power. The hearth power density will increase to 187 kW/m^2. The electrode diameters will remain at 1.25 m.
- Installation of copper plate coolers on sidewalls

  Given the increase in the smelting intensity planned for the furnace at higher power, and to standardise the Mortimer furnace design with the Waterval furnaces, water-cooled copper plate coolers are to be installed in the sidewalls in the slag zone.

- Upgrade of the flash dryer

  In order to provide the upgraded furnace with sufficient feed, the flash dryer at Mortimer will be upgraded to supply ~50 t/h of dry concentrate. The upgrade will include installation of a new hot-gas generator, refurbishment of the baghouse, and additional dry-concentrate storage capacity.
- Upgrade of the slag-granulation circuit

  The greater throughput of concentrate in the furnace will give rise to greater volumes of slag and the current granulation circuit will be upgraded to cater for this.
- Replacement of the off-gas system with a new electrostatic precipitator

  The existing furnace off-gas is treated in three old electrostatic precipitators (ESPs). A new off-gas train will be installed on the higher capacity furnace, and dust will be separated by means of a new large ESP.

Second converter

The ACP technology was commissioned in 2002, with the Phase-A converter installed. The process was developed and optimized successfully, which led to the complete de-commissioning of the Peirce Smith converters in April 2004. The second, Phase-B converter was then installed in 2005. It incorporated some design lessons from Phase A, and was commissioned in 2006. The motivation for a second converter was based on risk mitigation in the event that a catastrophic failure of the Phase-A converter halted the entire Anglo Platinum metal output for weeks to months.

The design changes that were incorporated into the Phase-B converter were—

- Waffle- and transition-cooler design

  The converter makes use of Hatch waffle coolers in the slag zone. In the Phase-B converter certain waffles were extended to create smaller shear planes and improve accretion retention. Transition coolers and an expansion joint are located above the waffle coolers and lead to the gas uptake. The transition coolers on the Phase-B converter were modified to freeze any slag splashes that land at the expansion joint, and thus prevent slag leaks.
- Freeboard design

  The biggest operational challenge faced during the initial operation of the Phase-A converter was the formation of accretions at the freeboard zone of the converter, which blocked the gas flow to the uptake. Many different means were tried to eliminate the problem, including stopping the converter and cleaning. Adequate coal injection in the roof, to provide higher temperatures in the upper freeboard, ultimately resolved the issue. The geometry of the Phase-B converter freeboard was further modified to reduce heat losses and improve slag washing on the sloping section of the uptake, thus eliminating the support surface for accretion build up.

The commissioning of the Phase-B converter was highly successful, resulting in a timeous and quick changeover from Phase A to Phase B in January 2006. The success of the project was attributed to a number of things; however, a major factor was the contribution of a dedicated Owners Team. The team was assembled only from the operational staff that had operated and optimized Phase A and this ensured proper alignment between the project and the operation. The converting duty has been switched twice since then to Phase A and back to Phase B.

KEY ADVANCES

The high value of the Platinum Group Metals (PGMs) dictates the shortest possible pipeline from mine to market and low inventory levels. As a result, extensive stockpiling of different feedstocks (concentrates) for blending purposes, as is practised in smelting of almost all other commodities, cannot be tolerated. Consequently, the smelters have had to become far more reliant on feedback control, and some limited feed-forward control, where possible, to ensure safe and stable furnace operations. Advances made in recent years are contributing significantly to more stable furnace operations and prolonged furnace campaign lives. Improvements to the flash dryers, converter and acid plants have led to improved efficiencies, greater throughput and reduced emissions.

Chromium control

The negative effects of chromium on the primary PGM furnaces are described widely in literature,[8, 9, 11, 14, 17] and selected effects include the following:

- Increased liquidus temperature of constituent components of the concentrate blacktop and resulting slag, which tend to drive up the overall furnace operating temperature
- Highly viscous intermediate layers which form between the matte and slag layers owing to accumulation of chromium spinels. This further leads to problematic tapping of matte, which is characterised by very slow tapping rates and/or freezing of the "matte" in the launder and ladle.
- Hearth build-up
- Inefficient matte disengagement from slag owing to a more viscous slag because of the presence of a solid phase.

A variety of strategies have been reported to deal with the issue:

- Increasing furnace intensity to keep the spinels in suspension in the slag and prevent build-up,[17] e.g., Lonmin No. 1 furnace and Polokwane
- Discontinuing the recycle of converter slag to the primary furnaces[9, 11]
- Discontinuing lime addition to the primary furnaces[11]
- Selective reduction to improve the solubility of chromium in the slag (reductive matte smelting)[12, 17]
- DC-arc smelting in combination with roasting of the concentrate for S removal and increased reduction, e.g., ConRoast (reductive alloy smelting)[13]

- Intentionally tapping out the intermediate layer and separating externally to the primary furnace[14]
- Decreasing the chromium input to the smelters

Anglo Platinum Ltd is in the fortunate position of having the flexibility to deal with the chromium problem by decreasing the chromium input to the smelters. The approach entails the following:

- The concentrators have made progress in reducing mass pull and chromium content in concentrates, while maintaining recovery.[1] There are several other concentrator initiatives in progress to provide further decreases of chromium in concentrate with no sacrifice of recovery.
- The Mogalakwena concentrators treat Platreef ore and produce large quantities of low-Cr_2O_3 concentrate. Given the geographical proximity of the mine to Polokwane Smelter, the majority of the Mogalakwena concentrate is treated at Polokwane. However, some concentrate is trucked to Mortimer and Waterval Smelter as required for dilution of chromium to levels generally below the saturation limit at conventional slag temperatures (1500 to 1550°C). The rationale and methodology for the concentrate allocation is discussed elsewhere.[7] As mentioned above, concentrate stockpiling is not practised; thus there can be variation in the chromium input at any given time; however, operation below the Cr_2O_3 saturation limit is generally achieved. Certainly, intermediate layers, hearth build-up and inefficient matte disengagement from slag are not a major concern within the Anglo American furnaces. Figure 3 indicates the historical chromium levels in the concentrate feed to Waterval Smelter, which follows the trend of increased mining of UG2 reserves. However, from 2008, chromium has been controlled to generally below the saturation point.

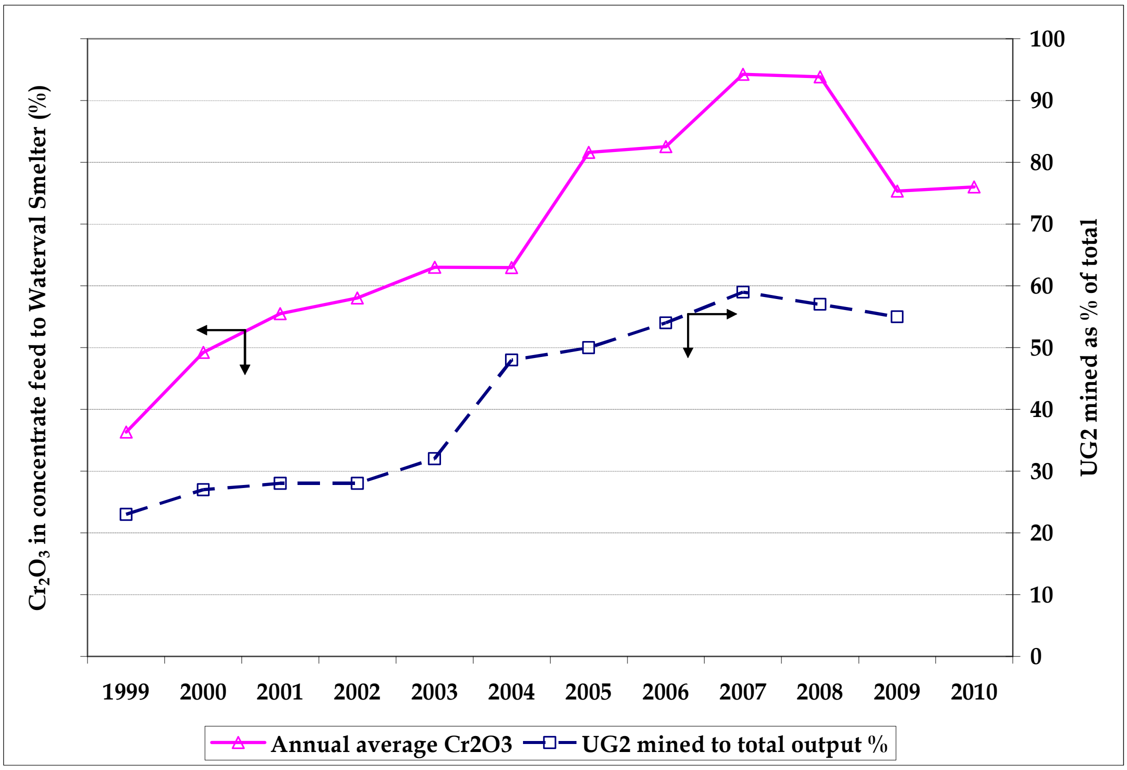

Figure 3: Chromium in the concentrate feed to Waterval Smelter

Furnace control

Through the control of chromium levels in the feed to the furnaces, matte and slag temperatures can be controlled to within acceptable limits, which in turn lowers all-important matte and slag superheats. One of the major concerns when smelting high chromium-containing concentrates in a high-intensity furnace is high matte temperature. The specific concern is that the matte temperature is potentially higher than the liquidus temperature of the slag freeze lining on water-cooled copper components, a principle well-known from the ferronickel industry.[10] On all of the smelters, strict guidelines have been implemented regarding matte temperatures, to the point where furnace operating power may be reduced if required. Obviously, power reduction is undesirable and other variables are monitored and controlled to minimise periods of high matte temperature.

Feed-forward control of the furnaces is limited to knowledge of the properties of the concentrates received several hours to several days beforehand. Consequently, feedback control has been advanced to ensure that stable furnace control is achieved and furnace longevity is promoted.

Good feedback control is possible owing to the comprehensive instrumentation available on each of the furnaces, the quality of the data provided by the instrumentation, the methodical monitoring of the instrumentation, and the pro-active management of setpoints, alarms and trip conditions.

- Crucible instrumentation available:
    - Roof, freeboard, upper sidewall temperatures
    - Copper temperatures in all copper components
    - Circuit-water temperatures and differential water temperatures over each copper tapblock, copper cooler (Polokwane) or set of coolers (Waterval and Mortimer)
    - Hearth and bottom-plate temperatures
- Quality of data available:
    - Remote monitoring of critical instrumentation has been developed and the system automatically detects bad instruments, instruments erroneously reading ambient temperatures, and instruments reporting values which do not change at all
    - Reports are reviewed daily by the instrumentation departments on each of the smelters and faulty instruments are repaired.
- Pro-active management of setpoints, alarms and trips
    - Appropriate setpoints and alarm and trip limits have been selected in conjunction with the furnace designer. The basis for calculation of the aforementioned parameters is reasonably well understood in terms of the physical implications of a high temperature in a particular location. Appropriate actions are taken when alarm and trip limits are breached.

At Polokwane the furnace monitoring leads further to development of an on-line heat balance for feedback on the thermal condition of the furnace, while automated feeding systems ensure that the feed is matched to the power and distributed evenly across the furnace.[17] Good-quality instrumentation is essential to support this.

As an illustration of the improvement in control of the furnaces, Figure 4 provides a comparison of the average freeboard temperature in Furnace 1 at Waterval Smelter for the period from October to December 2007 versus the same period in 2010. The average furnace operating power for the 2007 period was 26.5 MW with a standard deviation of 10.1 MW, while for the 2010 period the power was 27.6 MW with a standard deviation of 7.4 MW. The 2010 temperatures are far more consistent (standard deviation of 40°C versus 77°C for 2007) with considerably fewer high-temperature excursions. Also, the average overall temperature is 70°C lower. The freeboard temperature provides a measure of the efficiency of the smelting process:

- Lower temperatures indicate lower heat losses
- More consistent temperatures indicate more consistent feeding, and hence less stress on the furnace crucible due to better matching of the feed to the power input.

Similar improvements have been achieved on the other furnaces.

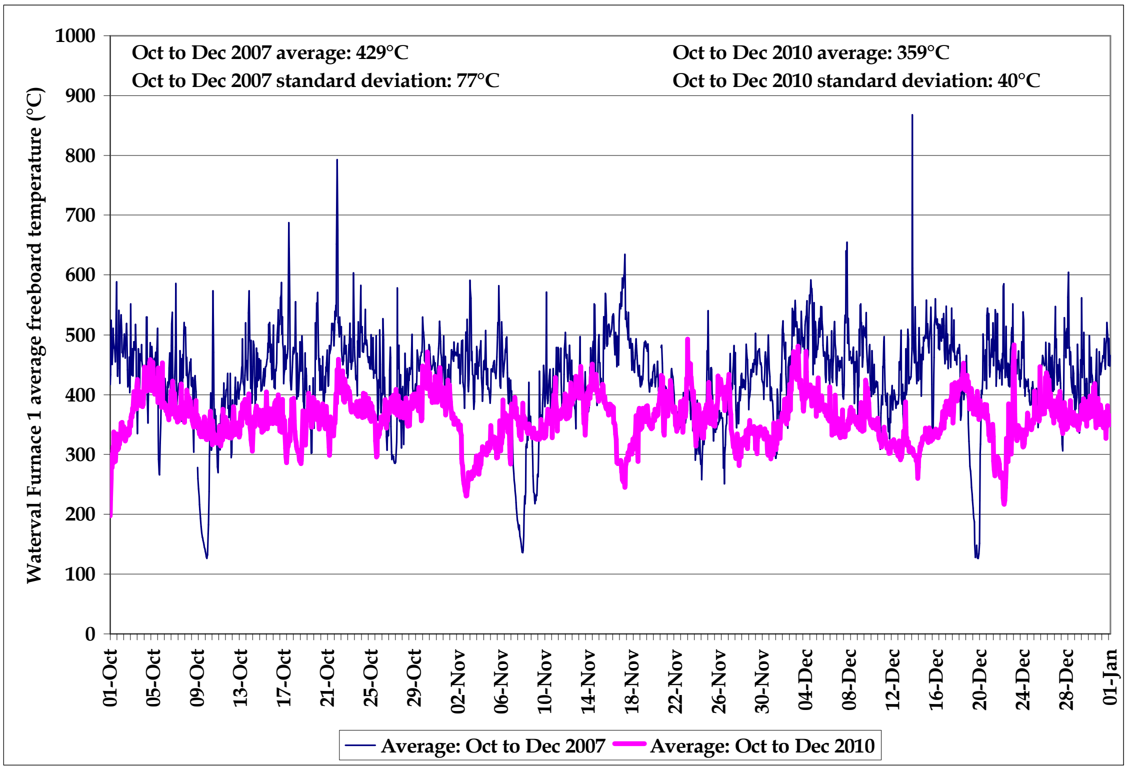

Figure 4: Waterval Furnace 1 average freeboard temperature comparison: October to December 2007 versus October to December 2010

Discontinuation of lime fluxing

Lime or limestone has traditionally been added to the primary PGM furnaces for fluxing purposes. The rationale for the lime addition used to be for reduction of slag viscosities in conjunction with lowering of the slag liquidus temperature and decreased wear rates of the basic refractory linings.

Lime has not been added to the Polokwane furnace since November 2003,[17] and lime addition to the Waterval and Mortimer furnaces was discontinued in 2008. The removal of lime from the furnaces has released additional concentrate smelting capacity, decreased operating costs, and produced no adverse impacts. For example, with slag PGM content nominally at the same level as when adding lime, PGM losses are now effectively lower, owing to lower equivalent slag volume dilution. Refractory wear is no different, as the furnaces are equipped with copper coolers to force a protective-accretion freeze lining on the walls. In addition, slag and matte temperatures are, if anything, lower following the attention given to lowering the chromium content in feeds. Lime will only now be added to furnaces when a more fluid slag is required in preparation for furnace draining ahead of repairs.

Flash dryer control

Improvements in the efficiencies of the flash dryer operations have been achieved through the implementation of advanced process control. The developments at Polokwane Smelter[16] have been rolled out at the flash dryers at Waterval Smelter and will be incorporated into the upgrade of the Mortimer Smelter flash dryer.

ACP

The replacement of the Peirce-Smith converters by the ACP converter was largely driven by the need to reduce environmental SO_2 emissions. The environmental objective has been achieved and will be discussed below. However, significant process benefits have also been realised:

- The overall intensity of the ACP operation is sufficient such that one ACP has replaced six Peirce-Smiths. The ACP is able to treat up to 1000 t/day of furnace matte, at a specific throughput as high as 60 t/day/m^2 of hearth area.
- Despite the high intensity, the integrity of the converter crucible is maintained through the novel use of water-cooled copper waffle coolers constrained in a three-dimensional binding system,[8] and the campaign life of the converter is primarily determined by statutory inspections on the water-cooled gas uptake, as opposed to the vessel refractory lining.
- The quality of converter matte product and the consistency with which it is achieved ensures that the correct alloy content in the WCM facilitates the optimum PGM separation in the downstream operations. The quality of matte is controlled by measuring the oxidation state of the slag. The oxygen injection is controlled to achieve the desired oxidation state, which ensures the required Fe and S levels in the product matte. Quick-turnaround analyses for all the converter process control samples are enabled through a robotic laboratory on site to affect the requisite control.

Acid plants

The initial ACP project included the installation of two acid plants: the contact section (single contact, single absorption) to process high-strength SO_2 converter gases, and the tower-plant section to process low-strength SO_2 electric furnace gases. The tail gas from the contact section was intended for treatment in the tower-plant process. Owing to operational difficulty and instability on the tower plant, the capacity to treat the contact plant tail gas was poor, which resulted in lower site-sulfur-fixation levels. In 2005 the contact section of the acid plant was modified, and a new 4-pass, double-contact SO_2-SO_3 converter was constructed. The double-contact, double-absorption plant was commissioned in 2006 with the Phase-B switch-over, and given the greater conversion efficiency, this further reduced the site-sulfur emissions. Optimisation of the acid-plant converter during 2008, through improved process control, has led to additional improvements on conversion efficiency and further reduced emissions.[15]

The recovery of SO_2 from the off-gas of the electric furnaces is carried out in the tower plant. The details of the process are discussed elsewhere.[2] The presence of both nitric acid and sulfuric acid in the reactor vessels presents a unique challenge in terms of materials of construction, for the vessels and packing. ACP went through a comprehensive study process to identify and test suitable materials. Materials of construction which provide good lifespan are now in place in the tower plant. Further technical innovations now also allow for condition monitoring of the materials. From a process perspective, further automation of the control has yielded good results in lowering NO_x emissions.

The advances discussed above have all contributed towards achieving the prime objective of the ACP site; namely, to reduce the site emissions to comply with permit requirements (Figure 5), while increasing the throughput of Anglo Platinum Ltd.

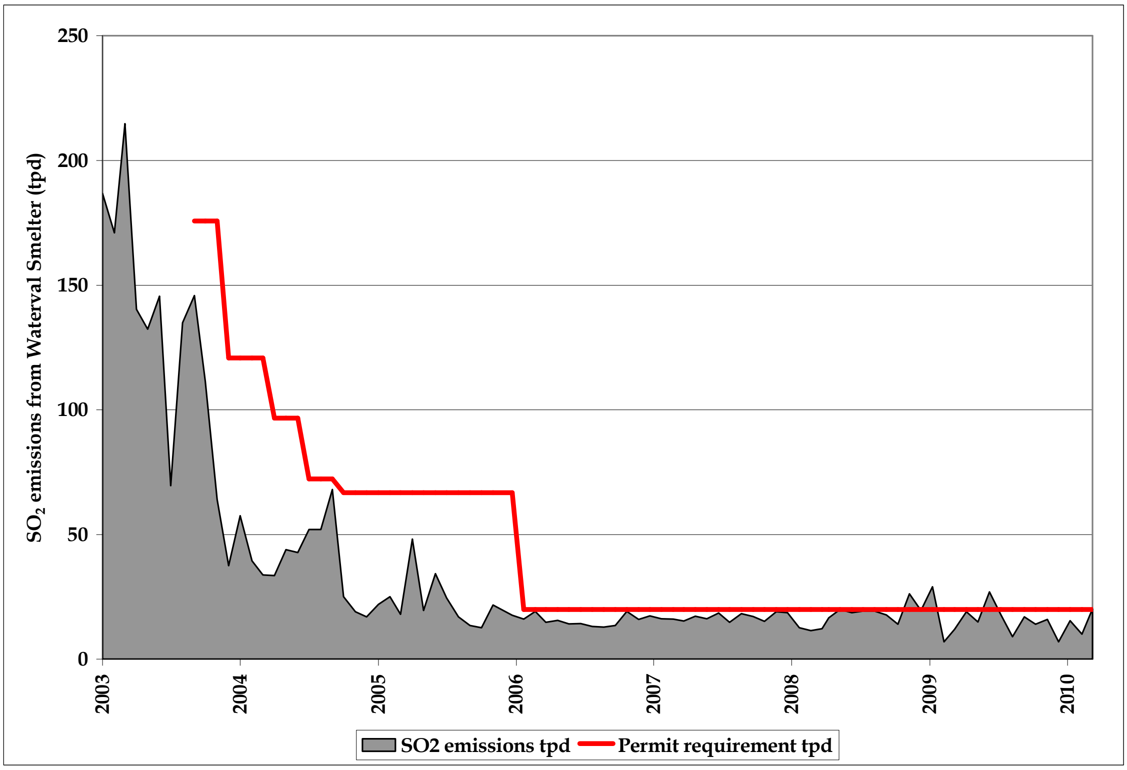

Figure 5: Decrease in SO_2 emissions from Waterval Smelter

CONCLUSIONS

An update has been provided on the Anglo Platinum Ltd smelting operations, particularly focusing on the second ACP converter and the upgrade to Mortimer Smelter. Many advances have been made on the smelting operations to improve the efficiency and campaign lives of the primary furnaces, and enhance the ACP converter and acid plants to improve throughput and quality with lower emissions. Future objectives are to advance further the smelting operations to improve safety, increase efficiencies and throughput while reducing the impact on the environment.

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This paper is published by permission of Anglo Platinum Ltd. The contributions of all the smelting operations' team members are recognised in the quest for excellence and the advances made thus far.

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