Furnace energy efficiency at Polokwane Smelter

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Synopsis

Anglo Platinum's Polokwane Smelter is situated outside Polokwane, in the Limpopo Province in South Africa. A single 168 MVA six-in-line rectangular furnace smelts dry concentrates containing platinum group metals (PGMs).

Furnace energy consumption since commissioning is presented, showing that energy efficiency improves as capacity utilization increases. An energy balance for the furnace is outlined, indicating the measured or calculated energy losses from the hearth and side-wall cooling, the copper coolers, the upper furnace walls and roof, and the energy losses in off-gas, matte, and slag.

From the energy balance, the potential to improve energy efficiency by controlling the slag temperature, the slag level, and the off-gas volume is derived. Furthermore, the impact on the energy balance of different concentrate types is discussed, as well as the potential impact of replacing all upper waffle coolers by plate cooler panels.

Introduction

Anglo Platinum's Polokwane Smelter is situated outside Polokwane, in the Limpopo Province in South Africa. The plant was commissioned in March 2003. Wet concentrate is received from various concentrators along the Eastern Bushveld Complex and occasionally from the Western Bushveld Complex. On a daily basis, approximately 50% to 80% of the total concentrate received is from the UG2 reef and 50% to 20% is from the Platreef and from the Merensky Reef. The concentrate is dried in two flash driers and smelted in a single 168 MVA furnace. Nominal throughput of the furnace is 650 000 t/a of concentrate at nominal power input of 68 MW.

In the furnace, the concentrate smelts into a matte phase, a slag phase, and some gas. Furnace slag is granulated, dewatered, and deposited onto a dump. A PGM-rich nickel-copper matte is cast, crushed, and transported to Rustenburg for converting. The process has been described in detail previously[1].

Electricity is the single biggest input cost for smelting platinum concentrate in an electric furnace, currently exceeding 25% of cash operating cost. In combination with the electricity shortage experienced in South Africa since January 2008, and consistent with a formal Anglo American drive to effect a 15% reduction in specific energy consumption across all operations by 2014 (against an adjusted 2004 baseline), improving furnace energy efficiency is of paramount importance.

Furnace design

The furnace at Polokwane Smelter (see Figure 1) is a large high-intensity furnace for smelting platinum group metal concentrates. The inside furnace dimensions are 29.2 m long and 10.1 m wide. The electrode diameter is 1.6 m. The furnace has three matte tapholes and three slag tapholes located on opposite ends of the furnace.

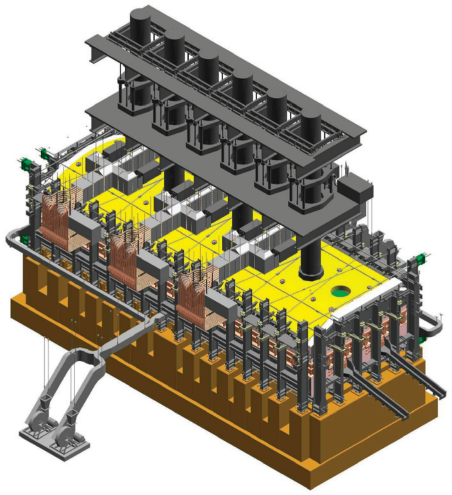

Figure 1—Polokwane Smelter furnace

* *Polokwane Smelter.*

As a relatively high proportion of UG2 concentrate in the furnace feed was expected, the furnace was designed to treat concentrates containing up to 4% Cr_2O_3. Deep electrode immersion (up to 75%) and high power intensity (up to 250 kW/m^2) should provide adequate stirring to prevent hearth build-up and the formation of a chrome-rich intermediate layer between matte and slag.

Given the processing conditions described above, higher matte and slag temperatures and higher sidewall energy fluxes were expected. To ensure furnace sidewall integrity, Hatch waffle coolers were installed in the slag and lower concentrate zone. The intense cooling of the waffle coolers results in the formation of a freeze lining. The waffle coolers have been designed for a maximum energy flux of 220 kW/m^2, but normal operating energy fluxes are 50–80 kW/m^2 with peaks of 110 kW/m^2. The bottom and sidewall plates of the refractory hearth are force-cooled by air.

The original Hatch waffle coolers unexpectedly showed significant corrosion of copper at the slag/concentrate interface. As a consequence, the waffle coolers have had to be replaced four times since March 2003, while significant research and testwork was done to solve this problem. At the first replacement, waffle coolers of the original design were installed because of the urgency to get the furnace back in production. However, at the second replacement, the design was changed from a 1.2 m single-height waffle cooler to two half-height coolers (lower and upper waffle coolers), with the upper coolers being split again vertically in half. The reason for this was the observation that the corrosion occurred predominantly on the upper half of the coolers at the slag-concentrate interface.

Sulphidation (and even some chlorination) of copper appeared to be the main corrosion mechanism. Different materials were tested to protect the upper waffle coolers, but the installation of graphite blocks on the hot face appeared to be the most effective. Therefore, graphite has now been installed on all the upper waffle coolers. Some of the upper waffle coolers were replaced by a ‘plate cooler panel’, as a test. The plate cooler panel is a staggered arrangement of three copper plate coolers and three graphite plates. The corrosion process and remedial action have been described in detail elsewhere[2].

This paper focuses on the furnace energy efficiency. It shows the historical energy consumption during the five campaigns (the period between two waffle cooler replacements is referred to as a campaign) and the trend in (gross) specific energy consumption. An energy balance is presented based on actual measurements of the energy losses, and the potential to improve energy efficiency by reducing energy losses is discussed.

The specific energy consumption is also a function of the mineralogy of the concentrates smelted. Therefore, the impact of different concentrate blends on the day-to-day specific energy consumption is evaluated. Finally, the potential improvement in energy efficiency if the upper waffle coolers were replaced by plate cooler panels is shown.

Furnace energy balance

On an hourly basis, and even on a daily basis, the furnace is seldom in true thermal equilibrium, as matte, slag, and bone-dry levels and concentrate blends change continuously. Therefore, it was decided to do monthly energy balances (Table I). The losses from the furnace are shown schematically in Figure 2.

The furnace power input is calculated by the process control system from the electrical parameters on the primary side of the transformers, giving a daily power input figure.

The energy required for smelting concentrate is calculated

Table II

Average (net) specific energy requirement for smelting Platreef, Merensky, and UG2 concentrate, using July 2008 data

Concentrate type	Specific energy requirement (kWh/t concentrate)
Platreef	579
Merensky	554
UG2	667
47/3/50 % mix of Platreef/Mer/UG2	622
17/3/80 % mix of Platreef/Mer/UG2	649

Table I

Analysis of monthly furnace energy losses for May and July 2008.

	Design	May 08	July 08
Energy output (MWh/h):			
Off-gas energy losses	4.96	4.5	3.4
Dust in off-gas	0.58	0.26	0.34
Copper coolers		2.6	2.1
Hearth cooling		1.2	1.2
Sidewall cooling		0.3	0.3
Cooling of LV buses and contact pads		0.43	0.53
Roof energy losses		0.2	0.2
Sidewall energy losses		0.11	0.11
Transformer no-load losses		0.14	0.14
Transformer energy losses		0.19	0.25
Electrode energy losses		-0.09	-0.11
Total energy losses	10	9.84	8.46

Numbers are in MWh/h (or MW) unless stated otherwise

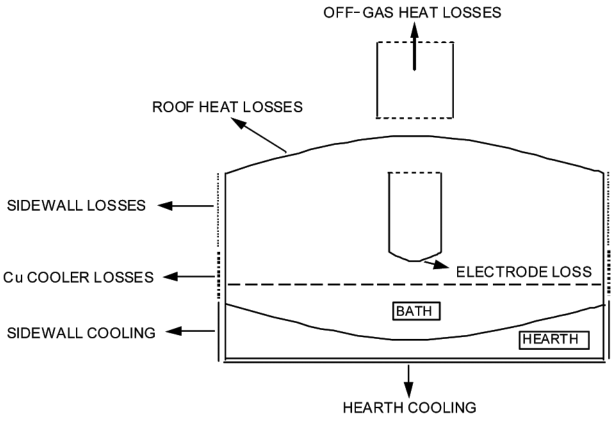

Figure 2—Schematic representation of energy losses around the furnace

by converting the monthly weighted average chemical composition of each concentrate type into a mineralogical composition. The enthalpy increase and enthalpy of fusion for each sulphide and oxide mineral is used to calculate how much energy is required for melting each concentrate type. Table II gives an overview of the average energy requirement for the main types of concentrate smelted (Platreef, Merensky, and UG2).

It can be seen that the specific energy requirement is predicted to increase by about 4% from a 50% UG2 concentrate mix to an 80% UG2 concentrate mix. This change can occur from one day to the next and will affect the feed rate required for a fixed furnace power input. However, the changes occur gradually during the day and can be managed easily by hourly soundings and slag temperature measurements.

The energy losses consist of the following components:

- *Low voltage bus and contact pad cooling*—there is a separate cooling water circuit for the low voltage buses and contact pads. The energy loss was calculated from the water flow and the temperature difference between the supply and return cooling water.
- *Roof energy losses*—these were calculated using the thermal conductivity of the bricks (high density alumino-silicate fire brick) and the average temperature difference between the inside and the outside surface of the bricks (300°C).
- *Upper side-wall energy losses*—these were also calculated using the thermal conductivity of the bricks and the average temperature difference between the inside and the outside surface of the bricks (433°C).
- *Copper cooler heat losses*—the waffle coolers are cooled by a closed water circuit operating between 39°C and 41°C. The energy removed by the waffle coolers and plate coolers is estimated from the rise in temperature of the closed-circuit cooling water before and after passing through the coolers.
- *Sidewall cooling energy losses*—these are calculated by estimating the air flow from the fan curve, motor power, and pressure differential. With the 'specific heat' of air, and the temperature difference between inlet and outlet, the energy loss can then be calculated.
- *Hearth cooling energy losses*—the energy loss is calculated in the same way as for the sidewall cooling.
- *Off-gas energy loss*—this is calculated using an off-gas volume from the furnace of 20 000 Nm^3/h at a temperature of 600°C and 0.7% SO_2 and 3% moisture.
- *Dust in off-gas energy loss*—this was calculated assuming 3% of feed mass is entrained in the off-gas flow and leaves the furnace at 500°C. The dust is returned to the furnace at 25°C and a 'specific energy' of 1 MJ/t/K has been used.
- *Electrode energy losses*—the solid electrode paste must be heated, melted, baked, and further heated to at least 1 600°C. It has been assumed that the fixed carbon in the paste is oxidized to carbon monoxide inside the furnace and that the carbon monoxide is heated to 1 700°C at the electrode tip. The oxidation of the carbon in the paste provides more energy than is required for heating the paste and the casing steel, so that there is an energy gain. It has also been assumed that the paste heaters provide the energy for melting the paste. A paste consumption of 2.9 kg/MWh and a steel consumption of 0.3 kg/MWh has been used.
- *Transformer losses*—these consist of no-load losses (obtained from the transformer manual) and energy losses dissipated to cooling water, which are calculated from the water flow and the temperature difference between incoming and outgoing cooling water. All water temperatures were measured by taking a 5 ℓ water sample and measuring the temperature with a mercury thermometer.

Comparing the May and July energy balances with the design, it can be seen that the actual energy losses are as much as 15% lower than the design heat losses. This was to be expected for a conservative design.

Historical furnace energy consumption

Figure 3 shows the historical energy consumption for each of the five campaigns since January 2004. Although the furnace was commissioned in March 2003, only data from January 2004 is taken into account, as the furnace operated at very low power input and with lime addition during 2003, and the concentrate mix smelted was not comparable to later periods. Campaigns 1 to 4 show that specific energy consumption reduces as average furnace power increases. This is to be expected, as the energy losses do not increase proportionally with the increase in furnace power.

In order to show the impact of a period of operation at higher furnace power, a data point for July 2008 was added, when the average furnace power input for the month was high, and gross specific energy consumption was reduced by 6% compared to the average of campaigns 3 and 4. This clearly demonstrates that as the furnace power increases from 44 MW to the nominal design of 68 MW, the energy efficiency improves less than when the furnace operates at lower power. Campaign 5 is an outlier and no obvious reason has been found for the lower specific energy consumption.

Potential to improve energy efficiency

A large furnace operates more energy-efficiently at higher

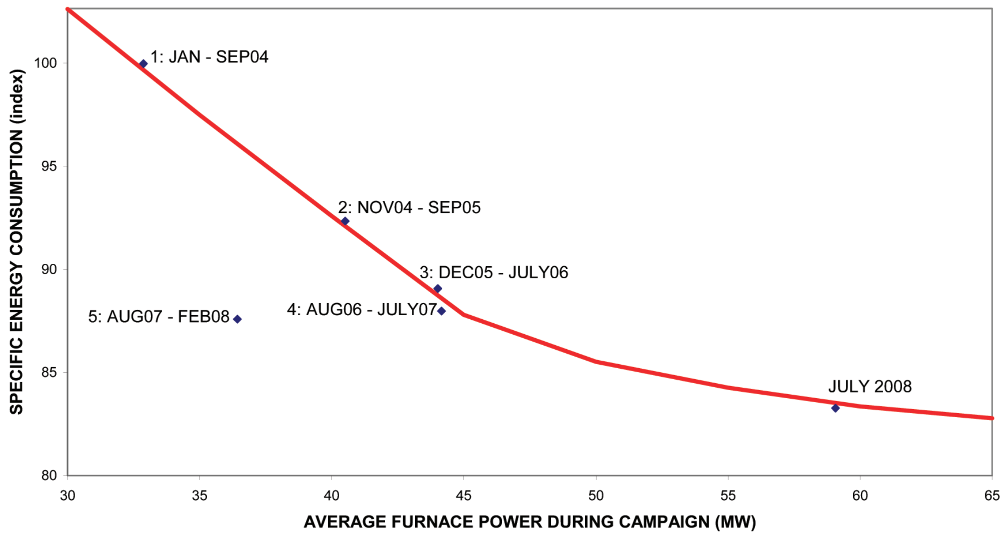

Figure 3—Historical indexed specific energy consumption as a function of furnace power input per campaign (data for campaign 1 is taken to represent 100%)

smelting rates, as the energy losses do not increase proportionally with the smelting rate. However, regardless of the throughput, energy efficiency can be improved by lowering the slag temperature and the slag and matte levels, and by reducing the off-gas energy losses. The lower energy losses should result in a lower electrical power input for the same smelting rate or result in a higher smelting rate for the same electrical power input, or a combination of both.

Slag temperature

The slag temperature plays a role with the energy transfer from the slag bath to the 'black top' (unmelted concentrate layer on top of the slag), and with the smelting rate of concentrate that is stirred into the slag bath. Higher smelting rates require higher energy transfer rates and therefore at higher smelting rates the slag temperature tends to be higher, especially if the concentrates being smelted contain species of high incipient fusion that can adversely promote sintering in the blacktop. At 65 MW, slag temperatures as measured in the slag launder with a handheld optical pyrometer range from 1 570°C to 1 600°C (although historically slag tapping temperatures have been measured as high as 1 700°C). It is assumed that the slag temperatures can be at least 50°C higher inside the furnace (although this remains to be quantified).

During conditions of underfeeding, the slag temperature can increase by 20°C within 30 minutes. Assuming a concentrate feed mix as for July 2008, the impact on the furnace energy balance is predicted as follows: At typical feed rates a 20°C increase in slag temperature would consume 0.5 MW of additional power, or 0.8% of the average electrical power input, and smelter production for the day would be reduced commensurately.

Slag level

After the furnace off-gas, the main source of energy loss is that from the copper coolers (about 25% of the measured energy losses), which are at the slag level. However, if the matte level is lower, less area of copper cooler is covered by slag, so both slag and matte levels affect the energy losses through the copper coolers. The energy loss through the copper coolers was measured at 'high' slag levels and at 'low' slag levels (see Table III).

The data suggest that 0.4 MW would be saved for every 10 cm decrease in slag level, or, alternatively, if the slag level would be operated 10 cm higher, 0.4 MW additional power would be required for the same smelting rate, or less concentrate would be smelted.

The ability to lower slag levels is limited because the slag-concentrate interface must always be at the upper waffle coolers to ensure that the lower waffle coolers are not unnecessarily exposed to corrosion.

Off-gas volume

The energy loss in the off-gas has been calculated assuming a gas volume of 20 000 Nm^3/h at 600°C. The off-gas volume is made up predominantly of sulphur dioxide and moisture from the concentrate (assume 0.5 mass %), air supplied

Table III

Energy loss through copper coolers at high and low slag levels

Slag level	Total bath height (cm)	Rate of energy loss (MW)	Cooler area covered by slag (m^2)	Difference (kW/m^2)
High	178	2.8	75.1	
Low	151	1.4	53.4	52.6

Table IV

Breakdown of off-gas volumetric rate

Source	Volume (Nm^3/h)
Sulphur dioxide	356
Moisture	605
Feed system	4 300
Ingress air	14 739
Total	20 000

through the concentrate feed system and ingress air (CO/CO_2 combustion products of the electrodes have been ignored for the purposes of this analysis—Table IV).

It can be seen that most of the off-gas volume consists of ingress air. Therefore, the off-gas volume can be reduced by improved sealing of the furnace. A reduction in off-gas volume of 10% would make 0.44 MW more available for smelting, and achieve an equivalently higher amount of concentrate smelted.

Slag temperature, slag level and off-gas volume each allow relatively small changes. However, together these small improvements could add at least 2% to the smelting rate, which becomes significant from an economic point of view if the furnace is the bottleneck, and when optimum energy efficiency is a driving force for smelter improvement.

The impact of plate cooler panels

As part of the investigations to mitigate the corrosion of the copper coolers, some upper waffle coolers were replaced by a 'plate cooler test panel'. The plate cooler test panel consists of a staggered arrangement of three copper plate coolers and three graphite plates. There are two upper waffle coolers (UWC) for one lower waffle cooler (LWC) and two sets of plate coolers for one lower waffle cooler. Plate coolers were installed above lower waffle coolers 39 and 40. Lower waffle coolers 38 and 41 had one set of plate coolers and one upper waffle cooler installed on top of them. Lower waffle coolers 37 and 42 had normal upper waffle coolers installed above them (see Figure 4). Therefore, the plate coolers above lower waffle coolers 39 and 40 are compared to the upper waffle coolers above lower waffle coolers 37 and 42.

Compared to the normal upper waffle coolers, only half the surface area of the hot face consists of water-cooled copper. Therefore, it is to be expected that the energy removed from the plate cooler test panel is less than the energy removed from a normal upper waffle cooler. The difference in energy flux is estimated using historical data of cooling water temperature differences from September 2007. The reason for using historical data is that the plate cooler test panels were not reinstalled after the run-out in February, as this would have delayed the restart of the furnace.

When the slag levels are low, only a small part of the upper waffle coolers or plate coolers is covered by slag. Therefore, the difference in energy loss between the upper waffle coolers and the plate coolers is postulated to be insignificant when slag levels are low.

Data have been collected when cooling water temperatures, and thus slag levels, were relatively high, and the energy removed by plate coolers versus upper waffle coolers has been calculated using temperature differences between inlet and outlet cooling water for each cooler. Figures 5 and 6 show the detail arrangements of coolers and water circuits for

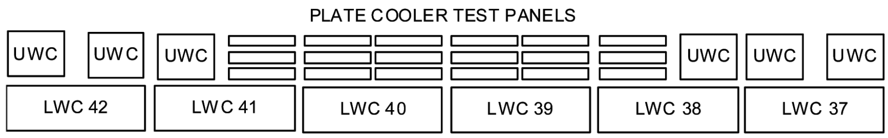

Figure 4—Arrangement of coolers around plate cooler test panel

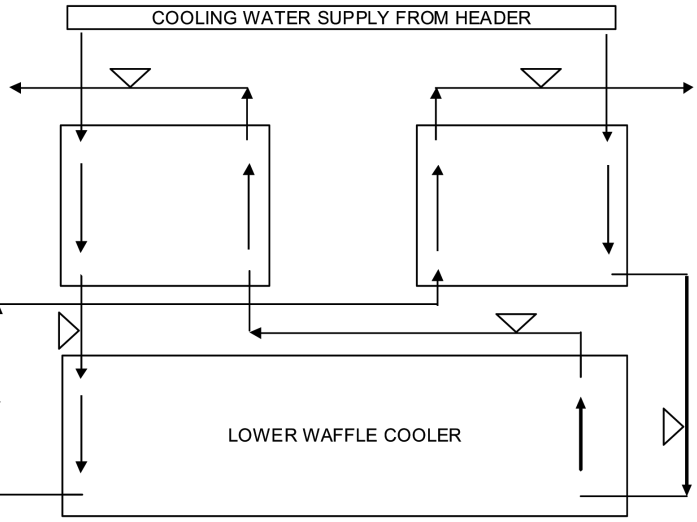

Figure 5—Arrangement of two upper waffle coolers and water circuits

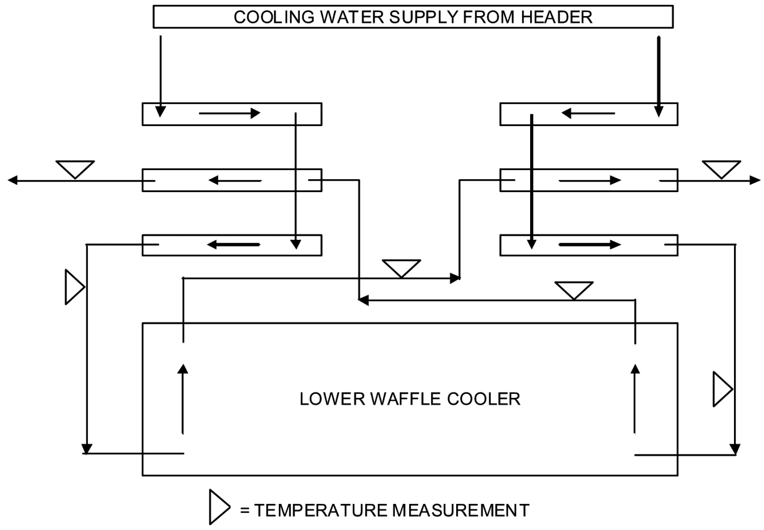

Figure 6—Arrangement of one plate cooler test panel and water circuits

upper waffle coolers and plate coolers. The energy loss has been calculated for a set of plate coolers and for a set of upper waffle coolers above lower waffle coolers 37, 39, 40, and 42, assuming that all coolers are exposed to the same conditions at the same time (Table V).

The energy removed above LWC 40 is not in line with the other data, and it is suspected that there is a problem with one of the water temperature measurements. Therefore these data are discarded. At high slag levels, there is a 7.1 kW difference between the rate of energy removed from the plate coolers above LWC 39 and the average rate of energy transfer from the upper waffle coolers above lower waffle coolers 37 and 42. The area of one set of plate coolers above a lower waffle cooler is 1.138 m^2. The total area of upper waffle coolers is 50.69 m^2. For the whole furnace the reduction in energy losses is estimated to be 0.3 MW, if slag levels are high, which occurs typically less than half the total operating time.

Since the requirement is to keep slag levels low to reduce the loss of energy through the copper coolers, and since the difference in energy removed by plate coolers and upper waffle coolers is small, it would not be worthwhile replacing the upper waffle coolers by plate coolers from an energy savings perspective. It might make more sense to cover the lower waffle coolers with graphite as well, allowing the furnace to operate at a lower slag level, provided that this has no adverse impact on electrode proximity to the matte, and matte temperatures.

Table V

Energy removed by plate cooler test panels and upper waffle coolers at low and high slag levels

Plate or UWC	LWC number	Energy removed	
		Low slag level (kW)	High slag level (kW)
UWC	37	30.5	52.0
Plate cooler	39	38.5	44.1
Plate cooler	40	10.5	20.5
UWC	42	29.6	50.5

Conclusions

The energy balance shows that actual energy losses are lower than design energy losses, so that the furnace should be able to achieve design throughput.

Historical energy consumption by campaign, excluding furnace heat-up, shows that specific energy consumption decreases as average furnace power increases, up to input levels of 59 MW.

The smelting rate could be increased by at least 2% to realize specific energy savings by further optimizing slag temperature, total bath level, and off-gas volume.

It is not recommended that upper waffle coolers are replaced by plate coolers, from an energy savings perspective.

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