



## Impala Platinum Smelter, Rustenburg—an integrated smelter off-gas treatment

only. The existing Sulfacid™ plant is upgraded from 8 to 12 pots and treats off-gas from the three operational furnaces. The tail gases from the expanded acid and Sulfacid™ plants are combined and treated in a new lime scrubbing plant, which produces gypsum. The cleaned tail gas from this plant is vented to atmosphere via a new stack. Fugitive gases from the converters and furnaces are captured and treated in a new lime scrubbing plant. The tail gas from this plant is vented to atmosphere via a new stack.

- *Option 2*—New gas cleaning section and double conversion, double catalysis sulphuric acid plant with sulphur burner.

A new double conversion, double catalysis sulphuric acid plant with sulphur burner of 44 Nm<sup>3</sup>/s capacity is built for the treatment of converter primary and fugitive gas and furnace primary off-gas. The cleaned gas is vented to atmosphere via a new stack. The existing Sulfacid™ plant is utilized for the treatment of furnace fugitive gases. The cleaned gas is vented to the existing Sulfacid™ stack.

### Introduction

In all pyrometallurgical processes, vapours develop over the liquid slag/metal phase or on the surface of the solid particles under high temperature conditions. These vapours contain reaction products of the slag or metal phase with the gas phase and/or simply products of evaporation formed due to the extremely elevated temperatures. The solid and vapour contents in the gas may have to be removed for the following reasons:

- The removal of hazardous components for environmental protection
- The recovery of valuable contents from the gas phase.

Engineering and Projects Company and Outokumpu Technology undertook a detailed study for the Impala Platinum Smelter, evaluating the treatment of the entire smelter complex off-gases through a single large gas cleaning and acid plant. This included both the constant volume, low SO<sub>2</sub> content electric furnace off-gases and the highly variable volume and variable SO<sub>2</sub> content converter off-gases.

The brief was to ensure world-class standards in terms of particulate capture and SO<sub>2</sub> emissions. A double catalysis, double absorption plant was designed incorporating sulphur burning to supplement the thermal requirements for auto-thermal operation. The resultant design met all the particulate removal criteria and would have resulted in no visible stack emissions with all discharges well within the applicable environmental legislation. The discussion below refers to the proposal made for treating these off-gases.

Impala Platinum currently operates two 6-in-line electric furnaces for the smelting of platinum concentrate at its Rustenburg smelter. As part of Impala's expansion programme, a third electric furnace will be brought on line in 2008. The continuous off-gas flow from all three of these furnaces contains:

- Considerable quantities of dust
- SO<sub>2</sub> generated by sulphide combustion

- SO<sub>3</sub> generated by sulphide combustion
- Metalloids contents such as As, Se and other evaporated traces
- Halogens such as HF and HCl.

Dust was to be recovered mainly for the PGM content, but is also associated with other impurities in the gaseous phase. The separation of solid particles is primarily done in the hot gas precipitators, leaving the other impurities as vapours in the gas phase.

The gases are collected from the furnaces and ducted under suction to hot gas electrostatic precipitators. The proposed option was to then pass these gases to a scrubbing, cleaning and cooling section prior to entering double absorption sulphur burning acid plant for the conversion of SO<sub>2</sub> and the absorption of SO<sub>3</sub>.

There are also 6 Pierce-Smith converters, which are used to oxidize the furnace matte. These provide another major source of discontinuous gas flow with large fluctuations. Two of these are large converters of 77 m<sup>3</sup> capacity and four are smaller converters of 33 m<sup>3</sup> capacity. Another large converter will be brought into operation during the expansion programme. The operation of the Peirce-Smith converters will be cyclical and the sequence will be dependent upon matte production in the electric furnaces. Due to the cyclic nature of the converting operation, the SO<sub>2</sub> strength of the converter gas feed to the acid plant will vary. A sulphur burning section is incorporated into the proposal in order to stabilize the amount and strength of the SO<sub>2</sub> gas and provide for steady and reliable operation.

Before the gas enters the acid plant, it is important that the majority of the impurities are removed as these can be contaminants and lead to the production of sub-standard product acid. Impurities in the product acid are of particular concern where the acid will be used in the production of fertilizers. Contaminants also cause blinding of the catalyst bed and excessive pressure differential through the system. It is also important that the gas is cooled to the correct temperature so that the water balance is optimal and so that excessive water is not introduced into the system.

This paper describes the unique solution of treating the combined converter and furnace off-gases, supplemented with sulphur burning to ensure strike temperature is maintained for optimum catalytic conversion of SO<sub>2</sub> to SO<sub>3</sub>. The importance of a sequential methodology for cleaning the off-gases from the furnace and converter operations is also detailed.

Each stage of cleaning has its own unique characteristics and equipment selection is important for optimal cleaning operations.

### Auto-thermal converter operation

Double conversion, double catalytic plants typically require an SO<sub>2</sub> content in the region of >6% for auto-thermal operation. The converter off-gas stream will typically average 7% SO<sub>2</sub> strength, but this can vary from 0% to 9%. Shown in Figure 1 is the SO<sub>2</sub> strength measured as a function of time with two converters cycling.

## Impala Platinum Smelter, Rustenburg—an integrated smelter off-gas treatment

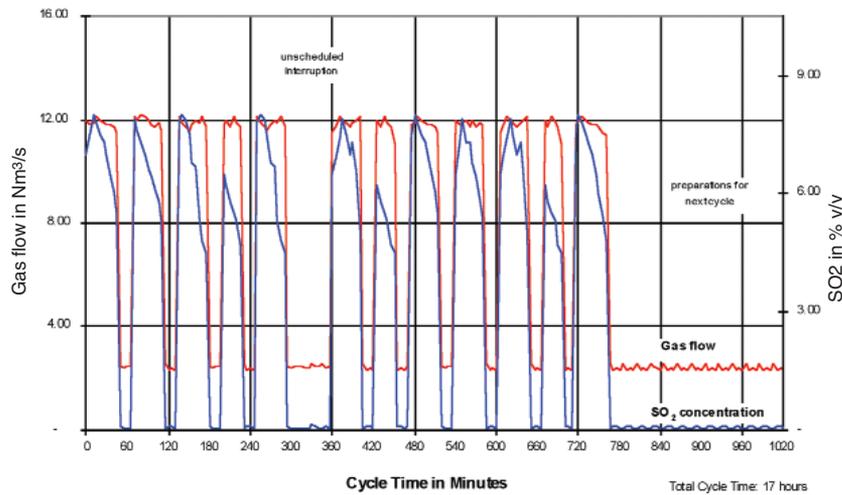


Figure 1—SO<sub>2</sub> gas strength versus converter cycle time

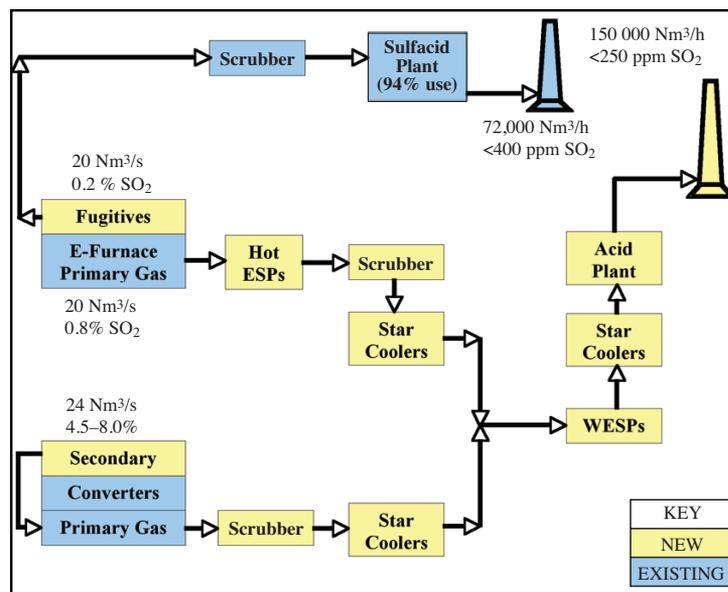


Figure 2—Basic block flow diagram

The introduction of the proprietary spin cup burner allows rapid ramp-up and turn-down of the SO<sub>2</sub> content from the sulphur burner. As can be seen in Figure 1, the SO<sub>2</sub> off-gas concentration can vary considerably with the cycling of the Pierce-Smith converters. In order to keep the plant in auto-thermal operation at relatively constant temperatures, approximately 59 tons of sulphur must be burnt each day. This results in an additional 170 tons per day of 98.5% acid production.

### Furnace off-gas collection, electrostatic precipitation and scrubbing

Off-gases from the electric furnaces will be treated separately from the converter off-gases through hot ESPs and a wet venturi scrubber before being combined at the primary star cooler outlet.

The primary reason for the separate treatment of gases from the furnaces and converters, is to ensure the recapture of dry, entrained dust in the furnace gas. Due to the removal of the furnace gases under suction, dust from the furnace black top is carried towards the gas treatment section (Table I). As this dust originates from the concentrate feedstock to the furnace, it contains substantial valuable elements and it is preferable to recover the material prior to wet treatment so that it can be returned to the furnace concentrate silos as a dry feed.

The off-gas from the three electric furnaces will be ducted to two new hot gas electrostatic precipitators for the removal of solid dust particles. Each precipitator will have 4 fields where 3 fields of one hot gas ESP will give the required cleaning efficiency. This ensures that the second ESP is able to give standby capacity for maintenance periods. It is of

## Impala Platinum Smelter, Rustenburg—an integrated smelter off-gas treatment

extreme importance that the temperature of the gas be kept above 300°C as this ensures that the gas remains above its dew point and that there is no condensation and consequent corrosion of the precipitator shell and internals. Despite the requirement for excess capacity in the hot ESPs, it is important that the vessels are not vastly overdesigned as this will result in a large drop in gas velocity from the inlet duct into the vessel and a large resultant cooling of the gas in contact with the outer casing of the ESP. This would increase the risk of cooling this gas below its dew point and the likelihood of casing corrosion would be increased, as observed frequently in past operations.

The off-gas will be drawn from the electric furnaces and through the hot gas precipitators by the furnace ID fans, and ducted to the primary off-gas scrubbing plant. In the hot gas electrostatic precipitators, the dust load in the off-gas will be reduced from 65 000 mg/Nm<sup>3</sup> to less than 30 mg/Nm<sup>3</sup>.

Most dust particles in the off-gas such as Si, Cu, Zn, Fe and Pb are removed. The dust collected in the hot gas precipitator hoppers will be pneumatically conveyed to existing concentrate silos. The temperature of the off-gas entering the hot gas ESPs should be kept above 300°C so that the traces of SO<sub>3</sub> in the gas do not drop below the dew point and form corrosive sulphuric acid.

Larger solid particles are removed in the hot gas ESPs, but the fine particles, volatilized metalloids and other gaseous compounds require further wet gas cleaning for removal. The electric furnace off-gas leaving the ID fans will be ducted to the venturi scrubber, where the gas will be cooled by contact with a dilute sulphuric acid spray. The cooled gas leaving the venturi scrubber will pass through a droplet eliminator, before entering the gas cooling stage. Process water will be added to the venturi scrubber circuit to make up the losses due to evaporation and the bleed to the converter gas radial flow scrubber circuit. During the scrubbing process, vapours of SO<sub>3</sub>, As and Se as well as other metal vapours will be transformed into submicron particles to be removed in the downstream wet ESPs (WESPs).

### Pierce-Smith converter gas collection and scrubbing

The combined Pierce-Smith converter off-gas stream (Table III), collected by the converter primary and secondary hoods, will be received at a terminal point in the converter off-gas duct, and ducted to the new converter off-gas primary gas scrubbing plant. As the converter off-gas does not contain the levels of dust evident in the furnace off-gas, it will not be necessary to pass this gas through hot gas ESPs.

The converter off-gas will be ducted directly to the high efficiency (radial flow) scrubber, where the gas will be cooled and partially cleaned by contact with a dilute sulphuric acid stream. The cooled gas leaving the scrubber will pass through the droplet eliminator. Dissolved impurities in the converter off-gas are collected in a similar manner to the impurities removed from the furnace off-gas in the venturi scrubber. The variable throat of the radial flow scrubber ensures that there is a constant scrubbing efficiency and constant pressure drop with the varying gas volume through the system as the

converter blow cycle continues.

There is a brick lining at the dry/wet interface in both the venturi and high efficiency scrubbers. This lining resists abrasion as well as chemical attack by fluorine.

The converter ID fans will draw the off-gases from the converters and through the radial flow scrubber. The level of suspended solids in the scrubber liquor circuit will be controlled at an acceptable level by pumping a side stream to the settler. The collected solids will be drained from the settler and recycled to the smelter.

The bleed out of the scrubber circuit will be pumped to the stripping tower, where the dissolved SO<sub>2</sub> will be stripped out by air drawn in under suction and the SO<sub>2</sub> gas returned to the main off-gas stream. The stripped weak acid bleed stream will be combined with the underflow from the settler and recycled to the Smelter.

### Gas cooling

The off-gas streams leaving the furnace venturi scrubber and the converter ID fans will be ducted to the primary star coolers as independent streams as the gas volume of the converter off-gas stream will vary. The gas cooling is necessary to achieve the correct gas temperature to meet the water balance requirements in the acid plant as well as cooling the gas to substantially assist the removal of halides from the gas stream. If halides such as Cl<sup>-</sup> and F<sup>-</sup> are not efficiently removed from the system, they are detrimental to product acid quality as well as possibly causing problems with corrosion to acid piping and coolers, deterioration of candle filters and the destruction of the catalyst carrier.

Table I

#### Furnace off-gas design characteristics

Off-gas temperature	maximum	°C	400
	minimum	°C	300
Maximum flow		Nm <sup>3</sup> /s	18
Pressure		mbar g	-20
Dust burden:	maximum (dry)	g/Nm <sup>3</sup>	65
Analysis:	SO <sub>2</sub> (normal—in a wet basis)	% v/v	0.9
	(maximum—in a wet basis)	% v/v	1.1
	SO <sub>3</sub>	g/Nm <sup>3</sup> (wet)	3.5
	H <sub>2</sub> O	g/Nm <sup>3</sup> (dry)	20
	O <sub>2</sub>	% (wet)	19
	Cl <sup>-</sup>	mg/Nm <sup>3</sup>	4.3
	F <sup>-</sup>	mg/Nm <sup>3</sup>	121.8

Table II

#### Analysis of dust collected at current ESPs

Element	Design value (%)
Silica	43.0
Magnesium oxides	18.0
Alumina	12.0
Sulphides	4.50
Calcium oxides	3.50

# Impala Platinum Smelter, Rustenburg—an integrated smelter off-gas treatment

Table III

### Converter off-gas design characteristics

Gas temperature at gas cleaning inlet	maximum	°C	550
	minimum	°C	250
Gas dew point at gas cleaning section inlet		°C	180
Gas flow	maximum	Nm <sup>3</sup> /s	24
	minimum	Nm <sup>3</sup> /s	6
Dust loading at gas cleaning section inlet		g/Nm <sup>3</sup>	2
Pressure at converter hoods		-mm W.G.	-4
SO <sub>2</sub> gas strength	maximum	% v/v wet	8
	minimum	% v/v wet	4.5
Converter off-gas analysis :	SO <sub>3</sub>	g/Nm <sup>3</sup> (wet)	5
	H <sub>2</sub> O	g/Nm <sup>3</sup> (dry)	20
	F <sup>-</sup>	g/Nm <sup>3</sup> (wet)	0.005–0.0016
	Cl <sup>-</sup>	g/Nm <sup>3</sup> (wet)	0.03–0.11
	O <sub>2</sub>	v/v (dry)	12–15 %
	N <sub>2</sub>	v/v (dry)	balance

Cooling water will be supplied to the primary star coolers from the water cooling tower. The cooling water leaving the primary star coolers will flow into the hot well tank, from where it will be pumped back to the water cooling tower. Both the primary and secondary star cooler tubes are lead lined to prevent attack by Cl<sup>-</sup> and F<sup>-</sup>.

Spray water for the primary star coolers will be pumped from the star cooler spray tank, and the bleed from the liquor circuit will be pumped to the radial flow scrubber liquor circuit.

Once the gas streams from the venturi scrubber and converter ID fans have passed through the primary star coolers, the partially cooled streams are combined and ducted to the wet electrostatic mist precipitators. The gas stream leaving the wet electrostatic mist precipitators will then be ducted to the secondary star coolers, where a chilled water circuit will be utilized to further reduce the off-gas temperature.

The chilled water will be supplied from the package chiller plant.

The chilled water leaving the secondary star coolers will flow into the chiller hot well tank, from where it will be pumped back to the chiller plant. The water cooling tower will supply cooling water for the chiller plant, from where it will flow to the primary star coolers hot well tank.

### Mist precipitation

The combined off-gas stream from furnace and converters leaving the primary star coolers will then flow to the wet electrostatic precipitators (WESPs), where remaining particulate matter and acid mist will be removed. The off-gas will undergo two stages of precipitation, initially in the primary WESPs and then in the secondary WESPs. All parts of the precipitator vessels in contact with the gas stream are made of PVC or FRP with PVC lining. The discharge electrodes are made either of lead with a steel core or of stainless steel and are suspended from the upper support and frame and held firmly in the tube centre lines.

The upper and lower frames are supported by insulators housed in lead-lined compartments situated at the side of the precipitator casings, thereby protecting them from acid mist. Any mist and water saturated gas is prevented from migrating into the insulator compartments by preheated ambient air that is continuously purged into the compartments.

Cleaning of the gas stream by the WESPs occurs via the centrally placed discharge electrodes imparting a charge to the particles in the gas. The charged particles are then drawn to the outer collecting electrodes. Particle removal is effective to a sub-micron level. It has been proven in the past that the removal of these smaller, sub-micron particles such as the volatilized metalloids of As, Te and Be is inefficient in wet scrubbing and other gas cleaning equipment such as hot ESPs and lime scrubbing. These particles must be charged and then collected for removal. Additionally, WESPs remove SO<sub>3</sub> mist from the gas stream before it moves on to the oxidation section.

The WESPs will be provided with flushing sprays for cleaning of the electrodes and collecting surfaces. The flushing water will be pumped to the sprays from the flushing tank. Particles separated from the gas will be removed continually along with the condensate. A blow-down stream from the WESP flushing tank is pumped to the radial flow scrubber, allowing the impurities to leave the system.

A vacuum breaker will be provided in the duct leaving the secondary star coolers to protect equipment from excessive suction conditions observed when there is a blockage in the system.

The demisted gas will be further cooled by means of chilled water in the secondary stage of star coolers to remove surplus water and to facilitate the production of a high market grade acid of 98.5 % H<sub>2</sub>SO<sub>4</sub>.

The particulate loading at the inlet to the main blower is to be kept to a value less than 2 mg/Nm<sup>3</sup> to ensure a minimum rate of catalyst fouling.

# Impala Platinum Smelter, Rustenburg—an integrated smelter off-gas treatment

## Acid plant

The acid plant for this complex metallurgical application requires a high degree of flexibility in order to cope with the varying gas volumes and compositions.

The design of the acid plant is such that any changes in smelter operations will be efficiently dealt with in the acid plant without affecting the smelter operations. This high level of flexibility is required to optimize primary production.

The operation window of any metallurgical acid plant is defined by:

- ▶ the auto-thermal operation: minimum SO<sub>2</sub> content in gas to keep catalyst hot enough for reaction
- ▶ water balance to keep the absorption circuits within design acid strength windows.

Extreme daily operating variations of the existing acid plant have been traditionally handled by shutting down the acid plant. This in turn led to the typical consequence that catalyst was outside of the optimal reaction temperature leading to reduced SO<sub>2</sub> conversion, cooling of absorption acid, and finally resulting in visible stack conditions.

The study design proposed the inclusion of a sulphur burner with a very high load flexibility, which would smooth out the variable volume and SO<sub>2</sub> concentrations from the smelter, resulting in more optimal acid plant operations.

## Control philosophy

The control philosophy is explained with reference to Figure 3 illustrating the expected operating conditions range. As shown, the acid plant should be able to cope with a range of flows from off-gases of only the electric furnaces at 80 000 Nm<sup>3</sup>/h and < 0.7% SO<sub>2</sub>, to 158 400 Nm<sup>3</sup>/h of 3.4–4.7% SO<sub>2</sub>, combined electric furnace and two converters blowing simultaneously.

Included in the special Impala plant case is an integral sulphur burner to provide thermal energy and SO<sub>2</sub> gas to compensate for smelter downturn conditions. The acid plant has a normal operating window defined by:

- ▶ volume flow (controlled by the main blower)
- ▶ SO<sub>2</sub> content (controlled by variable sulphur burning quantity)
- ▶ catalyst temperatures (also controlled by variable sulphur burning and heat exchanger bypass mechanisms)
- ▶ acid strength and temperature.

## Priority in acid plant control loops

The priorities are defined by the operating requirements of the acid plant at the interface with the smelter off-gas sources.

The volume flow consists of two main sources:

- ▶ The continuous volume from the electric furnaces of nominal (18 Nm<sup>3</sup>/s and 20 Nm<sup>3</sup>/s at hot ESP outlet), i.e. 72 000 Nm<sup>3</sup>/h of approximately 0.8% v/v SO<sub>2</sub> content.

- ▶ The continuous volume from the converter group as fugitives/secondary gas volume of approximately 8,000 Nm<sup>3</sup>/h of approximately 0.2% v/v SO<sub>2</sub> content resulting in the continuous base load gas flow of 80 000 Nm<sup>3</sup>/h with approximately 0.7% v/v SO<sub>2</sub>.

The converter blow gas flow is discontinuous, with short interruptions of approximately 20 minutes per hour and one extended interruption of 4 to 6 hours per day.

The converter flow gas flow could be from:

- ▶ two large converters
- ▶ one large converter
- ▶ one large converter plus one small converter
- ▶ two small converters.

This in practical terms means any gas flow oscillating between 8 and 24 Nm<sup>3</sup>/s for a period of approximately 18 to 20 hours per day.

Due to practical smelter aisle operating constraints, it can be assumed that the hourly oscillation is active on only one converter at a time. The same applies to the daily operating campaigns. This is the basis for the frequent gas volume change of approximately 35 000 Nm<sup>3</sup>/h caused by the hourly converter flow interruptions. The difference to the full flow volume is the 'fugitives from the secondary hoods' during converter turn-out.

## Base cases for acid plant operation

- ▶ No converter activities (6 hour period) 80 000 Nm<sup>3</sup>/h with approximately 0.7% v/v SO<sub>2</sub>
- ▶ One converter blow campaign (large converter) 115 000 Nm<sup>3</sup>/h with approximately (0.5%–3.4% v/v SO<sub>2</sub>)
- ▶ Two converter blow campaigns (large converters) 158 400 Nm<sup>3</sup>/h with approximately (3.4%–4.7% v/v SO<sub>2</sub>).

Volume variation for the acid plant main blower will be for only the start/end of the daily converter campaign for each converter—not for the hourly converter flow interruptions.

These three conditions/scenarios are presented in Figure 3. (SO<sub>2</sub> strength after sulphur burning)

Acid plant volume control is based on smelter input variation signals, e.g. converter positions as base case input to ID fans and simultaneously to the main blower vane control.

The number of converters in operation should be a manual input to ensure that the volume flow in all plant sections is operational prior to the converter blow itself.

## SO<sub>2</sub> gas content control

For optimal operation, the acid plant catalyst requires a precise temperature range. The complete balance and temperature range of the catalytic converter group is based on two heat sources:

- ▶ the direct combustion heat of the sulphur to SO<sub>2</sub> gas
- ▶ the conversion reaction heat of the SO<sub>2</sub> oxidation to SO<sub>3</sub>.

## Impala Platinum Smelter, Rustenburg—an integrated smelter off-gas treatment

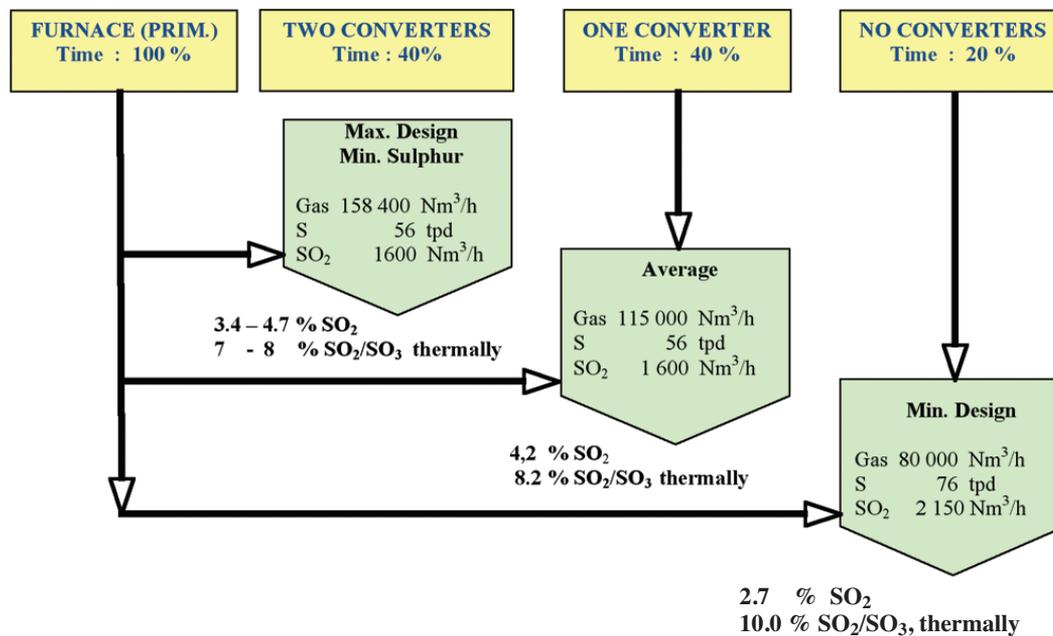


Figure 3—Base cases for design and control purposes

The heat exchanger group is designed to recover the optimal amount of energy from the outgoing SO<sub>3</sub> gas flows through the incoming cold SO<sub>2</sub> gas flows by means of heat exchangers. The range is controlled by bypasses around the heat exchangers to maintain temperatures of the catalyst.

If the bypasses are completely closed and all heat exchangers are fully online, and temperatures are still too low, then the quantity of sulphur burnt and SO<sub>2</sub> generated will be increased.

The sulphur burner operates in two base operating modes:

- with converter operation
- without converter operation.

The quantity of sulphur to be burned is a function of the SO<sub>2</sub> concentration coming from the smelter.

- Electric furnace operation only = low SO<sub>2</sub> concentration = high sulphur burning demand
- Furnace plus converter gas = higher SO<sub>2</sub> concentration = lower sulphur burning demand.

The sulphur burner/furnace has its own operating window defined by:

- gas/sulphur flow proportion controlled by the resulting combustion temperature
- gas flow through the sulphur burner to control the total sulphur input into the system.

The sulphur burner system is installed in parallel to the heat exchanger system, which leads to a proportional reduction/increase in gas flow through the furnace due to changes dictated by the main blower. This is followed automatically by the proportional sulphur flow through the sulphur burner.

### Conclusions

- The opportunity exists to treat variable volume, variable SO<sub>2</sub> strength metallurgical off-gas using a sulphur burning double contact, double absorption acid plant in order to provide thermally stable operation and still meet government requirements for emissions.
- Metalloid off-gas contents such as As, Se and other evaporated traces should be removed in a gas cleaning section prior to gas conversion to ensure good quality product acid and lengthened equipment lifespan as a result of lower corrosion rates.
- Certain volatilized metalloids such as Te and Be are not sufficiently removed by wet or lime scrubbing and, for efficient removal, require the application of a charge to the particles to enable their collection on the electrodes of a wet electrostatic precipitator.
- In order to achieve stable thermal operation of the acid plant, particularly with a variable gas volume, it is essential that the control system be designed to compensate for the frequent gas flow oscillations. The control system should also be designed with sufficient predictive capacity to cope with the converter cycling.

### Acknowledgements

The authors thank Impala Platinum Limited, Engineering and Projects Company Limited, and Outokumpu Technology for permission to publish this paper. ♦