An overview of the Namakwa Sands ilmenite smelting operations

by M. Gous*

Synopsis

Namakwa Sands is a heavy minerals mining and beneficiation business in the Anglo Base Metals Division, and operates along the West Coast of South Africa. The business encompasses mining, mineral concentration, separation, and smelting operations. The smelting process comprises the carbonaceous reduction of ilmenite to produce titania slag with a TiO_2 content of 86%, and iron with a carbon content of 2.5%. The Namakwa Sands smelter, situated near the Saldanha Bay harbour, commenced smelting operations in 1994, when a 25 MW DC-arc furnace was commissioned. The smelting operations were expanded in 1999, with the commissioning of a second 35 MW DC-arc furnace. Despite the fact that ilmenite smelting poses a technical challenge in terms of the high temperatures required, the physical characteristics of the slag, the constraints placed on the feedstock, and the tight product specifications, Namakwa Sands has continually increased slag production since 1995. High furnace feed-on utilization and furnace stability, complemented by continuous improvement drives, will be the vehicle to drive performance in the short-term, with longer-term performance enhancements due to strategic process development.

Keywords: Pyrometallurgy, Namakwa Sands, ilmenite, DC-arc furnace, titania slag, pig iron

Introduction

Namakwa Sands is a heavy minerals mining and beneficiation business that operates along the West Coast of South Africa, and is the only heavy minerals operation within Anglo American plc. The company falls under the Anglo Base Division of the London-based Anglo American plc. The business consists of mining, mineral separation, and smelting operations, as shown in Figure 1.

The mine is situated at Brand-se-Baai, 385 km north of Cape Town, and is divided into an east and west section where opencast strip-mining activities occur, together with primary and secondary concentration of heavy mineral sands containing zircon, rutile, and ilmenite. The non-magnetic (zircon and rutile) and magnetic (ilmenite) concentrates are transported separately to the mineral separation plant, approximately 60 km south of the mine, near Koekenaap.

At the mineral separation plant, electrostatic, dry magnetic, and gravity methods further separate ilmenite, rutile, and zircon. The three products are dispatched by rail, via the Sishen-Saldanha line to the smelter.

The smelter is located near Saldanha Bay. Zircon and rutile are stored here, prior to bulk shipping to predominantly overseas markets via the Saldanha harbour. Ilmenite is smelted to produce two grades of saleable titania slag, and several grades of pig iron, and is also shipped via the Saldanha harbour to overseas markets.

The project was initiated in two phases, at a total cost of R2.1 billion. At full capacity, 18 million metric tons per annum of ore is mined to produce 200 000 tons of titania slag, 120 000 tons of high-purity pig iron, 25 000 tons of rutile products, and 125 000 tons of zircon.

Process flow

The Namakwa Sands process flow is indicated in Figure 2.

The smelter processes

The DC-arc ilmenite-smelting technology was developed and tested to pilot scale, in conjunction with Mintek, between 1992 and 1994. The first furnace, a 25 MW direct-current furnace, was commissioned in June 1995, and a second furnace, a 35 MW direct-current furnace, was brought on line in February 1999.

The smelting process comprises the carbonaceous reduction of ilmenite to produce titania slag with a TiO_2 content of 86%, and iron with a carbon content of 2.5%.

The main reaction in the furnace can be summarized as:

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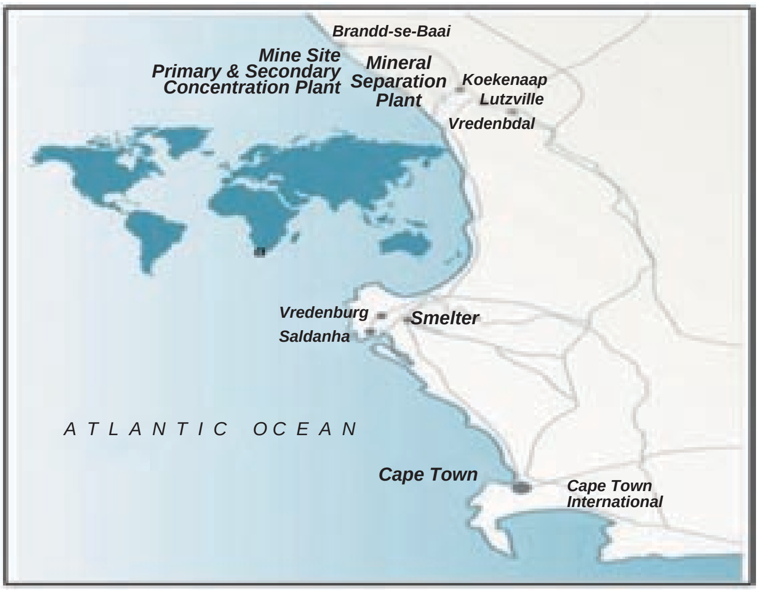

Figure 1—Map of Namakwa Sands operations

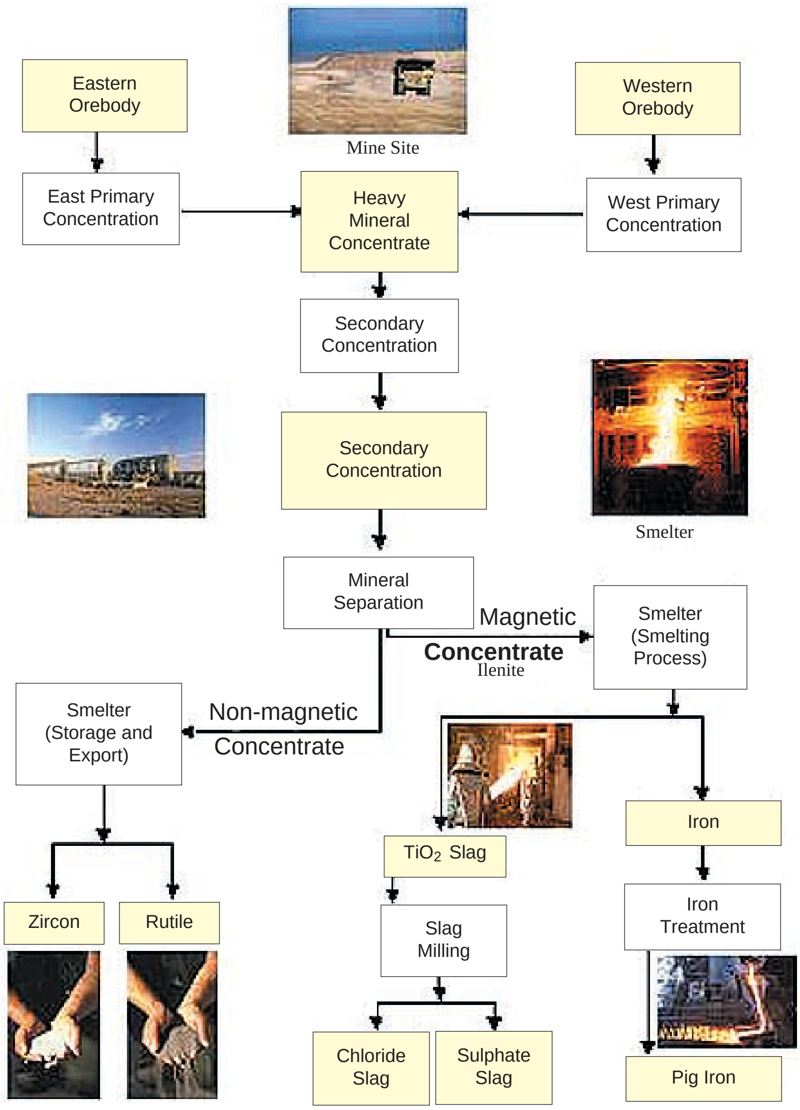

Figure 2—Namakwa Sands flowsheet

$$FeTiO_3 + C \rightarrow TiO_2(slag) + Fe(metal) + CO(gas)$$ [1]

Ilmenite and anthracite are fed via a hollow electrode into the furnace where the endothermic reduction of ilmenite occurs. The control variables for slag chemistry are:

- Ratio of ilmenite to power
- Ratio of anthracite to ilmenite
- Arc length
- Slag and iron inventory.

The amount of reduction, and energy availability, are the spill points around which the furnace chemistry has to be operated. Over- or under-reduction situations can lead to tapping problems, refractory wear, and eruptions.

A schematic of the furnace is shown in Figure 3.

The furnace is refractory-lined with MgO refractories. The roof panels and off-gas ducting, as well as the outer shell, are water cooled, while the hearth is air cooled. The conductive furnace hearth consists of refractory bricks clad with stainless steel, a layer of high carbon refractory, and a copper base plate.

Most of the energy is generated in the arc between the electrode and the surface of the bath, providing the energy necessary for the smelting and reduction of the ilmenite and anthracite feed charge. By feeding ilmenite and anthracite through the hollow electrode, the feed is placed directly into the plasma arc attachment zone, thereby making efficient use of the energy of the arc.

Slag and iron are tapped from the furnace at 1750°C and 1450°C respectively. The circular furnace has two slag tapholes and two iron tapholes. Two clay-gun units rotate around the taphole area of the furnace, and can be used to drill and plug all four tapholes.

The three products from the furnace follow different processing routes:

Gas

The CO gas produced by the furnaces passes through the gas-cleaning plants (shown in Figure 4), where the gas is cooled, scrubbed, and washed, to remove entrained dust from the furnace. The cleaned gas can be routed to the gas-holder for use in the preheating of ilmenite and the drying of anthracite. Excess gas is flared to the atmosphere. When the gas plants are down, the gas is flared to the atmosphere via the raw-gas stacks.

A portion of the ilmenite feed can be preheated in the preheaters, thereby lowering the specific energy requirement of the process, and consequently increasing throughput. The CO gas is then burnt with oxygen in the gas burner of the preheater, and provides enough energy to preheat the ilmenite to 880°C.

Both preheat plants were shut down in June 2003, due to the severe destabilizing effects they had on the furnaces. The increased feed-on utilization of the furnaces have subsequently compensated for the fact that the preheaters are not operational.

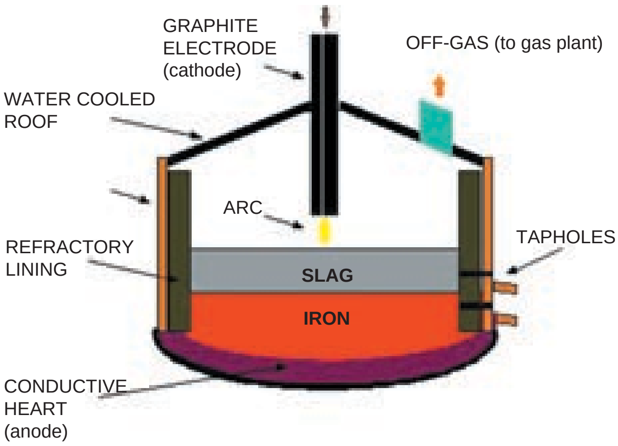

Figure 3—Schematic of DC-arc furnace

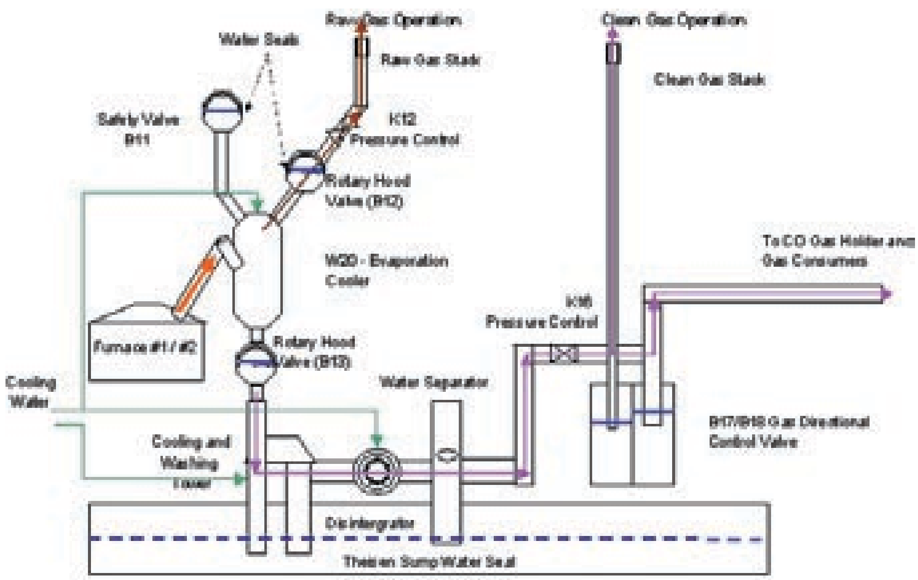

Figure 4—Gas cleaning plant

Slag

Slag is tapped into slag pots, 25 tons at a time. After tapping, the slag pots are allowed to air cool for approximately four hours. Thereafter, they are taken to primary cooling (shown in Figure 5), where water is sprayed onto the sides of the pots.

After two days in primary cooling, the pots are taken to secondary cooling (shown in Figure 6), where the slag buttons are tipped out into the secondary cooling bays. Water is sprayed onto the buttons to reduce decrepitation of slag.

Cooled slag is broken down to 300 mm, in preparation for crushing. The slag is crushed in a jaw crusher to less than 50 mm. The crushed slag is then dried, and screened via a Hummer screen and three Rotex screens. The oversize material is sent to a Loesche mill, which has a rotating table and two static rollers (shown in Figure 7).

The slag falls onto the centre of the table, and the centrifugal force moves the slag underneath the rollers causing the grinding action. The milled slag is conveyed back to the Rotex screens. The Rotex screen undersize is fed into the classifier units that classify the slag into chloride slag (106–850 μm) and sulphate slag (75–106 μm).

The slag plant was hot commissioned in September 1995. Throughput through the classification section, at acceptable split values, proved to be the bottleneck and this led to a doubling-up in classification capacity as part of the Phase 2 extensions in 1999. Excess Phase 2 pneumatic transfer capacity could be utilized to transport material directly to sulphate slag product since the beginning of 2000.

Figure 5—Primary cooling

Figure 6—Secondary cooling

Iron

Molten iron is tapped, 32 tons at a time, from the furnaces, into refractory-lined ladles, and transported to the injection station to be recarburized and desulphurized.

At the injection station, carbon is injected to increase the carbon content of the metal from approximately 2.5% to 4.1%. Calcium carbide is injected to decrease the sulphur content to below 0.012%. Ferrosilicon is also added to the molten iron, to increase the silicon content. The amount of ferrosilicon required depends on whether high- or low-silicon pig iron products are being produced.

Figure 7—The Loesche mill rollers

Figure 8—Pig casting

After injection, the ladle is taken to the pig-casting machine (shown in Figure 8), where the molten iron is poured into moulds to form 8 kg pigs. Mould wash is sprayed onto the moulds, and preheated before the casting process commences, thereby preventing the pigs from sticking to the moulds.

After the casting process has been completed, the pigs are taken to a dirty bay for cooling. Thereafter, the pigs are screened over a 35 mm vibrating screen, separating iron chips from the pigs. The pigs are then stored in the designated clean bay before being shipped to the client.

The iron plant was commissioned in 1995, and became fully operational in August 1996. A second pig-casting machine was added to accommodate the increase in production with the construction of the second furnace in 1999.

Production

The slag and iron produced from the furnaces have been steadily increasing over the past ten years, with marked improvements since 2002 mainly due to:

- ➤ Improved chemistry control
- ➤ Increased refractory life from the furnace lining, due to less side-wall and hearth MgO excursions
- ➤ Improved taphole management with regard to operation, maintenance, and refractory type
- ➤ Improved centre-roof design.

The slag and iron production history is indicated in Figure 9.

The major detrimental events influencing the slag production over the smelter lifespan have been:

1997 – Eruption on Furnace 1
1999 – Furnace 2 commissioned
2001 – Furnace 1 reline (October 2001 to January 2002)
2003 – Smaller furnace eruption events on both Furnace 1 and 2
2004 - Taphole rebuild (‘V-down’) on Furnace 1
2005 - Furnace 2 reline (June to July 2005)

Major improvements have, however, been made to decrease the frequency and duration of the furnace relines.

The duration of the reline (including refractory curing) of Furnace 2 in 2005 was 52 days, with a return to normal slag tapping operation four days later. It is estimated that the total slag tapped, if normalized to exclude the reline, would have been in excess of 180 000 t for 2005.

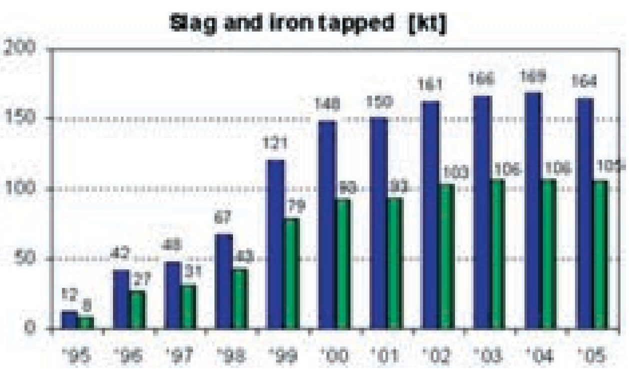

Figure 9—Production history of titania slag and pig iron

Safety and environment

Safety

All three operations have been graded in the NOSA Integrated SHE System, and hold the NOSA Platinum 5 Star status. The Namakwa Sands behavioural safety process, implemented in 2003, also plays a major role in the prevention of accidents and injuries. The behavioural safety programme is named the MEERKAT Process—Making the Effective Elimination of at-Risk Behaviour a Key Attitude Together.

The Anglo American policy of Zero Tolerance, Target Zero (OTTO) is practised, and has been implemented through to all levels of operation via the NOSA, the Behavioural Safety MEERKAT Process, Visible Felt leadership, and risk assessment processes. Focusing on the smelter operations, the historical safety performance over the life of the smelter is indicated in Figure 10.

Notwithstanding the 5 lost-time injuries at the smelter during 2005 (comprising 3 lost-shift injuries and 2 restricted-work cases), the smelter has shown a marked overall improvement in safety performance. This is particularly evident in the significant reduction in the total number of injuries, from 107 in 2003, to 94 in 2004, and 68 in 2005.

Environmental

ISO 14001 certification was obtained in 2003. The main environmental issues at the smelter are:

- ➤ Energy consumption, as Anglo American has committed Namakwa Sands to reduce energy consumption by 15% over the next 10 years.
- ➤ Water usage, due to the operations being situated in the arid west coast region.
- ➤ Air emissions, as the smelter site is the only direct emitter of carbon dioxide to the atmosphere.

The environmental performance of the smelter is tabled in Table I:

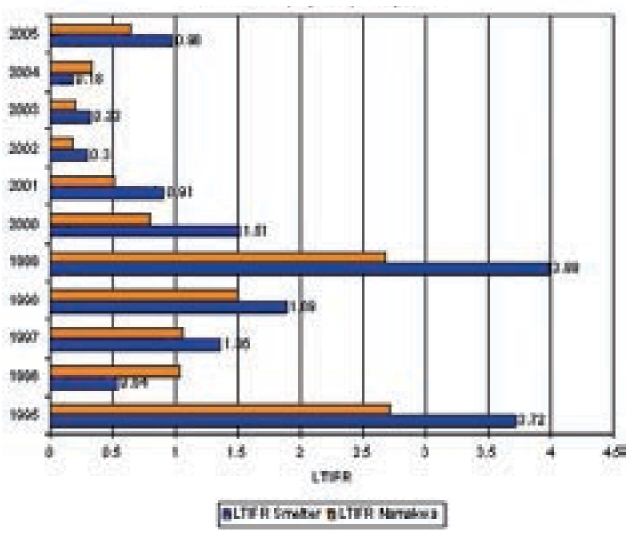

Figure 10—Historical LTIFR (lost tme injury frequency rate)

Table I

Environmental performance

Parameter	2003	2004	2005
Water [m^3/t]	3.29	2.59	2.25
Energy [GJ/t]	10.41	10.22	9.91
CO_2 [t/t]	3.09	3.01	2.94

The smelter implemented a project in 2004, which has been responsible for a large reduction in potable water consumption. Slurried effluents generated on the plant are sent through a thickener and pumped to a residue dam were solid material settles out. Instead of losing that water to evaporation, it is now returned as cooling water to the two largest water consumers: primary and secondary cooling.

Improvements were also made to the air emissions from the smelter, after modifications to the gas-cleaning plant sequences were made. The modifications included:

- Prevention of gas-cleaning plant stoppages during short furnace outages, less than 1 minute, pending that the furnace did not trip out due to high hydrogen or oxygen levels in the clean-gas system,
- Elimination of nitrogen purging if the clean-gas plant has been off for less than 5 minutes, pending the furnace or gas plant did not trip due to high hydrogen or oxygen levels in the clean-gas system.

Energy reduction initiatives are based on decreased energy requirements per ton of product delivered by the furnaces, and are dependent mainly on improvements planned with regard to the feed regimes to the furnaces, and the reduction of unwanted downtime and subsequent heat-up periods.

Product specifications

The ISO 17025 quality management system has been implemented at Namakwa Sands, and all analyses of final products are performed according to the ISO 17025 accredited methods.

Typical smelter product analyses are indicated in Tables II and III.

Table II

Typical chemical and size analyses of slag products

Chemical analysis	Chloride slag	Sulphate slag
Total Ti as TiO_2	86.5%	82.0%
Ti_2O_3	26.0%	20.0%
Total Fe as FeO	10.0%	10.5%
Metallic Fe	0.20%	0.10%
Al_2O_3	1.25%	1.40%
SiO_2	2.00%	3.20%
CaO	0.16%	0.30%
MgO	0.68%	0.65%
MnO	1.85%	1.90%
Size analysis		
+850 μm	10%	-
+106μm	-	20%
-106μm	5%	80%
-75μm	2%	55%

Table III

Typical chemical analyses of iron products

Major elements	
C	4.0%
S	0.005%
P	0.035%
Mn	0.05%
Silicon	
High Si Grade	1.00%
Low Si Grade	0.25%

Future projects and development

The main focus at the furnaces will remain on stable operations, with increased furnace utilization and production throughput. The following projects will focus on increased furnace utilization:

- Optimization of feed system and feed regimes to the furnace, to reduce specific energy requirements, and optimize utilization
- Optimization of the type, size, and chemical composition of the anthracite reductant
- Improved scheduling and maintenance regimes on tapholes, to increase overall furnace refractory-lining lifespan
- Increased life of centre roofs, electrode seals, and roof panels
- Installation of automated pressure port cleaning devices
- Installation of mechanical electrode torquing equipment to prevent stub losses and improve electrode consumption.

Subsequent improvements will also be investigated and implemented at the iron plant:

- The replacement of ferrosilicon (FeSi) additives with silicon carbide (SiC)
- Improved ladle life
- Improved iron scrap recycling
- Alternative desulphurisation methods, due to the high safety risks associated with the calcium carbide currently used.

Due to the difference in product price of chloride and sulphate slag, the main focus at the slag plant is the optimization of the product split to chloride slag via:

- Improved slag-cooling regimes at primary and secondary cooling
- Recovery of entrained chloride slag from the sulphate slag product
- Optimized milling regimes, to prevent over reduction in size of near-size material fed to the mill.

References

1. *Namakwa Sands Footprints*, ISSUE III, February 2005. ◆