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Heavy Mineral Processing at Richards Bay Minerals

G.E. Williams and J.D. Steenkamp
Richards Bay Minerals, Richards Bay, South Africa

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Abstract – Located on the eastern shores of South Africa, 180 km north of Durban, Richards Bay Minerals (RBM) produces approximately 2.0 million metric tonnes of product annually making RBM a leading producer of titania slag, high purity pig iron, rutile and zircon.

Heavy minerals are extracted from the nearby dunes by dredging and concentration on a floating gravity separation plant, followed by separation of the ilmenite, rutile and zircon at the mineral separation plant located at the smelter site. The ilmenite is processed through an oxidizing roast followed by magnetic separation and is then partially reduced to an 85 per cent TiO_2 slag in one of four six-in-line a.c. electric arc furnaces. The slag is milled and then classified into two product sizes suitable as a raw material for both the sulphate and chloride pigment processes. The high quality iron produced during the reduction process is further processed to produce various grades of low-manganese iron.

Around 95 per cent of the products are exported, yielding a world market share of about 25 per cent of titania slag, rutile, high quality pig iron, and zircon.

INTRODUCTION

History

Richards Bay Minerals is the trading name for two registered companies, Tisand (Pty) Ltd and Richards Bay Iron and Titanium (Pty) Ltd (RBIT). Tisand undertakes the dune mining and mineral separation operations, while the smelting and beneficiation processes are carried out at RBIT. The company is jointly owned by Rio Tinto plc and BHP Billiton, and is one of the largest stand-alone mining operations in South Africa.[1,2]

The presence of the relevant minerals on the north coast of KwaZulu-Natal, South Africa was first scientifically reported in the 1920s, but it was not until 1971 that the Industrial Development Corporation (IDC) began a detailed investigation of the Richards Bay area. A Canadian producer of titania slag, Quebec Iron and Titanium (QIT Fer et Titane), was also independently looking for major ilmenite deposits in 1974.

These two organisations, together with Union Corporation (later Gencor, now BHP Billiton), formed RBM in 1976 to mine and beneficiate the vast mineral-rich sands in the coastal dunes that at the time extended 17 kilometres in a two kilometre wide strip from just north of Richards Bay. In 1985, the company also acquired the mining rights to additional ore reserves both north and south of the original deposit with mining of the Zulti North ore deposit commencing in 1987[1]. The approximate location of these ore bodies is shown in Figure 1.

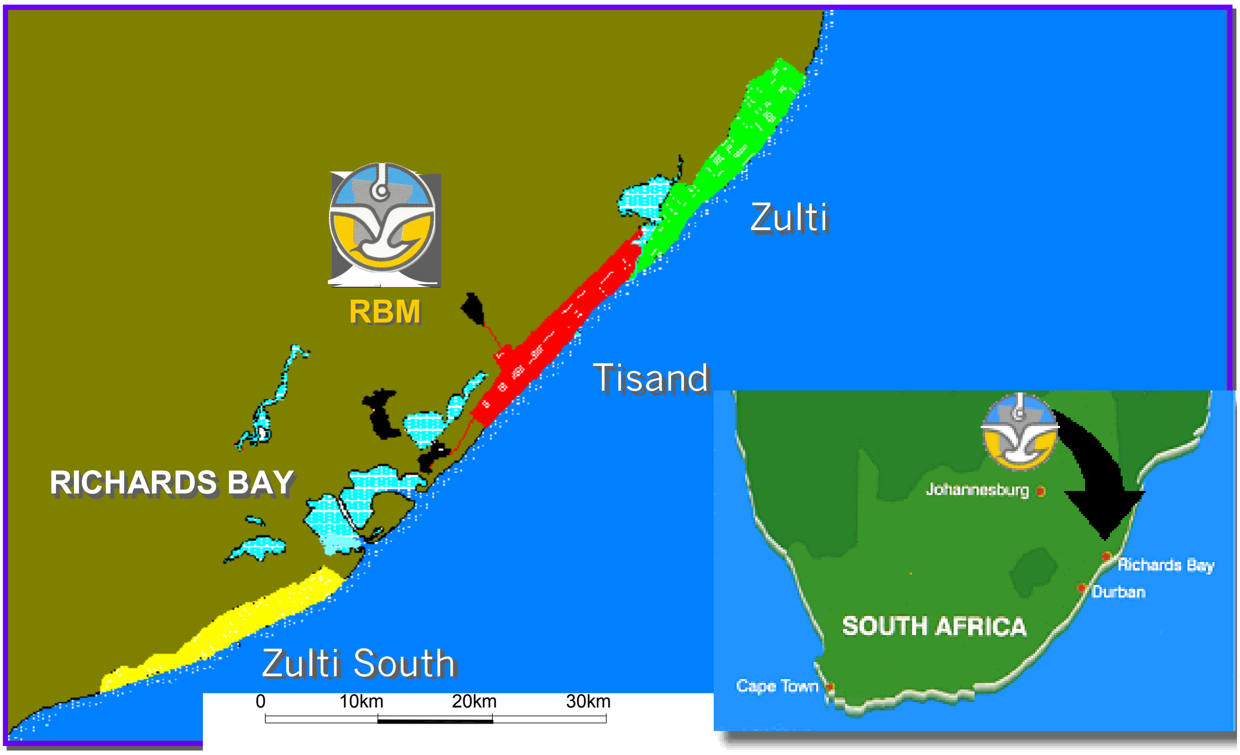

Figure 1: RBM has the rights to mine a number of lease areas: Tisand, Zulti North, and Zulti South (Richards Bay Minerals)

OVERVIEW

Operations commenced in 1977 with one dredge mining plant and two furnaces producing approximately 400 000 t/year of titania slag. In 1986, an additional mining plant and furnace were added, increasing slag output to 750 000 t/year. The largest major investment in capacity took place during the early 1990s when a fourth furnace and mining plant were installed, increasing RBM's titania slag capacity to l Mt/year and pig iron production to 550 000 t/year.

RBM currently has the capacity to produce approximately 2 Mt of product annually, including approximately 100 000 t/year of rutile and 250 000 t/year of zircon. Of this, 95 per cent is exported, yielding a world market share of about 25 per cent of titanium feedstocks (titania slag and rutile), 33 per cent of the worlds zircon output and 25 per cent of the worlds high purity pig iron.[1]

Since its inception, RBM embarked on a dune rehabilitation programme that has received worldwide recognition. Research by independent scientists has concluded that a fully functional coastal dune forest ecosystem is being restored through this programme.[1]

The surrounding communities have also benefited from RBM's social investment programme, which comprises health care, water and sanitation, agriculture, business development, education, and a number of specialised initiatives.[1]

PRODUCT MARKETS

Titania slag, which comes from ilmenite, contains 85 per cent titanium dioxide and is RBM'S primary product, while rutile contains 94 per cent titanium dioxide.[1]

The largest application of titanium dioxide is as a white pigment representing between 95 and 98 per cent of worldwide TiO_2 consumption. The remaining uses are as a flux for electric welding rods and in certain metallurgical and electronic applications.[3]

RBM's high purity pig iron, a by-product of the smelting operation, is used as a raw material in foundries for the production of ductile iron castings. Ductile iron is used extensively throughout the world for the production of safety-critical automotive parts, such as brake calipers and steering knuckles in cars and trucks.

Zircon is used in the production of ceramic tiles and sanitary ware. Refined to zirconia, it is used in a wide range of advanced ceramics, refractories, jewellery, electronic applications, and many other industrial and domestic products.

Zircon sand is also used in the foundry industry as moulding sand, as it is resistant to high temperatures. The high melting point of zircon makes it suitable as a refractory lining.

ORE RESERVES

Ilmenite, rutile, and zircon are common minerals found all over the world, but not always in economic concentrations. One of the exceptions is the coastal area of northern KwaZulu-Natal - the Zululand Coast.[1]

The heavy minerals found in the dunal deposits along the coast of northern KwaZulu-Natal originate from inland. Over the years, weathering of host rock has released the minerals, which, because of their durability, relatively high density, and high chemical stability, withstand the weathering process and are transported down rivers to the ocean.[4] It is from here that the minerals ilmenite, rutile, and zircon originate. Once in the sea, the sand is transported up the coast by currents and wave action. Wave action deposits the sand containing the heavy minerals onto the beaches. From here, the sand is then blown into dunes by the prevailing onshore winds.[1]

From a geological point of view, the ore bodies are highly complex and the behaviour of the minerals in the plant may vary considerably across the ore body. Optimal performance of the separation processes carried out in the plant is thus dependent on investigating and characterising the behaviour of the minerals as they flow through the plant. Flowsheet specification and fine-tuning is achieved through extensive characterization of the ore body through a series of laboratory and pilot-scale trials.[5]

BENEFICIATION PROCESSES

Mining Process

RBM employs a dredge mining operation, pioneered in Holland and Australia, to extract and separate the heavy minerals - ilmenite, rutile, and zircon (about 5% in volume) - from the sand, as shown in Figure 2.

Figure 2: Dredging operation at RBM (Anthony Bannister)

A large artificial freshwater pond is created in the dunes, on which float the dredger and concentrator plant. While the dredge removes the material from the front end of the pond, the tailings generated by the separation process are stacked at the back; as a result the pond continuously moves in a forward direction.[6] Burrowing into the mining face of the dune, the dredger advances at a rate of 2 - 3 metres per day, depending on the height of the dune. As the sand face is undermined it collapses into the pond forming a slurry, which is sucked up and pumped to a floating concentrator. At this point, the heavy minerals are separated from the sand by exploiting differences in mineral density via a multi-stage circuit of sluices.[1]

A portion of the magnetite and the chromium-containing minerals are removed magnetically, and the resulting heavy mineral concentrate (HMC) stockpiled for transportation by road to the mineral separation plant.[1]

Mineral Processing

Upon arrival at the mineral separation plant, located at the smelter site, the heavy mineral concentrate is re-slurried and pumped into the feed preparation circuit. Here the slurry is passed over successive stages of low- and high-intensity magnets to remove the ilmenite that is set aside as feedstock for the smelter.[1]

The non-magnetic materials, including zircon and rutile, are concentrated for further processing in the dry mill.[1] These two minerals are separated and upgraded in a series of circuits comprising a number of stages of high-tension electrostatic separation, magnetic separation, gravity separation, and screening. Essentially, rutile and zircon are separated by their difference in conductivity while residual gangue is removed by magnetic and gravity separation circuits[2].

At this point, the zircon and rutile can be dispatched and sold in their raw form as mineral sands. Some zircon is upgraded to produce a higher-grade product by removing various impurities.[1]

Roasting Process

The ilmenite, as mined, has a high Cr_2O_3 content and is not suitable for direct smelting to titania slag. Some of this Cr_2O_3 is removed at the mine when the ilmenite is passed through a magnetic separation step in which the highly susceptible Cr_2O_3-rich fraction of the ilmenite is removed. The remaining minerals containing Cr_2O_3 are not readily separable from the ilmenite by magnetic means since their magnetic susceptibility is almost identical to that of ilmenite. The separation is therefore affected by subjecting the ilmenite to an oxidizing roast that alters the magnetic susceptibility of the ilmenite while leaving the Cr_2O_3-containing minerals unchanged. The roasting process is carried out in two three-stage fluidized bed roasters operated in the temperature range of 730°C to 800°C.[6] After being roasted and cooled to ambient temperature, the roaster product is passed over low-intensity drum magnets to separate out the now more magnetic low-chromium fraction of ilmenite, yielding a feed material suitable for the smelter.[4]

Anthracite is dried on two Peabody grate-type units to produce a reductant for the furnaces. A portion of the reductant is screened out for use as a re-carburising agent for the iron.

Smelting Process

The grade of ilmenite produced at RBM is of too low a grade to be used directly in the production of pigment or synthetic rutile. The TiO_2 content is increased by smelting the ilmenite with anthracite to produce a slag containing approximately 85 per cent titanium dioxide and a high-purity (low-manganese) pig iron as a co-product.[5]

The smelting technology used at RBM was originally developed and proven at Quebec Iron and Titanium (QIT Fer et Titane) in Sorel, Canada where coarse ilmenite is smelted to produce a high-TiO_2 slag and pig iron in similar furnaces. This technology was adapted for RBM to process the fine ilmenite concentrate mined on the north coast of KwaZulu-Natal.[5]

The process generates very little in the way of waste products. The ilmenite ($FeTiO_3$) is partially reduced with char to yield a low-manganese iron, a slag containing 85 per cent TiO_2 (which is the primary product) and a gas containing roughly 85 per cent CO and 12 per cent H_2 according to the reaction:

$$FeTiO_3 + C = TiO_2\,(l) + Fe\,(l) + CO\,(g) \qquad [1]$$

The gas is cooled, scrubbed, pressurized, and used around the site as a fuel for heating and drying. Any excess smelter gas is burnt in a flare stack. The small amount of dust that is scrubbed from the furnace off-gas is the only discard produced.[4]

No fluxes are added to modify the slag properties such as density, fluidity, melting point, or electrical conductivity, because this would dilute the titania in the slag and more reductant would be required to provide the required degree of reduction to yield the 85 per cent titania tapped slag.[4]

The smelter consists of four of the world's largest six-in-line a.c. electric arc furnaces. The furnaces are rectangular in shape, being 18 m long and 8 m wide, and have six electrodes in line. The process is highly energy intensive, with each pair of electrodes being supplied by one 35 MVA transformer, giving a total of 105 MVA per furnace.[4]

The furnace power is controlled by the electrode regulator that moves the electrodes to achieve the target power level. This is effected by controlling the arc lengths under each electrode to maintain balanced electrode voltage and power.[7]

The slag produced is highly aggressive towards the furnace refractories. For this reason, control of the thermal balance is essential, with the furnace being operated to form a protective frozen layer of material along the side and end walls of the furnace. Undercharging of the furnace results in melting of the freeze lining, widening the bath, and exposing the refractory wall to the slag. Along the same vein, the molten slag cannot be permitted to attain any significant degree of superheat.[4]

On the other hand, overcharging of the furnace results in freezing of the bath, which can cause a phenomenon known as frothing. This results from gases being released from the ongoing reaction within the slag layer, causing the slag to foam and expand to many times its original volume. The frothing can be so severe that the increasing slag bath causes the electrodes to retract from the expanding slag until the power is automatically switched off when the electrodes reach the uppermost point of travel.[4]

Further operational challenges complicate the problem of the thermal balance. If too much reductant is charged, the titania content of the slag increases, raising its melting point and, unless corrective action is taken, freezing of the bath can result, with a possible consequence of frothing.[4]

The furnaces are operated continuously with a relatively constant inventory of slag and iron being maintained, with tapping of the slag and iron being done intermittently.

The slag and iron tapholes are located along the same (tapping) side of the furnace with each furnace having two slag tapholes and four iron tapholes. Molten slag or iron is removed from only one of these holes at a time. The slag leaves the furnace at a temperature of approximately 1700°C and is tapped into four 20 t moulds mounted on a specially designed mould car. Shortly after the slag taphole has been plugged, the mould car is pulled by track mobile to a weighbridge and then to a holding area where it is further allowed to cool. The iron is tapped into 60 t preheated refractory-lined ladles mounted on specifically designed ladle cars. As with the slag, the ladle car is pulled away shortly after the taphole is plugged.

These furnace products are further upgraded in subsequent processes. The titanium dioxide slag is crushed and classified according to particle size and sold largely to pigment manufacturers.[1]

Slag and Iron Processing

On receipt of the iron ladle at the iron processing plant, the ladle is weighed and the iron temperature taken with a dip thermocouple. The ladle is placed on a ladle tilter, and an injection hose connected to an angled tuyère in the ladle hood. Nitrogen is fed through the tuyère and the ladle tilted until the tuyère is suitably submerged. Injection reagents are then fed sequentially into the nitrogen stream until processing is complete. As a general rule, the more stringent quality iron grades are produced from the larger taps of hot iron.[4]

Fine char is added to increase the carbon content, and calcium carbide is added to reduce sulphur. Small quantities of ferrosilicon are added for de-oxidation and improved physical quality, while larger quantities are added if high-silicon iron is required.

On completion of the injection process, the iron is cast into pigs on a twin-strand pig-casting machine. Several grades of iron are produced, and individual heats are either stockpiled on site or loaded onto rail cars for transport to Richards Bay Harbour or to customers in South Africa.

The cooled slag is crushed and then ground and dried in an Aerofall mill. The mill product is classified to produce the size fractions required by the chloride and sulphate slag markets. The slag is then stored in silos ready for dispatch by rail to the harbour or to the local customer.

An overview of the entire process is shown in Figure 3.

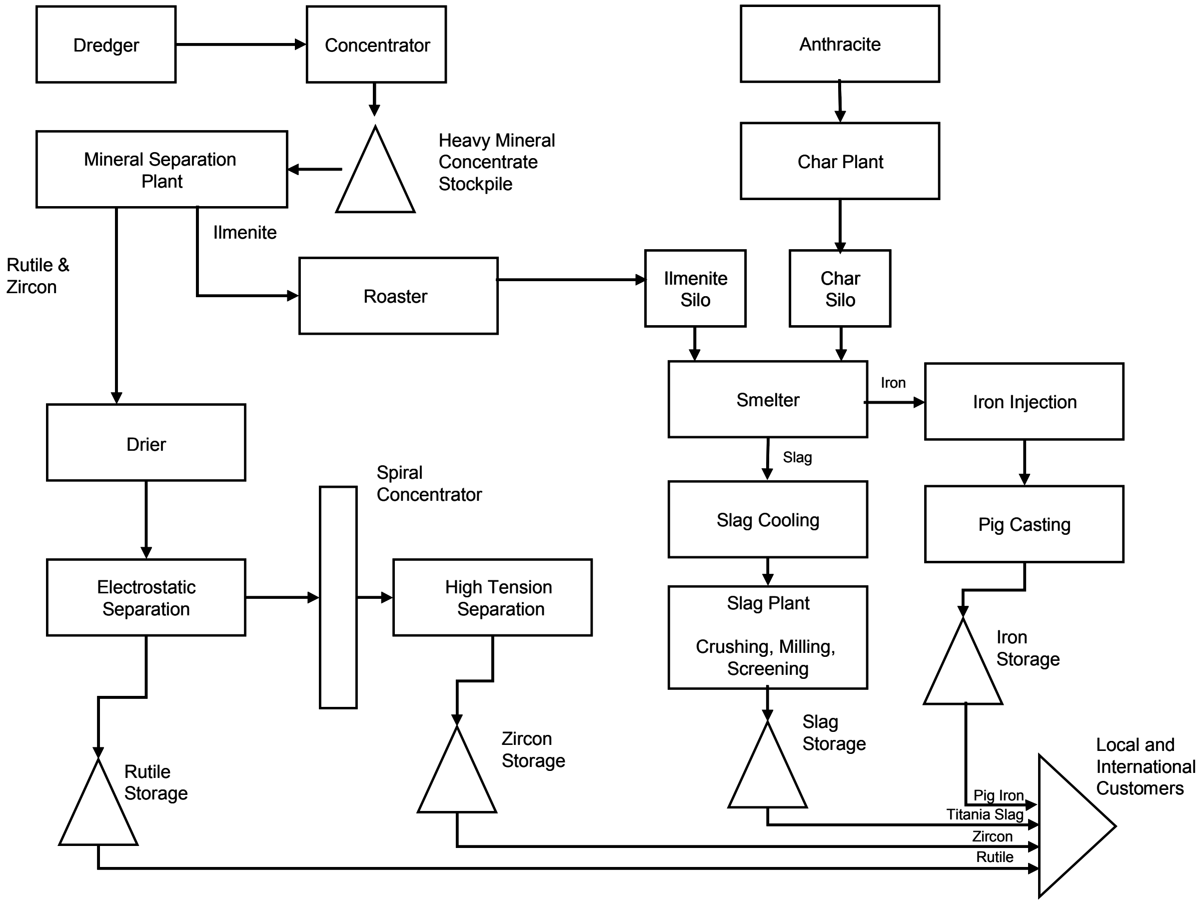

Figure 3: RBM process overview

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