ELECTRO SMELTING OF ILMENITE FOR PRODUCTION OF TiO_2 SLAG – POTENTIAL OF INDIA AS A GLOBAL PLAYER

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ABSTRACT

The principal mineral sources of titanium are rutile, anatase (both TiO_2), ilmenite ($FeTiO_3$) and leucoxene (a weathered ilmenite of variable concentration of TiO_2 but similar to pseudorutile $Fe_2Ti_3O_9$). These titaniferous minerals along with their value added products like Synthetic Rutile and TiO_2 slag constitute "Titanium Feedstocks" for TiO_2 pigment, Ti metal and welding electrodes industries.

Unlike in other industries, the demand driver for titanium minerals is not the metal, but the TiO_2 pigment – a specialty chemical. Of the total titanium feedstocks usage in the world, about 93 % is consumed in TiO_2 pigment, with only about 3 % is utilized in metal production.

India's heavy mineral sands resources are among the largest and also one of the richest grades in the world. The country's Ilmenite resource base stands at 348 million tonnes of Ilmenite (18% of the total world reserves) along with 18 million tonnes of Rutile, 21 million tonnes of Zircon, 8 million tonnes of Monazite, 107 million tonnes of Garnet and 107 million tonnes of Sillimanite.

Though the grades (Total Heavy Minerals (THM) present in the sand) of Indian deposits are relatively rich, the contained ilmenite are termed as sulphate grade with 50-53% TiO_2 (Chavra deposit of Kerala and Ratangiri deposit of Maharastra are an exception with 60% of TiO_2). While superior grades with adequate reserves lead to a cost advantage in ilmenite production, the lower TiO_2 percentage allows the direct use of Indian ilmenite only in the production of TiO_2 pigment through sulphate route and for the chloride pigment production; such ilmenite is required to be upgraded either to Synthetic Rutile (SR) or TiO_2 slag.

However, in order to produce TiO_2 slag in India at a globally competitive cost, the issues like high power tariff, inadequate infrastructure, expensive logistics, less enthusiastic market preferences, supply-demand gaps are to be adequately addressed.

This paper deals with some of the above issues and possible solutions thereto in production of TiO_2 slag from Indian ilmenite.

1. INTRODUCTION

Titanium is the 9^{th} most abundant element (0.6%) in the earth's crust. It occurs in nature in chemical combination with oxygen and / or iron. Because of the high strength-to-weight ratio of its alloys and their resistance to corrosion, titanium is an important strategic material and is used widely in both engines and airframes of high-performance military and civilian aircraft [(1)].

The principal mineral sources of titanium are rutile, anatase (both TiO_2), ilmenite ($FeTiO_3$) and leucocxene (a weathered ilmenite of variable concentration but similar to pseudo-rutile $Fe_2Ti_3O_9$). These titaniferous minerals along with their value added products like synthetic rutile and TiO_2 slag constitute "titanium feedstocks" for the TiO_2 pigment, Ti metal, welding electrodes and titanium chemicals industry. Rutile and anatase have the highest TiO_2 content but with restricted occurrence – hence, world supplies are diminishing. Ilmenite and leucocxene are more commonly found, typically as heavy minerals in beach sands (rock deposits and inland dunal sand deposits are also available) along with zircon ($ZrSiO_4$), sillimanite ($Al_2O_3SiO_2$) and garnet.

Unlike other minerals, for titanium minerals, the demand driver is not titanium metal but a speciality chemical, TiO_2 pigment .Of the total titanium mineral production in the world, about 93% is consumed in TiO_2 pigment, with only about 3% by metal [(2)].

The relative values of titaniferous feedstocks (ilmenite, synthetic rutile, TiO_2 slag) is largely determined by the TiO_2 content (the higher the TiO2 content, the greater the value). For comparison, the value of ilmenite is US$ 60-80 / t, whereas the value of synthetic rutile (92% TiO_2) is about US$ 360-440 / t, slag (82-84% TiO_2) is about US$ 370-410 / t and the value of TiO_2 pigment is US$ 1700-1900 / t.

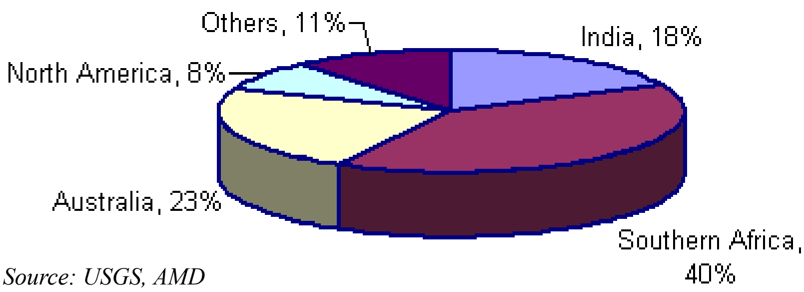
Though ilmenite is the most important primary source of TiO_2, its direct use has been declining in absolute terms and, more significantly, as a proportion of the total titanium feedstock consumption [(3)]. The direct consumption of ilmenite in end-product manufacture (predominantly TiO_2 pigment) peaked in 1980 at 1.9 million tonnes of TiO_2, or 58% of the total TiO_2 units consumed. By 1990, the quantity of ilmenite consumed directly had declined to 1.4 million tonnes of TiO_2 (37% of total), and although it had reached 1.6 million tonnes of TiO_2 in 2000, this represented only 35% of total TiO_2 consumption. While the trend of direct consumption of ilmenite has been declining, consumption of upgraded or beneficiated ilmenite has been increasing rapidly. These products accounted for 29% (0.9 million tonnes of TiO_2) by 2000. It is clear that ilmenite upgradation has become the most significant aspect of titanium feedstock production. This trend is likely to continue in the future, as a high proportion of feedstock production from proposed new projects is also based on upgradation of ilmenite. Further, the desire of end use customers like TiO_2 pigment producers to use high TiO_2 feedstocks with minimum impurities at competitive prices also necessitates ilmenite upgradation.

As such, for Indian ilmenites with less than 55% TiO_2 (barring Chavra and Ratnagiri deposits), the value addition by ilmenite upgradation to either synthetic rutile or TiO_2 slag is the right approach for gainful utilisation of titanium mineral resources of the country. The subsequent sections however deal with the prospects and pitfalls in upgradation of Indian ilmenite.

2. RESERVES

India is well known for its beach sand minerals for the last several decades**.** The accidental discovery of monazite by Schomberg, a German Scientist, drew the attention of the entire world towards the coastal tracts of the erstwhile Travancore State. The reserves are mostly located in the coastal stretches of peninsular India (with the exception of a few inland deposits). According to the off Shore Investigation Group in the Atomic Minerals Directorate for Exploration and Research, who have so far surveyed 2088 kilometers out of the 6000 kilometers of coastal tract, the Indian ilmenite resources are as high as 348 million tonnes (mt)[(4)] .It constitutes about 18% of world reserves, ranking 3rd in world.

Cake Size: 2 billion tonnes

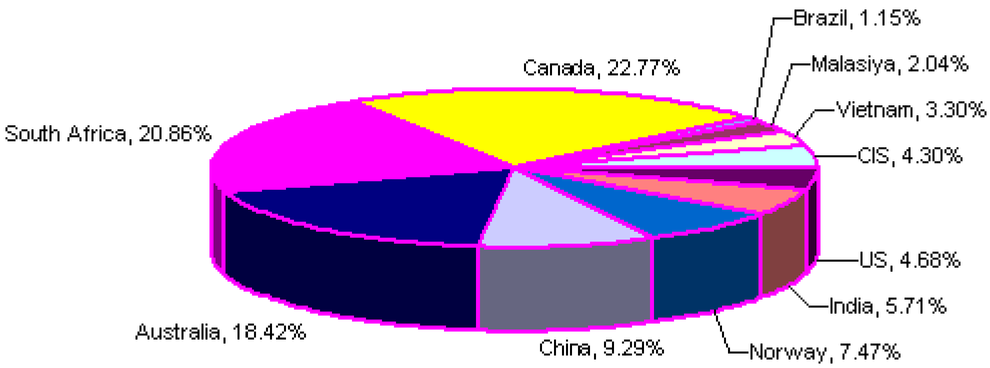


Source: USGS, AMD

Figure 1: World and Indian Reserves of Ilmenite

The world's production of ilmenite was 10.85 million tonnes in the year 2005[2]. The country-wise world production of ilmenite in the year 2005 is shown in Fig. 2. While Canada (2.48 million tonnes) and south Africa (2.27 million tonnes) are in the number one and two positions respectively, India, with a production of 0.62 million tonnes, has 5.7% share of the world production.

Cake Size: 10.85 million tonnes



Source: TZMI

Figure 2: World Production of Ilmenite in the Year 2005

3. THE VALUE CHAIN IN THE TITANIUM INDUSTRY

The feedstock flow and value chain in the titanium industry is shown in Fig. 3 .

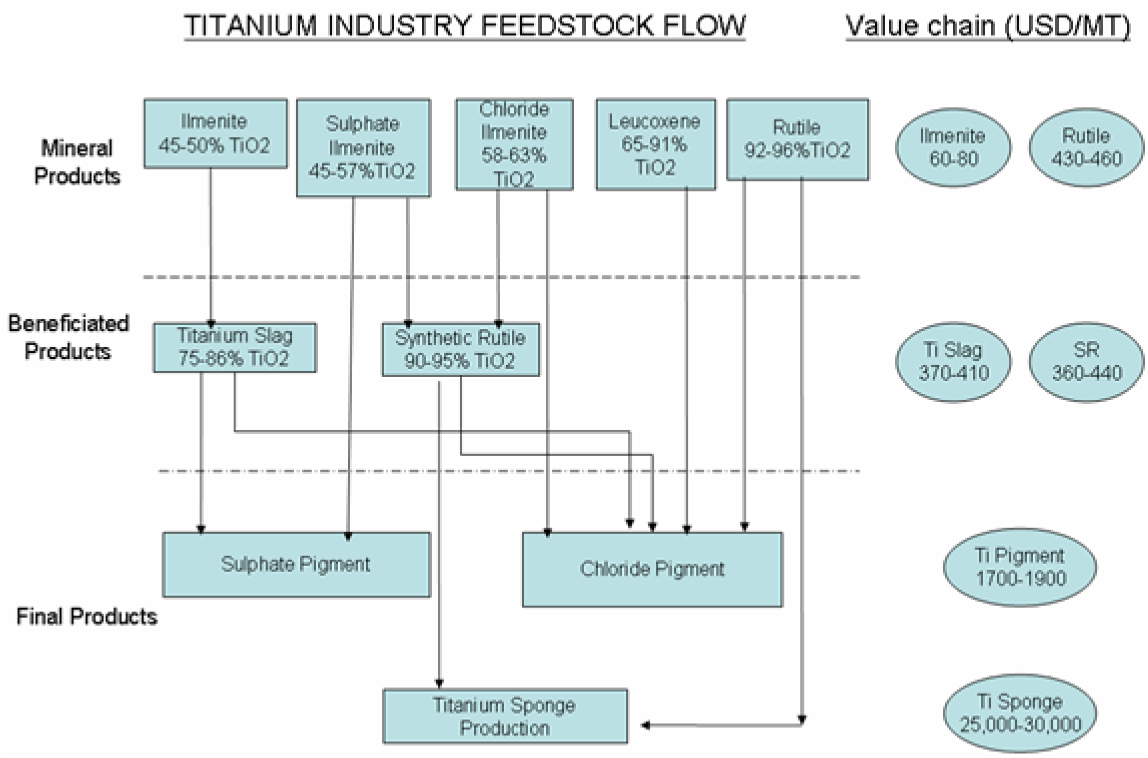


Figure 3: The Value Chain in the Titanium Industry

4. ILMENITE UPGRADATION TECHNOLOGIES

The various technologies (both existing technologies and technologies at the development stage) are shown in Fig. 4

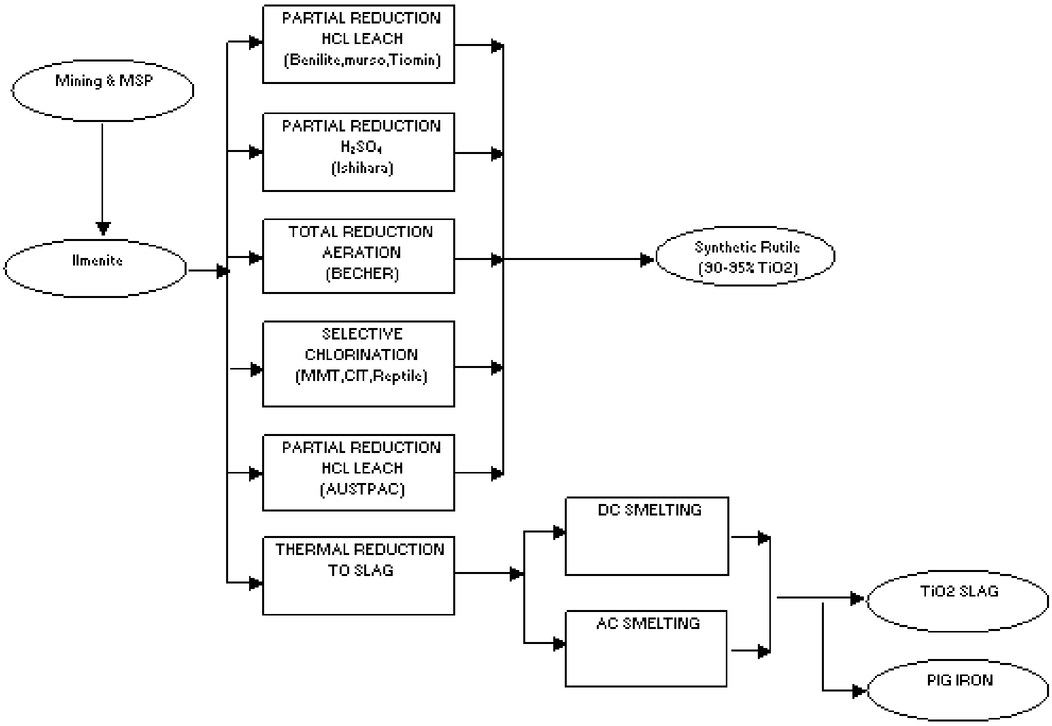


Figure 4: Ilmenite Upgradation Technologies

4.1. TiO_2 Slag

Ilmenite smelting is a carbothermic process to upgrade the mineral ilmenite, yielding TiO_2-rich slag (which is mainly used as a feed stock for TiO_2 pigment production) as primary product and pig iron as a by-product. This smelting process is unusual in having slag as its primary product and metal as a by-product. Another unusual aspect of the process is that no fluxes are added to control the slag properties. The final quality of the slag is highly dependent on the quality of the ilmenite as virtually all the impurities, together with any impurities in the reductant, report to the slag.

Ilmenite used for smelting typically contains 36% to 50% TiO_2. These lower TiO_2 ilmenites are the preferred feedstock for smelting, as the high iron content provides suitable thermodynamic conditions for smelting to take place and high grade pig iron is produced as a valuable by-product.

In smelting ilmenite, a temperature in the range of 1650°C-1700°C is required to ensure that the thermodynamics of the process works correctly. For slag to be used in the sulphate process, it is important that excessive amounts of the rutile phase are not formed. One of the limiting factors in ilmenite smelting is the inability to lower the FeO content beyond a given level. In essence, two main reactions occur in parallel:

$$FeO + C = Fe + CO \tag{1}$$

$$TiO_2 + C = Ti_2O_3 + CO \tag{2}$$

As the FeO levels decline, the TiO_2 content increases, requiring higher operating temperatures due to the fluxing role played by FeO. This places a limit on the minimum level of FeO that can be present in a typical slag, which is generally in the range of 8% to 10%. Attempts to produce higher TiO_2 content slag also result in reduction of a portion of the Ti to Ti_2O_3, which is less soluble in sulfuric acid and hence such slags are not suitable for the sulfate process pigment production.

4.1.1 Overview of Technology

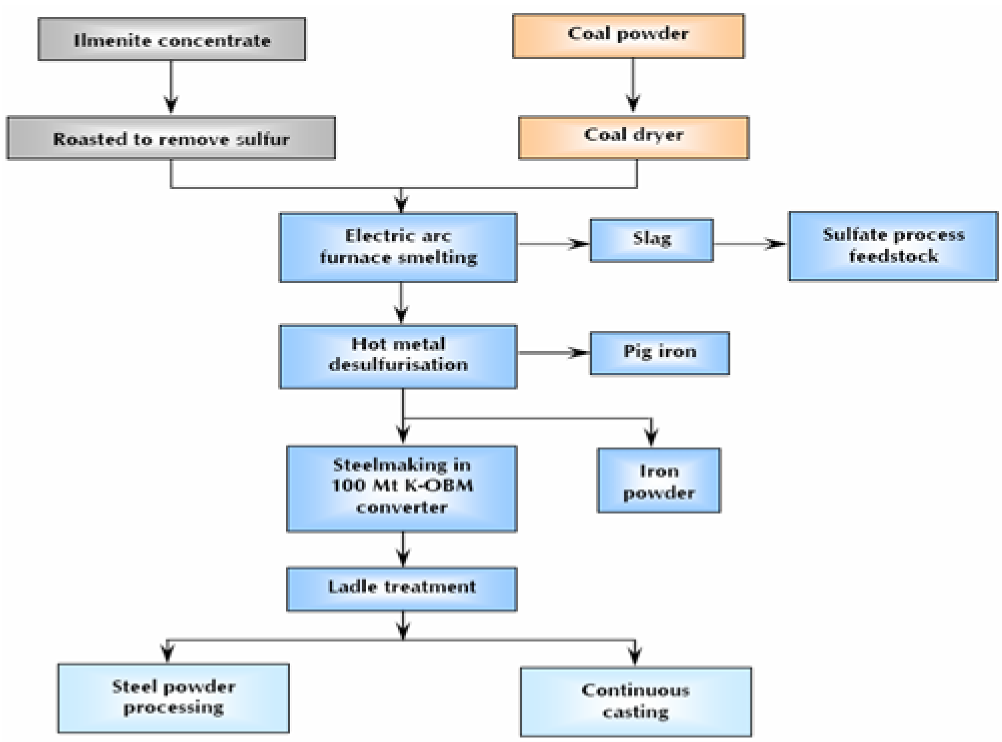
There are two processes for the direct smelting of ilmenite that have been used commercially. These are:

- AC open arc smelting - developed by QIT and is used at QIT's plant at Sorel, Canada and at Richards Bay Minerals (RBM) in South Africa.
- DC open arc (or plasma arc) smelting - developed by Mintek in South Africa and adopted by Namakwa Sands Limited on the west coast of South Africa and by Ticor South Africa at Empangeni near Richards Bay.

The use of preheating and/or pre-reduction of the ilmenite are possible variants to these two direct smelting technologies.

4.1.2 AC smelting

AC smelting of ilmenite as applied by QIT uses large, rectangular six in line electrodes, open arc, high power furnaces each with a capacity of up to 250,000 tpa of slag. A high quality reductant, such as anthracite, is charged in the furnace with the ilmenite. The QIT technology is very tightly held, with its application being limited to the present Rio Tinto group. There is no known external provider of this particular technology. A general flow sheet of the QIT used for production of standard Sorel slag is shown in Figure 5. The same basic flow sheet is used at RBM in South Africa, with the exception that there is no further processing of iron beyond the initial product.

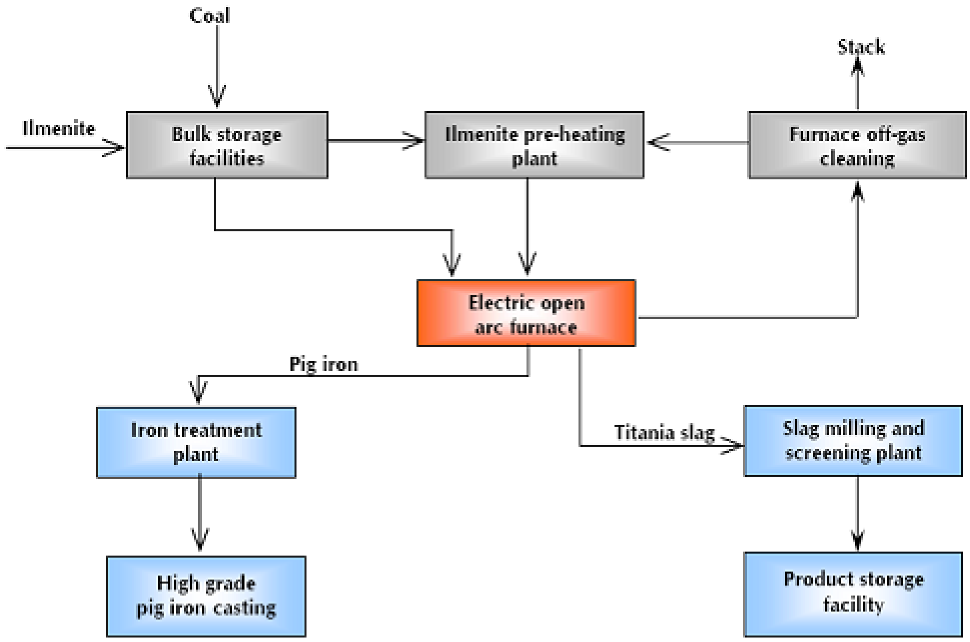


Source: Sommerville and Yang (1999)

Figure 5: QIT – Sorel Slag and Iron Operation Flow-Sheet

4.1.3 DC Smelting

The DC smelting technology employed by Namakwa Sands was developed jointly by Anglo American Corporation (Anglo American) and Mintek in South Africa. Patents to the process are held by Anglo American and Mintek and are constrained from providing technological assistance to other parties. The Namakwa operation was established with ilmenite preheating, but this aspect of the process has proven difficult to operate and it is understood that the preheaters have been effectively decommissioned, with a consequent reduction in the plant's capacity. The general flow sheet of this operation is shown in Figure 6.



Source: Namakwa sands

Figure 6: Namakwa Sands: DC Plasma ARC smelting flow sheet

DC smelting has also been installed at the Ticor South Africa operation, based on technology developed and piloted by Iscor. This operation also includes ilmenite pre-heating, but the pre-heaters had not been operated for a significant period. With the spread of DC smelting technology it is now generally acknowledged that groups with significant prior metallurgical expertise could develop the technology for specific applications. However, it is also acknowledged that it is a difficult technology to operate and people with previous operating experience are essential.

4.1.4 Commercial Operations

Five western world operations (Table 1) produced an estimated 2.99 million tonnes of slag in 2005. [2]

Table1: Global TiO_2 Slag Capacities

Company	*Location*	*Capacity (tpa)*	*Feedstock*
QIT	Sorel, Quebec, Canada	1.20 million	Lac Allard 35 % TiO_2 rock ilmenite
Richards Bay Minerals	Richards Bay, South Afric	1.05 million	49 % TiO_2 roasted sand ilmenite
Namakwa Sands	Saldanha Bay, South Africa	180,000	48 % TiO_2 sand ilmenite
Tinfos Titan and Iron	Tyssedal, Norway	200, 000	Tellnes 45 % TiO_2 rock ilmenite and minor sand ilmenite
Ticor	Empangeni,South Africa	250,000	49% TiO_2 ilmenite

4.1.5 Feedstock and raw material requirements

Historically, only low TiO_2 ilmenite (52% TiO_2 and lower) have been used as feedstock for the production of titania slag. This is due to the suitability of these high iron content ilmenite for the smelting process and because they have limited markets for direct use in TiO_2 pigment production. However, there is a possibility that higher TiO_2 ilmenite could be used in the future (e.g. 60% TiO_2 ilmenite from Madagascar could be used as feedstock at QIT, Canada).

It is the level of impurities in the ilmenite, rather than its TiO_2 content that is the most important criterion for slag production. Some ilmenites, notably those from hard rock sources, are suitable only for the production of sulfate slag, due to the high level of alkali impurities (CaO and MgO). For the production of chloride grade slag, the most important criteria are low levels of alkalis, low U and Th and low SiO_2 and Al_2O_3. In addition, the quality of the pig iron by-product can be influenced by impurities such as manganese and phosphorus.

A high quality reductant, such as anthracite, is required. Impurities like SiO_2 and Al_2O_3 in the reductant will report to the slag product. For smelting without pre-reduction, around 0.14 tonnes of reductant per tonne of ilmenite are required. If pre-reduction is used, less reductant is required in the furnace and hence the quality requirements of the reductant can be relaxed. The actual quality requirements will be dependent on the level of impurities in the ilmenite and the desired quality characteristics of the slag product.

4.1.6 Key cost drivers

The key cost drivers for titania slag production and their estimated consumption norm for 120,000 tpa slag plant are [5]:

Ilmenite feedstock	214,286 tpa
Power	1160 kWh /ton of ilmenite
Reductant	0.14 kg /ton of ilmenite
Electrodes	3.5 kg/MWh
Water	2 kl/ton of ilmenite

4.1.7 Location issues

Titania slag production facilities are typically located close to the source of ilmenite (to minimise transport costs) and in a location with low cost electric power. All current producers are located in areas where power can be purchased at no more than 3 US cents per kWh.

4.1.8 By-products

The by-product from production of titania slag is a low manganese pig iron (sometimes termed nodular iron), which is sold for specialty foundry applications, particularly for automotive parts. The product generally commands a price premium compared to standard blast furnace pig iron.

4.1.9 Environmental impacts

There are very few environmental impacts arising from the production of titania slag. The only waste product is dust collected from the furnace off-gas.

4.1.10 Technology ownership

Ilmenite smelting technology is not sold or licensed by existing producers. The AC smelting technology used by QIT and RBM is tightly held and would not be made available to a potential competitor. The DC technology is more freely available, but the necessary operating know-how is held by the two existing producers (Namakwa Sands and Ticor South Africa). Companies, which profess to be able to supply ilmenite smelting technology include:

- Titaco (a subsidiary of Bateman) – DC smelting technology;
- Outo Kumpu – both AC and DC smelting technology.

4.1.11 Product suitability for pigment production

There are essentially three issues that determine the suitability of slag products for TiO2 pigment production.

4.1.11.1 Product chemistry

This relates primarily to the level of impurities. For chloride pigment production, the product must be low in CaO and MgO. For sulfate pigment production, low levels of Cr_2O_3 are necessary. In both instances, low U and Th content is necessary, due to the generally low levels in competing products. These impurity levels are all determined by their respective contents in the ilmenite feedstock. The level of SiO_2 and Al_2O_3 is also important for chloride pigment production. The level of these impurities in the final slag product can be influenced by the quality of reductant, as well as the ilmenite feedstock.

4.1.11.2 Particle size and density

The particle size and density are important for chloride pigment production, as these characteristics affect the extent of blow over losses from the chlorinator. After tapping the slag and allowing it to cool, the slag blocks are crushed and ground to produce suitably sized particles. In chloride slag production, the product is sized with the minus 800 micron plus 100 micron fractions and sold to the chloride market , the oversize and fines to the sulfate market. Because of the more limited market for sulfate feedstocks, the generation of fines should be minimized.

Slag particles have relatively high density; lower than natural rutile but higher than synthetic rutile. Consequently, the blow over losses for slag are considerably lower than for synthetic rutile, which is a positive feature partly reflected in the relative pricing of these two products.

4.1.11.3 Oxidation state of Ti

For the sulphate process, the oxidation state of the titanium is important: tetravalent Ti (TiO_2) is more soluble than the trivalent species (Ti_2O_3). Consequently, if the Ti is over-reduced, the slag may be less amenable to sulfate processing. The reactivity of the slag can also be influenced by the rate and manner of cooling the slag blocks, which influences the proportion of the insoluble rutile phase that is formed.

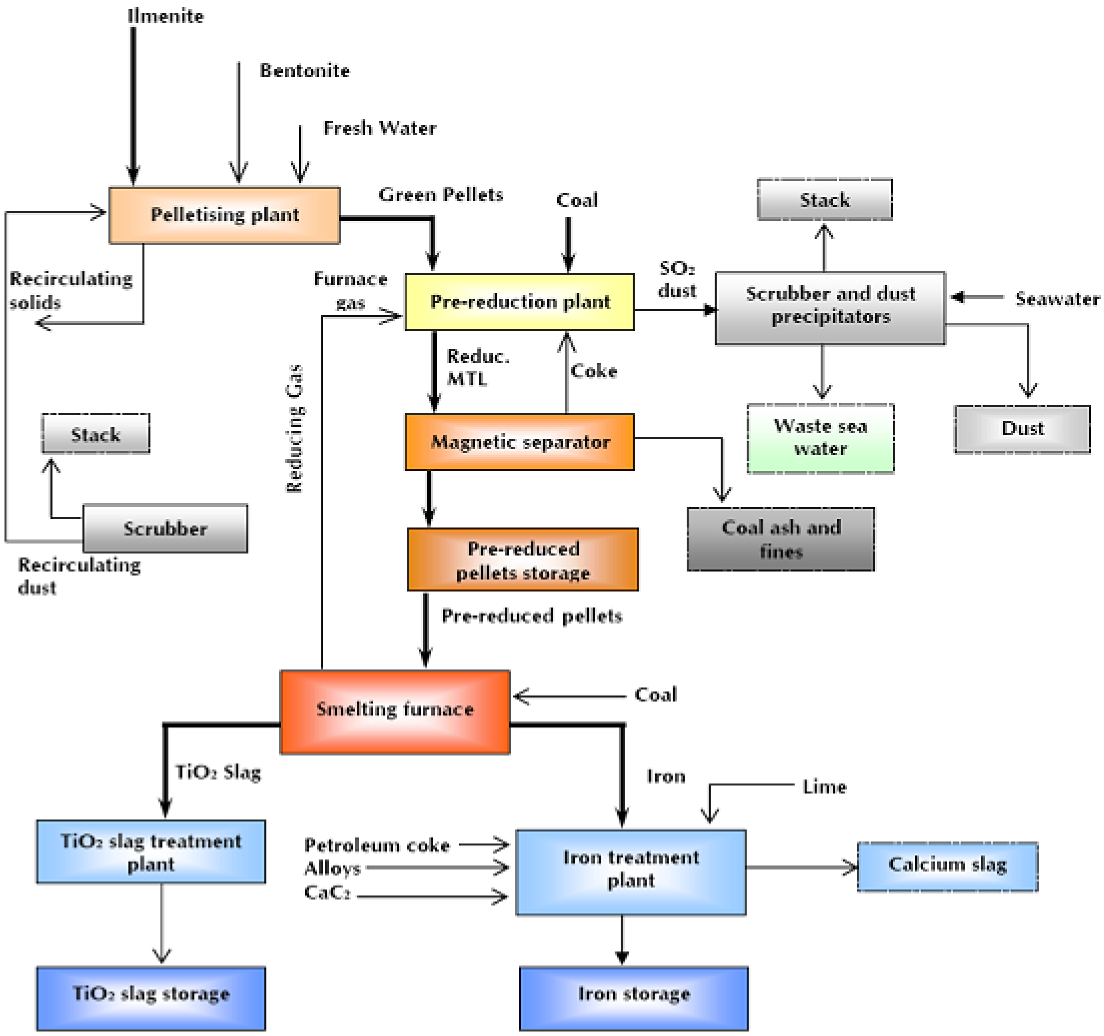
4.2 Titania slag with pre-reduction

A variant to the direct smelting of ilmenite is to pre-reduce the ilmenite prior to feeding this material to an electric furnace. In this instance, a high proportion of the necessary reduction is carried out ahead of the furnace using a solid or gaseous reductant, thereby reducing the consumption of electric power. This process therefore has advantages in locations where power is relatively more expensive or in limited supply. There are also advantages in the electric furnace operation being easier to control. In the only commercial application of this technology, ilmenite is pre-reduced in a rotary kiln

using coal as reductant. Lurgi has proposed the use of a circulating fluidized bed for pre-reduction in its CFB (CircoSmelt) slag production technology. While the technology probably requires some modification in detail for it to commercially applicable, the concept has potential, particularly for situations where low cost electric power is not available.

The only commercial titania slag operation involving pre-reduction of ilmenite is the Tinfos Titan and Iron operation at Tyssedal in Norway. The Tinfos project was originally developed in the late 1980s for the processing of 45% TiO_2 ilmenite produced from a rock ilmenite mine at Tellnes in Norway. The ilmenite contains high levels of MgO and hence the slag produced from this feedstock is suitable only for sulfate pigment production.

The Tinfos process involves pelletising of the relatively fine-grained ilmenite and pre reduction in a kiln, which results in quite an elaborate feed preparation circuit as shown in Figure 7. A circular, three-electrode, open arc furnace with a nameplate slag capacity of 200,000 tpa is used for slag production. The technology for this operation was developed in conjunction with Elkem of Norway. The slag product resulting from the smelting of the ilmenite originally assayed around 75% TiO_2, although in recent years this has been upgraded to around 80% TiO_2 by the use of higher TiO_2 ilmenite in the feedstock blend, and lower ash content coal.



Source: KS ilmenittsmelteverket AS publication, 1987

Figure 7: Flow-Sheet for Tyssedal Smelter

5. POTENTIAL FOR PRODUCTION OF TIO_2 SLAG IN INDIA

5.1 Advantages in favour of TiO_2 slag

The following advantages of Indian ilmenite are in favour of production of TiO_2 slag in India.

5.1.1 Favorable Government Policy

Till 1998, the mining of heavy mineral sands was limited to the public sector only. However, a low exploitation ratio of the reserves coupled with factors like the need for faster economic development, the demand for these minerals and their value added products in the domestic as well as international markets and high capital requirement for green field project, led to a policy guideline by the Government of India on October 6, 1998, allowing private sector participation including foreign direct investment in the heavy mineral industry. However, after the initial enthusiasm of major global players of this industry, value addition projects have not really taken off. The reasons are discussed in the later part of this paper.

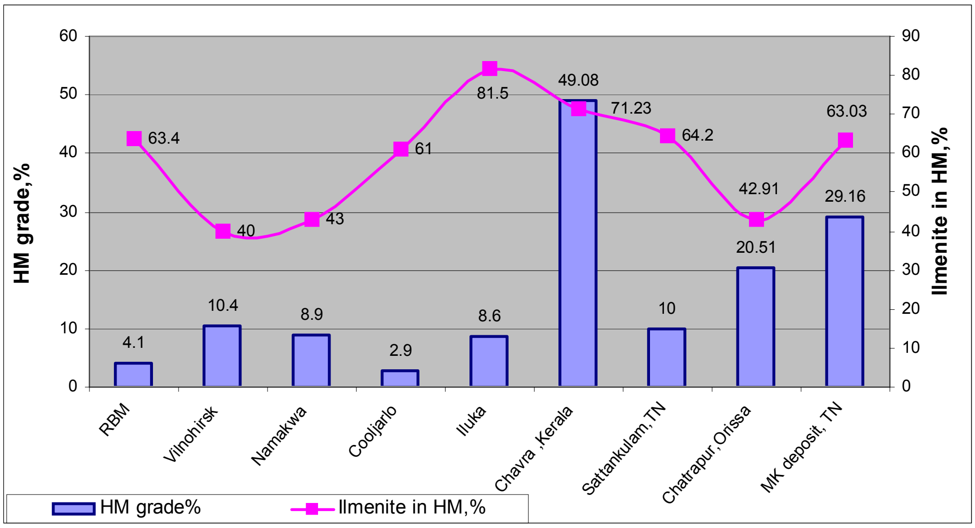
5.1.2 Large Reserves

As mentioned earlier, the ilmenite reserves in India are very vast as estimated by AMD. The region-wise reserves given in Table 3 indicate that the reserves in India can support a titanium feedstock industry of a global scale [6].

Table 3: Region-wise Reserves in India

	Mineral Sand Deposits of India									
	Andhra Pradesh		*Tamil Nadu*		*Kerala*		*Orissa(IREL)*		*Orissa (others)*	
	million ton	*%*	*million ton*	*%*	*million ton*	*%*	*million ton*	*%*	*million ton*	*%*
Sand	441.81	100	604.85	100	48.72	100	230.51	100	964.13	100
THM	68.46	13.09-21.10	73.35	10-13.37	21.72	29.20-49.10	47.28	20.51	153.23	8.40-20.51
Ilmenite	24.03	4.08-9.71	40.57	6.42-6.88	15.2	18.38-34.97	20.29	8.8	65.352	36.48-52.58
Rutile	1.04	0.15-0.46	2.53	0.29-0.64	1.13	1.17-2.66	0.88	0.38	2.817	0.71-5.41
Leucocxene	0.92	0.17-0.32	2.85	0.46-0.49	0.51	0.67-1.16			0.043	0.29
Zircon	0.63	0.12-0.18	3.7	0.43-0.72	1.16	1.59-2.60	0.71	0.33	2.146	0.56-2.93
Garnet	19.66	3.38-5.12	11.11	2.91	0.49	0.33-3.33	15.45	6.7	48.073	24.71-35.55
Sillimanite	19.13	4.05-4.79	8.7	1.15-1.92	2.76	2.89-6.48	7.84	3.4	28.804	16.59-29.52
Kyanite			0.09	0.02	0.13	0.13-0.32				
Monazite	0.44	0.06-0.16	0.96	0.10-0.20	0.28	0.47-0.88	0.62	0.27	1.794	0.23-1.32

Source : AMD



Adopted from Ilmenite in Focus, December2002-TZMI publication, AMD publication

Figure 8: HM Content in Various Deposits in the World

5.1.3 High Grade Reserves

India is better placed in terms of Heavy Mineral (HM) percentage or grade. Though India is not highly placed in terms of the ratio of (rutile + zircon) to Ilmenite (0.12 -Capel , 0.45-Eneabba,0.08 Orissa , 0.17 Chavara) ,yet has an edge over others in terms of the heavy minerals. The contained HM ranges between 2 and 10% in the world, whereas the same is 10-50% (Fig. 8) in India [6, 7]

5.1.4 Superior Quality of Ilmenite

Though Indian ilmenites are considered to be of sulphate grade in terms of TiO_2 percentage, upgraded Indian ilmenites are highly suitable for production of chloride grade pigment. Lower levels of Al_2O_3, MgO, CaO, ZrO_2, SiO_2,V_2O_5, Cr_2O_3, MnO and P_2O_5 of Indian ilmenites are favourable for the use in production of chloride grade pigment after ilmenite upgradation as shown in Table 4.

Table 4: Quality of Indian Ilmenites

	Q India	*MK India*	*OR India*	*TN (others) India*	*AP India*	*Target Specs, Slag*
TiO_2	60	55	50.2	51-54	48-52	
Fe_2O_3	25.5	18.9	12.8	11-16	7.0-17.4	
FeO	9.7	20.9	34.1	28-33	30.9-37.0	
Al_2O_3	1.1	0.8	0.6	0.5-0.55	0.30-0.77	1.2
SiO_2	0.90	0.90	0.80	0.44-0.90	0.40-0.45	1.5
ZrO_2	0.4	0.06	0.01	NA	NA	
MnO	0.40	0.40	0.55	0.3-0.37	0.38-0.4	1.2
Cr_2O_3	0.13	0.08	0.05	0.04-0.06	0.04-0.07	0.11
V_2O_5	0.15	0.22	0.24	0.21-0.25	0.20-0.22	Not imp
MgO	0.60	1.0	0.6	0.6-0.67	0.48-0.82	0.70
CaO	0.2	0.2	0.2	0.02-0.03	0.04-0.13	0.1
P_2O_5	0.20	0.12	0.03	0.02	0.02-0.57	0.02
U+Th (ppm)	150	225	50-60	39-78	NA	30

Source: AMD

The expected quality of TiO_2 slag from a typical Indian ilmenite along with others major slag producers in world are given in Table 5 [2].

Table 5: Indicative Quality of Slag from Typical Indian Ilmenites vs Other Sources

Quality, %	*TiO_2 Slag from Indian Ilmenite*	*RBM - Chloride Slag*	*Namakwa - Chloride Slag*	*Tinfos- Sulphate slag*	*QIT- Sulphate Slag*
TiO_2	88	85.5	86	80	80
Fe (T)	10	10.6	9.0		
Al_2O_3	1.3	1.3	1.4	1.7	2.9
SiO_2	1.7	2.1	1.8	4.5	2.4
MnO	0.6	1.7	1.7		0.25
Cr_2O_3	0.08	0.17	0.08	0.13	0.17
V_2O_5	0.28	0.44	0.40		0.57
MgO	1.2	1.1	0.7	5.5	5
CaO	0.03	0.17	0.16		0.6
S					0.06
U(ppm)	17	15-30	10		
Th (ppm)	130	15-30	10		

From the above, it can be seen that the envisaged slag analysis from typical Indian coastal ilmenite is suitable for production of chloride grade pigment.

5.1.5 Cost Competitiveness

A potential titanium feedstock project needs to be assessed in terms of its competitiveness relative to existing producers and other potential new projects. In other mining sectors, this conventionally implies positioning the project on an industry cost curve. However, the issue is considerably more complex for the titanium feedstock industry because of its multi-product nature.

An attempt has been made to calculate the in-ground value of heavy mineral per tonne of sand (Fig. 9) for Indian as well as potential deposits elsewhere [8]. Kerala tops the list with a value of US$ 35/ t of sand in terms of in - ground value, while Tamil Nadu stands highest in terms in-ground value and quantum of reserves when taken together. With superior resources (in terms of in ground value and volumes of reserves) and cheaper labour, a reasonable assumption can be made that any proposed heavy mineral sands industry in India will be globally cost competitive, at least upto minerals production.

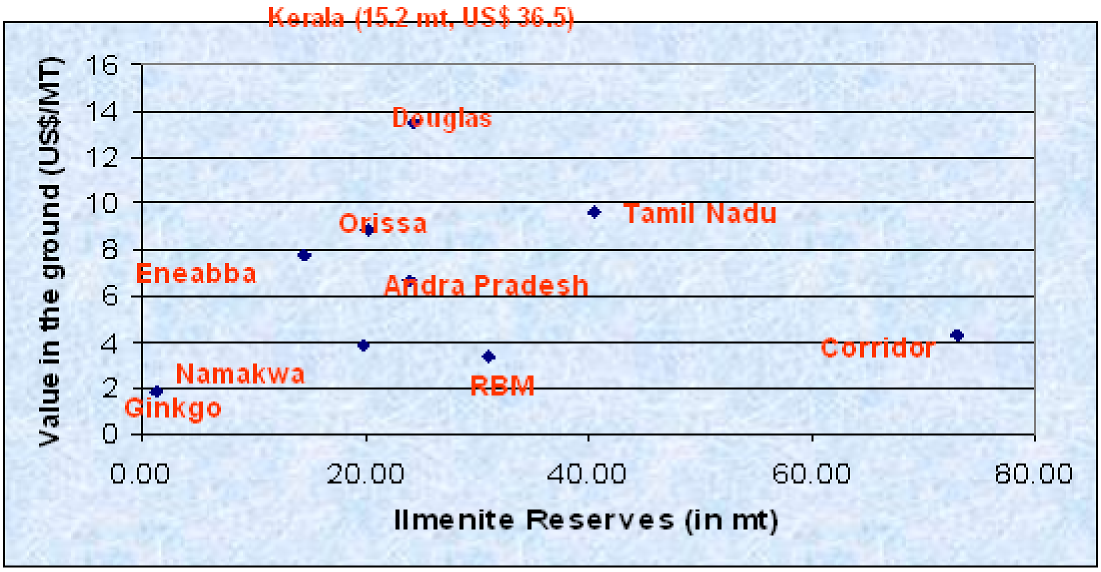


Figure 9: In-ground Value of Heavy Mineral Resources – India vs Others

5.2 Issues

There are a few issues which are becoming major bug bears in production of TiO_2 slag in India. The same are:

5.2.1 High Power Tariff

Though Indian ilmenite is found ideally suitable for production of TiO_2 slag (which is a very environmental friendly process), the biggest impediment to the use of slag technology in India is the high cost of electric power which is 3-4 times higher than the slag producing countries as can be seen from below:

	US cents/kWh
India (Electricity Board)	6-8
India (captive)	5-6
Canada[9]	=<3.0
Norway	<2.0
South Africa	2.2

With such a high power tariff, the power cost alone could be about US$ 97-176/t of slag, whereas the same is of the order of US$ 44/t of slag for South African slag producers.

5.2.2 Shortage of Water in States like Tamil Nadu

The titanium feedstock industry including mining and mineral processing of heavy mineral sands requires large quantities of water of the order of 0.5 to 1 m^3/t of sand depending on the type of mining adopted and the proportion of slimes content. Meeting such high water requirement in states like Tamil Nadu at competitive rates is a challenging task.

5.2.3 Closely Held Technology

Technology for production of TiO_2 slag is closely held and is generally not accessible. Further, ramp up , reaching and sustaining at the installed capacities is an issue particularly so in the case of DC smelting. This is so evident from the fact that Ticor and Namakwa sands are struggling to reach their name plate capacities even after operation of 3-7 years.

5.3 New Projects

There are a number of new feedstock supply projects under consideration. QIT, Canada is increasing its capacity of upgraded slag production from 0.325 tonnes to 0.375 tonnes by late 2006. WMC Resources' Corridor Sands Project in Mozambique is being considered for development before the end of this decade. QIT Medagarcar minerals' QMM Fort-Dauphin is expected to start production in 2008.The project plans to produce 750,000 tpa of ilmenite that will be shipped to QIT fer-et for conversion into 91% TiO_2 chloride slag. This, in turn, would affect any new Ilmenite upgradation prospects, as these projects can result in a significant over-supply situation. Ability to compete is contingent on the lowest cost position (at least in the bottom quartile in the industry cost curve) of the project.

6. WAY FORWARD FOR PRODUCTION OF TIO$_2$ SLAG

6.1 Reduction in Power Consumption in Production of TiO$_2$ Slag

The relative abundance of low TiO_2 ilmenite of suitable quality for chloride processing will lead to continued emphasis on the use of slagging technology for ilmenite beneficiation. In order to produce TiO_2 slag at the lowest cost, a two pronged approach needs to be pursued – one is to reduce the specific power consumption and second is to make the power tariff as low as possible.

Pre-reduction in a CFB, followed by feeding of hot charge to an AC furnace or DC furnace is one of the options to achieve lower power consumption levels. If successful, the power consumption can perhaps be reduced to a level of 1200-1300 kwh/t of slag.

Captive generation of power, large capacity pit head plants, wheeling of power from low cost production areas like Bhutan without cross subsidies and linking up of power tariff with international prices of slag may be other options that deserve a serious look within India.

7. CONCLUSION

India's titanium bearing heavy mineral sands resources are one of the largest in the world and are also of relatively high grade. While ilmenite is the most important primary source of TiO_2, its direct use for pigment has been declining in absolute terms and, more significantly, as a proportion of the total titanium feedstock consumption. While direct consumption of ilmenite has been declining, consumption products produced by upgradation of ilmenite has been increasing markedly (accounting for 29% of total consumption). Further, the desire of end use customers like TiO_2 pigment producers to use purer feedstocks with minimum impurities at competitive costs also necessitates ilmenite upgradation. For Indian ilmenites, with TiO_2 content less than 58% (barring the Chavra & Ratangiri deposit), value addition through ilmenite upgradation for production of

TiO_2 slag can be a potential business model for gainful utilisation of titanium bearing mineral resources of the country in the short and middle term subject to site specific economic viability.

Government's liberalization policy coupled with certain inherent advantages like huge reserves, high THM grade, superior quality of ilmenite, relative cost competitiveness at least upto minerals, encourage the production of TiO_2 slag in India. However, issues like prevailing high power tariff, inadequate infrastructure facilities, closely held technology, over supply scenario of TiO_2 slag pose challenges to upgradation of Indian ilmenites at least within India.

The following are a few suggested measures for encouraging ilmenite upgradation in India:

- Need for development of new technology which is less power intensive.
- Stretch the economic boundaries of the Becher synthetic rutile process to enable the processing of lower TiO_2 ilmenites.
- Focus on reduction of power consumption in slagging process, accompanied by support from the Government to make power available at globally competitive tariffs without cross subsidy burden to power intensive production process such TiO_2 slagging process.

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