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# Beneficiation of Indian Heavy Mineral Sands – Some New Possibilities Identified by Tata Steel

**Ch. V.G.K. Murty, D. Rathod, S. Asokan** and **Amit Chatterjee**

*Tata Steel Limited*

**Abstract**

*Titanium, the 9th most abundant element on the earth's crust, is available mostly (90%) in the form of ilmenite (FeO.$TiO_2$) and leucoxene (weathered ilmenite). These titanium-bearing minerals occur either as placer minerals or some times, as rock deposits (e.g. in Canada and Norway).*

*As a part of its vision to grow in the mineral and metal related industries, Tata Steel is looking at business opportunities in the field of titania. The titania business will involve stage-wise development of mining, separation of ilmenite as well as other co-minerals, beneficiation of ilmenite to synthetic rutile, $TiO_2$ pigment production and ultimately the production of titanium metal. The 'Teri' mineral sands (inland iron coated dunes) of Sattankulam in Tamil Nadu will be the feed raw material.*

*Since normally in the heavy mineral sand industry, it is customary to pre-concentrate the material to produce heavy mineral concentrate (HMC). While primary concentration is carried out employing gravity concentration techniques to separate the heavy minerals (ilmenite, rutile, zircon, leucoxene, sillimanite and monazite) from sand (quartz) based on their significant differences in specific gravity, individual separation of minerals relies on techniques such as electrostatic separation, magnetic separation and flotation. However, difficult-to-treat type of sand deposits such the Teri deposits of Sattankulam, which are characterised by a wide size range, higher proportion of slimes, and the presence of near gravity materials like kyanite and corundum, necessitate an altogether different approach for pre-concentration. The all-spiral-circuit that is normally used has to be supplemented by free settling classifiers (for feed preparation) and hindered settling classifiers (for the removal of fine sillimanite).*

*While the use of electrostatic separators for separation of HMC into conducting and non-conducting fractions is traditionally used at the initial stage of dry milling in the magnetic separation circuit, the recent trend is to focus on the advantages of using rare earth dry magnetic separators in place of electrostatic separators for the separation of ilmenite, especially in the case of ilmenite-rich deposits such as the one at Sattankulam.*

*This paper describes some new possibilities that have been identified by Tata Steel for the development of appropriate flow sheets for the beneficiation of the Sattankulam heavy mineral sands deposits.*

## INTRODUCTION

As a part of the Steel Company's vision to grow outside steel, Tata Steel is studying the possibility of exploiting the extensive titania deposits in Tamil Nadu. It is planned that this venture, to be taken up in phases would involve mining of the inland sand dunes followed by the separation of ilmenite and other valuable minerals, up-gradation of the ilmenite to synthetic rutile, production of titanium dioxide pigment and ultimately the production of titanium metal.

In its effort to utilise the Sattankulam deposits, Tata Steel has entered into a Memorandum of Understanding (MoU) with the Tamil Nadu Government according to which, the Tamil Nadu Government is providing the support including mineral rights and environmental clearance required to begin work on this venture. To be able to undertake the task of exploiting the titania deposits in Sattankulam, Tata Steel has signed an agreement (in the month of September, 2003) with an international consortium headed by Outokumpu to conduct a bankable feasibility study, including geological assessment of the deposits over an area of 80 square kilometers granted to Tata Steel under a Prospecting License. Besides Outokumpu, the consortium comprises PAH and L&T; Dasturco has been appointed as the consultant for the project; and TZMI (TZ Minerals International) of Australia, were selected to advise on the process to be selected for optimum utilisation of the deposit and marketing of the product (s).

The entire feasibility study was split into two parts – Part A comprised the geological evaluation of the resources, including drilling, resource evaluation, mining concepts and mine planning, metallurgical test work, flow sheet development and an evaluation of the suitability of the ilmenite for beneficiation, while Part B consisted of pilot plant tests for mineral separation, validation and optimisation of flow sheets, environmental studies and optimisation of mine scheduling. Part A of the feasibility study was completed in December 2004 and Part B in February 2006.

## LOCATION

The heavy mineral resources to be utilised in Tata Steel's titania venture are located near Sattankulam and Kuttam villages in the Tuticorin and Tirunelveli districts of Tamil Nadu. The Sattankulam deposit is located at a distance of about 60 km SE of Tirunelveli town (Fig.1); the port town of Tuticorin is located at a distance of about 80 km NE of Sattankulam thereby providing opportunities for export of the finished product(s).

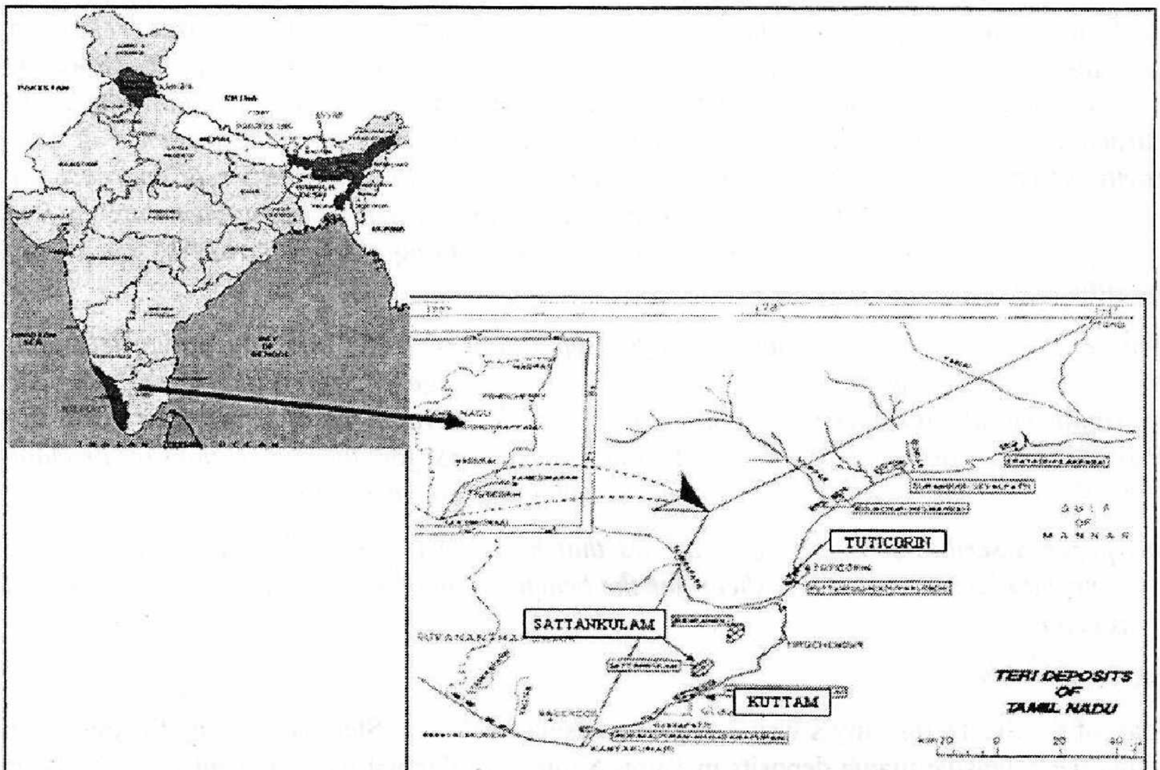


**Fig. 1: Map of the Sattankulam Region in Tamil Nadu**

## GEOLOGY OF THE DEPOSIT

The Sattankulam deposit is made up of very homogeneous grains, 85% of which is between 2mm and 63 micron in size and the remaining 15% is fines below 63 microns. The particles have a bright red colour owing to an iron oxide coating on the surface. The thickness of the sand column varies between 0.8m and 15.7m with an average thickness of 6.9m. The contact zone between the bottom weathered sandstone and the sand column is gradational.(1)

Based on the slime content as well as the colour of the sand, two layers have been identified within the sand column both of which have similar heavy mineral contents and mineral assemblage distribution, but the distribution of fines is somewhat different. The upper sand layer having a thickness of upto 4m consists of brick-red unconsolidated sand and generally has a low content of fines (11.5%). On the other hand, the lower sand layer with thickness varying from 0 to 6 m is medium brown; is unconsolidated and contains higher amount of fines (16.7%).(2) A typical geological section showing the upper and lower sand columns along with the profile of the bottom sand stone formation is given in Fig. 2.

## MINERAL CHARACTERISATION

Mineral sands contain ilmenite, rutile, leucoxene, sillimanite, garnet, kyanite, monazite, zircon and other co-minerals. The average total heavy mineral (THM) and slime (below 63 microns) contents within the Sattankulam deposit are 10.27 % and 15.30 % respectively; the heavy minerals being concentrated in the -0.25 to +0.075 mm size fraction. (3)

The typical heavy mineral assemblage in the THM is given below:

| Minerals | % of HM |
|---|---|
| Ilmenite | 63.7 |
| Rutile | 4.3 |
| Zircon | 4.3 |
| Sillimanite | 15.4 |
| Leucoxene | 2.1 |
| Monazite | 1.0 |
| Garnet | 1.3 |
| Magnetite | 0.5 |
| Others | 7.4 |

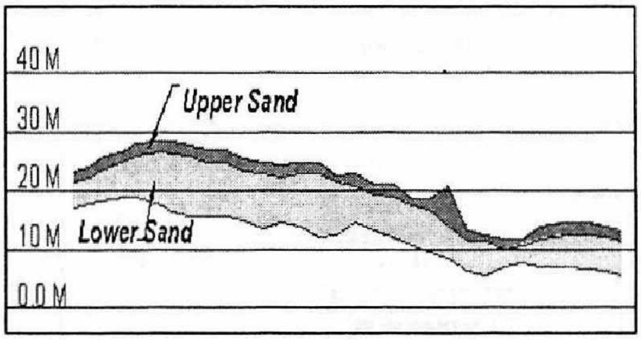


**Fig. 2: Typical Geological Section of the Upper and Lower Sand Columns**

Most of the ilmenite separates efficiently in the 3000 to 6000 gauss fraction, and altered ilmenite in the 7000 to 10000 gauss fraction; the size of ilmenite falls between 75µm and 212 µm, the majority being in the size range of 150 to 106 µm. A preliminary mineralogical study indicated that the ilmenite is present in the following forms:

- Iron-rich ilmenite, where stoichiometrically excess iron in the form of exsolved hematite as well as fine intergrowths with ilmenite mineral is present.
- Ferro-magnetic (ferrian) ilmenite (easily attracted by a hand magnet with about 500 gauss) – probably this ilmenite contains magnetite in ultra fine intergrowths.
- Stoichiometric ilmenite with a Ti: Fe ratio of around 1:1.16.
- Titania-rich ilmenite with no exsolved hematite phase.

It was also found that:

- The MnO content of the ilmenite is low compared with ilmenites found elsewhere.
- $Cr_2O_3$ occurs in altered ilmenite but only in traces (7,000-10,000 gauss).
- $V_2O_5$ is evenly distributed in all the sizes and in all the magnetic fractions.

- The $Al_2O_3$ and $SiO_2$ contents indicated the presence of either sillimanite or garnet in minor amounts as a locked mineral or as separate particles in juxtaposition with ilmenite.
- Rutile and zircon are relatively fine – over 75% of rutile and over 65% of zircon are below 150 micron in size.

## PRIMARY CONCENTRATION PLANT (PCP) – WET CIRCUIT

The development of the flow sheet for the PCP was undertaken on the basis of achieving the best product quality coupled with maximum possible recovery and the envisaged production levels of ilmenite, rutile and zircon. Various processes of wet gravity concentration circuits were evaluated for fulfilling these requirements. Traditionally, an all-spiral-circuit (Fig. 3) or a spiral-plus-table combination is employed in primary concentration plants (wet circuit) to produce heavy mineral concentrates (HMC).

Such equipment operate effectively as long as the ore body does not contain fine sillimanite, kyanite, corundum, garnet, etc. Since the Sattankulam deposit contains about 16% sillimanite in fine form in the total heavy minerals, it is essential to devise an effective method of removal of sillimanite at the first opportunity; otherwise, it would make the mineral separation circuit quite complex. Therefore, the use of hindered settling classifiers such as a Floatex separator was considered in the test work conducted for the development of the flow sheet.[4]

The test work was designed to compare the recovery and grade of valuable heavy minerals (VHM) in an all-spiral-circuit with a spirals-plus-Floatex circuit in which the spirals are used as the rougher and scavenger and the Floatex density separator is used for cleaning as shown in Fig.4.

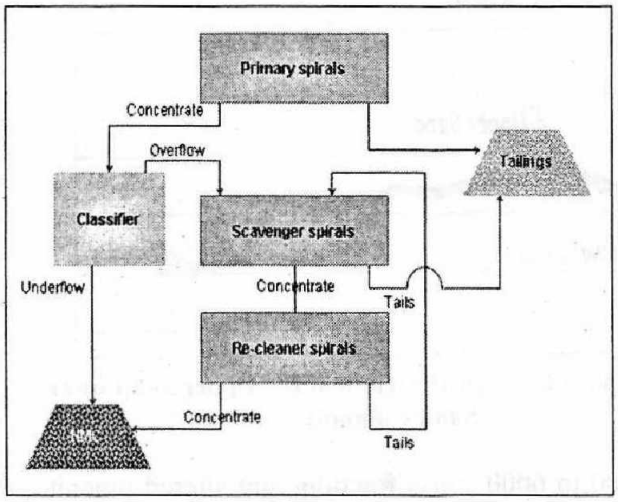


**Fig. 3: Normal All Spiral Flow Sheet used for Primary Concentration**

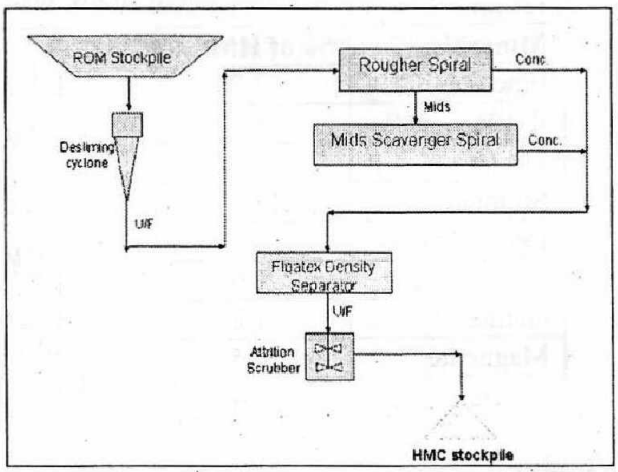


**Fig. 4: Primary Concentration Plant Flow Sheet using Spirals-Plus-Floatex Separator**

The results obtained in the study using both sets of equipment are summarised in Table 1.

The data in Table 1 shows that:

- The Floatex separator recovered higher amounts of magnetic $TiO_2$ and $ZrO_2$ – the underflow contained as much as 99% of the Ti and Zr minerals. This underflow contained equal or higher percentages of $TiO_2$ or $ZrO_2$ compared with the spiral concentrate.
- The Floatex separator underflow product contained only a small percentage of non-valuable heavy minerals – ilmenite, zircon, rutile and leucoxene accounted for 96.6% of the HMC; only 1.4 % of the underflow was non-valuable heavy minerals.
- The Floatex separator overflow analysed 87.9% quartz and 12.1% of heavy minerals. The latter contained 2.8% ilmenite and 8.7% sillimanite (corresponding to 71.5 % of the total sillimanite).

**Table 1: VHM Results Using an All-Spiral-Circuit Vis-À-Vis Spiral-Plus-Floatex Combination**

| Products | Wt% | Mag $TiO_2$ (Ilmenite), % | Non-mag $TiO_2$ (Rutile), % | %, $ZrO_2$ | Distribution of mag $TiO_2$, % | Non-mag $TiO_2$ dist., % | $ZrO_2$ dist., % |
|---|---|---|---|---|---|---|---|
| **Spirals** | | | | | | | |
| Conc T1 | 73.6 | 50.31 | 40.43 | 25.01 | 87.8 | 80.6 | 91.1 |
| Mid T1 | 7.5 | 42.87 | 26.21 | 6.63 | 6.8 | 9.6 | 4.5 |
| Tails T1 | 19.0 | 17.65 | 5.67 | 1.41 | 5.4 | 9.8 | 4.4 |
| Conc T2 | 78.9 | 50.17 | 41.28 | 24.23 | 92.8 | 87.1 | 93.8 |
| Mid T2 | 5.4 | 36.41 | 17.86 | 2.91 | 3.7 | 6.6 | 2.0 |
| Tails T2 | 15.7 | 14.68 | 4.14 | 1.54 | 3.6 | 6.3 | 4.2 |
| Conc T3 | 83.1 | 49.86 | 40.37 | 22.97 | 96.2 | 92.5 | 97.9 |
| Mid T3 | 5.2 | 33.13 | 12.73 | 1.10 | 2.8 | 5.7 | 0.9 |
| Tails T3 | 11.8 | 7.90 | 1.14 | 0.38 | 1.0 | 1.8 | 1.2 |
| **Floatex** | | | | | | | |
| U/F | 83.6 | 50.29 | 42.36 | 26.94 | 98.9 | 98.9 | 99.3 |
| O/F | 16.4 | 3.76 | 0.79 | 0.35 | 1.1 | 1.0 | 0.7 |

A comparison of the recovery of VHM in the case of the all-spiral-circuit and the spirals-plus- Floatex combination is presented in Table 2.

Based on the test work and computer simulations, it was evident that:

- When the Floatex density separator is used in the final "cleaning" stage of concentration, it is more effective than spirals.
- The Floatex separator generates HMC that is higher in both grade and recovery percentages.
- It also allows for single point control and can be readily adjusted unlike the adjustment of numerous spiral splitters.

Keeping the superior performance of the spirals-plus-Floatex separator combination in view, the same has been chosen for inclusion in the wet circuit. A distinct advantage of this combination is that sillimanite will be concentrated into the Floatex overflow stream, thereby reducing the load on the main dry plant.

## ATTRITIONING AND SCRUBBING OF HEAVY IRON OXIDE COATINGS

One of the unique features of the Sattankulam deposit is that all the minerals have a coating of iron oxide on them as shown in Fig. 5. The coating is either thick or thin – silicate minerals, especially quartz form the predominant thick coatings over minerals like ilmenite, while the quartz coating on

**Table 2: Comparison of Recovery of VHM in the Two Options**

| Parameter | Spirals-plus-Floatex | All spirals |
|---|---|---|
| VHM grade, % | 94 | 91 |
| Recovery, % | | |
| Ilmenite | 94 | 90 |
| Rutile | 89 | 87 |
| Zircon | 94 | 94 |

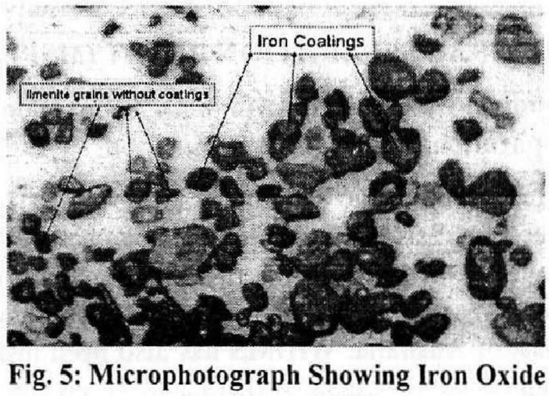


**Fig. 5: Microphotograph Showing Iron Oxide Coating on HMC**

the lighter particles is relatively thin. Such particles can be rejected by gravity separation without requiring any treatment to remove the coating (leaving only the heavy mineral fractions to be treated).

To remove the heavy coating, HMC first has to be attritioned at high density using process water, which removes most of the surface coating thereby rendering the HMC sufficiently clean to produce high quality products in the dry mill. On the other hand, rutile and zircon production requires an additional surface cleaning step using water, NaOH and $H_2SO_4$ as the scrubbing agents. Laboratory and pilot scale test work conducted on attrition and scrubbing revealed the following:

- There was little improvement when the scrubbing time was increased from 6 to 9 minutes.
- Attrition scrubbing with water effectively liberated the individual minerals from the agglomerated particles; it also removed some of the surface coating.
- Scrubbing with NaOH (0.5 kg/tonne) and $H_2SO_4$ (10 kg/tonne) followed by
- magnetic separation and electrostatic separation of the non-magnetic fraction revealed that the scrubbing agent used to attrition the HMC affects the efficiency of the subsequent electrostatic separation as shown in Fig. 6.

The cumulative **$TiO_2$** distribution for both acid ($H_2SO_4$) and caustic (NaOH) treatments was almost identical for the conductor as well as the non-conductor products. Fig. 6 also shows that there was less zircon in compartments 1-7 for the acid scrub and therefore, more zircon in the non-conductor product.

- For the recovery of TiO2, there was little difference between the two agents (see Table 3) – the slightly higher TiO2 in the case of NaOH was within permissible sampling/ analytical errors.

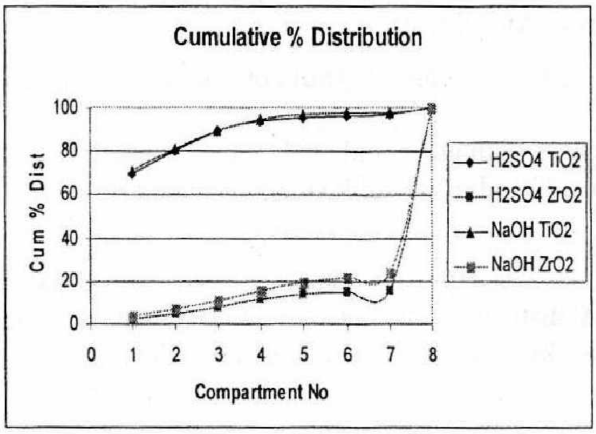


**Fig. 6: Cumulative Distribution of $Tio_2$ and $Zro_2$ in Electrostatic Separation**

**Table 3: Test Data on Attrition and Scrubbing**

| Scrubbing | Conductor | | Non conductor | |
|---|---|---|---|---|
| | Wt% | $TiO_2$ dist | Wt% | $ZrO_2$ dist |
| NaOH | 46.6 | 71.0 | 32.5 | 76.5 |
| $H_2SO_4$ | 45.4 | 69.6 | 35.6 | 84.9 |

- For zircon, however, acid scrubbing gave better recovery results – 84.9% compared with 76.5% for NaOH; the grade of non-conductors was the same at 24.9% $ZrO_2$, in both cases.

## MINERAL SEPARATION PLANT (MSP)

### Ilmenite Circuit – Dry Magnetic Separation Vis-À-Vis Wet High Intensity Magnetic Separation/Electrostatic Separation

While electrostatic separation is the first step in treating HMC after drying in India, normal flow sheets in Eastern Australia employ wet high intensity magnetic separators (WHIMS) to produce magnetic (ilmenite-rich) and non-magnetic concentrates. During the 1970s, Readings developed electromagnetic versions of WHIMS that have been used in many operating mines along the East coast of Australia. WHIMS has also been installed in the South African Sands Project and there is a high probability that WHIMS will be employed in the Corridor project (when it comes up). On the other hand, many plants in Western Australia and in the US do not use WHIMS – the HMC is dried and processed using rare earth drum (RED) magnets. Though a few operations continue to use dry electromagnets, in the past ten years the use of dry electromagnets has been largely superseded by vastly improved rare earth magnetic separators.

WHIMS is used when there is a preferential market for non-magnetic products such as rutile and zircon over ilmenite. The various advantages of WHIMS are as follows:[5]

- Unusable material can be discarded using WHIMS before any drying – this is of great advantage, particularly with increasing fuel prices.
- WHIMS is generally suitable for extracting primary ilmenite from HMC. Once ilmenite begins to weather and loses its high magnetic susceptibility, WHIMS becomes less efficient in holding the ilmenite in the magnetics stream.
- In many MSP flow sheets, the zircon wet gravity circuit immediately follows the ilmenite removal step. In such cases, the use of WHIMS obviates the necessity to dry the non-magnetics fraction twice.

The advantages of using a dry magnetic circuit include:

- Such a circuit can be installed at a lower capital cost than a WHIMS circuit.
- More controlled partitioning is possible because the separation medium is air, rather than water and it is easier to move the separating particles apart in air.
- In the laboratory under ideal conditions, separation of primary ilmenite from non-magnetics often exhibits similar performance for both types of magnets. Industry experience, however, has shown that the performance of REDs is easier to control and maintain than that of WHIMS, the performance of the latter depending on the level of operator attention, water quality and maintenance.
- Dry magnetic separation circuits are simpler to operate and the maintenance cost is lower. WHIMS, on the other hand, has many more wear parts and requires more complicated feed pumping and distribution equipment.

Based on the above comparison, it has been decided that Tata Steel's project in Tamil Nadu would use REDs. 100% drying of HMC followed by the use of REDs would provide the optimum solution for the Sattankulam ilmenites.

## ZIRCON CIRCUIT – HOT ACID LEACHING

The sand particles in the Sattankulam deposit have a heavy coating of iron oxide and the production of premium ($Fe_2O_3 < 0.1\%$) grade zircon would call for hot acid leaching, which has been found to be the most effective for removing the coating.

The non conducting fraction from the rutile circuit, which contains the crude zircon concentrate, will be subjected to hot acid leaching followed by de-sliming at -63 microns (Fig. 7). The zircon concentrate will be dried at 120°C before being further processed in an electrostatic separator unit to remove the remaining $TiO_2$ minerals, and a magnetic separator to remove the magnetic aluminum silicates and monazite.

As shown in Table 4, hot acid leaching can help reduce $Fe_2O_3$ from 0.15 to 0.07%, thereby rendering it a premium grade product.

## CONCLUSION

In the heavy minerals industry it is vital to produce high quality saleable products to meet the ever stringent demands of customers. Tata Steel's proposed titania venture in Tamil Nadu envisages mining of raw sand in the Sattankulam deposit, for an initial annual production of 500,000 tonnes of ilmenite, 34,000 tonnes of rutile and 22,000 tonnes of zircon. This would be followed in stages by the production of 130,000 tonnes of synthetic rutile (if found feasible) and ultimately, 60,000 tonnes of $TiO_2$ pigment.

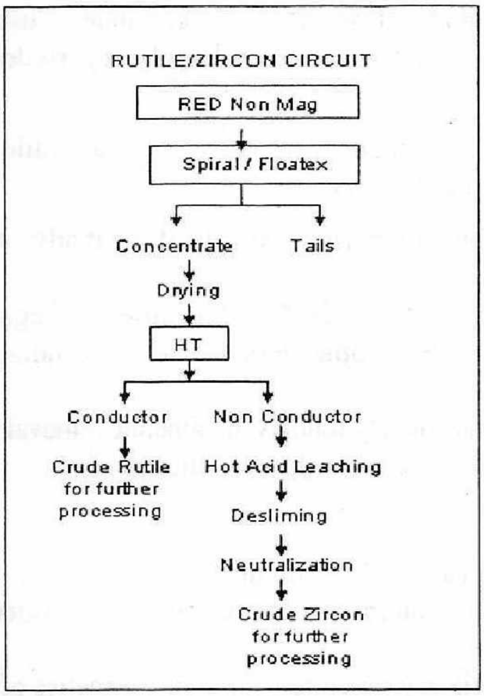


**Fig. 7: Hot Acid Leaching in the Wet Zircon Circuit**

**Table 4: Effect of Hot Acid Leaching on $Fe_2O_3$ Content of Concentrate**

| Oxide | Before leaching | After leaching |
|---|---|---|
| $ZrO_2$ | 64.4 | 66.6 |
| $TiO_2$ | 0.75 | 0.08 |
| $Al_2O_3$ | 2.21 | 0.29 |
| $Fe_2O_3$ | 0.15 | 0.07 |

Detailed geological, mineralogical and process option studies have been carried out to arrive at the optimum flow sheet for the raw material feed. It has been found that the difficult to treat type of deposits in the Teri deposits of Sattankulam are characterised by a wide size range of minerals, higher proportion of slimes and the presence of near gravity products like kyanite and corundum, all of which necessitate an altogether different approach if optimum exploitation has to be carried out. Dry mining using a combination of front end loaders and conveyors/trucks has been chosen as the mining method. A combination of spirals and Floatex separators has shown better recovery compared with an all spirals circuit in pilot plant trials along with the advantage of sillimanite separation at a very early stage. A combination of dry magnetic and high tension electrostatic separators is envisaged for ilmenite production. While very clean rutile can be produced in a traditional rutile circuit employing high tension separators, the crude zircon concentrate would require hot acid leaching (because of heavy iron oxide coatings) to produce zircon of premium grade for ceramic applications.

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## REFERENCES

[1] Rita A.M.Gardner, Dept. of geography, Kings College, London – Quaternary Coastal Sediments & Stratigraphy, Southeast India, ISPQS-Man & Environment Vol.X (10), 1986, pp 51-72.

[2] Pincock Allen & Holt, USA, Report -Tata Integrated Titania Project Part A – Preliminary Feasibility Study, Tirunelveli, Tamil Nadu, India, December'04 and Septermber'05 interim reports.

[3] S Mohan Rao, R. Sripriya, K. Chandrakala, P. Panigrahi and Ch.V.G.K. Murty, Internal Report - Characterisation and Beneficiation Studies of Mineral Sands from Tamil Nadu, March (2005).

[4] Ch.V.G.K.Murty, Dr. S.Asokan, D.Rathod, Development of Sattankulam Heavy Mineral Sands, Tamilnadu, India by Tata Steel, Heavy Minerals 2005, Society for Mining, Metallurgy & Exploration, 2005, pp 73-82.

[5] Steve Gilman, (2005), Dry Magnetic Separation Vis-à-vis Wet High Intensity Magnetic Separation, Internal Communication, July 2005.