CHAPTER – VI

TITANIUM: VALUE ADDITION TECHNOLOGIES AND COST ESTIMATES

6.1 General

Titanium is the value added product processed out of ‘ilmenite’ which commands a good foreign market. Export market gives generally more profit margin which is a boon to a developing country like India. Titanium is a strong, lightweight metal often used in electrode, ferro-alloy, iron and steel, paint and airplanes. When titanium combines with oxygen, it forms titanium dioxide (TiO₂), a brilliant white pigment used in paint, paper, and plastics. Major deposits of titanium minerals are found in Australia, Canada, India, Norway, South Africa, Ukraine, and the United States. However, it is not typical of the black sand often used to produce titanium metal or TiO₂ pigment (www.mii.org).

In 1791, Reverend William Gregor, an English clergyman and mineralogist, reported that he had discovered magnetic black sand near the beaches of Cornwall, England. The mineral was named menachanite after the local parish of Menaccan. A few years after Gregor’s discovery, Klaproth, a German chemist, separated TiO₂ from the mineral rutile. Klaproth named the new element titanium after the giants of Greek mythology. In 1825, Berzelius, a Swedish chemist, performed a crude separation of titanium metal. However, it was not until 1910 that Hunter, an

Titanium is a hard, silvery-gray metallic element. Its atomic number is 22 and its symbol is Ti. It is the 9\textsuperscript{th} most common element in the Earth’s crust. It is also found in meteorites, the moon, and the sun.

Titanium metal has a number of useful physical properties. It is very much resistant to corrosion. It is hard and has a high melting temperature and is lightweight. Its strength is similar to steel, but is 45 per cent lighter. Titanium alloys can be twice as strong as aluminum alloys.

Titanium has no known nutritional benefit for animals. It does, however, have some slight benefits for plant health. Titanium has been found to be very compatible with the human body and is often used in surgical instruments and medical implants. Titanium is the only element that burns in a pure nitrogen atmosphere.

Titanium was named by M.H. Klaproth after Titans. The Titans were the giant sons of Uranus and Gaea. They set out to rule heaven, but were defeated by Zeus. Although the name seems quite appropriate, it was not meant to impart any particular meaning.

Titanium is found in many minerals. Ilmenite (FeTiO₃) and rutile (TiO₂) are the most important sources of titanium. Ilmenite provides about 90 per cent of the titanium used every year. It is estimated that the resources of ilmenite in the world
contain one billion tonnes of titanium dioxide. The estimated resource of rutile in
the world is about 230 million tonnes of titanium dioxide.

Rutile and ilmenite are extracted from sands that may contain only a few
percent by weight of these minerals. After the valuable minerals are separated, the
remaining sands are returned to the deposit and the land recultivated.

Even though the United States mines and process titanium and titanium
dioxide, they still import significant amount of both. Metallic titanium is imported
from Russia (36%), Japan (36%), Kazakhstan (25%), and other nations (3%). TiO₂
pigment for paint is imported from Canada (33%), Germany (12%), France (8%),
Spain (6%), and other nations (36%).

Most titanium is used in its oxide form. TiO₂ is a white pigment used in
paint, varnishes and lacquers (49%), plastics (25%), paper (16%), and other
products such as fabrics, printing inks, roofing granules, and special coated
fabrics.

Titanium is lighter than steel but still is very strong. It also has a very high
melting temperature. These physical properties make titanium and titanium alloys
(an alloy is a mixture of metals) very useful in the aerospace industry where they
are mostly used to make engines and structural components for airplanes,
satellites, and spacecraft. An estimated 60 per cent of metallic titanium is used in
the aerospace industry. The remaining 40 per cent is used in a number of other
areas that require titanium’s unique properties.
For example, one physical property of titanium is that it is very much resistant to corrosion. Since it is very much resistant to corrosion by sea water, it is used to make propeller shafts and other ship parts that will be exposed to ocean water. For medical uses, titanium is considered to be bio-compatible and often is used to make joint replacement parts such as hip joints. Because of its strength, it is also used to make armour plated vehicles for the military. Titanium is also used to produce silvery-white sparks in some fireworks.

There are few good substitutes for titanium for its aerospace uses. Substituting other metals for titanium usually results in alloys that are not as lightweight or as strong as titanium alloys. For applications that require corrosion resistance, titanium alloys compete with nickel, stainless steel, and zirconium alloys.

As a white pigment, TiO$_2$’s brightness and opacity are nearly unsurpassed. However, a number of less expensive compounds can be used to substitute or reduce the amount of titanium dioxide needed. These alternative materials include calcium carbonate, the mineral talc, and the clay kaolin.

### 6.2 Titanium Mineral Resources

The total estimated world reserves of titanium bearing placers viz. ilmenite, rutile and leucoxene are placed at 2,030 million tonnes. According to Gambogi (2000), the total world ilmenite reserves have one billion tonnes of TiO$_2$ and the rutile reserves have 230 million tonnes of TiO$_2$. India has 291.0117 million tonnes
of estimated reserves of titanium bearing minerals, which is about 14.34 per cent of the estimated total world resources. India has an additional titanium mineral reserve of 6.281 million tonnes in the form of leucoxene. Table 6.1 gives the state-wise titanium mineral resources of India. Besides India, Norway has 244 million tonnes; China, 216 million tonnes; USSR, 211 million tonnes; Canada, 200 million tonnes; Australia, 180 million tonnes; South Africa, 162 million tonnes; USA, 82.2 million tonnes and Sri Lanka 14.8 million tonnes of ilmenite reserves.

**Table: 6.1 - State wise Reserves of Ilmenite, Rutile and Leucoxene**

<table>
<thead>
<tr>
<th>State</th>
<th>Ilmenite Reserves</th>
<th>Rutile Reserves</th>
<th>Leucoxene Reserves</th>
<th>Total Titanium Mineral Reserves</th>
<th>Percentage in Total Reserves</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>277,5200</td>
<td>13,4917</td>
<td>6,2810</td>
<td>297,2927</td>
<td>100.00</td>
</tr>
<tr>
<td>Andhra Pradesh</td>
<td>72,3400</td>
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<td>0,8532</td>
<td>75,5492</td>
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<tr>
<td>Bihar</td>
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<td>0,0110</td>
<td>--</td>
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<td>00.25</td>
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</tr>
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<td>--</td>
<td>0,0828</td>
<td>01,7528</td>
<td>00.59</td>
</tr>
<tr>
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<td>1,6234</td>
<td>0,0419</td>
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<tr>
<td>Tamil Nadu</td>
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<td>4,2339</td>
<td>95,5932</td>
<td>32.15</td>
</tr>
<tr>
<td>W.Bengal</td>
<td>02,0800</td>
<td>0,1920</td>
<td>--</td>
<td>02,2720</td>
<td>0.77</td>
</tr>
</tbody>
</table>

Industrial Applications of Titanium Minerals

Nagar (1995) and Bagde (2001) have explained the uses of titanium mineral. Ilmenite (FeO TiO\(_2\)), a major feedstock of the titanium mineral industry, contains 50 to 60 percent TiO\(_2\) while rutile (TiO\(_2\)) a di-oxide of titanium mineral, contains 92 to 96 percent TiO\(_2\). Leucoxene is the most pure and least naturally available titanium mineral. About 90 per cent of these minerals are absorbed in the production of high quality white pigments. According to Nina Keegan (2000) and Bagde (2001), the most important constituent of paint is titanium di-oxide, an opaque substance which gives paint a high gloss and a high degree of brightness and brilliant whiteness to the product. Before the arrival of TiO\(_2\) pigments in paint industry, the environmentally dangerous metal lead was used to give the above characters to paints. TiO\(_2\) also gives paper a high quality finish. It enhances the whiteness and imparts opacity, colour base and UV resistance to plastics. The excellent covering power, refractive index, and high durability properties make titanium dioxide pigments superior to all other known white pigments. The remaining 10 per cent are used in the nuclear powered submarines, sports and medicines and in the production of textiles and ceramics. Titanium alloys are immensely used in space industry because of their high strength, light weight and corrosion resistance. Titanium minerals are also used in chemical and desalination plants, in the production of heat exchange tubings in power stations, surgical implants, cardiac makers, and in bullet proof vests. Their non-toxic, non-fibrogenic, and biological inertness make them very useful in the pharmaceutical
and foodstuff industries. Rutile is mainly used in the production of welding electrodes.

The USA, Australia, China and India are the major garnet reserve holding countries. The world has an estimated reserve of 234.89 million tonnes of garnet. Mining started in recent years in Russia and Turkey. Additional resources are also located in Canada, Chile, Czech Republic, Pakistan, South Africa, Spain, Thailand and Ukraine (Olson, 1999; Balazik, 1997). In Western Australia, the recent exploration proved the presence of rich garnet deposits at Broken Hill, Gumbe and Mt Tennyson.

**Uses of Titanium Minerals**

Global demand for titanium and its compounds resulted in a high level of mineral exploration and development activities. Nearly 90 per cent of the titanium mineral is used for production of titanium dioxide, a white pigment and the remaining is used to produce titanium metal, titanium based chemicals, welding rod coatings, fluxes and other miscellaneous products. Titanium and its compounds are used in desalination plants, electrical compounds, glass products, artificial gemstones, jewelry and even smoke screens. Titanium alloys are used in high tech airplanes, missiles, space vehicles and surgical implants.

Ilmenite and rutile are the important minerals for titanium products. Ilmenite is an economically important material containing 45-70 per cent titanium dioxide and forms as a primary mineral in mafic igneous rocks and is concentrated
into layers by a process called ‘magnetic segregation’. Ilmenite is mined in Australia, Brazil, Russia, Canada, China, Sri Lanka, Norway, Chine, South Africa, Thailand, India, Malaysia and United States. Canada, China, Norway and Australia contribute more than 40 percent of world resources of ilmenite. India has ilmenite resources totaling 300 million tonnes, which is 20 per cent of the world’s known ilmenite. Rutile is the more common mineral with 92 to 96 percent titanium dioxide, but is less useful as an ore for titanium compounds. The world wide production of ilmenite, natural rutile in 2000 was 4.1 million metric tonnes and 4.5 million metric tonnes respectively (Rajna et al, 2004).

Titanium dioxide is produced either in the anatase or rutile crystal form. Most titanium dioxide in the anatase form is produced as a white powder, whereas various rutile grades are often off-white and can even exhibit a slight colour, depending on the physical form, which affects light reflectance. Titanium dioxide may be coated with small amounts of alumina and silica to improve technological properties. Commercial titanium dioxide pigment is produced by either the sulfate process or the chloride process. The principal raw materials for manufacturing titanium dioxide include ilmenite (FeO/TiO₂), naturally occurring rutile, or titanium slag. Both anatase and rutile forms of titanium dioxide can be produced by the sulphate process, whereas the chloride process yields the rutile form.

Titanium dioxide with a high level of purity can be prepared. Specifications for food use currently contain a minimum purity of 99 per cent. Titanium dioxide is the most widely used white pigment in products such as paints, coatings,
plastics, paper, inks, fibres, and food and cosmetics because of its brightness and high refractive index (>2.4), which determines the degree of opacity that a material confers to the host matrix. When combined with other colours, soft pastel shades can be achieved. The high refractive index, surpassed by few other materials, allows titanium dioxide to be used at relatively low levels to achieve its technical effect. The food applications of titanium dioxide are broad. US regulations authorize its use as a colour additive in foods in general at levels not to exceed one per cent.

The European Union also permits its use in foods, in general, with some specified exceptions, at *quantum satis* levels. India restricts its uses to chewing gum and bubble gum at not more than one per cent and to powdered concentrate mixes for fruit beverage drinks not to exceed 100 mg/kg. Japan lists its use as a food colour without limitation, other than specifying certain foods in which it is not permitted. Finally, titanium dioxide is listed in Table 3 of the Codex General Standard for Food Additives, which lists additives that may be used in food, in general, unless otherwise specified, in accordance with GMP (Paul M. Kuznesof, 2006).

**Description**

Natural titanium dioxide exists in nature in one of three crystalline forms, the two most important of which are anatase (CAS no. 1317-70-0) and rutile (CAS no. 1317-80-2), the third being brookite (12188-41-9). Although these minerals
are essentially pure titanium dioxide, they do not appear white, because of the
presence of impurities, such as iron, chromium, or vanadium, which darken them.
Rutile is the thermodynamically stable form of titanium dioxide; anatase rapidly
transforms to rutile above 700°. Rutile melts between 1830° and 1850°
(Kuznesof, 2006).

Commercial titanium dioxide is generally marketed as a white to slightly
coloured amorphous powder. A platelet form is also manufactured. Most titanium
dioxide in the anatase form is produced as a white powder, whereas various rutile
grades are often off-white and can even exhibit a slight colour, depending on the
physical form affecting light reflectance. Titanium dioxide may be coated with
small amounts of alumina and silica to improve technological properties. Such
coatings can prevent possible reactions between the highly reactive surfaces of the
extremely fine titanium dioxide crystals and the matrix in which the pigment is
dispersed and they can improve the dispersion of the titanium dioxide in the host
matrix.

Titanium dioxide is insoluble in water, hydrochloric acid, dilute sulfuric
acid, and organic solvents. It dissolves slowly in hydrofluoric acid and hot
concentrated sulfuric acid. It is almost insoluble in aqueous alkaline media
(Kuznesof, 2006).

This chapter deals with the various types of mining and processing
technologies adopted in Tamil Nadu and cost estimation of the mining and
processing methods suited to the minerals of the Tamil Nadu.
6.3 The Manufacturing Process of Titanium

Titanium is produced using the Kroll process. The steps involved include extraction, purification, sponge production, alloy creation, and forming and shaping. In the United States, many manufacturers specialize in different phases of this production. For example, there are manufacturers that just make the sponge, others that only melt and create the alloy, and still others that produce the final products. Currently, no single manufacturer completes all of these steps.

**Extraction**

At the start of production, the manufacturer receives titanium concentrates from mines. While rutile can be used in its natural form, ilmenite is processed to remove the iron so that it contains at least 85 per cent titanium dioxide. These materials are put in a fluidized-bed reactor along with chlorine gas and carbon. The material is heated to 1,652°F (900°C) and the subsequent chemical reaction results in the creation of impure titanium tetrachloride (TiCl4) and carbon monoxide. Impurities are a result of the fact that pure titanium dioxide is not used at the start. Therefore the various unwanted metal chlorides that are produced must be removed.

**Purification**

The reacted metal is put into large distillation tanks and heated. During this step, the impurities are separated using fractional distillation and precipitation.
This action removes metal chlorides including those of iron, vanadium, zirconium, silicon, and magnesium.

**Production of the Sponge**

Next, the purified titanium tetrachloride is transferred as a liquid to a stainless steel reactor vessel. Magnesium is then added and the container is heated to about 2,012°F (1,100°C). Argon is pumped into the container so that air will be removed and contamination with oxygen or nitrogen is prevented. The magnesium reacts with the chlorine, producing liquid magnesium chloride. This leaves pure titanium solid since the melting point of titanium is higher than that of the reactor.

The titanium solid is removed from the reactor by boring and then treated with water and hydrochloric acid to remove excess magnesium and magnesium chloride. The resulting solid is a porous metal called a sponge.

**Alloy Creation**

The pure titanium sponge can then be converted into a usable alloy via a consumable-electrode arc furnace. At this point, the sponge is mixed with the various alloy additions and scrap metal. The exact proportion of sponge to alloy material is formulated in a lab prior to production. This mass is then pressed into compacts and welded together, forming a sponge electrode.

The sponge electrode is then placed in a vacuum arc furnace for melting. In this water-cooled, copper container, an electric arc is used to melt the sponge electrode to form an ingot. All of the air in the container is either removed
(forming a vacuum) or the atmosphere is filled with argon to prevent contamination. Typically, the ingot is remelted one or two more times to produce a commercially acceptable ingot. In the United States, most ingots produced by this method weigh about 9,000 lb (4,082 kg) and are 30 inches (76.2 cm) in diameter.

After an ingot is made, it is removed from the furnace and inspected for defects. The surface can be conditioned as required for the customer. The ingot can then be shipped to a finished goods manufacturer where it can be milled and fabricated into various products.

**Byproducts / Waste**

During the production of pure titanium a significant amount of magnesium chloride is produced. This material is recycled in a recycling cell immediately after it is produced. The recycling cell first separates out the magnesium metal then the chlorine gas is collected. Both of these components are reused in the production of titanium.

Future advances in titanium manufacture are likely to be found in the area of improved ingot production, the development of new alloys, the reduction in production costs, and the application to new industries. Currently, there is a need for larger ingots than can be produced by the available furnaces. Research is ongoing to develop larger furnaces that can meet these needs. Work is also being done on finding the optimal composition of various titanium alloys. Ultimately, researchers hope that specialized materials with controlled microstructures will be
readily produced. Finally, researchers have been investigating different methods for titanium purification. Recently, scientists at Cambridge University announced a method for producing pure titanium directly from titanium dioxide. This could substantially reduce production costs and increase availability.

**Production and Manufacturing Process of Commercial Titanium Dioxide (TiO₂)**

Commercial titanium dioxide pigment is produced by either the sulphate process or the chloride process. Because of significant environmental and cost issues associated with the sulphate process, most new manufacturing capacity is based on the chloride process. Older manufacturing plants that used the sulphate process have had to modify their processes to accommodate stricter environmental requirements by recycling waste acids and roasting metal sulphates to recover sulphur trioxide.

The principal raw materials for manufacturing titanium dioxide include ilmenite (FeO/TiO₂), naturally occurring rutile, and titanium slag. The last is produced by removing the iron from ilmenite by reduction with coke at 1200-1600o. At these temperatures, the iron oxide is reduced to the metal, which melts and separates from the formed titanium-containing slag, which is 70-75 per cent titanium dioxide (Kuznesof, 2006).
**Sulphate Process**

In the sulphate route, there are three main stages. The ore, usually the ilmenite, is dissolved in sulphuric acid to form a mixture of sulphates. Any iron is removed from the solution so the colour of the final product is not spoiled. The titanyl sulphate is then hydrolysed in solution to give insoluble, hydrated titanium dioxide.

The final stage involves heating the solid in a calciner to evaporate the water and decompose the sulphuric acid in the solid. It also turns the solid into seed crystals which can be milled to the size needed. These crystals can be coated with another substance, such as aluminium oxide, to make the titanium dioxide mix more easily with liquids or extend the life of the paint manufactured from them.

Both anatase and rutile grades of titanium dioxide can be produced by the sulphate process, depending on particular processing conditions. Briefly, ilmenite or ilmenite and titanium slag is digested with sulphuric acid and the product is diluted with water or dilute acid. Most of the titanium dioxide from the ore is solubilized as a titanium oxo-sulphate and iron is present in its +II oxidation state. The resulting liquor is clarified by sedimentation to remove insoluble residues such as silica. Iron is removed by crystallization from its sulphate salt (FeSO4•7H2O), followed by filtration.

To produce the anatase form of the titanium dioxide, a small portion of the clarified liquor is neutralized with alkali to produce anatase microcrystals. These
microcrystals are then introduced into the mother liquor, which is then hydrolysed under carefully controlled conditions to produce crystals of anatase. These are subsequently filtered, washed, calcined, and micronized. During calcination, the final temperature reaches about 800-8500. To produce the rutile form of the titanium dioxide, the clarified liquor is hydrolyzed in the presence of a specially prepared rutile seeding agent obtained by neutralizing a small portion of the mother liquor in the presence of hydrochloric acid or some other monohydric acid. Formed crystals are filtered, washed and calcined at temperatures between 900 and 9300, and micronized (Kuznesof, 2006).

**Chloride Process**

There are two main stages to the chloride process. First, the dry ore is fed into a chlorinator together with coke and chlorine to make titanium chloride. Once the fluid bed has been preheated, the heat of reaction with the chlorine is sufficient to maintain the temperature and recycled liquid titanium chloride may be used to control the temperature.

The next step involves the oxidation of titanium chloride by burning it in oxygen together with another combustible gas (often carbon monoxide). By adding seed crystals, the titanium dioxide is formed as a fine solid in a gas stream and is filtered out of the waste gases. Crystal growth is controlled by adding nucleating agents to the gas stream and the products are cooled by mixing with
chlorine gas. The product is then washed and dried before milling and surface treatment.

The chloride process yields the rutile form of titanium dioxide. At temperatures between 800 and 1200\(^\circ\)C, chlorine is reacted in a fluidized bed reactor with a titanium-containing mineral, e.g., mineral rutile (which is not readily attacked by sulfuric acid), under reducing conditions (presence of coke) to form anhydrous titanium (IV) chloride. Purification of the anhydrous tetrachloride requires separation by fractional condensation. Conversion of the tetrachloride to titanium dioxide may be accomplished by either direct thermal oxidation or reaction with steam in the vapour phase at temperatures in the range of 900-1400\(^\circ\)C. A minor amount of aluminium chloride is generally added to promote formation of the rutile form. The titanium dioxide is washed, calcined, and packaged. Alternatively, the titanium-containing mineral can be reacted with concentrated hydrochloric acid to form solutions of titanium (IV) chloride which are then further purified. Hydrolysis of the tetrachloride will yield the dioxide which is filtered off, washed, calcined, and packaged (Kuznesof, 2006).

The surface treatment of the base pigment is very important and the surface finishing unit can account for, up to one-third the cost of a titanium dioxide plant. The treatment is needed to maximise optical properties, improve durability and reduce yellowing, and improve dispensability.

The main use of titanium dioxide (TiO\(_2\)) is as a white powder pigment because of its brightness and very high refractive index. It provides good opacity
to products such as paints, coatings, plastics, paper, inks, fibres, food and cosmetics. In particular, high performance grades of TiO₂ are finding a growing market in the cosmetics sector. (ICIS Newsletter. 2010).

**Titanium Dioxide / Platelet Form**

A platelet form of titanium dioxide (rutile) can be produced by first coating the surface of mica (i.e., potassium aluminum silicate) platelets, which act as templates, with the titanium dioxide (rutile). The titanium dioxide-coated mica nacreous pigment is then subjected to an extractive dissolution in acid followed by an extractive dissolution in alkali. All of the mica is removed during this process and the resulting product is a platelet form of rutile titanium dioxide. This product cannot be obtained from anatase titanium dioxide as a starting material. The specific properties of the pigment are determined by controlling the thickness of the titanium dioxide layer and the coating process used to coat the mica substrate. The thickness of the rutile titanium dioxide coated on the mica determines the interference colour of the final product. The resulting platelet titanium dioxide contains low levels of impurities comparable to other standard pigment grades of titanium dioxide typically used in the food industry (Paul M. Kuznesof, 2006).

**Titanium Product Chart**

Titanium is obtained from various ores that occur naturally on the earth. The primary ores used for titanium production include ilmenite, leucoxene, and
rutile. Other notable sources include anatase, perovskite, and sphene. Ilmenite and leucoxene are titaniferous ores. Ilmenite (FeTiO₃) contains approximately 53 per cent titanium dioxide. Leucoxene has a similar composition but has about 90 per cent titanium dioxide. They are found associated with hard rock deposits or in beaches and alluvial sands. Rutile is relatively pure titanium dioxide (TiO₂). Anatase is another form of crystalline titanium dioxide and has just recently become a significant commercial source of titanium. They are both found primarily in beach and sand deposits.

Perovskite (CaTiO₃) and sphene (CaTi-SiO₃) are calcium and titanium ores. Neither of these materials are used in the commercial production of titanium because of the difficulty in removing the calcium. In the future, it is likely that perovskite may be used commercially because it contains nearly 60 per cent titanium dioxide and only has calcium as an impurity. Sphene has silicon as a second impurity that makes it even more difficult to isolate the titanium. In addition to the ores, other compounds used in titanium production include chlorine gas, carbon, and magnesium (www.enotes.com). The following chart explains the titanium product.
Rutile Grade Titanium Dioxide

Travancore Titanium Products (TTP) Limited has recently launched a Rutile Grade Titanium dioxide pigment viz., TTP RD-01. This product was developed in the year 2002 indigenously through the Sulphate route pigment. TTP markets this product without surface treatment at very competitive price.
ANATASE (Special Grade)

This low phosphorous anatase grade is used in the manufacture of special quality welding rods, due to its insulating properties and high melting point.

**Composition:**  
- TiO$_2$ 98 - 98.5%  
- P$_2$O$_5$ 0.1% (max.)  
- S 0.10 (max.)

ANATASE (GP)

General purpose pigment is recommended for use in non-decorative paints, cement paints, distempers and rubber products.

**Composition:** TiO$_2$ ------ 97.5% (min.)

ANATASE (GR)

This is non-milled granular type of commercial titanium dioxide, having excellent dry mixing and free-flowing properties, for use in vitreous enamel and metallurgical industries.

**Composition:** TiO$_2$ ------ 97.5% (aprox.)

ANATASE (ISI)

This is a pigmentary form of TiO2 having the following desirable properties:- high brightness, tinting strength, good colour, excellent dispersion characteristics in both aqueous and non-aqueous media, suitable for use in paints,
paper, plastics, linoleum, rubber, leather finishes, soap and cosmetics and other applications.

**Composition:** TiO₂ 97.5% (min.) Fe. 84 - 140 ppm.

**Specifications:** IS 411:1991

**Potassium Titanate**

Potassium titanate possesses low thermal conductivity and high reflectance ranging from ultra-violet to infra-red region. Used in the manufacture of special quality welding rods, due to its high insulating property and high melting point.

**Composition:**

TiO₂ 72 - 75%

K₂O₂ 17 - 20%

**Sodium Titanate**

Sodium titanate finds use in fluxes for different types of welding electrodes.

**Composition:**

TiO₂ 75 - 80%

Na₂O 15 - 18%

**Antase (RG)**

Rayon grade anatase pigment with excellent dispersion properties for specific use in rayons is extremely fine and free from over-size particles. It is used in de-lustrin artificial fibre in textile industry.

**Composition:**

TiO₂ 97.5% (min.)

Fe. 100 ppm

Residue 0.05 (max.)
**Titanium Dioxide (ANATASE)**

Titanium dioxide is a brilliantly white, non-toxic pigment. The unique properties of titanium dioxide, which make it supreme among the white pigments, are its excellent opacity, extreme whiteness and chemical stability, which lead to considerable economy in usage, when compared to other white pigments. The titanium dioxide of our manufacture is marketed under the trade name of 'ANJATOX' and is available in four grades- ISI, RG, GP and GR.

**Titanium Minerals and Pigments**

World resources of titanium bearing minerals are reasonably vast and mainly contributed from ilmenite and rutile. The available information reveals that the total resources of ilmenite and rutile so far estimated, in terms of available titanium is 1232 mt and 130 mt respectively. The major global producers of these minerals are Australia, Malaysia, USA, India, Sierra Leone, Brazil and Sri Lanka. Some other countries notably Madagascar, Mozambique, Senegal are likely to emerge as future producers. The production details of China and Russia are not available.

Australia has earned prime position as a producer of beach sand minerals despite its limited resources. The deposits are mainly concentrated in east and west coasts. Some deposits are identified in south coast. The east coast deposit is primarily rich in rutile and zircon. The west coast deposit is the main source of sulphate grade ilmenite for pigment manufacturing which is free from chromium
impurities. The deposits at Victoria contain 12.5 metric tonnes of ilmenite, 4.6 metric tonnes of leucoxene and 3.4 metric tonnes of rutile along with small fraction of anatase. The extensive heavy mineral sand deposit near Cata-bay, 140km north of Perth, contains 569 metric tonnes of proven reserves consisting of 60 per cent ilmenite, 12 per cent zircon, five per cent rutile along with leucoxene and monazite. A complex has been commissioned to explore Eneabba west deposit, which produce annually 1,80,000 tonnes of ilmenite, 40,000 tonnes of rutile and 68,000 tonnes of zircon.

In USA, the titanium bearing mineral resources is estimated to be 22.6 metric tonnes and proven reserves around 28 metric tonnes in terms of available titanium.

The estimated reserve of new deposits in Sri Lanka is around 13 metric tonnes. The average mineral composition of Pulmoddai deposit contains 70 to 72 per cent ilmenite, eight per cent of rutile, 8 to 10 per cent zircon, one per cent sillimanite and 6 to 8 per cent monazite. Further exploration is in progress at the south western coastal areas with the help of United Nations revolving fund for national resources. The deposit at Beuwala is very rich in monazite, containing 8 to 10 per cent along with other heavy minerals.

India is favourably placed with good reserves of titanium minerals. The resource so far identified is estimated to be 133mt in terms of available titanium mainly from ilmenite and rutile minerals. Indian reserves of titanium minerals are superior to many other world reserves because of its low chromium, vanadium,
manganese and other heavy metal contents. The low radioactivity in the separated minerals is also internationally preferred in view of stringent environmental control and guidelines. The mineral processed in Brazil and Malaysia are not preferred by developed countries because of high level of vanadium in the products. The mineral processed from Australian east coast reserves had more chromium, which makes it unsuitable for pigment production. The presence of heavy metals in ilmenite and rutile also causes increase in toxicity level in the pigments which is not desirable. The ilmenite from Chatrapur deposit is more reactive and this may be due to the advantageous proportions of ferrous to ferric ions as well as appropriate grain size distribution. This makes it more suitable for the production is synthetic rutile by acid leach.

Rutile is estimated to contribute about 17 to 18 per cent of the total titanium reserves from beach sand deposits. It is not out of place to mention that the economics of beach sand processing in the country is mainly supported by the recovery of these minerals. The ilmenite produced from different locations has varying contents of titanium dioxide, followed by 54 to 55 per cent from Manavalakurichi. Ilmenite processed from Chatrapur deposit contains 50 per cent titanium dioxide and 47 to 48 per cent is reported in the ilmenite processed from Bhimanipatnam. The ilmenite from Kudiraimoli deposit contains 52 to 53 per cent titanium dioxide. The ferrous to ferric ratio in ilmenite varies from deposit to deposit. Table 6.2 illustrates the chemical composition of ilmenite from different sand deposits in India.
### Table: 6.2 - Chemical Composition of Ilmenite from Different Sand Deposits in India

<table>
<thead>
<tr>
<th>Deposit</th>
<th>TiO₂</th>
<th>FeO</th>
<th>Fe₂O₃</th>
<th>Cr₂O₃</th>
<th>V₂O₅</th>
<th>P₂O₅</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Chavara</td>
<td>60.00</td>
<td>9.23</td>
<td>25.60</td>
<td>0.13</td>
<td>0.15</td>
<td>0.20</td>
</tr>
<tr>
<td>2. Manavalakurichi</td>
<td>55.00</td>
<td>20.90</td>
<td>18.90</td>
<td>0.08</td>
<td>0.22</td>
<td>0.12</td>
</tr>
<tr>
<td>3. Nevra (Ratnagiri)</td>
<td>53.25</td>
<td>23.56</td>
<td>22.50</td>
<td>0.07</td>
<td>0.41</td>
<td>0.16</td>
</tr>
<tr>
<td>4. Kudiraimoli</td>
<td>52.63</td>
<td>29.52</td>
<td>16.86</td>
<td>0.001</td>
<td>&lt;0.004</td>
<td>0.29</td>
</tr>
<tr>
<td>5. Kalpakkam</td>
<td>51.00</td>
<td>30.40</td>
<td>15.96</td>
<td>0.06</td>
<td>1.10</td>
<td>0.59</td>
</tr>
<tr>
<td>6. Chatrapur</td>
<td>50.20</td>
<td>34.10</td>
<td>12.76</td>
<td>0.05</td>
<td>0.24</td>
<td>0.03</td>
</tr>
<tr>
<td>7. Satankulam</td>
<td>49.56</td>
<td>28.08</td>
<td>14.41</td>
<td>0.001</td>
<td>&lt;0.004</td>
<td>0.22</td>
</tr>
<tr>
<td>8. (i) Surangudi (1)</td>
<td>47.13</td>
<td>31.26</td>
<td>21.05</td>
<td>0.08</td>
<td>0.30</td>
<td>0.07</td>
</tr>
<tr>
<td>9. (ii) Surangudi (2)</td>
<td>50.85</td>
<td>32.20</td>
<td>13.56</td>
<td>0.07</td>
<td>0.30</td>
<td>0.04</td>
</tr>
<tr>
<td>10. (iii) Surangudi (2)</td>
<td>48.30</td>
<td>32.22</td>
<td>18.36</td>
<td>0.07</td>
<td>0.30</td>
<td>0.06</td>
</tr>
<tr>
<td>9. Overi – Navalodi</td>
<td>47.80</td>
<td>32.58</td>
<td>17.91</td>
<td>0.001</td>
<td>&lt;0.004</td>
<td>0.13</td>
</tr>
<tr>
<td>10. Nevra (Magnetite)</td>
<td>39.28</td>
<td>17.23</td>
<td>38.32</td>
<td>0.09</td>
<td>0.54</td>
<td>0.23</td>
</tr>
</tbody>
</table>


The titanium dioxide content of rutile is more or less identical in all the deposits. Unlike the minerals from Chavara and Manavalakurichi, the rutile and other minerals from other deposits have slime and ferruginous coatings over the grain which adversely affects the separation and product purity.
Titanium Sponge

In the manufacturing process for titanium sponge, pure titanium tetrachloride is reacted in a stainless steel reactor with magnesium metal heated to 900\(^\circ\)C. The titanium tetrachloride is reduced by the magnesium to produce the sponge. Magnesium chloride is extracted at regular intervals during the reaction by the application of pressure. After the reaction has completed, the magnesium chloride and magnesium included in the lump of titanium sponge are eliminated by high temperature vacuum extraction (vacuum separation process), to leave the titanium sponge.

![Titanium sponge](image)

*Titanium sponge*
*(10 ton batch)*

*2.5 to 3 m high x 2 m across*
Crushing the Titanium Sponge (crushing, sizing and packing process)

After reduction and separation, the titanium sponge is crushed by first shearing into large lumps and then into smaller pieces using shears and crushers. Levels of minor components differ from piece to piece, so the pieces are mixed together in a blender to produce a uniform quality, then distributed evenly into drum cans using a splitter. After the titanium sponge has been adjusted into the required particle size and quality, it passes through strict quality control checks before shipment.

**Crushing Process**

![Crushing Process Image]

One of the features of our titanium sponge products is that the supply is very stable and reliable. Shipments include a variety of high quality titanium sponge products manufactured by Kroll process and subject to strict quality control to meet customers' needs. These products are utilized by the aerospace industry for uses, including crucial engine parts, by general industry, mainly for uses such as plate heat exchangers, and also as an additive in manufacturing special stainless steels. The titanium sponge used for crucial engine parts in
particular is called a premium grade, and is manufactured under extremely strict quality control (OSAKA Titanium technologies Co. Ltd, 2009).

**Titanium Powder Production**

The titanium powders include two different types of titanium powder and titanium hydride powder. Such titanium powders use high-quality titanium sponge as a material, and are manufactured by gas-atomization or hydride-dehydride processes. The properties of titanium powder give it a very wide range of uses. In particular, it is used as a material for powder metallurgy, or as a getter, and its application field is spreading steadily. The quality of our titanium powder has gained a high evaluation from users worldwide.

**Appearance**

(1) Gas-atomized Titanium Powder  2) Titanium hydride-dehydride Powder

![TILOP (x 100)](image1)

![TSP-350 (x 250)](image2)
6.4 Various Technologies

The mineral separation plants use variety of equipment such as gravity concentrators, high tension separators and magnetic separators. Making use of difference in physical properties like electrical conductivity, magnetic susceptibility and difference in specific gravity etc., individual minerals like ilmenite, rutile, zircon, sillimanite and garnet are separated. The mined beach sands are per-concentrated and dried after sieving (30-mesh) to separate the heavies from rejects. The heavy minerals are passed through electrostatic separators where conducting minerals like ilmenite and titanium are separated from other non-conducting minerals. Ilmenite and titanium are further subjected to low-intensity magnetic separators where magnetic fraction-titanium is separated from ilmenite. Similarly non-conducting fractions are subjected to high-intensity (monazite and garnet) is separated from non magnetic fraction (zircon and sillimanite).

Magnetic Separator

The magnetic separator is a device used to separate a mixture of fine, dry minerals based upon their magnetic properties. The principles governing this process are magnetism and the interaction between magnetic, gravitational and centripetal forces. Magnetic properties of a material are based upon atomic structure and magnetic field intensity. The principles involved in the separation apparatus include feed rate, velocity of the particles and magnetic field strength.
Magnetic separation has two general applications, purification of feeds via the magnetic removal of impurities or the collection of the magnetic components from the mixture. The capabilities include wet and dry magnetic separation in both low and high intensity magnetic separations with field strengths up to 25,000 gauss (Placer 2005).

**Figure: 6.1 – Schematic Diagram for Magnetic Separation**

The three main components of magnetic separator

- Magnetic roll assembly
- Feed hopper and vibratory feeder
- Separator collection system.

The vibratory feeder pan control is located on the power box.
Figure: 6.2 – Components of Magnetic Separator

![Diagram of Magnetic Separator Components]

Courtesy: Placer 2005, p.7

**Equipment Description**

The magnetic roll assembly consists of a motor driven magnetic roll, and idler, roll (which freely rotates), an ionization bar, and there graphite-impregnated separator belts, varying in thickness.

**Mechanism**

A belt is aggranged around the motor driven magnetic roll and the idler roll to form a conveyor system. A dry feed mixture enters on to the belt over the idler roll section of the conveyor system and carried into the magnetic field (magnetic roll section). The roll speed controller is located on the power box. Also included
in the magnetic roll assembly is the ionization bar, which is attached to the frame near the idler roll. The ionization bar creates negative and positive ions, which help to eliminate electrostatic charge that may be present on the feed particles.

The feed hopper and vibratory feeder are mounted on a separate frame that can be moved over the separator so that the feed point may be varied (i.e. separations utilizing the strong section of the magnet). The hopper and pan should be leveled relative to the separator belt in order to give a uniform feed. The feed is a trough which is spring mounted to a vibrating source. The vibratory feeder pan control determines the feed rate and is located on the power box. The exit of the feeder pan is positioned over the idler roll section of the assembly.

- Silica sand
- Illmenite
- Garnet
- Magnetite
- Rutile
- Zircon and other materials

Unlike flotation, the bubble-particle aggregated do not need to have sufficient buoyancy to rise to the top of the cell. Instead, the teetering effect of the hindered-bed forces the low-density agglomerates to overflow into the product launder. Hydrophilic particles that do not attach to the air bubbles continue to move down through the teeter bed and eventually settle into the dewatering cone.
These particles are discharged as a high solids stream (e.g., 75% solids) through a control valve at the bottom of the separator. The valve is actuated in response to a control signal provided by a pressure transducer mounted on the side of the separation chamber.

The hydro float can be theoretically applied to any system where differences in apparent density can be created by the selective attachment of air bubbles. The preferred mode of operation would be to make the low-density component hydrophobic so that the greatest difference in specific gravity is achieved compared to traditional flotation processes, the hydro float offers important advantages for treating coarser materials including enhanced bubble-particle contacting, increased residence time, lower axial mixing / cell turbulence, and reduced air consumption (Placer 2005). The operation of hydro float separator is presented in Figure 6.3.
Figure: 6.3 – Conceptual Illustration of the HydroFloat Separator

Equipment Setup

A schematic diagram of the pilot-scale test circuit of the hydro float separator, consist of three primary unit operations, i.e., pilot-scale classifier, slurry conditioner, and hydro float separator as shown below. In this circuit, the coarse underflow from an existing bank of classifying cyclones was fed to a 5 ft x 5 ft teeter – bed classifier. The preliminary tests showed that the classifier was capable of handling solid flows in excess of 150 tonne / hour (6 tonne/hour/feet) despite significant variations in the feed solids content from 15% to 60%. This ability was attributed to the tangential feed presentation system that allows for a consistent
underflow stream regardless of plant operating conditions (i.e., feed tonnage, percent solids). The underflow from the classifier was passed to the conditioning unit where a appropriate reagents were added to control PH (ammonia) and particle hydrophobicity (fatty acid/fuel oil blend).

**Figure: 6.4 – Pilot-Scale Test Circuit**

![Diagram](image)

The feed conditioning could be performed using either a stirred – tank (four stage) or a single-stage rotary drum (30-inch diameter) conditioner. The conditioner circuit was able to operate reliably at approximately 40-75% solids at a maximum mass flow rate of 4-6 ton/hr (dry solids). The conditioned slurry flowed by gravity to the feed inlet for either the hydro float separator or a 20-inch diameter flotation column. The arrangement made it possible to directly compare the effectiveness of the hydro float separator with existing column technology.
The test circuit was installed with all necessary components (i.e., feeder, conditioner, reagent pumps, etc.) required to operate the separator in continuous mode at a maximum capacity of 4-6 tph.

**Mineral jigs**

Mineral jigs are widely used in industry to separate materials of different specific gravities. Typically, the particles are being transported via slurry and are comparable in size due to milling in prior unit operations. Mineral jig separation is based on pulsations of water through a bed of coarse materials causing heavy particles to sink as light materials pass across the bed; then each product can be collected separately. These coarse particles, ragging, hinder the light particles from falling to the bottom, yet still allow the heavier particles to move downward. This device is typically used to light concentrate and to treat heavy metallic and heavy nonmetallic ores respectively.

A mineral jig is designed to separate materials varying in density through the oscillation of ragging, which is a bed of particles larger than the feed, in a pool of water. A diaphragm pulsing the water upward and drawing it downward causes the vibration with a frequency variant that is optimized for the feed being separated.

The jig can be used to separate almost any feed of differing densities as long as the supply of ragging is versatile and the amplitude and frequency of the diaphragm can be adequately adjusted.
Figure: 6.5 – Mineral Jig Separation

Figure: 6.6 – Schematic Diagram of the Process

Courtesy: Placer 2005, p.10

Courtesy: Placer 2005, p.11
To obtain sufficient separation, several variables other than the feed composition should be changed such that separation of the feed is more efficient.

- The size and density of the ragging particles can be varied to change the amplitude of ragging oscillation and the space provided by the ragging for the dense particles to flow downward.

- Replacement water flow rate can also be adjusted to vary the up ward force on the lighter particles to control their tendency to flow downward through the ragging.

- Feed spray flow rate should be adjusted to control the rate of which the feed is fed into the bed of ragging.

- The frequency of water oscillation is a variable that can be controlled simply be adjusting the dial on the control box of the unit.

- The amplitude of the ragging displacement can be adjusted by changing the position of the cam eccentric on the pump drive shaft.

A mineral jig consists of an open water-filled tank, a hutch fitted with a valve at the bottom of the unit, and two mesh screens that support the top and the bottom of the ragging. Water-particle slurry is fed through the bed of materials known as ragging. A motor-controlled piston oscillates a diaphragm to produce pulsations of the water that covers the ragging depending on the amplitude and frequency of the oscillations, pulsated water modulates the motion and acceleration of the particles. Resulting buoyant forces, which are equivalent to the weight of the displaced fluid but in the opposite direction, cause the heaviest
particles to sink to the collecting hutch as lighter particles pass over the ragging and flow into a separate collector.

The dilution water is no longer pumped by the motion of the diaphragm but is now continually supplied by water header and flows upward through the ragging at a specified constant flow rate.

There are five parameters that can be varied and quantified in order to obtain optimal separation. The five parameters that will be varied and recorded are:

1. Ragging size
2. Feed spray flow rate
3. Replacement 9Dilution) water flow rate
4. Frequency of oscillation
5. Amplitude of displacement

The feed will fit through the available ragging screens and have specific gravities greater than 1.00. This feed can be entirely arbitrary but the densities must vary and the particles should be relatively similar in size. The feed is to be introduced at a constant, relatively slow rate for optimal separation. The feed will be separated than collected from the hutch valve at the end of the batch; and, the portion of the feed that exits the feed chute (preferably the light particles) is to be continuously collected from the stream of overflowing water using a sieve of a large enough mesh to keep both light and heavy particles from being lost.
Feed spray flow rate should be quite low but high enough to slowly and regularly introduce the feed into the ragging bed. Caution should be taken when choosing the initial rate, as there are many feeds that will be forced off of the opposite end of the feed chute without contacting the ragging bed if the flow is too high. There is a flow meter on the line that will quantify the rate.

Replacement (Dilution) water flow rate should be adjusted to a higher value for more dense feeds. At lower flow rates, all particles, are likely to overcome the frictional forces provided by the upward flow of the replacement water. Therefore, higher flow rated will grant better separation as the frictional forces on the “light” become more significant than on the heavier particles. Careful modulation of replacement water is recommended with feed particles that have very little difference in density, as both particles of this kind will be almost equally affected by this flow rate.

Many different materials can be used for ragging, such as rocks, gravel, pellets, spheres of polymer, anything that will be denser than water and preferably denser than the feed as well. It is important to have the entire ragging compartment filled or else the void spaces between ragging particles will vary too greatly causing some of the feed to become trapped. Ragging size should be chosen such that it will create channels large enough to allow the denser particles to flow downward otherwise they will be carried over with the lighter particles. If the ragging is too small, for instance, the channels that are created during oscillation may never become wide enough for a large particle to pass through. In
contrast, if theragging particles are too large, the lighter particles will have a
greater tendency to fall with the “heavies” due to the wider channels formed by
this type of ragging.

The frequency of oscillation is the driving force behind the separation of
the feed. Without oscillation there will be no separation. In most cases, a coarser,
larger feed will separate best with a slower frequency and the reverse is true for
finer feeds. This variable is more of a fine-tuning of the separation efficiency and
part of this lab is to determine an optimal frequency for a given feed.

The amplitude of the pump may be increased or decreased which affects the
displacement of the ragging, and, hence, the interstitial spacing between the
ragging. More dense raggings usually require greater amplitude.

Ragging support screens are not much of a factor in separation efficiencies
but it is essential that the feed particles are able to pass through both the top and
bottom screens for full contact with the ragging and for no accumulation of feed in
the ragging compartment. It is also essential that the ragging particles are held
securely by the screens and that no ragging leakage from the compartment occurs.

6.5 Cost Estimates of Titanium Mining Plant

Thus, the discussion on the pre-processing and processing technologies
needs the estimation of capital and operating costs of the titanium mining plant in
Tamil Nadu. The capital cost is estimated under three heads, viz., pre-processing
sector, processing sector and transport sector. Here, the plant capacity is assumed
to be 3,000 tonnes throughput per year. Total capital cost is estimated at `1,757.94 lakhs and the different components of it are explained below.

**Capital Cost for Pre-processing Sector**

The cost incurred under pre-processing works out to be `215 lakhs. Here, land is acquired for the construction of primary concentration unit and the related stockyard and drying yard. The building cost includes the cost incurred on the building structure. At this stage, the stock of raw materials, loading and reloading work and other related works are done. Therefore, the cost of labour is included under this sector. The various items under capital cost are separately given in Table 6.3.

**Capital Cost for Processing Sector**

The processing sector the total cost is estimated to be `1,529.94 lakhs. Here, land purchased is used for the construction of the processing plant, office buildings, godowns, labs, drying yards, gardens, power room etc. The machinery of the processing plant contains ballmills, digesters, temperature regulating tanks, black end doors, reduction tank, crystallizers, evaporators, hydrolyser, filters, leaching machines, treatment tanks, calciner, recocmills, notch filter, boilers, generators, bucket elevators and screw conveyers, door tank, belt conveyer, compressor etc. Building cost represents the cost incurred by the firm for the construction of buildings for processing plant, office, laboratory, canteen, power
room, godown, and car shed. The cost of getting power connection services including the various amounts paid to the electricity department, expenditures incurred on the purchase of materials in connection with the installation of power system and supplies. Machine cost includes the cost of acquiring the power generation unit to run the plant in the event of general power failure.

Table: 6.3 - Capital Cost of Titanium Mining Plant
(Throughput Capacity = 3,000 tonnes per year)

<table>
<thead>
<tr>
<th>Sl.No.</th>
<th>Item</th>
<th>'in Lakhs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Pre-processing Sector</td>
<td>215.00</td>
</tr>
<tr>
<td></td>
<td>Land (20 acre x 2 lakh)</td>
<td>40.00</td>
</tr>
<tr>
<td></td>
<td>Building</td>
<td>50.00</td>
</tr>
<tr>
<td></td>
<td>Machinery (PCU)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1. Tipper – 2 Nos</td>
<td>50.00</td>
</tr>
<tr>
<td></td>
<td>2. Excavator – 1</td>
<td>45.00</td>
</tr>
<tr>
<td></td>
<td>Working Capital</td>
<td>30.00</td>
</tr>
<tr>
<td>2.</td>
<td>Processing Sector</td>
<td>1,529.94</td>
</tr>
<tr>
<td></td>
<td>Land (20 acre x 2 lakh)</td>
<td>40.00</td>
</tr>
<tr>
<td></td>
<td>Building</td>
<td>60.00</td>
</tr>
<tr>
<td></td>
<td><strong>Machinery</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1. Balmill – 2 Nos</td>
<td>200.00</td>
</tr>
<tr>
<td></td>
<td>2. Digester – 3 Nos</td>
<td>6.00</td>
</tr>
<tr>
<td></td>
<td>3. Temperature Regulating Tank – 2 Nos</td>
<td>79.12</td>
</tr>
<tr>
<td></td>
<td>4. Black End Door – 3 Nos</td>
<td>2.25</td>
</tr>
<tr>
<td></td>
<td>5. Reduction Tank – 1 No.</td>
<td>22.00</td>
</tr>
<tr>
<td></td>
<td>6. Crystallizer – 3 Nos</td>
<td>65.07</td>
</tr>
<tr>
<td></td>
<td>7. Evaporator – 4 Nos</td>
<td>303.32</td>
</tr>
<tr>
<td>Sl.No.</td>
<td>Item</td>
<td>`in Lakhs</td>
</tr>
<tr>
<td>-------</td>
<td>-----------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td></td>
<td><strong>Processing Sector</strong></td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Hidraliser – 3 Nos</td>
<td>3.75</td>
</tr>
<tr>
<td>10.</td>
<td>Leaching Machine – 3 Nos</td>
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</tr>
<tr>
<td>11.</td>
<td>Treatment Tank - 2 Nos</td>
<td>48.00</td>
</tr>
<tr>
<td>12.</td>
<td>Callciner – 1 No.</td>
<td>1.40</td>
</tr>
<tr>
<td>13.</td>
<td>Reccomill – 2 Nos</td>
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</tr>
<tr>
<td>14.</td>
<td>Notch Filter – 1 No.</td>
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</tr>
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<td>15.</td>
<td>Boiler – 2 Nos</td>
<td>216.98</td>
</tr>
<tr>
<td>16.</td>
<td>Generator – 4 Nos</td>
<td>5.00</td>
</tr>
<tr>
<td>17.</td>
<td>Bucket Elevator – 3 Nos</td>
<td>42.00</td>
</tr>
<tr>
<td>18.</td>
<td>Screw Conveyer – 5 Nos</td>
<td>85.72</td>
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<td></td>
<td><strong>Effluent Treatment</strong></td>
<td></td>
</tr>
<tr>
<td>19.</td>
<td>Filter – 1 No.</td>
<td>32.78</td>
</tr>
<tr>
<td>20.</td>
<td>Door Tank – 1 No.</td>
<td>0.80</td>
</tr>
<tr>
<td>21.</td>
<td>Belt Conveyer – 1 No.</td>
<td>12.60</td>
</tr>
<tr>
<td>22.</td>
<td>Compressor – 3 Nos.</td>
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</tr>
<tr>
<td></td>
<td>Power connection</td>
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</tr>
<tr>
<td></td>
<td>Working Capital</td>
<td>50.00</td>
</tr>
<tr>
<td>3.</td>
<td><strong>Transport Sector</strong></td>
<td><strong>13.00</strong></td>
</tr>
<tr>
<td></td>
<td>Vehicle – 2 Nos</td>
<td>10.00</td>
</tr>
<tr>
<td></td>
<td>Spare &amp; Parts</td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td>Working Capital</td>
<td>11.00</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>1,757.94</strong></td>
</tr>
</tbody>
</table>

Source: Compiled form Primary Data
Capital Cost for Transport Sector

In the transport sector the major item of expenditure is on the purchase of buses to transport the labourers from their villages to the main plant and mining spots and then take them back to their villages. The supervisors and manager often visit the mining spots and various offices and so the purchase of vehicles is justified. Expenses are required for the maintenance of the spare parts. The cost of transport sector is `13 lakhs and the break-up of the total capital cost of all the three major sectors are given in Table 6.3. An amount of `30, `50, and `11 lakhs are set apart as working capital in order to meet out the expenses incurred in the mining, processing, and transport sectors with a view to have smooth functioning of the plant.

Operating Cost Estimation

Operating cost is also estimated under three sectors as in the case of capital cost, viz., pre-processing sector, processing sector and transport sector. The total operating cost works out to be `1,033.53 lakhs. The break up of different items under capital cost is given in Table 6.4.
Table: 6.4 - Operating Cost of Titanium Mining Plant
(Throughput Capacity = 3,000 tonnes per year)

<table>
<thead>
<tr>
<th>Sl.No.</th>
<th>Item</th>
<th>`in Lakhs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Pre-processing Sector</td>
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</tr>
<tr>
<td></td>
<td>Raw materials – Ilmenite</td>
<td>403.20</td>
</tr>
<tr>
<td></td>
<td>Sulfuric and Other Acids</td>
<td>200.00</td>
</tr>
<tr>
<td></td>
<td>Labourers</td>
<td>20.83</td>
</tr>
<tr>
<td></td>
<td>Fuel &amp; Electricity</td>
<td>20.00</td>
</tr>
<tr>
<td>2.</td>
<td>Processing Sector</td>
<td>374.00</td>
</tr>
<tr>
<td></td>
<td>Fuel &amp; Electricity</td>
<td>143.00</td>
</tr>
<tr>
<td></td>
<td>Packaging</td>
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<tr>
<td></td>
<td>Handling</td>
<td>12.00</td>
</tr>
<tr>
<td></td>
<td>Maintenance &amp; Repair</td>
<td>75.00</td>
</tr>
<tr>
<td></td>
<td>Labourers</td>
<td>73.00</td>
</tr>
<tr>
<td></td>
<td>Insurance</td>
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</tr>
<tr>
<td></td>
<td>Other expenses</td>
<td>41.00</td>
</tr>
<tr>
<td>3.</td>
<td>Transport Sector</td>
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</tr>
<tr>
<td></td>
<td>Fuel</td>
<td>5.00</td>
</tr>
<tr>
<td></td>
<td>Maintenance &amp; Repair</td>
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</tr>
<tr>
<td></td>
<td>Wage for drivers &amp; Others service charges</td>
<td>5.50</td>
</tr>
<tr>
<td></td>
<td>Others expenses</td>
<td>3.50</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>1,033.53</strong></td>
</tr>
</tbody>
</table>

Source: Compiled from Primary Data
Operating Cost for Mining Sector

The major item in the operating cost of pre-processing sector is the raw materials and wages paid to the labourers, both men and women, employed in the unloading, reloading and packaging of the raw materials. It is here estimated that at least 30 women and 20 men labourers are employed in warehouse. The charges on fuel and electricity are for running the primary concentration unit. The total operating cost of mining sector is found at `644.03 lakhs.

Operating Cost for Processing Sector

The important heads of expenditures under operating cost of processing sector are royalty, handling charges, electricity and fuel consumption charges, and the wages and salaries paid to the labourers and officials.

Royalty amount is included in the price of the finished goods. The total handling charges comprise the expenditure incurred on the transportation of the concentrates from the warehouse spots to the main processing plant and taking the finished product from the plant to the nearest port. The expenditure on maintenance and repair is calculated to be `75 lakhs, nearly about five per cent of the machine cost, which is normally found to be the same in mining industries. The insurance premium is paid for the safety of the plant, loss of transit of finished products, life of the workers, and on the security against the risk of unexpected
shut downs if any. The total operating cost of the processing sector is calculated to be `374 lakhs.

**Operating Cost for Transport Sector**

The expenditure on the fuel for by the transport vehicles, maintenance and repair expenses for these motor vehicles and the wages and service charges are considered for the operating cost of mining sector which is estimated at `15.50 lakhs.

The cost estimate for the titanium mining plant having a capacity of 3,000 tonnes throughput per year in the study area are `1,757.94 lakhs and `1,033.53 lakhs for capital and operating costs respectively. In the economic return analysis, which is carried out in the next chapter, the cost estimate will be used to find out the viability of the titanium mining industry.

**6.6 Overview**

This chapter deals with the various types of mining and processing technologies adopted in Tamil Nadu and cost estimation of the pre-processing and processing methods suited to the titanium minerals of the Tamil Nadu. The cost estimate for the titanium mining plant having a capacity of 3,000 tonnes throughput per year in the study area are `1,757.94 lakhs and `1,033.53 lakhs for capital and operating costs respectively.