MANUFACTURE OF TITANIUM DIOXIDE
(20000 TONS PER ANNUM)
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</table>
PROPERTIES:

Chemical name: Titanium (IV) oxide
Other name: Titania
Chemical formula: TiO₂
Molecular mass: 79.87 g/mol

APPEARANCE:

Titanium dioxide appears as a white crystalline solid with high opacity.

STRUCTURE:

Titanium dioxide exhibits a Tetragonal crystal structure.
PHYSICAL PROPERTIES:

**Appearance:** White Powder.

**Odor:** Odorless.

**Solubility:** Insoluble in water.

**Specific Gravity:** 4.26

**pH:** ca. 6 - 7

**% Volatiles by volume @ 21C (70F):** 0

**Boiling Point:** 2500 - 3000C (4532 - 5432F)

**Melting Point:** 1855C (3371F)

**Vapor Density (Air=1):** Not applicable.

**Vapor Pressure (mm Hg):** Not applicable.

CHEMICAL PROPERTIES:

**Stability:**

Stable under ordinary conditions of use and storage.

**Hazardous Decomposition Products:**

No hazardous products are formed.

**Hazardous Polymerization:**

Will not occur.

**Incompatibilities:**

For Titanium Dioxide: A violent reaction with lithium occurs around 200C (392F) with a flash of light; the temperature can reach 900C. Violent or incandescent reaction may also occur with other metals such as aluminum, calcium, magnesium, potassium, sodium, and zinc.

**Conditions to Avoid:**

Dusting and incompatibles.
MECHANICAL PROPERTIES:

Density = 4 gcm\(^{-3}\)

Porosity = 0%

Modulus of Rupture = 140MPa

Compressive Strength = 680MPa

Poisson’s Ratio = 0.27

Fracture Toughness = 3.2 Mpa.m\(^{1/2}\)s

Shear Modulus = 90GPa

Modulus of Elasticity = 230GPa

Micro hardness (HV0.5) = 880

Resistivity (25°C) = 10\(^{12}\) ohm.cm

Resistivity (700°C) = 2.5x10\(^{4}\) ohm.cm

Dielectric Constant (1MHz) = 85

Dissipation factor (1MHz) = 5x10\(^{-4}\)

Dielectric strength = 4 kVmm\(^{-1}\)

Thermal expansion (RT-1000°C) = 9 x 10\(^{-6}\)

Thermal Conductivity (25°C) = 11.7 WmK\(^{-1}\)
APPLICATIONS:

Applications for sintered titania are limited by its relatively poor mechanical properties. It does however find a number of electrical uses in sensors and electro catalysis. By far its most widely used application is as a pigment, where it is used in powder form, exploiting its optical properties.

**Pigments**

The most important function of titanium dioxide however is in powder form as a pigment for providing whiteness and opacity to such products such as paints and coatings (including glazes and enamels), plastics, paper, inks, fibers and food and cosmetics.

Titanium dioxide is by far the most widely used white pigment. Titania is very white and has a very high refractive index – surpassed only by diamond. The refractive index determines the opacity that the material confers to the matrix in which the pigment is housed. Hence, with its high refractive index, relatively low levels of titania pigment are required to achieve a white opaque coating.

The high refractive index and bright white color of titanium dioxide make it an effective opacifier for pigments. The material is used as an opacifier in glass and porcelain enamels, cosmetics, sunscreens, paper, and paints. One of the major advantages of the material for exposed applications is its resistance to discoloration under UV light.

**Photo catalysis**

Titania acts as a photo sensitizers for photo voltaic cells, and when used as an electrode coating in photo electrolysis cells can enhance the efficiency of electrolytic splitting of water into hydrogen and oxygen.

**Oxygen Sensors**
Even in mildly reducing atmospheres titania tends to lose oxygen and become substoichiometric. In this form the material becomes a semiconductor and the electrical resistivity of the material can be correlated to the oxygen content of the atmosphere to which it is exposed. Hence titania can be used to sense the amount of oxygen (or reducing species) present in an atmosphere.

**Antimicrobial Coatings**

The photo catalytic activity of titania results in thin coatings of the material exhibiting self cleaning and disinfecting properties under exposure to UV radiation. These properties make the material a candidate for applications such as medical devices, food preparation surfaces, air conditioning filters, and sanitary ware surfaces.

**For wastewater remediation**

TiO$_2$ offers great potential as an industrial technology for detoxification or remediation of wastewater due to several factors.

1. The process occurs under ambient conditions.

2. The formation of photo cyclized intermediate products, unlike direct photolysis techniques, is avoided.

3. Oxidation of the substrates to CO$_2$ is complete.

4. The photo catalyst is inexpensive and has a high turnover.

5. TiO$_2$ can be supported on suitable reactor substrates.
VARIOUS MANUFACTURING PROCESSES:

There are basically two main processes for the manufacture of Titanium dioxide. They are the Chloride and the Sulphate process.

CHLORIDE PROCESS:

The chloride process yields the rutile form of titanium dioxide. At temperatures between 800 and 1200 °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 °C. A minor amount of aluminum chloride is generally added to promote formation of the rutile form. The titanium dioxide is washed, calcined, and packaged.

SULPHATE PROCESS:

Ilmenite and titanium slag is digested with sulfuric 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-sulfate 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 as its sulfate 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 micro crystals. These micro crystals are then introduced into the mother liquor, which is then hydrolyzed 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 - 850 ºC.

**COMPARISON & PROCESS SELECTION**

**COMPARISON OF CHLORIDE AND SULPHATE PROCESSES:**

The Chloride and the Sulphate processes are compared on the basis of the following aspects and the suitable process is selected.

<table>
<thead>
<tr>
<th>Aspects</th>
<th>Sulfate Process</th>
<th>Chloride Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste Disposal</td>
<td>FeSO₄ is formed in large amounts leading to disposal problem.</td>
<td>No such huge amounts of solid wastes is encountered.</td>
</tr>
<tr>
<td>Product quality</td>
<td>Produces low grade anatase pigment.</td>
<td>Produces a higher grade rutile pigment.</td>
</tr>
<tr>
<td>Water Pollution</td>
<td>Disposal of spent acid into water bodies causes pollution</td>
<td>No such problem is encountered.</td>
</tr>
<tr>
<td>Water usage</td>
<td>Huge amount of water is required.</td>
<td>Comparatively less amount of water is required.</td>
</tr>
</tbody>
</table>

From the above comparison, the Chloride process has been selected for the project.
PROCESS DESCRIPTION

MANUFACTURE OF TITANIUM DIOXIDE BY CHLORIDE PROCESS:

BACKGROUND:

Titanium dioxide containing feedstock is subjected to high temperature carbo-chlorination to produce titanium tetra chloride, which is thereafter converted to titanium dioxide by oxidation.

PRODUCTION REACTIONS:

The reactions involved in the manufacture of titanium dioxide are,

\[ 2\text{TiO}_2 + 4\text{Cl}_2 + 3\text{C} \rightarrow 2\text{TiCl}_4 + \text{CO}_2 + 2\text{CO} \] (Impure)

\[ \text{TiCl}_4 + \text{O}_2 \rightarrow \text{TiO}_2 + 2\text{Cl}_2 \] (Pure)

PROCESS DESCRIPTION:

Feedstock containing, titanium dioxide (85% pure) and finely divided coke are added to chlorine gas in a reactor, where the titanium dioxide undergoes chlorination reaction at 800 °C. Titanium tetrachloride and chlorides of iron and silicon are formed by the following reactions.

\[ 2\text{TiO}_2 + 4\text{Cl}_2 + 3\text{C} \rightarrow 2\text{TiCl}_4 + \text{CO}_2 + 2\text{CO} \]
\[ \text{SiO}_2 + 2\text{Cl}_2 + \text{C} \rightarrow \text{SiCl}_4 + \text{CO}_2 \]
\[ 2\text{FeO} + 3\text{Cl}_2 + \text{C} \rightarrow 2\text{FeCl}_3 + \text{CO}_2 \]
Pressure is maintained at about 1.5 atm and the residence time in the reactor is about 1 hour. The outlet stream from the chlorinator at 800°C is fed to a cooler and cooled to 320°C using water as coolant. Iron chloride condenses and settles down as liquid. Unreacted solids also settle down and are separated. The vapor stream from the top is fed to the condenser.

The gas stream from the cooler is cooled to 137°C where TiCl₄ is condensed. The effluent gas is then sent to a converter, where Carbon monoxide is converted into Carbon dioxide. The condensed pure TiCl₄ liquid at its bubble point is fed to the oxide burner.

Pure TiCl₄ liquid is vaporized and burnt with oxygen to form titanium dioxide solid (0.3µm particle size) and chlorine gas. The reaction takes place at a temperature of 1000°C.

\[ \text{TiCl}_4 + \text{O}_2 \rightarrow \text{TiO}_2 + 2 \text{Cl}_2 \]

The stream containing chlorine gas and titanium dioxide solids are separated using a high efficiency Cyclone Separator. The Chlorine gas is recycled to the Chlorinator. The product is removed, cooled and surface treated.

**SURFACE TREATMENT OF PRODUCT:**

'Pure' TiO₂ base pigments, whether anatase or rutile, provide high opacity and excellent color but have a relatively reactive surface. The majority of commercial pigments are therefore coated with an inorganic treatment or coating, and often an organic treatment.

**Reasons for surface treating titanium dioxide pigment**

Nearly all commercial TiO₂ pigments have a surface treatment or coating to:

- Improve wetting and dispersion in different media (water, solvent or polymer)
- Improve compatibility with the binder and dispersion stability
- Improve color stability
- Improve durability
- Increase air in the film in flat latex paints
Depending on the end application, the surface treatment is usually a combination of alumina, silica and/or zirconia, deposited onto the core TiO$_2$ particles from either the chloride or sulfate base pigment process, by a wet precipitation process. A final coating of polyol or other organic chosen to enhance the dispersion of the pigment in a resin system and/or dry bulk handling characteristics is then added.

Following surface treatment, the pigment is dried, intensively milled and packed into bags. It may also be supplied in semi and full bulk deliveries or, especially in North America, converted to high concentration slurry for direct use in water based paint systems.

The coatings on TiO$_2$ pigments are deposited under very closely controlled conditions of time, temperature and pH to develop the required characteristics. The final analysis of a surface coating shows only part of the expertise in making high performance TiO$_2$ pigments. Order of addition and precipitation as well as the processes parameters are critical to making the optimum product.
MATERIAL BALANCE

RAW MATERIAL REQUIREMENTS:

REACTIONS CONSTITUTING THE PROCESS:

\[ 2\text{TiO}_2 + 4\text{Cl}_2 + 3\text{C} \rightarrow 2\text{TiCl}_4 + \text{CO}_2 + 2\text{CO} \]

\[ \text{TiCl}_4 + \text{O}_2 \rightarrow \text{TiO}_2 + 2\text{Cl}_2 \]

\[ \text{SiO}_2 + 2\text{Cl}_2 + \text{C} \rightarrow \text{SiCl}_4 + \text{CO}_2 \]

\[ 2\text{FeO} + 3\text{Cl}_2 + \text{C} \rightarrow 2\text{FeCl}_3 + \text{CO}_2 \]

\[ \text{CO} + \frac{1}{2} \text{O}_2 \rightarrow \text{CO}_2 \]

MOLECULAR WEIGHTS OF VARIOUS COMPOUNDS:

<table>
<thead>
<tr>
<th>COMPOUNDS</th>
<th>MOLECULAR WEIGHT (g/gmol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TiO(_2)</td>
<td>79.87</td>
</tr>
<tr>
<td>TiCl(_4)</td>
<td>190.11</td>
</tr>
<tr>
<td>Cl(_2)</td>
<td>71.12</td>
</tr>
<tr>
<td>CO(_2)</td>
<td>44</td>
</tr>
<tr>
<td>O(_2)</td>
<td>32</td>
</tr>
<tr>
<td>C</td>
<td>12</td>
</tr>
<tr>
<td>FeO</td>
<td>71.85</td>
</tr>
<tr>
<td>SiCl(_4)</td>
<td>169.89</td>
</tr>
<tr>
<td>FeCl(_3)</td>
<td>162.22</td>
</tr>
<tr>
<td>SiO(_2)</td>
<td>60.06</td>
</tr>
</tbody>
</table>
BASIS: 20000 TPA of 98% TiO₂ (Capacity of Plant)

\[
\text{TiO}_2 \text{(pure)} = \frac{19600 \times 1000}{365 \times 24}
\]

\[
= 2237.44 \text{ kg/hr}
\]

\[
\text{TiCl}_4 + \text{O}_2 \rightarrow \text{TiO}_2 + 2\text{Cl}_2
\]

TiCl₄ required for 2237.44 kg/hr of TiO₂ = \[
2237.44 \times \frac{190.11}{79.87}
\]

\[
= 5325.65 \text{ kg/hr}
\]

Assuming 90% conversion,

Actual TiCl₄ required = \[
\frac{5325.65}{0.9}
\]

\[
= 5917.38 \text{ kg/hr}
\]

O₂ required = \[
5917.38 \times \frac{32}{190.11}
\]

\[
= 996.03 \text{ kg/hr}
\]

Cl₂ formed = \[
2237.44 \times \frac{142.24}{79.87}
\]

\[
= 3984.64 \text{ kg/hr}
\]

Material entering:

TiCl₄ = 5917.38 kg/hr

O₂ = 996.03 kg/hr

Material leaving:

TiO₂ = 2237.44 kg/hr

Cl₂ = 3984.64 kg/hr

Unreacted TiCl₄ = 591.438 kg/hr

Unreacted O₂ = 99.603 kg/hr
\[ 2\text{TiO}_2 + 4\text{Cl}_2 + 3\text{C} \rightarrow 2\text{TiCl}_4 + \text{CO}_2 + 2\text{CO} \]

TiO\(_2\) required = \(\frac{5917.38 \times 159.74}{380.22}\)

= 2486.04 kg/hr

Assuming 85\% conversion,

Total ore required (85\% pure TiO\(_2\)) = \(\frac{2486.04}{(0.85 \times 0.85)}\)

= 3440.88 kg/hr

Cl\(_2\) required = \(\frac{2924.75 \times 284.48}{159.74}\)

= 5208.67 kg/hr

Coke required = \(\frac{2924.75 \times 36}{159.74}\)

= 659.14 kg/hr

\(\text{CO}_2\) formed = \(\frac{5917.38 \times 44}{380.22}\)

= 684.77 kg/hr

\(\text{CO}\) formed = \(\frac{5917.38 \times 56}{380.22}\)

= 871.53 kg/hr

\textbf{Composition of Ore:}

TiO\(_2\) (85\%) = 0.85 \times 3440.88 = 2924.748 kg/hr

FeO (10\%) = 0.10 \times 3440.88 = 344.088 kg/hr

SiO\(_2\) (5\%) = 0.05 \times 3440.88 = 172.044 kg/hr
\[
\text{SiO}_2 + 2\text{Cl}_2 + C \rightarrow \text{SiCl}_4 + \text{CO}_2
\]

The ore contains 172.044 kg/hr of SiO\(_2\).

- \(\text{Cl}_2\) required = \(172.044 \times 142.24 / 60.06\) = 407.45 kg/hr
- Coke required = \(172.044 \times 12 / 60.06\) = 34.37 kg/hr
- \(\text{SiCl}_4\) required = \(172.044 \times 169.89 / 60.06\) = 486.66 kg/hr
- \(\text{CO}_2\) required = \(172.044 \times 44 / 60.06\) = 126.04 kg/hr

\[
2\text{FeO} + 3\text{Cl}_2 + C \rightarrow 2\text{FeCl}_3 + \text{CO}_2
\]

FeO available in ore = 344.088 kg/hr

- \(\text{Cl}_2\) required = \(344.088 \times 213.36 / 143.7\) = 510.89 kg/hr
- Coke required = \(344.088 \times 12 / 143.7\) = 28.73 kg/hr
- \(\text{FeCl}_3\) formed = \(344.088 \times 324.44 / 143.7\) = 776.87 kg/hr
- \(\text{CO}_2\) formed = \(344.088 \times 44 / 143.7\) = 105.36 kg/hr
CO + ½ O₂ → CO₂

CO formed in the chlorinator = 871.53 kg/hr

CO₂ formed = 871.53 * 44 / 28

= 1369.55 kg/hr

O₂ required = 871.53 * 8 / 28

= 249 kg/hr

RAW MATERIAL REQUIREMENTS

<table>
<thead>
<tr>
<th>RAW MATERIAL</th>
<th>REQUIRED AMOUNT (kg/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TiO₂ (ore)</td>
<td>3440.88</td>
</tr>
<tr>
<td>Chlorine</td>
<td>2142.37</td>
</tr>
<tr>
<td>Carbon</td>
<td>722.24</td>
</tr>
<tr>
<td>Oxygen</td>
<td>1245.03</td>
</tr>
</tbody>
</table>

MATERIAL BALANCE:

CHLORINATOR:

Material Entering = 2924.748 + 172.044 + 344.088 + 722.24 + 6127.01
Material Leaving = 5917.38 + 486.66 + 776.87 + 916.17 + 871.53 + 781.3 + 98.87 + 441.22 

= 10290.13 kg/hr

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>MASS (kg/hr)</th>
<th>MOLES (kmol/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TiO\textsubscript{2}</td>
<td>2924.748</td>
<td>36.62</td>
</tr>
<tr>
<td>SiO\textsubscript{2}</td>
<td>172.044</td>
<td>2.86</td>
</tr>
<tr>
<td>FeO</td>
<td>344.088</td>
<td>4.79</td>
</tr>
<tr>
<td>Coke</td>
<td>722.24</td>
<td>60.19</td>
</tr>
<tr>
<td>Cl\textsubscript{2}</td>
<td>6127.01</td>
<td>86.15</td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td><strong>10290.13</strong></td>
<td></td>
</tr>
</tbody>
</table>

LEAVING:

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>MASS (kg/hr)</th>
<th>MOLES (kmol/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TiCl\textsubscript{4}</td>
<td>5917.38</td>
<td>31.13</td>
</tr>
<tr>
<td>SiCl\textsubscript{4}</td>
<td>486.66</td>
<td>2.86</td>
</tr>
<tr>
<td>FeCl\textsubscript{3}</td>
<td>776.87</td>
<td>4.79</td>
</tr>
<tr>
<td>CO\textsubscript{2}</td>
<td>916.17</td>
<td>20.82</td>
</tr>
<tr>
<td>CO</td>
<td>871.53</td>
<td>31.13</td>
</tr>
<tr>
<td>Cl\textsubscript{2}</td>
<td>781.3</td>
<td>10.98</td>
</tr>
<tr>
<td>Coke</td>
<td>98.87</td>
<td>8.24</td>
</tr>
<tr>
<td>TiO\textsubscript{2}</td>
<td>441.22</td>
<td>5.52</td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td><strong>10290.13</strong></td>
<td></td>
</tr>
</tbody>
</table>
COOLER:

Mass entering = \(10290.13\) kg/hr

Mass leaving = \(1316.96 + 8973.17\)

\[= 10290.13\) kg/hr\]

CONDENSER:

Mass Entering = \(5917.38 + 916.17 + 871.53 + 781.3 + 486.66\)

\[= 8973.17\) kg/hr\]

Mass leaving = \(5917.38 + 3055.79\)

\[= 8973.17\) kg/hr\]
OXIDE BURNER:

\[
\begin{align*}
\text{Mass entering} & = 5917.38 + 996.03 \\
& = 6913.41 \text{ kg/hr} \\
\text{Mass leaving} & = 2237.44 + 3984.64 + 591.438 + 99.604 \\
& = 6913.41 \text{ kg/hr}
\end{align*}
\]

CYCLONE SEPARATOR:

\[
\begin{align*}
\text{Mass entering} & = 2237.44 + 3984.64 \\
& = 6222.08 \text{ kg/hr} \\
\text{Mass leaving} & = 2237.44 + 3984.64 \\
& = 6222.08 \text{ kg/hr}
\end{align*}
\]

CONVERTER:
Mass entering = 3055.66 + 498

= 3553.66 kg/hr

Mass leaving = 2285.78 + 486.66 + 781.3

= 3553.66 kg/hr
ENERGY BALANCE

Reactions involved

\[ 2\text{TiO}_2 + 4\text{Cl}_2 + 3\text{C} \rightarrow 2\text{TiCl}_4 + \text{CO}_2 + 2\text{CO} \quad \Delta H = -249.83 \text{ KJ/Kmol} \]

\[ \text{SiO}_2 + 2\text{Cl}_2 + \text{C} \rightarrow \text{SiCl}_4 + \text{CO}_2 \quad \Delta H = -173.4 \text{ KJ/Kmol} \]

\[ 2\text{FeO} + 3\text{Cl}_2 + \text{C} \rightarrow 2\text{FeCl}_3 + \text{CO}_2 \quad \Delta H = -1971.6 \text{ KJ/Kmol} \]

\[ \text{TiCl}_4 + \text{O}_2 \rightarrow \text{TiO}_2 + 2\text{Cl}_2 \quad \Delta H = -173.5 \text{ KJ/Kmol} \]

REACTOR:

Molecular Heat capacity data (Cp values at various temperatures)

<table>
<thead>
<tr>
<th>Material</th>
<th>At 298 K</th>
<th>At 1073 K</th>
<th>At 1273 K</th>
</tr>
</thead>
<tbody>
<tr>
<td>TiO₂</td>
<td>56.86</td>
<td>83.15</td>
<td>-</td>
</tr>
<tr>
<td>Cl₂</td>
<td>35.36</td>
<td>37.17</td>
<td>37.64</td>
</tr>
<tr>
<td>FeO</td>
<td>51.1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SiO₂</td>
<td>45</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Coke</td>
<td>8.94</td>
<td>22.52</td>
<td>-</td>
</tr>
<tr>
<td>CO₂</td>
<td>-</td>
<td>54.88</td>
<td>-</td>
</tr>
<tr>
<td>CO</td>
<td>-</td>
<td>33.02</td>
<td>-</td>
</tr>
</tbody>
</table>
Heat in + heat generated + heat added = heat output

$$Q = mC_p \Delta t$$

Heat accompanied with ore = 66.02*56.86*25+4.79*51.1*25+2.86*45*25

= 61392.055 KJ/hr

Heat in through coke = 60.19*8.94*25

= 13452.465 KJ/hr

Heat accompanied with chlorine = 56.03*37.64*1000+30.12*35.36*25

= 2135595.28 KJ/hr

Heat generated within the system = 31.1 * 249.83 + 2.86 * 173.4 + 4.79 * 1971.6

= 17709.601 KJ/hr

Heat associated with output stream = (31.13 * 107.57 * 800) + (20.82 * 54.88 * 800) + (31.13 * 33.02 * 800) + (4.79 * 77.78 * 800) + (10.98 * 37.17 * 800) + (2.86 * 136.88 * 800) + (8.24 * 22.52 * 800) + (5.52 * 83.15 * 800)

= 5868712.56 KJ/hr

Heat added to the system = 5868712.56-(61392+2135595.28+13452465+17709.601)
= 3640563.155 KJ/hr

**COOLER:**

<table>
<thead>
<tr>
<th>Material</th>
<th>Heat capacity(kJ/K.mol.k) At 593 k</th>
</tr>
</thead>
<tbody>
<tr>
<td>FeCl₃</td>
<td>77.78</td>
</tr>
<tr>
<td>TiO₂</td>
<td>7.65</td>
</tr>
<tr>
<td>Coke</td>
<td>16.29</td>
</tr>
<tr>
<td>TiCl₄</td>
<td>149.10</td>
</tr>
<tr>
<td>CO₂</td>
<td>47.76</td>
</tr>
<tr>
<td>CO</td>
<td>30.61</td>
</tr>
<tr>
<td>Cl₂</td>
<td>36.05</td>
</tr>
<tr>
<td>SiCl₄</td>
<td>136.88</td>
</tr>
</tbody>
</table>
Heat in to the cooler = heat of from the chlorinator

= 586812.56 KJ/hr

Heat out = (4.79*77.78*320)+(5.52*67.65*320)+(8.24*16.29*320)+
(31.13*149.44*320)+(20.82*47.76*320)+(31.13*30.61*320)+
(10.98*36.05*320)+(2.86*136.88*320)+(4.79*3093.63)

= 2636608.22 KJ/hr

Heat removed = 586712.56-2636608.22

= 3223320.784 KJ/hr

Cooling water required = 3116447.618

\[
4.186(65-25)
\]

= 19250 KJ/hr

**CONDENSER:**

<table>
<thead>
<tr>
<th>Material</th>
<th>Heat capacity (KJ/hr) at 410K</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>43.12</td>
</tr>
<tr>
<td>CO</td>
<td>29.68</td>
</tr>
<tr>
<td>Cl₂</td>
<td>35.62</td>
</tr>
</tbody>
</table>
Heat in = heat out from cooler with crude TiCl₄

= 31.13*149.10*320+20.82*47.76*320+31.13*30.61*320+
10.98*36.05*320+2.86*136.88*320

= 2360333.216 KJ/hr

Heat carried by the gas stream = 20.82*43.12*137+31.13*29.68*137+
10.98*35.62*137+2.86*137.88*137

= 356786.52 KJ/hr

Heat of pure TiCl₄ = 31.13*149.44*137+34936.356*31.13

= 1724901.969 KJ/hr

Heat to be removed = 2360333.216-(356786.52+1724901.9)

= 278644.72 KJ/hr

Cooling water required = 278644.72

4.16*(55-25)

= 2218.86 kg/hr

COMBUSTION CHAMBER:
Heat in + heat generated + heat added = heat output

Heat in = 31.13*149.44*137+31.13*26.09*25

= 657637.75 KJ/hr

Heat generated = 96.81*173.5

= 16796.5 KJ/hr

Heat output = 28.01*89.51*1000+56.03*35.51*1000

+3.11*1000*149.44+3.11*35.51*1000

= 5071994.15 KJ/hr

Heat added = 5071994.15-(657637.75+16796.5)

= 4397560.75 KJ/hr
CONVETER:

Heat in = heat carried by the gas stream from condenser

\[+ 76.565 \times 26.09 \times 25\]

\[= 356786.52 + 10804.52\]

\[= 367591.04 \text{ KJ/hr}\]

Heat output = 367591.04 + 31.13 \times 110.52

\[= 371030.905 \text{ KJ/hr}\]

COOLER 2:

\[931594.3 \to \text{Water in}\]

\[2963025.7 \to \text{TiO2}\]

\[25^\circ C \to \text{25^\circ C}\]

\[1000^\circ C \to \text{85^\circ C}\]

\[727154 \to \text{TiO2 PRODUCT}\]

\[3167464.5 \to \text{Water out}\]
Heat removed = mCp Δt

= 28.01*83.15*960

= 2235870.24 KJ/hr

Amount of cooling water = 2235870.24

4.186*60

= 8902 kg/hr

**COOLER 3:**

Heat in = heat out from the converter

= 371030.905 KJ/hr

Heat out = 51.95*43.12*40 + 10.98*37.64*40 + 2.86*136.88*40

= 121793.92 KJ/hr

Latent heat of SiCl₄ = 2.86*28715.96

= 82127.64 KJ/hr

Heat removed = 371030.905-121793.92

= 249236.98 KJ/hr

cooling water = 249236.98
DESIGN OF EQUIPMENTS

DESIGN OF CONDENSER

ASSUMPTIONS:

1) The flow pattern is assumed to be counter current flow.

2) No heat loss to the surroundings.

3) No. of passes
   Shell side -1
   Tube side -2

4) No sub-cooling.

SPECIFICATIONS

Shell ID = 0.3365m
Tube OD = 0.019m
Tube ID = 0.0157m
Tube length = 1.45m

HEAT BALANCE

Heat in = 2360333.216 kJ/hr
Heat out = 2081688.489 kJ/hr
Heat removed = 278644.72 kJ/hr
Amount of heat required = 2218.86 kJ/hr
To find LMTD

\[(\Delta T)_{lm} = \frac{(T_{h1}-T_{c2})-(T_{h2}-T_{c1})}{\ln((T_{h1}-T_{c2})/(T_{h2}-T_{c1}))}\]

\[= \frac{(320-55)-(137-25)}{\ln((320-55)/(137-25))}\]

\[= 177.65°C\]

LMTD Correction factor = 0.975

Corrected LMTD = 177.65 x 0.975

\[= 173.21°C\]

Heat transferred = \(U_d \times A \times \text{LMTD}\)

Overall heat transfer coefficient \(U_d = 50 \text{ Btu/hr.ft}^2.\text{°F}\)

\[= 50 \times 20.44\]

\[= 1022 \text{ KJ/hr.m}^2.\text{K}\]

Heat transfer area \(A = \frac{Q}{(U_d \times \text{LMTD})}\)

\[= \frac{278644.72}{(1022 \times 173.21)}\]

\[= 1.574 \text{ m}^2\]

\(A = n\pi DL\)

No. of tubes \(n = \frac{1.574}{(\pi \times 0.019 \times 1.45)}\)

\(n = 19\) tubes.
**DESIGN SPECIFICATIONS:**

**SHELL:**
- ID = 0.3365m
- No. of pass = 1

**TUBE:**
- OD = 0.019m
- ID = 0.0157m
- No. of pass = 2
- No. of tubes = 19

**DESIGN OF FLUIDIZED BED**

Design Equation:

\[
\frac{V}{F_{A0}} = \frac{X_{A}}{A} - \Gamma_{A}
\]

\[
2\text{TiO}_2 + 4\text{Cl}_2 + 3\text{C} \rightarrow \text{TiCl}_4 + \text{CO}_2 + 2\text{CO}
\]

Since the rate of reaction is constant throughout the reaction period. So this reaction can be Zero order then reaction kinetics is

\[-\Gamma_{A} = k\]

Where ‘k’ is zero order rate constant.

\[
\frac{V}{F_{A0}} = \frac{X_{A}}{k}
\]

Molar flowrate of reactants \( F_{A0} \) = \( 36.62 + 60.19 + 86.12 \)

= 182.96 kmol/hr

Initial concentration of the reactants \( C_{A0} = 0.703 \) kmol/m³

Rate constant \( K = 5.23 \) kmol/m³ hr

Volume of the reactor \( V = 182.96 \times 0.85 / 5.23 \)

= 29.735 m³
L/D ratio = 8

Diameter of the reactor \( D = 1.68 \text{ m} \)

Length of the reactor \( L = 13.43 \text{ m} \)

Space time \( \frac{V}{v} = 29.735 \)

\[
\frac{182.96 \times 0.703}{\text{182.96} \times 0.703} = 13.87 \text{ min}
\]

Minimum fluidization velocity \( u_{mf} = \frac{d_p^2 \times (\rho_p - \rho) \times (\epsilon^2 / (1 - \epsilon))}{150 \mu} \)

Diameter of the particle \( d_p = 0.154 \text{ mm} \)

Density of the particle \( \rho_p = 4260 \text{ Kg/m}^3 \)

Porosity \( \epsilon = 0.75 \)

Viscosity of the Chlorine gas \( \mu = 3.75 \times 10^{-5} \text{ Kg/ms} \)

Density of the Chlorine gas \( \rho = 0.808 \text{ Kg/m}^3 \)

\[
u_{mf} = \frac{(0.154 \times 10^{-3})^2 \times (4260 - 0.808) \times (0.75^2 / 0.25)}{150 \times 3.75 \times 10^{-5}}
\]

\[
= 0.040 \text{ m/s}
\]

Pressure drop

\[
\frac{\Delta p}{L} = \frac{150 \times \mu \times u_{mf} \times (1 - \epsilon)^2}{d_p^2 \times \rho \times C^3}
\]

\[
= \frac{150 \times 3.75 \times 10^{-5} \times 0.040 \times 0.25^2}{(0.154 \times 10^{-3})^2 \times 0.808 \times 0.75^3}
\]
Design specifications:

Volume of the reactor $V = 29.735 \text{ m}^3$

L/D ratio $= 8$

Diameter of the reactor $D = 1.68 \text{ m}$

Length of the reactor $L = 13.43 \text{ m}$

**DESIGN OF CYCLONE SEPARATOR:**

Gas flow rate $= 4335.32 \text{ m}^3/\text{hr}$

$= 1.204 \text{ m}^3/\text{s}$

Particle size $= 0.3 \mu\text{m}$

Inlet velocity $= 27 \text{ m/s}$

\[
\text{Area of inlet duct} = \frac{\text{gas flow rate}}{\text{Inlet velocity}}
\]

\[
= \frac{1.204}{27}
\]

\[
= 0.0446 \text{ m}^3
\]

\[
\text{Area of inlet duct} = 0.5D_c \times 0.2D_c
\]

\[
0.5D_c \times 0.2D_c = 0.0446
\]

Diameter of inlet duct $D_c = 0.668 \text{ m}$

**Pressure drop calculation:**
\[ \Delta p = \rho f \left\{ U_1^2 (1 + 2\Phi^2(2r_1/r_e - 1)) + 2U_2^2 \right\} \]

Velocity at the inlet \( U_1 = 27 \text{ m/s} \)

Area of exit duct = \( \Pi/4 \times (0.668 \times 0.5)^2 \)

\[ = 0.0876 \text{ m}^2 \]

\( r_1 = 0.334 \text{ m} \)

\( r_e = 0.167 \text{ m} \)

\( A_s = 2\Pi r l \)

\( r = 0.334 \text{ m} \)

\( L = 2.672 \text{ m} \)

\( A_s = 2\Pi \times 0.334 \times 2.672 \)

\[ = 5.607 \text{ m}^2 \]

\( A_1 = 0.0446 \text{ m}^2 \)

\( \Psi = f_c (A_s/A_1) \)

\[ = 0.005 \times (5.607/0.0446) \]

\[ = 0.63 \]

From graph \( \Phi \) vs \( r_1/r_e \)

\( r_1/r_e = 2 \)

\( \Phi = 0.95 \)

\[ \Delta p = 1.021 \left\{ 27^2[1 + 2 \times 0.95^2(2 \times 0.334/0.167 - 1)] + 2 \times 5.844^2 \right\} \]
The pressure drop obtained is <25 cm of H₂O, so the existing cyclone is satisfactory

\[ \text{Pressure} = 23.86 \text{ millibar} = 24.33 \text{ cm of } \text{H₂O} \]

**PROCESS ECONOMICS**

**COST ESTIMATION**

**PURCHASED EQUIPMENT COST (PEC) IN LAKHS:**

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Cost (Lakhs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor</td>
<td>55</td>
</tr>
<tr>
<td>Condenser</td>
<td>0.699</td>
</tr>
<tr>
<td>Cooler</td>
<td>5.98</td>
</tr>
<tr>
<td>Combustion chamber</td>
<td>85</td>
</tr>
<tr>
<td>Converter</td>
<td>45</td>
</tr>
<tr>
<td>CO₂ storage</td>
<td>30</td>
</tr>
<tr>
<td>Cyclone separator</td>
<td>20</td>
</tr>
</tbody>
</table>

**TOTAL PURCHASED EQUIPMENT COST = 251.68**

**DIRECT FIXED COST (DFC) IN LAKHS:**

Equipment installation cost = 75.504

(30% of PEC)
Instrumentation and control = 50.34
(20% of PEC)
Electrical equipment cost = 37.75
Land cost = 20
Building cost = 10
Piping cost = 25.17

TOTAL DIRECT FIXED COST = 218.76

INDIRECT FIXED COST (IFC) IN LAKHS:

Engineering & supervision = 75.50
(30% of equipment cost)
Construction expenses = 21.88
Contingency (8% of DFC) = 17.50

TOTAL INDIRECT FIXED COST = 114.88

WORKING CAPITAL (WC) = 5% of (PEC+DFC+IFC)
= 29.66 LAKHS

TOTAL FIXED CAPITAL INVESTMENT (TFCI) = PEC+DFC+IFC+WC
= 614.586 LAKHS
VARIABLE COST:

MANUFACTURING COST (DIRECT PRODUCTION COST) IN LAKHS:

<table>
<thead>
<tr>
<th>RAW MATERIAL</th>
<th>REQUIREMENT</th>
<th>COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>RUTILE ORE</td>
<td>30134.4 tons/annum</td>
<td>494.30</td>
</tr>
<tr>
<td>OXYGEN</td>
<td>6670660m³at NTP</td>
<td>133.4</td>
</tr>
<tr>
<td>CHLORINE</td>
<td>18765 tons/annum</td>
<td>185.34</td>
</tr>
<tr>
<td>COKE</td>
<td>6327 tons/annum</td>
<td>7.6</td>
</tr>
</tbody>
</table>

TOTAL MANUFACTURING COST = 820.64

UTILITIES:

<table>
<thead>
<tr>
<th>RAW MATERIAL</th>
<th>REQUIREMENT</th>
<th>COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>COOLING WATER</td>
<td>205797 tons/annum</td>
<td>8.23</td>
</tr>
<tr>
<td>FUEL</td>
<td>166 tons/annum</td>
<td>19</td>
</tr>
<tr>
<td>ELECTRICITY</td>
<td>16745 tons/annum</td>
<td>0.209</td>
</tr>
</tbody>
</table>

TOTAL UTILITIES COST = 27.44

OPERATING COST:
<table>
<thead>
<tr>
<th>LABOUR</th>
<th>NO.</th>
<th>SALARY PER MONTH PER LABOUR</th>
<th>SALARY PER ANNUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHIEF EXECUTIVE</td>
<td>2</td>
<td>25000</td>
<td>60000</td>
</tr>
<tr>
<td>WORKERS MANAGER</td>
<td>2</td>
<td>15000</td>
<td>360000</td>
</tr>
<tr>
<td>ASSISTANT MANAGER</td>
<td>5</td>
<td>12000</td>
<td>720000</td>
</tr>
<tr>
<td>SUPERVISOR</td>
<td>20</td>
<td>10000</td>
<td>2400000</td>
</tr>
<tr>
<td>SKILLED LABOUR</td>
<td>30</td>
<td>3000</td>
<td>1080000</td>
</tr>
<tr>
<td>UNSKILLED LABOUR</td>
<td>30</td>
<td>1500</td>
<td>540000</td>
</tr>
</tbody>
</table>

TOTAL OPERATING COST    = 5700000

MAINTANANCE COST PER ANNUM = 10 LAKHS

SUPERVISION & LABOUR COST = 8.55 LAKHS

(5% OF OPERATING COST)

DEPRECIATION

Plant Life = 10 years
Salvage = 10% of PEC

= 25.168 lakhs

Straight Line Depreciation = 251.68 - 25.168

10

= 22.651 lakhs
Building = 3% of Initial Building Cost
= 0.3 Lakhs

**TOTAL DEPRECIATION** = 22.951 LAKHS

LOCAL TAX = 3% OF TFCI
= 18.44 Lakhs

INSURANCE = 6.15 Lakhs

PLANT OVERHEAD = 50% of (OPERATING COST + MAINTANANCE + SUPERVISION)
= 37.775 Lakhs

**GENERAL EXPENSES IN LAKHS:**

Administrative Cost = 8.55

Distribution & Marketing cost = 710

R&D cost (5% of operating cost) = 2.85

**TOTAL GENERAL EXPENSES** = 721.4 LAKHS

**TOTAL VARIABLE COST (TVC) IN LAKHS** = MANUFACTURING COST + UTILITIES + LABOURCOST + MAINTENANCE COST + SUPERVISION
= 820.64 + 27.44 + 57 + 10 + 8.55 + 721.4
= 1644.63 Lakhs
\[
\text{TOTAL INVESTMENT} = \text{TVC + TFCI + TAXES} \\
= 1634.63 + 614.586 + 78.65 \\
= 2337.86 \text{ Lakhs}
\]

\[
\text{SALES PRICE (Rs/Kg)} = \text{Rs.34}
\]

\[
\text{PRODUCT COST} = 2928.66\text{Lakhs}
\]

\[
\text{PROFIT BEFORE TAX} = \text{Total Earnings –TVC + Depreciation} \\
= 2928.66 - 1644.63 + 256.168 \\
= 1309.2 \text{ Lakhs}
\]

\[
\text{TAX RATE} = 40\%
\]

\[
\text{PROFIT AFTER TAX} = 935.144 \text{ Lakhs}
\]

\[
\text{PAY BACK PERIOD} = \frac{2337.86}{935.144} \\
= 2.5 \text{ years}
\]

---

**PLANT LOCATION & LAYOUT**

**PLANT LOCATION**

The important part in the setting of a factory is to select a suitable site or location to house the factory because an inappropriate selection of location would end the activity of the plant no matter how efficient the equipments, management etc are. The problem can be divided in to two main parts:

1. General location of the factory
2. The selection of particular site
(a) For the general location of the factory following factors must be considered:

1) The Raw materials should be easily available at comparatively low cost and at low freight charges.

2) The market should be near the factory for the quick service to the customers and easy transportation.

3) There should be good transport facilities for bringing raw material and sending finished product.

4) Skilled and cheap laborers should be available near the plant site.

5) Availability of power and fuel were very influencing in olden days to day it has not much effect on plant site.

6) Climatic and atmospheric conditions are governing factor to several chemical industries. However, air conditioning systems have changed the situation.

7) All factories need soft and pure water especially in large quantities.

8) Availability of Capital.

9) Social and recreational facilities can be created near the factory site.

10) Banking facilities are necessary for the factories, which require constant feeding of the working capital.

11) Existence of related factories sometimes play very important role in selection of site.

12) The factors like local bye laws, taxes, fire protection facilities, post and telegraph facilities should also be considered.

SELECTION OF ACTUAL SITE:
The most important factors in this division are

- Availability of cheap land to build and expand the plant
- The cost of leveling the land are providing foundations, subsoil conditions for foundations and drainage
- The cost of bricks, sand, cement, limes, steel and other materials required for construction
- Facilities for the up keep and general maintenance
- Facilities for transport in getting and sending materials
- Facilities for housing the workers and if necessary their transport from their place of residence to work sites.
- Cost of laying the water supply, provide sewage and disposal work.
- Cost of installation of electricity, gas and other facilities etc.
- Any restrictions placed by the planning department are local by laws be well studied

**RAW MATERIALS**

The availability and the price of suitable raw materials will often determine the site location. Plants producing bulk chemicals are best located close to the source of the major raw material, where this is also close to the marketing area.

**TRANSPORT**

The transport of materials and products to and from plant will be an over ridding consideration in site selection. If practicable, a site should be selected that is close to at least two major forms of transport road, rail, water way or a sea port. Road transport is being increasingly used and is suitable for local distribution from a central ware house. Rail transport will be cheaper for the long distance transport of bulk chemicals. Air
Transport is convenient and efficient for the movement of personal and essential equipment and supplies and the proximity of the site to a major airport should be considered.

**AVAILABILITY OF LABOUR**

Labor will be needed for construction of the plant and its operation. Skilled construction workers will usually be brought in from outside the site, but there should be an adequate pool of unskilled labor available locally, and labor suitable for training to operate the plant. Skilled tradesman will be needed for the maintenance. Local trade union customs and restrictive practices will have to be considered when assessing the availability and suitability of the labor for recruitment and training.

**UTILITIES (SERVICES)**

The word ‘utilities’ is now generally used for ancillary services needed in the operation process. The services will normally be supplied from a central facility and this will include

**ELECTRICITY**

Power is required for operating the equipments, lightings, general use etc.

**STEAM**

Steam is required for the process are generated in the tube boilers using most economical fuels.

**WATER**

Natural and forced draft cooling towers are generally used to provide the cooling water required on site. Water required for the general purpose will be taken from the local water supplies like rivers, lakes and sea. Because of this reason all the plants located on the banks of river. Dematerialized water, from which all the minerals have been removed by ion exchange is used where the pure water is used for the process use, in boiler feed water.

**PLANT LAYOUT**
The economic construction and efficient operation of a process unit will depend on how well the plant an equipment specified on the process flow sheet is laid out the principal factors considered are

Economic considerations:

- Construction and operation costs.
- The process requirements.
- Convenience of operation
- Convenience of maintenance
- Safety
- Future expansion
- Modular construction

COSTS

The cost of construction can be minimized by adopting a layout that gives the shortest run of connecting pipe between equipments, and at least amount of structural steel work. However, this will not necessarily be the best arrangement ofr operation and maintenance.

PROCESS REQUIREMENT

An example of the need to take into account process consideration is the need to elevate the base of column to provide the necessary net positive suction head to a pump or the operating head for thermo-siphon re-boiler.

OPERATIONS

Equipment that needs to have frequent attention should be located convenient to the control room. Valves, sample points, and instruments should be located at convenient positions and heights. Sufficient working space and headroom must be provided to allow easy access to equipment.
MAINTENANCE

Heat exchanger need to be sited so that the tube bundles can be easily withdrawn for cleaning and tube replacement. Vessels that require frequent replacement of catalyst or packing should be located on the outside of buildings. Equipment that requires dismantling for maintenance, such as compressors and large pumps, should be places under cover.

SAFETY

Blast walls may be needed to isolate potentially hazardous equipment and confine the effects of an explosion. At least two escape routes for operators must be provided from each level in process buildings.

PLANT EXPANSION

Equipment should be located so that it can be conveniently tied in with any future expansion of the process. Space should be left on pipe alleys for future needs, and service pipes over-sized to allow for future requirements.

MODULAR CONSTRUCTION

In recent years there has been a move to assemble sections of plant at the plant manufacturer’s site. These modules will include the equipment, structural steel, piping and instrumentation. The modules are then transported to the plant site, by road or sea.

The advantages of modular construction are,

- Improved quality control
- Reduced construction cost
- Less need for skilled labor on site

Some of the disadvantage are,

- Higher design cost and more structural steel work.
SAFETY & HEALTH ASPECTS

MATERIAL SAFETY DATA SHEET

1. Substance name

TITANIUM DIOXIDE

2. Composition/information on ingredients

Chemical nature

• RUTILE

• ANATASE

3. Possible hazards

• Critical hazards to man and the environment:

• If breathable dust is formed it can irritate the respiratory tract.

4. First aid measures

• General advice: Remove contaminated clothing.

• If inhaled: keep patient calm, remove to fresh air, summon medical help

• On skin contact: Wash thoroughly with soap and water.

• On contact with eyes: Wash affected eyes for at least 15 minutes under running water with eyelids held open.

• On ingestion: Rinse mouth and then drink plenty of water.

5. Fire fighting measures
Suitable extinguishing media: water, carbon dioxide (CO2), dry extinguishing media, foam

Special protective equipment: In case of fire, wear a self contained breathing apparatus.

Further information: Dispose of fire debris and contaminated extinguishing water in accordance with local regulations.

6. Accidental release measures

- Personal precautions: Avoid dust formation.
- Environmental precautions: Do not let product enter drains.

Methods for cleaning up: Sweep/shovel up.

7. Handling and storage

Handling

- Protection against fire and explosion.
- Handle in accordance with good industrial hygiene and safety practice.
- Technical protective measures:

  Breathing must be protected when large quantities are decanted without local exhaust ventilation

Storage

- Keep tightly closed in a dry and cool place.

8. Exposure controls and personal protection

- Components with workplace control parameters
• Observe MAK value for inert dust: 6 mg/m3 Personal protective equipment

• Respiratory protection: if breathable dust is formed

• Hand protection: protective gloves

• Eye protection: safety glasses

• General safety and hygiene measures:

• The usual precautions for the handling of chemicals must be observed.

• Do not breathe dust.

9. Physical and chemical properties

Form: powder Colour: white

Odour: odourless

Melting point/melting range: >1000 °C

Density: (20 °C) 3.9 g/cm3 (approx.)

Bulk density: 500–750 kg/m3 (approx.)

Solubility in water: sparingly soluble

pH value: as slurry: neutral

10. Stability and reactivity

• Hazardous reactions: none

• Hazardous decomposition products: none

11. Toxicological information

• Acute toxicity In rat: > 10 000 mg/kg
• Primary skin irritation/rabbit/: non_irritant

• Primary mucous membrane irritation/rabbits’ eyes/: non_irritant

• If inhaled from dust: can irritate the respiratory tract

12. Ecological information

Elimination information

• The product is virtually insoluble in water and can thus be separated from water mechanically in suitable effluent treatment plants.

Behaviour and environmental fate

• Inhibition of degradation activity in activated sludge is not to be anticipated during correct introduction of low concentrations.

Ecotoxic effects

• No data available

Further ecological information

• Do not discharge product into natural waters without pretreatment (biological treatment plant).

13. Disposal considerations

• Product must be disposed of by special means, e.g. suitable dumping in accordance with local regulations.

14. Transport information

• Not classified as hazardous under transport regulations.

15. Regulatory information

• Labeling according to EEC Directives not subject to labeling

• Observe MAK value for inert dust 6 mg/m3
• National legislation/regulations

• Water hazard class: WGK (0) (Germany) (BASF self_classification)

16. Other information

• The information contained herein is based on the present state of our knowledge and does not therefore guarantee certain properties.

• Recipients of our product must take responsibility for observing existing laws and regulations.

REFERENCES

REFERENCE:

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