MCPI Private Limited

(Formerly MCC PTA India Corp. Private Limited
Materials Chemicals and Performance Intermediaries Private Limited)

Summer Training Project Report

"Theoretical Air Requirement Calculation of an Industrial Boiler
&
Caustic Requirement Check for a Desulphurization Tower"

Name: Soumyadeep Hati

Department: Chemical Engineering

Year: 3rd year

Semester: 6th

College: Haldia Institute of Technology, Haldia

Duration: 1 month (01.06.2022 - 30.06.2022)

DECLARATION

I hereby declare that the Industrial training report entitled "**Theoretical Air Requirement Calculation of an Industrial Boiler & Caustic Requirement Check for a Desulphurization Tower**" is an authentic record of my own work as requirements of industrial training from 1/06/2022 to 30/06/2022 under the guidance of **Mr. Sukhen Das**.

……………………………………

Sign of Student

Name: Soumyadeep Hati

Date:

Place:

ACKNOWLEDGEMENT

It's a great and pleasant opportunity for me to gain experience as well as knowledge in the industry. The time period that I have given at MCPI has truly motivated me and have helped me a lot by giving me the opportunity to develop both academically and professionally.

I would like to thank **Mr. Ambar Baran Bhowmik** (Vice President Production & Planning) for his guidance through the MCPI plant, as well his explanations of specific fields were truly helpful.

I would like to thank **Mr. Nishit Kumar Sarkar** (Process General Manager) for his guidance through the MCPI plant, as well his explanations of specific fields were truly helpful.

I would like to thank **Mr. Sukhen Das** (Additional Senior Manager-Process) who overviewed the internship as my project guide. I am very grateful for his help in explaining all the technicalities of the plant functions and his guidance for the project.

I would like to extend my heartfelt gratitude to **Mr. Sudhansu Ranjan** (Process Executive) for his detailed explanations of the equipment's, machines, and processes during our field visits.

I would like to express my gratitude to **Mr. Arnab Kanti Giri** (HR Department). His guidance and assistance during the internship period in solving any difficulty was truly appreciated.

In addition to the mentioned above, I would also like to thank all the employees and staff members at MCPI, for their assistance. Their guidance has helped us a lot in

preparing us for the future. It would not have been possible to gain all the experience and knowledge without their aid.

APPROVAL SHEET

THIS PROJECT REPORT ENTITLED -

"THEORETICAL AIR REQUIREMENT CALCULATION OF INDUSTRIAL BOILER.

CAUSTIC REQUIREMENT CHECK FOR A DESULFURIZATION TOWER".

BY '**MR. SOUMYADEEP HATI**' IS APPROVED BY-

Head of Department(s)

Signature & Date: ______________________

Name: ______________________

Strategist of Department(s)

Signature & Date: ______________________

Name: **MR. AMBAR BARAN BHOWMIK**

HR & A (s)

Signature & Date: ______________________

Name: ______________________

CERTIFICATE

This is to certify that the work contained in the project titled "**Theoretical Air Requirement Calculation of an Industrial Boiler & Caustic Requirement Check for a Desulphurization Tower**" has been carried out by **Mr. Soumyadeep Hati** under our supervision and can be presented in his university for academic purposes.

……………………………………………………………

Signature of Supervisor

Name: Mr. Sukhen Das

Department: Process

MCPI, Haldia

CONTENTS

CONTENTS

1. About MCPI Pvt. Ltd.

MCPI has been a leading provider of Purified Terephthalic Acid (PTA) in India for more than two decades now. Endowed with the proprietary Mitsubishi Chemicals Technology, it has been providing best-in-class PTA to downstream Polyester industries- i.e., Yarn, PET, and PET Film. MCPI's PTA unit has an annual capacity of 1.27 MTPA and is located in the industrial town of Haldia in West Bengal.

In November 2016, The Chatterjee Group (TCG), led by Dr. Purnendu Chatterjee, acquired MCPI from Mitsubishi Chemical Corporation (MCC). Since then, there has been a spectacular turnaround of the business of the company. In this period, the company has recorded the highest capacity utilization, highest sales, and highest profitability consistently year after year.

Led by the Management of TCG, MCPI has leveraged the Group's commitment to Environment, Society and Governance. The company aspires to be a front-runner in Sustainability – with its compliance towards Environment as well as reduction of carbon emissions.

MCPI practices the 'People First Policy'. The company invests in continuous skill development, knowledge enhancement and digital dexterity of its employees. A holistic Learning & Development programme is pursued to grow and nurture Talent.

MCPI has been focused on 'Digital Adoption', implementing state-of-the-art IT tools that provide for 'real time' data-driven decision making in plant operations. Also, steering transparent and governance driven in business processes.

Supported by its strong performance over the last five years, MCPI has been able to redefine its purpose and vision. In a bold and decisive step, MCPI has opted for forward integration as an essential part of its transformation strategy. The company has recently acquired Garden Silk Mills Private Limited (GSMPL), a reputed player in Polyester Yarn and Fabric under the famous brand name 'Garden Vareli'.

Based upon core values of Trust, Integrity, Compliance and Respect, the company is proud of its capability to adapt to a dynamic business circumstances climate and lead the change.

2. Product and its Applications

The product of MCPI Private Limited, Haldia, which is majorly a Business-to-Business Company, is Purified Terephthalic Acid (PTA). Refer Fig 1.

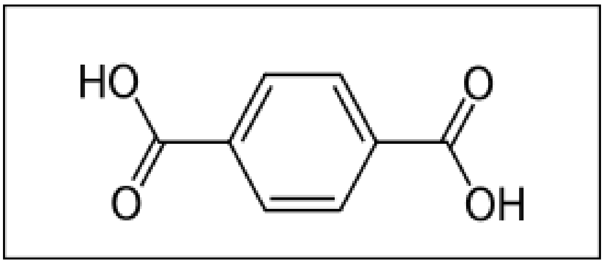


Fig 1: Purified Terephthalic Acid (PTA)

PTA is a commodity chemical, primarily used in the manufacturing polyester PET, plastic bottles and clothing. It has also been used in drug research. Applications also exist in the engineering fields, and it is used in the military as well. Refer Fig 2.

Its toxicity is very low, and has a molecular weight of 166.13. Refer Fig 3.

Main Applications

- Raw material and feed in Poly-Ethylene Terephthalate (PET) production.
- Base reagent in wool spinning factories.
- Additive in animal feed preparation
- As a lubricant in the preparation of industrial adhesives
- The main consumption of terephthalic acid is in production of saturated linear polyester resins used in production of bottles, thin films and polyethylene terephthalate (PET) fibres.

The raw materials required for the production of PTA are: para-xylene (PX), Acetic Acid (Solvent) and oxygen, which is obtained from air.

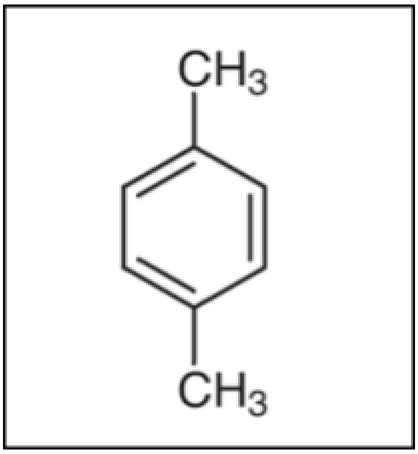


Fig 2: p-Xylene (PX)

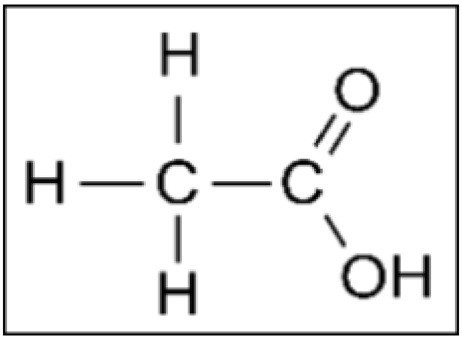


Fig 3: Acetic acid

The Block Flow Diagram for the production of CTA in as follows. Refer Fig 4.

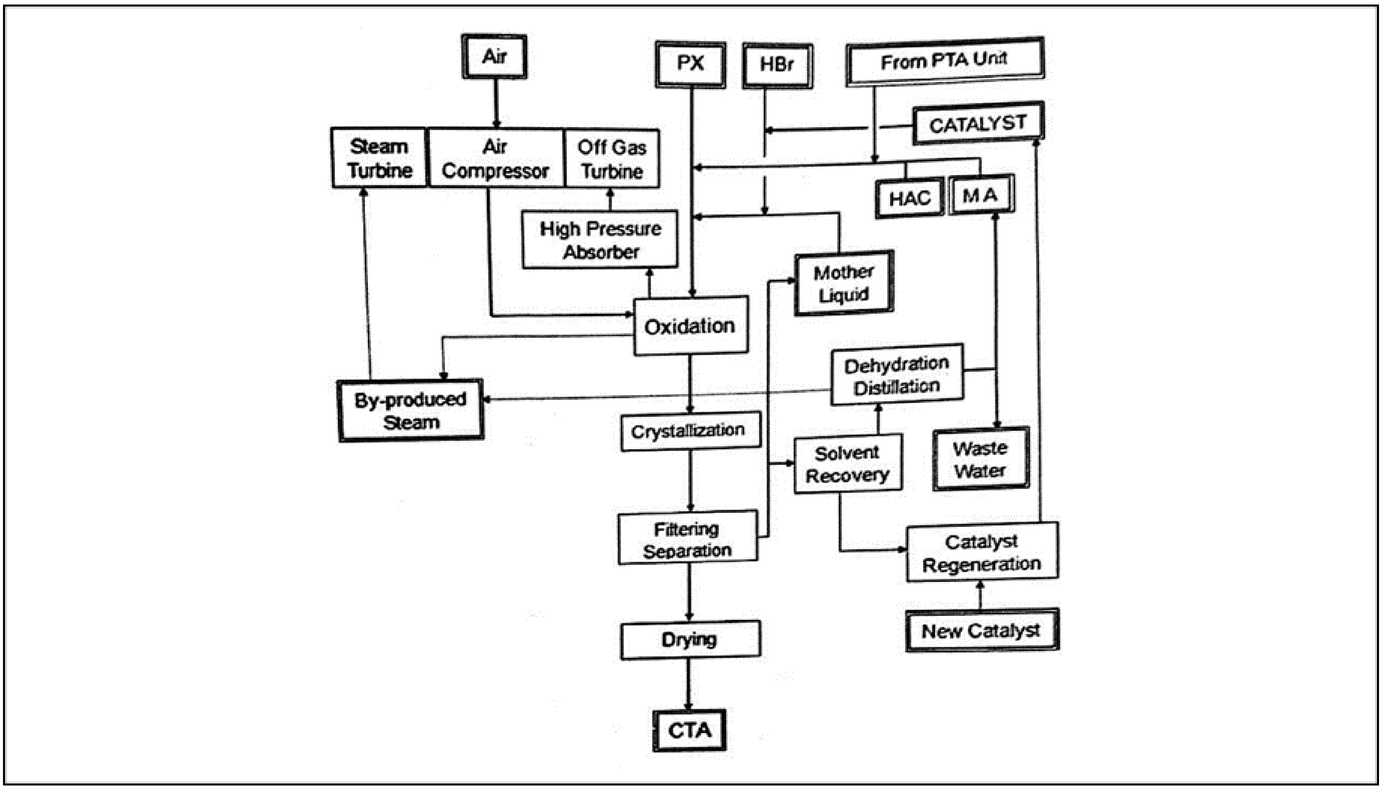


Fig 4: Production of Crude Terephthalic Acid

The Block Flow Diagram for the production of PTA in as follows. Refer Fig 5.

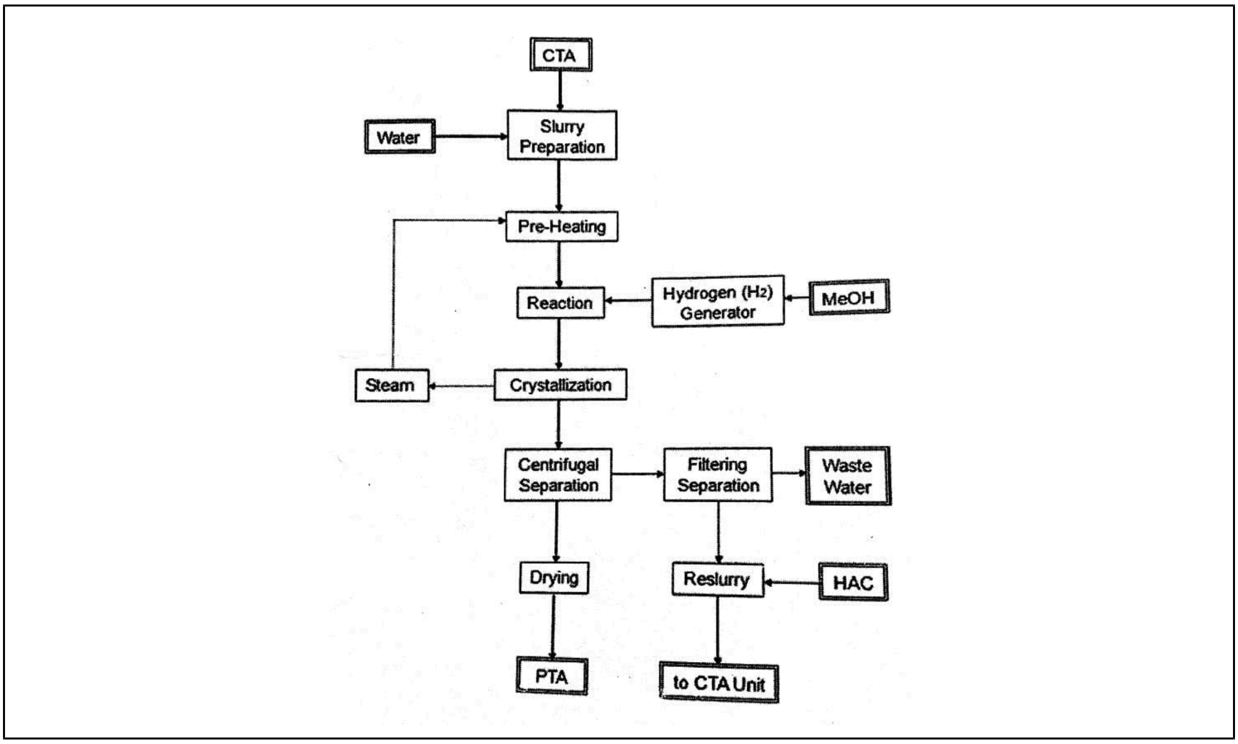


Fig 5: Production of Pure Terephthalic Acid

3. Health and Safety in MCPI (Haldia)

Safety is the first priority in MCPI. MCPI left no stones unturned to ensure the safety and sound health of all of its employees. Starting from entering into the company to processing to the supply of the product each and every field is well equipped with the adequate safety measures. All of its employees are given training on the health and safety in this chemical plant on the very first day and they are taken into the main processing area only after they acquire a handsome amount of knowledge in preventing any untoward accident in the chemical plant.

In each and every room of the MCPI-PTA there is speaker with the help of which the employees will be alerted in case any emergency occurs. In every nook and corner of the chemical plant alarms are installed so that the employees can immediately evacuate the plant.

Total 5 assembly points are there in the whole chemical plant where employees can gather in case emergency occurs. There are 5 assembly points (which is quite a large in number) to ensure a safe evacuation of the operators and technicians. So that they can immediately vacate the plant in case of emergency and reach a safer place.

There is a Non-Violable Safety Rules of MCPI Plant which is consisted of 9 points. It is a must follow for all of its employees. These safety points must be taken care of in day to day working in the chemical plant violating which stringent measures will be taken against the violators.

<u>The Non-Violable Safety rules are stated below</u>

1. Prohibited activities: Smoking, chewing of tobacco and carrying Lighter/ Match Box is strictly prohibited inside the factory Premises except designated places.
2. Entry to Plant: Unauthorized entry inside plant Battery Limit is strictly prohibited.
3. Vehicles Safety: Maintain speed limit up to 20km/hr and use of Spark Arrester is mandatory in vehicles inside Plant Battery Limit.
4. Information Reporting: All accidents/incidents must be reported to plant management.
5. Communication: Mobile Phone must be kept in Switch-Off condition inside Battery Limit.

6. General PPE: Use of Helmet, Safety Shoe, Full Sleeve Dress and Safety Spectacles inside Plant Battery Limit is mandatory.
7. Height Work: Full Body Harness and proper access (ladder etc.) is mandatory.
8. Confined Space Work: Spotter, Gas Testing and Full Body Harness are mandatory.
9. Hot Work: Isolation of Combustible/Flammable materials are mandatory and hot work to be confined.

Mitsubishi is a Japanese Chemical Company. Though TCG acquired it in 2016 financial year but company is still in a little touch with the Japanese accent.

The Company follows Go Anzen Ni!

Go **means** Please

Anzen **means** Safety

Ni **means** Keep

which in a single word means

Please Keep Safety

Each and Every Meeting starts with the say-

Go Anzen Ni!

And Ends with the say-

Safety First Yosh!

Which clearly indicates how much the company is promised to keeping safety of the employees and the entire nearby surroundings of the plant.

In a chemical Plant the major hazards are

- Chemical hazards- fumes and smoke, mists/aerosols, liquids etc.
- Mechanical hazards- unguarded/inadequate moving parts, defective tools.
- Physical hazards- combustible liquids, flammable fluids, oxidizer etc.
- Health hazards- toxicity, corrosiveness, carcinogen, reproductive toxins etc.

Which may arise due to some engineering failure or Leakage in the chemical storage container or pipes, damage of the materials, Corrosion, or improper maintenance of the preventive measures.

These causes are dealt with great care in MCPI (Haldia) plant. Time to Time full fledge maintenance work is carried out throughout the entire plant to ensure the good health of Boilers, Distillation Columns, Pipes, Storage Tanks each and every equipment.

A single mistake can destroy uncountable lives, massacring a lot number of families. When a person comes to work in the chemical plant his near and dear ones wait for him/her in the home. So, a single death can bring down a dark curtain on so many lives. Bereaved family's future will be in great uncertainty, so great care should be taken while working in the Chemical Plant, and employees must work safely.

- ❖ MCPI-PTA (Haldia) follows a HAZOP Study– Hazards and Operability Study.
- ❖ MCPI-PTA (Haldia) produces Purified Terephthalic Acid which is very much slippery in nature. The plant area where the PTA is produced, very frequently PTA falls on the staircase so technicians and workers working in that area should wear well gripped boots, and must step upon the floor very carefully otherwise they can fall and a serious injury is inevitable.
- ❖ The chemical leakage may occur due to build-up of excess pressure inside the pressure vessels so pressure valve must be operated properly to counter balance the build-up of pressure inside the vessel and avoid a bursting of the vessel.
- ❖ Chemical storage containers are provided with Dyke.
- ❖ Dyke is an embankment or wall built to act as a barrier blocking passage of liquids to surrounding areas.
- ❖ Whole plant of MCPI is well equipped with a sufficient number of fire extinguishers which will immediately take into control any fire hazard.

- ❖ All the employees and the persons coming inside the MCPI Plant must follow these 5 principles mostly stated as 5S Principles:
    - Sort (Seiri)- All unneeded items, tools, parts and supplies are removed from the area.
    - Systematic Arrangements (Seiton)- A place where everything is in its proper designated area.
    - Shine (Seisou)- The area is clean as the work is performed.
    - Standardise (Seiketsu)- Cleaning and identification methods are consistently applied.
    - Sustain/Self-discipline (Shitsuke)- 5S is a habit that is continually improved.

Necessity of 5S:

- To secure the workplace and safe passage to make sure that there are no obstacles.
- To prevent everyone from any unsafe condition on site.
- To find the sign of plant abnormality at early stages.
- Must prevent entry of foreign material to product.
- Must prevent lack of raw materials and equipment parts.
- To reduce the wasting time for searching.
- To utilize the workplace affectively.
- Improvement of workplace atmosphere through 5S principles.

MCPI (Haldia) is totally devoted to work in healthy and safe environment. Sufficient safety measures have been taken to avoid any untoward incidents. On the Entrance Main Gate, it is written in bold “Safety First”. Everywhere inside the plant big hoardings and murals are there to ensure safety whose main aim is to instil a feeling among its employees that in any condition Safety Rules and Regulations must be followed with great care.

The company also won the 1st prize in Health and Safety in the year 2020.

4. CTA Section and PTA Section Flow diagram

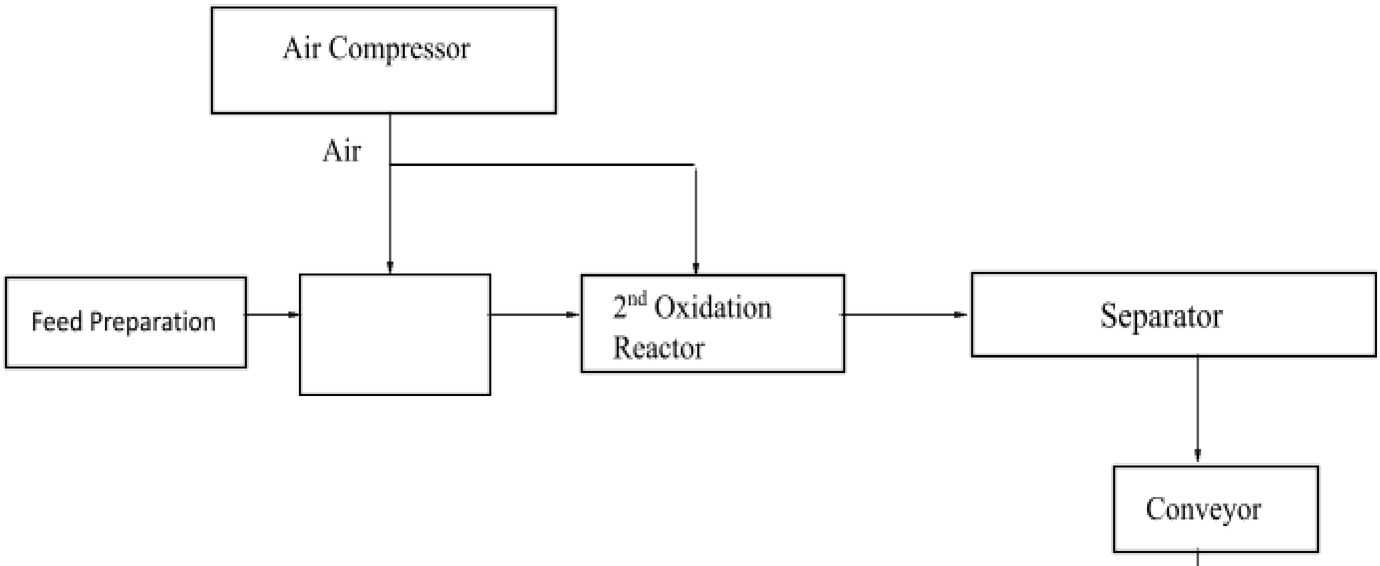
CTA Reactions

Main Reaction

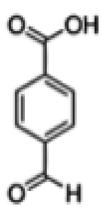
Side Reactions

$$CH_3COOH + 2\ O_2 \longrightarrow 2\ CO_2 + 2H_2O$$

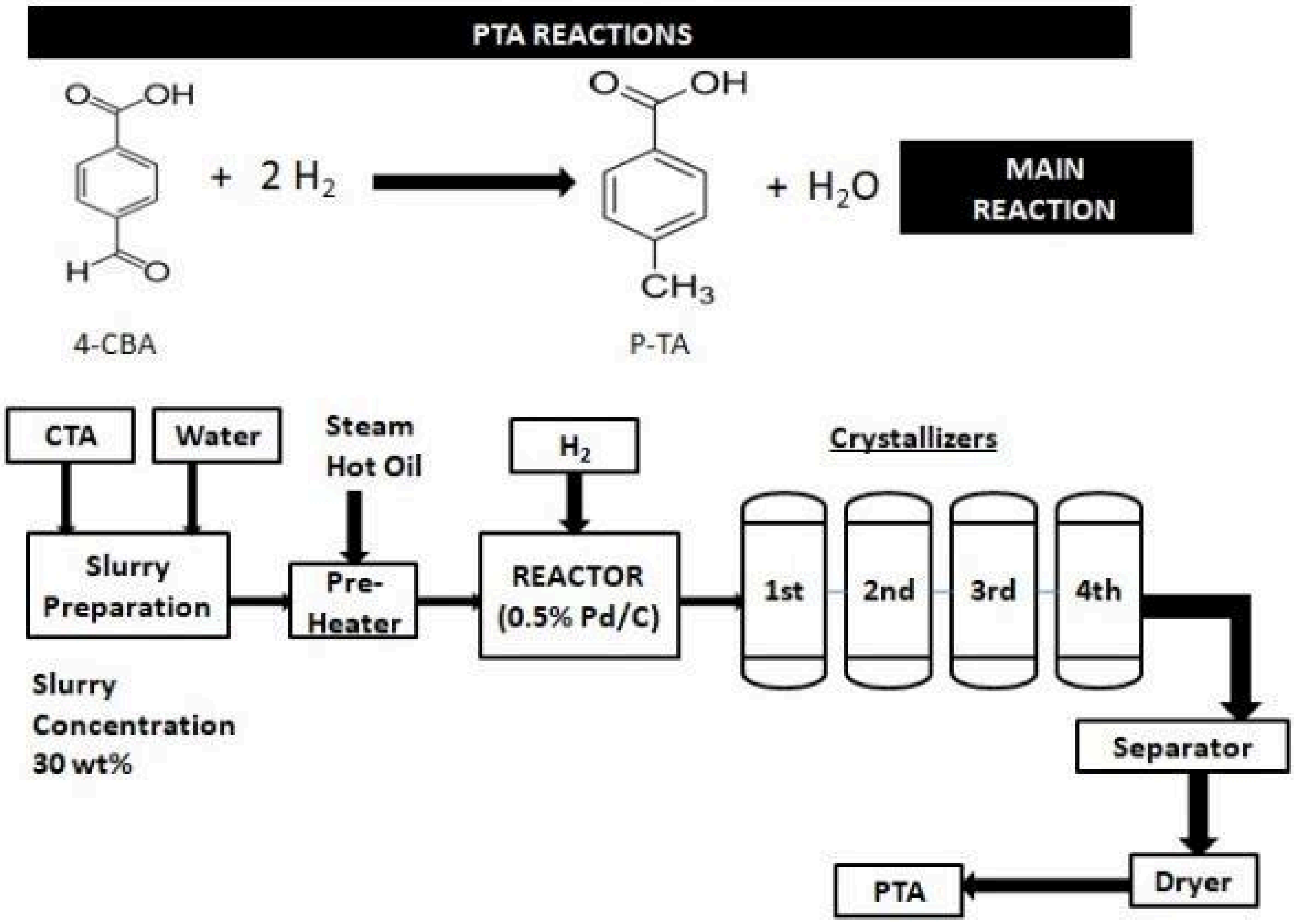
$$2\ CH_3COOH \longrightarrow CH_3COOCH_3 + CO + H_2O$$



Main Impurity



4 - Carboxyl Benzaldehyde
(900-1100 ppm in HP)
(2400-2500 ppm in DP)



PTA REACTIONS
OH
O
+ 2 H_2
H
O
4-CBA
O
OH
CH_3
P-TA
+ H_2O
MAIN
REACTION
CTA
Water
Steam
Hot Oil
H_2
Crystallizers
Slurry
Preparation
Pre-
Heater
REACTOR
(0.5% Pd/C)
1st
2nd
3rd
4th
Slurry
Concentration
30 wt%
Separator
Dryer
PTA

5. Details about the Process

Main Raw material is Para-Xylene

CTA Preparation Process is an exothermic process.

Exothermic process gives out heat which can utilized for other purposes, and also heat should not be released directly into the atmosphere because that may create environmental hazards.

First, look for any endothermic reaction taking place inside the plant the heat released can be utilized in carrying out the endothermic reaction.

MCPI (Haldia) has installed two plants,

I) DP Plant

This plant has been in operation since 2000 (April) the time when the company started its operation for the first time. Operation Making of this DP Plant is Mitsubishi Heavy Industries.

II) HP Plant

This plant has been in operation since 2010 (April). It has been installed a decade after the DP Plant started its operation. Operation Making of this HP Plant is Siemens Germany.

There are two sections in each plant.

I) CTA Section

II) PTA Section

Both the section does not run parallelly but in series. We can start the process as soon as we get CTA. We can store some amount of CTA in that case we can run both the CTA and PTA section parallelly. But both the sections CTA and PTA can be run parallelly only for a short period of time because we store the crude CTA in a small amount.

Crude Section Reaction is an Exothermic Reaction. Purification of Crude Terephthalic acid Section reaction is a Hydrogenation Reaction which is an Endothermic Reaction.

Oxygen is taken from ambient air. Oxidation reactions is taking place in certain conditions not in ambient conditions. The air must be pressurized. Air is pressurized by the use of compressor.

Compressor is the heart of the plant. 4 stage compressor is used in HP Plant.

The outlet pressure is taken at such a stage whose pressure is higher than the pressure required for the reaction. Because the way through which the compressed air is supplied may lead to frictional losses thereby reducing its pressure at the inlet of the oxidation reactor. Initial compressor is run by motor which takes electricity. Once the plant comes in operation condition then we get some energy from the plant in order to run the motor.

Waste heat is utilized to produce steam by adding water, then steam is taken into rotate the turbine. Compressor means a shaft which has to be rotated. If we can couple this shaft with the rotating turbine then that rotating turbine can rotate the compressor.

Finally, the flue gas after giving a good amount of heat almost no energy left in it the that flue gas (contains a little amount of energy) is introduced into a gas turbine.

Gas turbine also known as gas expander. Pressure gets lowered and the gas expands that is the boiling takes place at lower temperature only.

Flue gas is taken through a heat exchanger. Gas passes through the tube. Water is taken in shell side. Water gets heated up, and forms steam. Gas contains traces amount of acetic acid, moisture. This gas is taken into a condenser pot. There are a series of heat exchangers. After passing through heat exchanger low energy flue gas is taken into an expander. The heat exchanger is known as Boiler.

Series of heat exchanger according to the decreasing order of temperature

$T_1>T_2>T_3>T_4$ and so on.

When temperature gets reduced and the water has to be boiled at that reduced temperature then the pressure must be lowered. The water will start to boil at low temperature only after reducing the pressure.

Turbine has different section,

I) One section for the induction of high-pressure steam.

II) One section for the induction of low of low-pressure steam.

III) Another section for the induction of vacuum-steam.

Vacuum steam is the steam which is at a pressure lower than the atmospheric pressure.

<u>Difference between HP and DP Plant.</u>

H.P Plant: There is supply of huge amount of steam, which is enough to rotate the motor of compressor, but then even so much of heat energy left that the compressor can be converted to a generator.

So much amount of steam is there that we can generate electricity in the H.P Plant. Earlier in the operation of D.P Plant we were reducing the amount of power taken from the electricity board thereby reducing the amount of power required saving the cost. But now in the operation of H.P Plant even after reducing the electricity requirement of the compressor electricity can even be generated.

Then a synchronous motor is made inside the compressor in the H.P Plant. At a time, it can work as a motor as well as generator at another time. This generation of electricity mechanism is present in H.P plant but not in D.P Plant.

Electricity generation Capacity in H.P Plant: - 10-11 MW/ hour.

D.P Plant P.T.A Production Capacity → 470 kiloton/ year.

H.P Plant P.T.A Production Capacity → 800 kiloton/year.

5.1. CTA Section

Raw material: Para Xylene

Solvent: Acetic Acid

Promoter: HBr

Catalyst: Cobalt Acetate, Manganese Acetate.

This CTA reaction is same for both the D.P Plant as well as H.P Plant.

In H.P Plant;

L/D <1 (because it is of high capacity)

H.P Plant is of ellipsoid shape in nature.

For CTA Section reaction both the plants use CSTR.

Drawback of L/D<1 ⟶ Escape velocity of toxic gas particles is high and it can come out easily so operation should be carried out carefully.

D.P Plant contains Crystallizer.

Reactor I: Liquid to slurry.

Reactor II: Slurry gets dense.

Reactor II Operates at a pressure lower than the pressure at which reactor I operates. Then crystallizers are installed which forms crystals slowly.

After reactor II, 2 Crystallizers are installed (to slowly convert the liquid CTA into wet Particles). At consecutive crystallizer pressure decreases thereby temperature decreases and the wet particles crystallizes out. Agitator is there inside the reactor to prevent the particles from settling down inside the crystallizer.

H.P. Plant does not contain Crystallizer. H.P Plant contain reactor I then reactor II.

D.P Plant contain reactor-I then reactor- II then consecutive 2 crystallizer.

Dry CTA powder is required.

D.P Plant contains filter, which filters out the liquid from the solid. But after passing from the filter the solid is wet in nature. Liquid filtered out is again going back to the reactor for recycle process.

To dry the wet solid steam tube dryer is used. Boiler steam is utilized in dryer. In tube side wet powder is taken. Shell side contains steam.

Dryer will choke if remain stationary, so dryer should always be rotated at an inclined angle.

Solid-Liquid Separator (Decanter): It is a centrifugal separator. In the place of crystallizer, we use decanter in H.P. Plant. D.P. plant also contains one decanter but not in crude section decanter is present in the PTA section.

H.P Plant contains hybrid decanter.

Horizontal decanter + Super decanter.

Product from Reactor II directly enter into hybrid decanter at high pressure. Heavy particles settle down inside the decanter. Vessel is made which is at a slight negative pressure.

High pressure product from decanter enters into the vessel at a low pressure. Due to high pressure difference a flushing will take place. Moisture will immediately evaporate due to flushing. Powder gets dried.

In the place of steam tube drier which is present in the D.P. Plant In H.P Plant we use a large vessel.

No steam heating is required.

No rotation is required.

Nothing, only a large vessel is installed.

5.2. PTA Section

PTA is kept in large silo bags. Some amount of crude T.A is kept in storage so that we can carry out the PTA section for some days even if CTA section goes out of operation.

Solvent: Water

Catalyst: Pd and C

Palladium is impregnated on charcoal this catalyst is totally packed in packed bed reactor.

Firstly, Solid CTA is dissolved into water. In CTA plant we dry the CTA because liquid CTA contains acetic acid, which must not enter into PTA section. Therefore, to remove acetic acid from CTA we dry the liquid CTA in CTA section. In CTA section acetic acid carries moisture. In PTA section water carries moisture. So acetic acid must be prevented from entering into the PTA section.

The reaction taking place in PTA section is endothermic.

We give heat thereby temperature rises as a result pressure also rises.

CTA ⟶ 15.5 kg/cm^2 gauge.

PTA ⟶ 76-78 kg/cm^2 gauge.

Dissolved CTA in water is then passed through a series of pre-heaters. Gradually, temperature is increased in series of pre-heaters and dissolved CTA gets more and more dissolved. Finally, we get a very dilute solution of CTA in water.

This solution is then passed through PTA packed reactor. Hydrogen is also passed.

Hydrogen is prepared in MCPI plant only by steam cracking of methanol Zn-Cu catalyst. MCPI do not buy hydrogen from outside.

Reduction Reaction is taking place in PTA

Redox reaction is taking place in hydrogen preparation cracking of methanol. Since it is passed through a bed of reactor no more reactor is needed to carry out this reaction.

Again, we have to go for crystallization to get the solids i.e., to separate the liquid from solid.

Crystallizer order. I ⟶ II ⟶ III ⟶ IV

From such a high pressure to get down to low pressure we require a very large vessel which is not economical. So, step by step pressure is reduced. These 4 crystallizers are installed in both the plants.

76 kg/cm^2 gradually gets reduced to 5.5-6 kg/cm^2. (Pressure reduction)

Drop in 72 kg/cm^2. To reduce the high pressure into such a low pressure we use a series of crystallizers. Like this:

76 kg/cm^2 ⟶ 40 kg/cm^2 ⟶ 22.5 kg/cm^2 ⟶ 12.5 kg/cm^2 ⟶ 5 kg/cm^2

Reduction in pressure so it will give out heat that heat is utilized in another process going inside the plant. Solution preparation stage uses heat there we will use the heat rejected by crystallizer.

At the latest stage, before entering into final chamber, 288-275°C must be reached. Heat or vapors from crystallizer is not enough to produce that amount of temperature. So, at the latest we have to use something else which is above 280°C so it may create a temperature difference driving force. So, we use a thermic fluid. Temperature of thermic fluid kept at 320ºC After passing through series of crystallizer it is passed through a series of decanter. Liquid part is taken into recycle plant. Solid part is taken into dryer (Static dryer). Fluidized Bed Dryer is used in PTA.

Inert gas is heated. Bed contains a number of holes in it. Hollow steam plates are installed inside. Wet power is given as feed. Wet powder will not settle down because we are applying hot inert gas it will create a bubbling phase. Wet powder will collide with the steam plate and leave the moisture, zig-zag motion is initiated through the alternate holes on the steam plate.

Product ⟶ Dry Powder

Dry powder is packed. Binary distillation takes place in D.P Plant to separate acetic acid and water.77 trays are there. Number of trays are more in D.P Plant distillation column. Residue water must contain acetic acid as low as possible. Acetic acid is costly. Residue waste water contain acetic acid =0.9% or 0.8 %. (700-800 ppm).

H.P ⟶ Azeotropic Distillation.

So, size of installation column has reduced A entrainer is introduced into the solution.

Water Acetic acid, Entrainer ----N.B. A (Entrainer varies company-wise)

MCPI uses N.B.A

Para-Xylene itself is an entrainer. Entrainer is used to reduce the boiling point of solution. So, the acid content in residue water decreases. (400 ppm, 500 ppm, 600ppm)

Steam requirement for boiling the feed also decreases i.e., the steam requirement for distillation decreases. Mo of trays has been reduced as packings are introduced (40-45).

F.C.B ⟶ Flexible Container Bags

Within F.C.B products are packed, or big container are used to pack the product.

Inside the crystallizer agitator is used to prevent the crystals from settling down.

6. Equipment functioning in MCPI- PTA Plant

6.1. Pumps

Centrifugal Pumps

In this major class of pumps, the mechanical energy of the liquid is increased by centrifugal action. A simple but very common, example of a centrifugal pump is shown in the Figure. The liquid enters through a suction connection concentric with the axis of a high-speed rotary element called the impeller, which carries radial vanes integrally cast in it. Liquid flows outward in the spaces between the vanes and leaves the impeller at a considerably greater velocity with respect to the ground than at the entrance to the impeller. In a properly functioning pump, the space between the vanes is completely filled with the liquid flowing without cavitation. The liquid leaving the outer periphery of the impeller is collected in a spiral casing called the *volute* and leaves the pump through a tangential discharge connection. In the volute the velocity head of the liquid from the impeller is converted to pressure head. The power is applied to the fluid by the impeller and is transmitted to the impeller by the torque of the driveshaft, which usually is driven by a direct-connected motor at s constant speed, commonly art 1,750 or 3,450 rpm. Refer Fig 6.

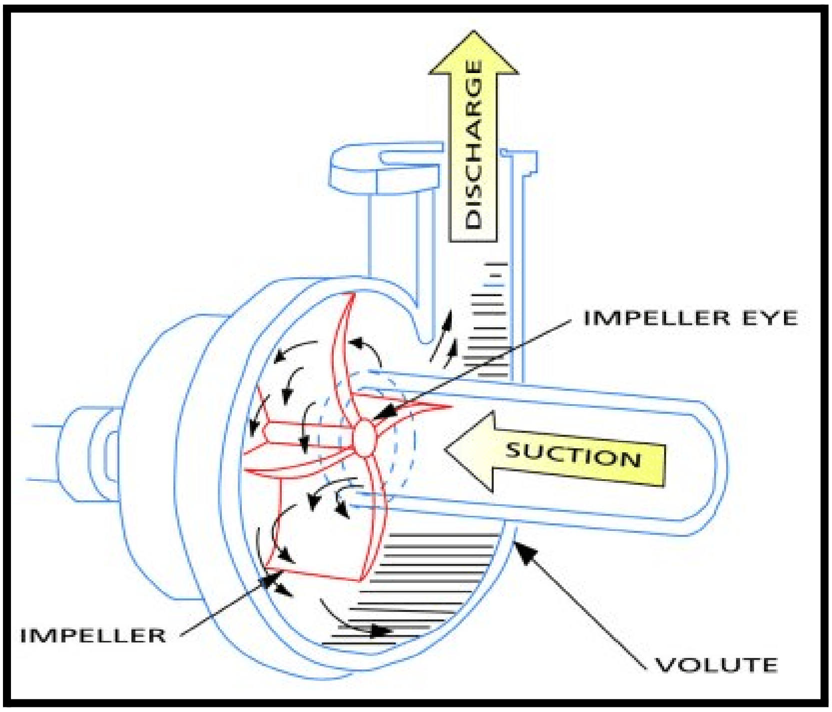


Figure 6: Centrifugal Pump.

Advantages of Centrifugal pump:

1. Small in size, space saving & less capital costs
2. No danger creates if discharge v/v is closed while starting
3. Able to work medium to low head
4. Able to work medium to low viscous fluid

Disadvantages of Centrifugal pump:

1. Extra priming P/P requires.
2. Cannot be able to work high head.
3. Cannot deal with high viscous fluid.

Multistage Centrifugal Pumps

Usage inside the PTA Section of H.P Plant: - Booster pump is used to increase the pressure head of the slurry coming from the pump in-stalled just after the slurry tank. Booster pump is there just before the pre-heaters, the slurry after passing through the booster pump directly goes into the pre-heaters.

The maximum head that is practicable to generate in a single impeller is limited by the peripheral speed reasonably attainable. A so-called high energy centrifugal pump can develop a head of more than 650 ft (200 m) in a single stage; but generally, when a head greater than about 200ft (60 m) is needed, two or more impellers can be mounted in series on a single shaft and a multistage pump so obtained, the discharge from the first stage provide suction for the second, the discharge from the second provides suction for the third, and so forth. The developed heads of all stages add to give a total head several times that of a single stage.

Reciprocating pumps

Piston pumps, plunger pumps, and diaphragm pumps are examples of reciprocating pumps. In a piston pump, liquid is drawn though an inlet check valve into the cylinder by the withdrawal of a piston and then is forced out through a discharge check valve on the return stroke. Most piston pumps are double acting with liquid admitted alternatively on each side of the piston so that one part of the cylinder is being filled while the other is being emptied. Often two or more cylinders are used in parallel with common suction and discharge headers, and the configuration of the piston is adjusted to minimize fluctuations in the discharge rate. The piston may be motor-driven through reducing gears, or a steam cylinder may be used to drive the piston rod directly. The maximum discharge pressure for commercial piston pumps is about 50 atm. Refer Fig 7.

Advantages of Reciprocating pump:

1. High efficiency.
2. No priming needed.
3. Delivery of fluid at high pressure and a wide pressure range.
4. Continuous rate of discharge.

Disadvantages of Reciprocating pump:

1. High initial and maintenance cost.
2. Low discharging capacity.
3. Non uniform torque.
4. Difficult to pump viscous fluids.
5. Pulsating flow.

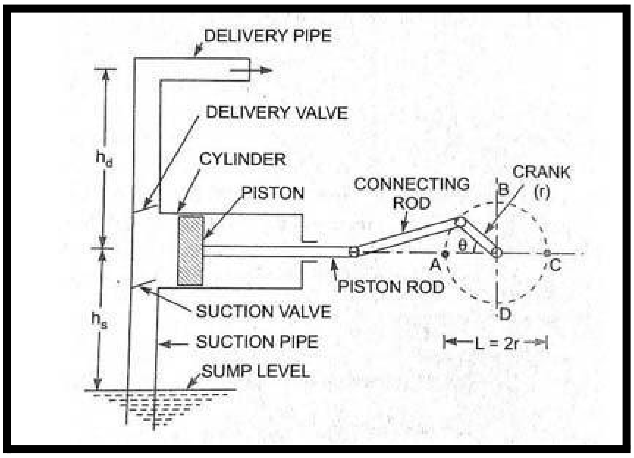


Fig 7: Reciprocating Pump

Rotary Pumps

Unlike reciprocating pumps, rotary pumps contain no check valves. Close tolerance between the moving and stationery parts minimizes the leakage from the discharge space back to the suction space; they also limit the operating speed. Rotary pumps operate best on clean, moderately viscous fluids, such as light lubricating oil. Discharge pressures up to 200 atm or more can be attained.

Gear Pumps

Usage in the MCPI Plant: - Gear pumps are there inside the furnace to pump the heavy oil.

In the spur-gear pump intermeshing gears rotate with close clearance inside the casing. Liquid entering the suction line at the bottom of the casing is caught in the spaces between the teeth and the casing and is carried around to the top of the casing and forced out the discharge. Liquid cannot short-circuit back to the suction because of the close meshing of the gears in the center of the pump. Refer Fig 8.

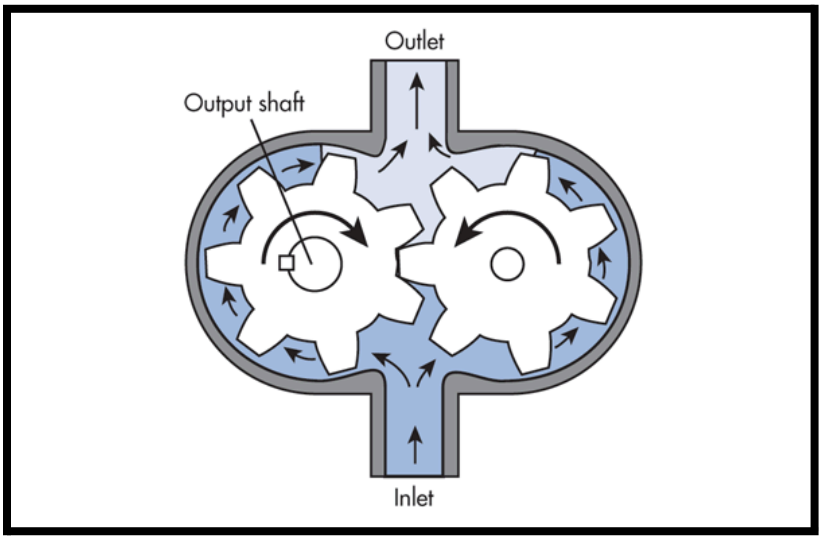


Fig 8: Spur -gear Pump

Internal Gear Pump: In the internal gear pumps a spur gear, or pinion, meshes with a ring gear with internal teeth. Both gears are inside the casing. The ring gear is coaxial with the inside of the casing, but the pinion, which is extremely driven, is mounted eccentrically with respect to the center of the casing. A stationary metal crescent fills the space between two gears. Liquid is carried from inlet to discharge by both gears, in the spaces between the gear teeth and the crescent. Refer Fig 9.

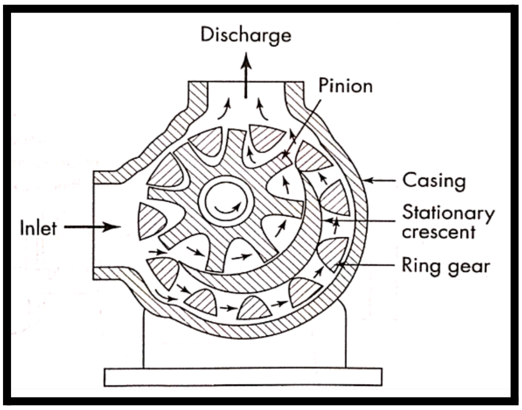


Fig 9: Internal Gear Pump

6.2. Blowers and Compressors

When the pressure on a compressible fluid is increased adiabatically, the temperature of the fluid also increases. The temperature rise has a number of disadvantages, Because the specific volume of the fluid increases with temperature, the work required to compress a pound of fluid is larger than if the compression were isothermal. Excessive temperature leads to problems with lubricants, stuffing boxes, and materials of construction. The fluid may be one that cannot tolerate high temperatures without decomposing.

For the isentropic (adiabatic and frictionless) pressure change of an ideal gas, the temperature relation is using Equation,

$$\frac{T_b}{T_a} = \left(\frac{p_b}{p_a}\right)^{1-\frac{1}{\gamma}}$$

Where Ta, Tb = inlet and outlet absolute temperatures, respectively

p_a, p_b = corresponding inlet and outlet pressures

γ = ratio of specific heats c_p/c_v

For a given gas, the temperature ratio increases with an increase in the compression ratio p_b/p_a. This ratio is the basic parameter in the engineering of blowers and compressors. In blower with a compression ratio below about 3 or 4, the adiabatic temperature rise is not large, and no special provision is made to reduce it. In, compressors, however, where the compression ratio may be as high as 10 or more, the isentropic temperature becomes excessive. Also, since actual compressors are not frictionless, the heat from friction is absorbed by the gas, and temperatures well above the isentropic temperature are attained. Compressors, therefore are cooled by jackets through which cold water or refrigerant is circulated. In small cooled compressors, the exit gas temperature may approach that at the inlet, and isothermal compression is achieved. In very small ones, air cooling by external fins cast integrally with the cylinder is sufficient. In larger units, where cooling capacity is limited, a path different from isothermal or adiabatic compression, called polytropic compression is followed. Refer Fig 10.

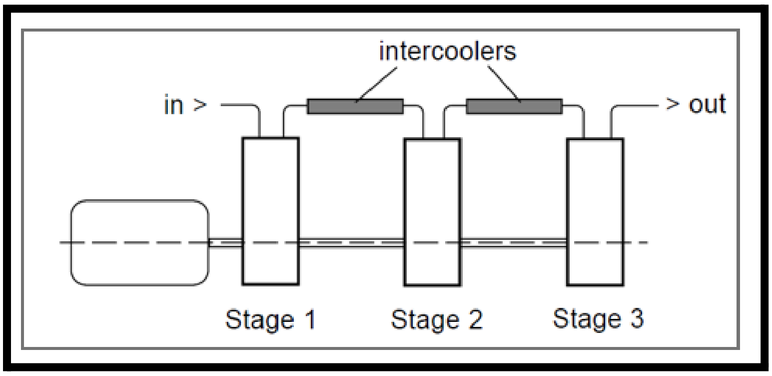


Fig 10: Structure of compressors

Centrifugal Compressors

Usage inside the CTA Section of H.P Plant: Centrifugal Compressor is used to compress the ambient air and increase the pressure up to 1.75 MpaG and pass the compressed air to the CSTR oxidation reactor where the oxidation of para-xylene takes place.

Centrifugal Compressors are multistage units containing a series of impellers on a single shaft rotating at high speeds in a massive casing. Internal channels lead from the discharge of one impeller to the inlet of the next. These machines compress enormous volume of air or process gas up to 200,000 ft^3/min (340,000 m^3/h) at the inlet-to an outlet pressure of 20 atm. Smaller-capacity machines discharge at pressure up to several hundred atmospheres. Interstage cooling is needed on the high-pressure units. Figure shows a typical centrifugal compressor.

Axial-flow machines handle even larger volume of gas, up to 600,000ft^3/min ($1*10^6$ m^3/h), but at lower discharge pressure of 2 to 12 atm. In these units the rotor vanes propel the gas axially from one set of vanes directly to the next, Interstage cooling is normally not required. Refer Fig 11.

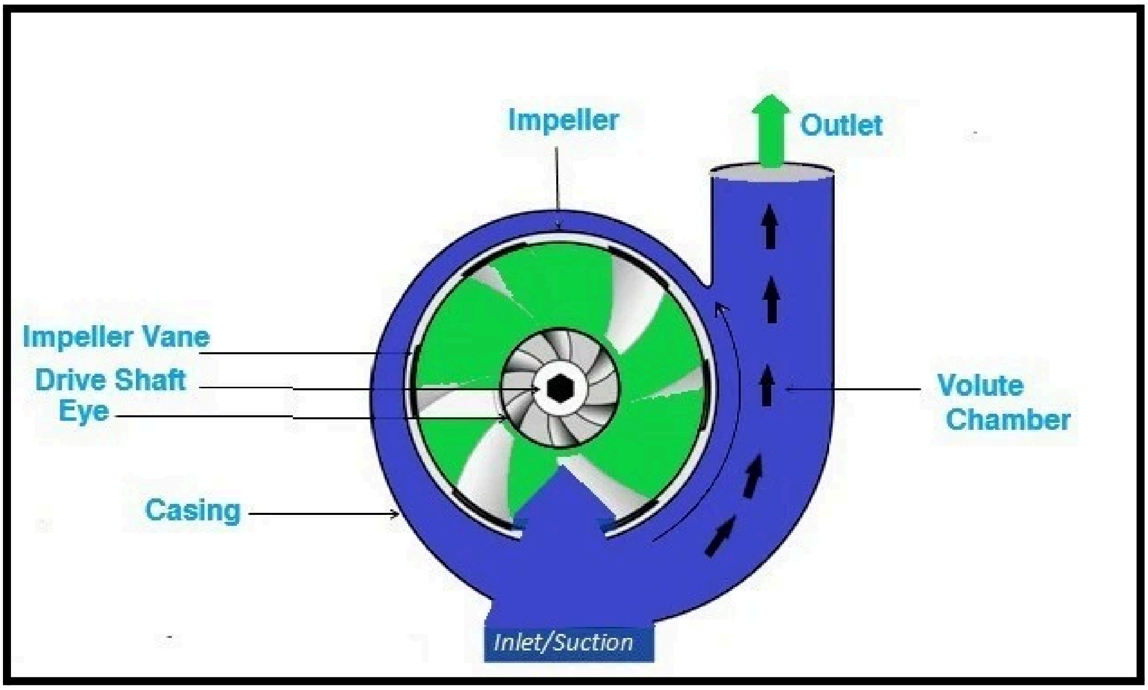


Fig 11: Centrifugal Compressor

Advantages of Centrifugal Compressor

1. Wide operating Range.
2. High Reliability.
3. Low maintenance.

Disadvantage of Centrifugal Compressor

1. Instability at reduced flow.
2. Sensitive to gas composition change.

Centrifugal Blowers

A single-stage centrifugal blower is shown in Figure. In appearance it resembles a centrifugal pump, except that the casing is narrower and the diameters of the casing and discharge scroll are relatively larger than in centrifugal pump. The operating speed is high--- 3,600 rpm or more. High speeds and large impeller diameters are required because very high heads, in meters or feet of low-density fluid, are needed to generate modest pressure ratios. Thus, the velocities appearing in a diagram like Figure are for a centrifugal blower, approximately 10 times those in a centrifugal pump. Refer Fig 12.

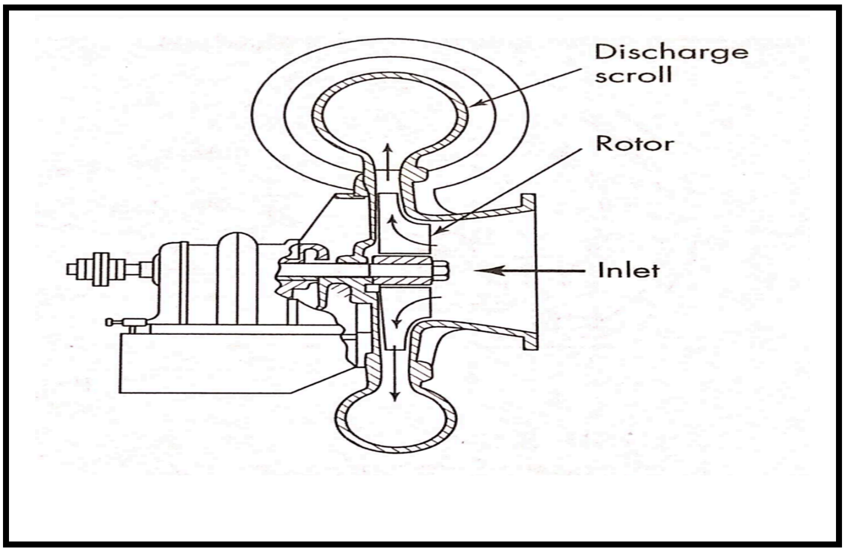


Fig 12: Single suction Centrifugal Blower.

6.3. Crystallizers

Usage in the MCPI Plant: - Crystallizers are used in series in the CTA section of the D.P Plant and also in the PTA section of both H.P Plant as well as D.P Plant. This is used to get the crystals of CTA or PTA. It converts the highly diluted solution to a concentrated one. Most crystallizers utilize some form of agitation to improve growth rate, to prevent segregation of supersaturated solution that causes excessive nucleation, and to keep crystals in suspension throughout the crystallizing zone. Internal propeller agitators may be used, often equipped with draft tubes and baffles, and external pumps also are common for circulating liquid or magma through the supersaturating or crystallizing zones. The latter method is called forced circulation. One advantage of forced-circulation units with external heaters is that several identical units can be connected in multiple effect by using the vapor from one unit to heat the next in line. Systems of this kind are evaporator-crystallizers. Refer Fig 13.

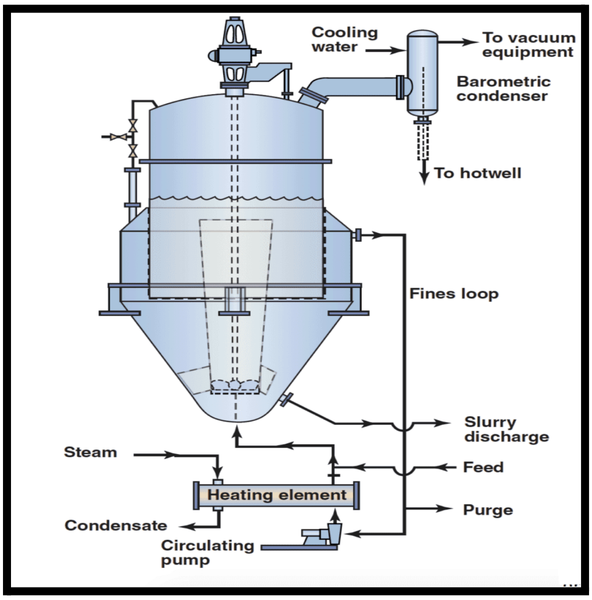


Fig 13: Crystallizer

6.4. Continuous Stirred Tank Reactor

A Continuous Stirred Tank Reactor (CSTR) is a reaction vessel in which reagents, reactants and often solvents flow into the reactor while the product(s) of the reaction concurrently exit(s) the vessel. In this manner, the tank reactor is considered to be a valuable tool for continuous chemical processing.

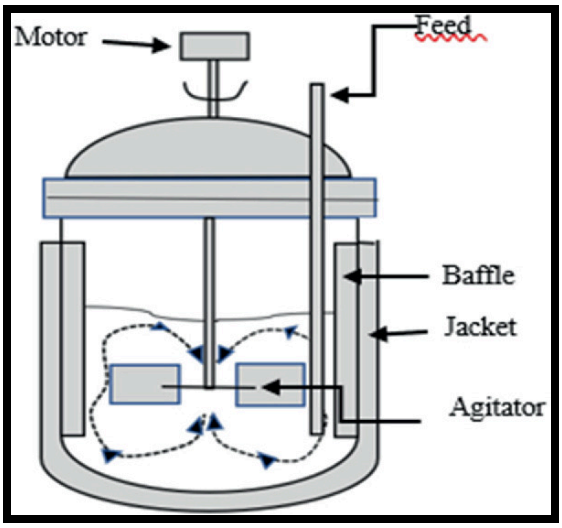


Fig 14: CSTR

CSTR reactors have effective mixing and perform under steady-state with uniform properties. Ideally, the output composition is identical to composition of the material inside the reactor, which is a function of residence time and reaction rate. In situations where a reaction is too slow or when two immiscible or viscous liquids are present requiring a high agitation rate, several Continuous Stirred

Tank Reactors (CSTRs) may be connected together forming a cascade. Refer Fig 14.

A Continuous Stirred Tank Reactor (CSTR) assumes ideal mixing. CSTRs are most commonly used in industrial processing, primarily in homogeneous liquid-phase flow reactions where constant agitation is required. However, they are also used in the pharmaceutical industry and for biological processes, such as cell cultures and fermenters.

6.5. Shell and Tube Heat Exchangers

Usage in the MCPI Plant: - Shell and Tube Heat Exchangers has a wide role to play in the whole process. The preheater unit contains a total of 7 shell and tube heat exchangers arranged in series. Boiler which is used to produce the steam to rotate the turbine is also a shell and tube heat exchanger.

In MCPI Plant preheater 1-2 Shell and tube pass heat exchangers are used. An even number of tube side passes are used in multi-pass exchangers. The shell side may be either single-pass or multi-pass. A common construction is the 1-2 parallel-counterflow exchanger, in which the shell-side liquid flows in one pass and the tube side liquid in two passes. Such an exchanger is shown in the Figure. The tube-side liquid enters and leaves through the same head, which is divided by a baffle to separate the entering and leaving tube-side streams.

The 1-2 exchanger is normally arranged so that the cold fluid and the hot fluid enter at the same end of the exchanger, giving parallel flow in the first tube pass and counterflow in the second. This permits a closer approach at the exit end of the exchanger than if the second pass were parallel.

Here in MCPI Plant preheater unit; 1st heat exchanger uses the steam from the condenser as a shell side fluid to heat up the slurry and dissolve it well, 2nd and 3rd heat exchanger uses heat rejected by 2nd and 3rd crystallizer, 4th and 5th heat exchanger uses the heat rejected by 1st crystallizer, and the last two 6th and 7th heat exchanger uses hot oil therminol-66 as the shell side fluid. Refer Fig 15.

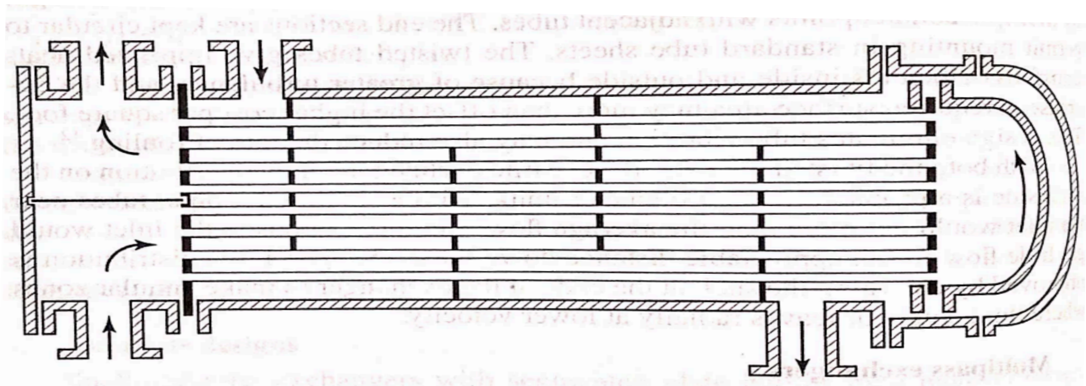


Fig 15: 1-2 parallel-counterflow exchanger.

<u>Hydrogen Production Unit</u>

Usage in the MCPI Plant: - Hydrogen required in the packed bed reactor for carrying out the hydrogenation reaction in PTA section is produced inside the plant only. MCPI does not buy hydrogen from the outside vendor. On the 13 m floor of the H.P Plant there is one hydrogen producing unit.

Steam-hydrocarbon Process: The reaction between hydrocarbons, especially methane and propane, and steam to produce carbon oxides and hydrogen is highly exothermic. With propane as the raw material the reactions are

$$C_3H_8\ (g) + 3H_2O\ (g) \longleftrightarrow 3CO\ (g) + 7\ H_2O\ (g)$$

Desulfurized propane is mixed with steam and passes through the hydrogen furnace where reaction take place at about 1500ºF over a nickel catalyst. At the furnace outlet, more steam is added to cool the gas to about 750ºF, and to increase the partial pressure of the H_2O. The mixture is passed into an iron oxide shift convertor where most of the CO is oxidized to CO_2. The gas is conducted through a heat exchanger and into the first CO_2 absorber where a stream of mono-ethanolamine's solution removes the CO. At the absorber outlet, steam is mixed with the gas, and the mixture is passed through the heat exchanger, where it is heated and the oxidation and absorption cycle are repeated two or more times. The final product (hydrogen) is more than 99.9 per cent pure, with less than 0.01 per cent of CO or CO_2, and less than 0.1 per cent residual hydrocarbons.

6.6. Steam Reformer

The reaction taking place inside is an endothermic reaction. At the lower end of the reformer tubes temperature reaches minimum level. When the catalyst loses its activity the minimum point of temperature reaches more down inside the reformer tubes. the temperature profile is seen from the D.C.S and the engineers comes to know that the catalyst is malfunctioning and then the arrangement is done to change the catalyst.

6.7. Centrifugal decanter

A decanter is an equipment used for the separation of suspended solids from a liquid. This separation is based on buoyancy, where the component with the higher density would fall to the bottom, and the component with the lower density would be suspended above it. By continuous rotation, the decanter enables the increase in the rate of settling.

The action of the centrifuge multiplies the g-force considerably, since it is the only variable that can be altered, provided that inlet conditions remain constant. The increase in the g-force results in an increase in the settling speed, which further results in the decrease of the time required for settling. Refer Fig 16.

In order to further increase the efficiency, a bowl is included within the decanter's construction. This bowl contains both a cylindrical and a conical section, along with a screw conveyor, which continuously scrapes the solids from the sides of the bowl.

The

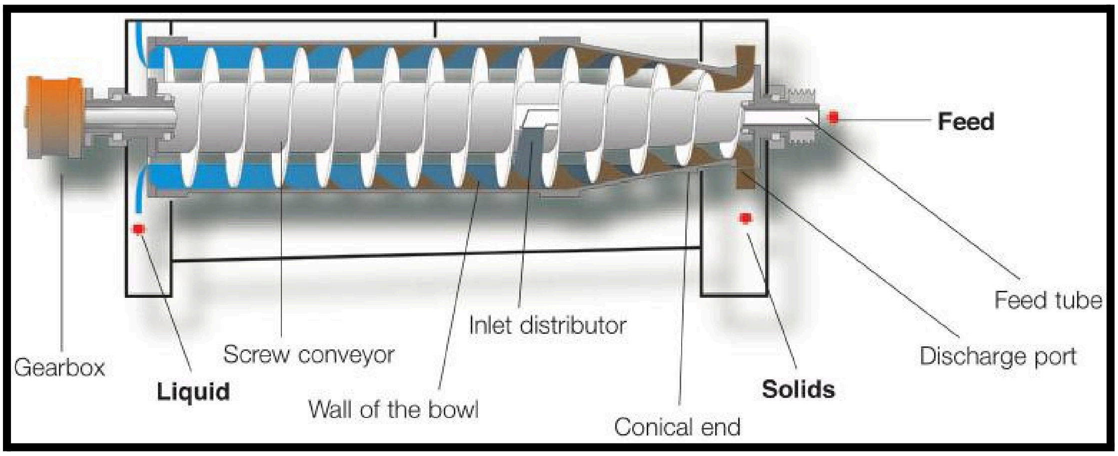


Fig 16: Centrifugal Decanter

slurry is fed to the centrifuge via a pipe. The conveyor then transports the slurry to a nozzle, and is transferred through it to the bowl area. The bowl rotates at high speeds to induce gravitational forces, thus separating the two components. The conveyor then passes the solids, which are discharged through the nozzle. The purified liquid exits via a different pathway.

6.8. Conveyers

Pneumatic Conveyor

The suspending fluid in a pneumatic conveyor is a gas, usually air, flowing at velocities between 15 and 30 m/s in pipes ranging from 50 to 400 mm in diameter. The principal types of systems are -

(1) negative-pressure (vacuum) systems, useful in transferring the solids from multiple intake points (railroad cars, ships, holds, etc.) to a single delivery point; (2) positive pressure systems best for one intake point and one or more points of delivery;

(3) vacuum-pressure systems, which combine the advantage of the negative pressure systems and positive pressure systems; and

(4) pre-fluidized systems, which require less air, and consequently less power, than any of the other methods. Refer Fig 17.

Materials handled range in particle size from fine powders to 6.5-mm pellets, and in bulk density from 16 to more than 3,200 kg/m^3. Vacuum systems are typically limited to solids flow rates less than 6,800 kg/h and equivalent conveyor lengths less than 300 m. 0 Pressure systems operate at 1 to 5 atm gauge and are used for free-flowing solids of particles less than 6.5 mm in size, where flow rates greater than 9,000 kg/h are needed. Typically, the pressure loss through the system is about 0.5 atm.

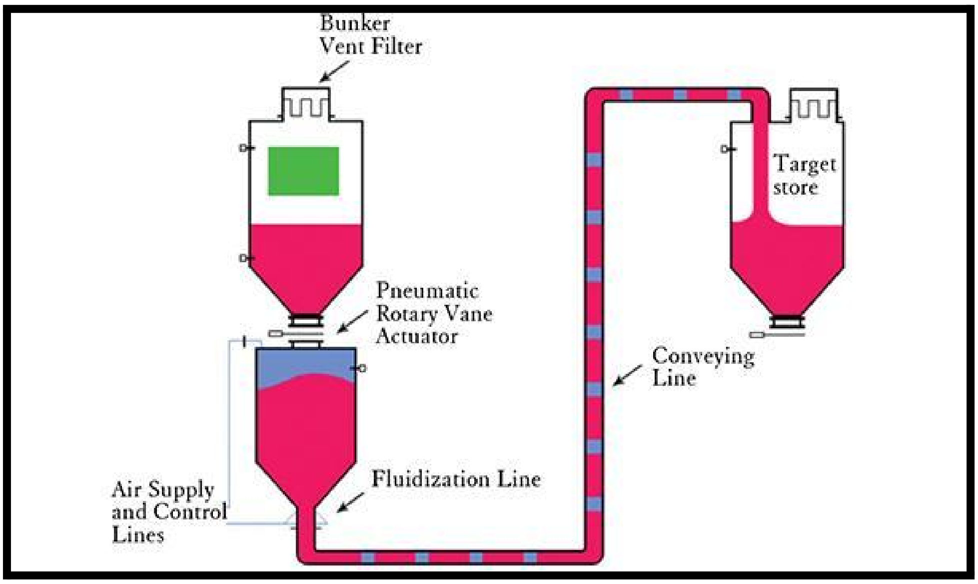


Fig 17: Pneumatic Conveyer

Disadvantages:

- High power consumption.
- Limitations in overall distance (up to 1000 m) and capacity (up to 300 ton/h).
- Severe wear of equipment.
- Attrition or degradation of material being conveyed.
- Most expensive methods.

Based on relative solids loading and velocity of system, they can be classified as for

- Dense phase systems.
- Plug phase conveyors, fluidized systems, blow tanks, and long-distance systems.

- Dilute phase systems.
- Pressure system, vacuum systems, combined systems and closed-loop system.

For bulk particulate or powder materials following classification of conveyors is appropriate.

- Belt conveyors.
- Chain conveyors (scraper conveyors, apron conveyors and bucket. elevators)
- Screw Conveyors.
- Pneumatic Conveyor.

Belt conveyors

Belt conveyors consist of, an endless belt operating between two or more pulleys, friction driven at one end and carried on an idler drum at the opposite end. Belt and its load have to be supported on idlers on both conveying and returning section. Belt conveyors are used for solids conveying at a distance from meters to kilometers. Heavy duty conveyors have thick belts and these require large diameter idler and drums. Damage to solids in transport is slight or negligible as there is no relative motion between belt and solids belt conveyors have carrying capacity.

- Belt Conveyors carry solid long distance mainly in horizontal plane,
- Through inclined conveying possible with restricted angle of elevation of 15-20^o.
- Belt Conveyors are used to avoid spillage or run-back,
- Special belts with corrugated sidewalks and lateral ribs are used for steeper inclination up to 45^o.

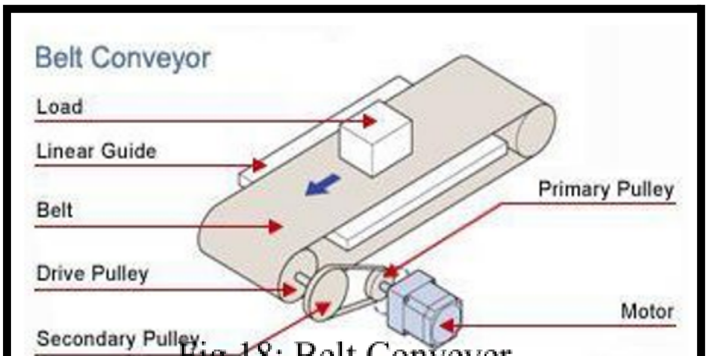


Fig 18: Belt Conveyer

Belt conveyors have the high installation cost. Properly designed belt conveyors have long service life. Refer Fig 18.

Elements of Belt Conveying systems

- Belt
- Drive System
- Tension elements
- Idlers
- Loading devices
- Discharge devices

Belts (stitched canvas, solid-woven balata and rubber belts) must be

● Flexible enough to confirm to the pulleys
● Wide enough to carry the quantity and type of material
● Sufficient strength to stand up under expected load and operating tension.
● Possess resistant surface.

<u>Bucket elevators</u>

Bucket elevators consist of high-capacity units primarily for bulk elevation of relatively free-flowing materials. They are simplest and most dependable equipment for vertical lifting of granular materials. Available in wide range of capacity and high efficiency. Material carrying elements are buckets which may be enclosed in a single housing called a leg or two legs may be used. Return leg may be located some distance from elevator leg. A single or double chain is used to attach the buckets.

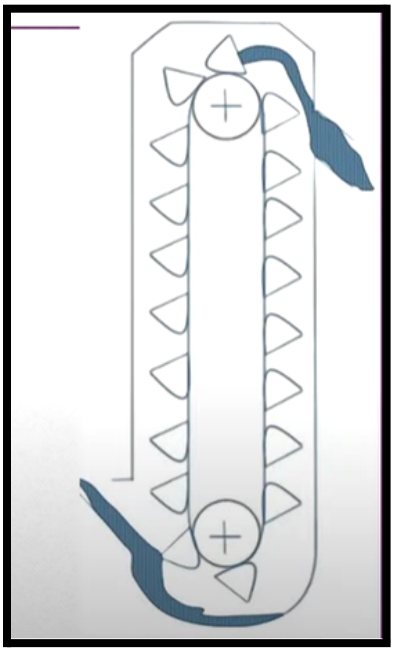


Fig 19: Bucket elevators

Important considerations affecting the design and operation of bucket elevators are

● Physical properties of conveyed material (particle size, lump size, moisture content, angle of repose, flowability, abrasiveness, friability and so on).
● Shape and spacing of buckets.
● Speed at which the elevator is driven.
● Method of loading the elevator.
● Method of discharging the elevator.

Mounting and spacing of buckets will conform into a specific elevator design. Buckets may be fastened to the chain at the back or at the side if mounted in two chains. Centre spacing of bucket varies with their size, shape, speed as well as head and foot wheel diameter. Mounting and spacing of buckets will confirm into a specific elevator design. Buckets may be fastened to the chain at the back or at the side if mounted in two chains. Centre spacing of bucket varies with their size, shape, speed as well as head and foot wheel diameter. Methods of loading bucket elevators: three different ways. Spaced buckets receive part of charge directly from chute and part by scooping. Continuous buckets are filled as they pass through a loading leg with a feed spout above the tail wheel. They can also be loaded in a bottomless boot without a clean out door. Refer Fig 19.

● Methods of discharging of bucket elevators- three different ways
● Spaced-bucket centrifugal-discharge elevators.

Most common and are usually equipped with malleable-iron round-shaped buckets spaced to prevent interface in loading or discharge. Handle almost any free- flowing fine or small-lump material. Speeds can be relatively high for fairly dense materials but must be lowered considerably for aerated or low bulk-density materials to prevent fanning action.

Spaced-bucket positive-discharge elevators

Essentially same as centrifugal-discharge units except that bucket are mounted on two strands of chain and are snubbed back under head sprocket to invert them to allow positive discharge.

Suitable for materials which are sticky or tend to pack.
Slight impact of chain seating on the snub sprocket combined with complete bucket inversion is sufficient to empty the buckets completely.

Continuous-bucket elevators

Used for larger-lump materials or for materials too difficult to handle with centrifugal-discharge elevators. Buckets are of steel type and are closely spaced and the back of the preceding one serves as a discharge chute for bucket which is dumping as it rounds the head pulley. Close bucket spacing reduces the speed at which the elevators operate to maintain capacities comparable with the space-bucket elevators. Gentle discharge is promoted to help preventing excessive degradation. Suitable for pulverized or aerated materials. Refer Fig 20.

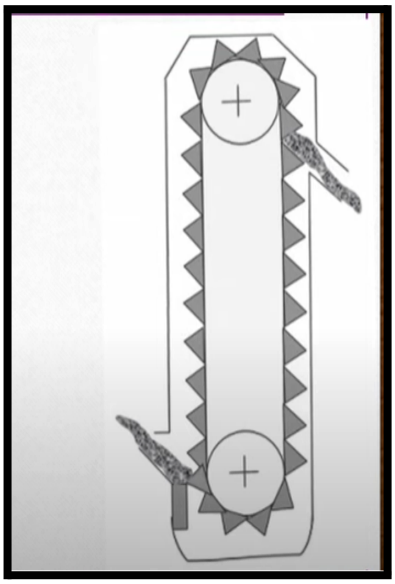


Fig 20: Continuous Bucket Elevators

Super-capacity continuous-bucket elevators

For high lifts and large lump material.

Can handle tonnages and are usually operated at an incline to improve loading as well as discharging. Running speeds are low

Screw conveyors

Operate on the principle of a rotating helical screw moving a given material in a trough or a casing and used to

Handle finely divided powders, damp materials, hot substances that may be chemically active granular materials of all types batch or continuous mixing, for feeding where a fairly accurate mass rate is required. Refer Fig 21. Components of screw conveyor

- Flight.
- Screw formed by mounting flights on axle.
- Tough or casing.

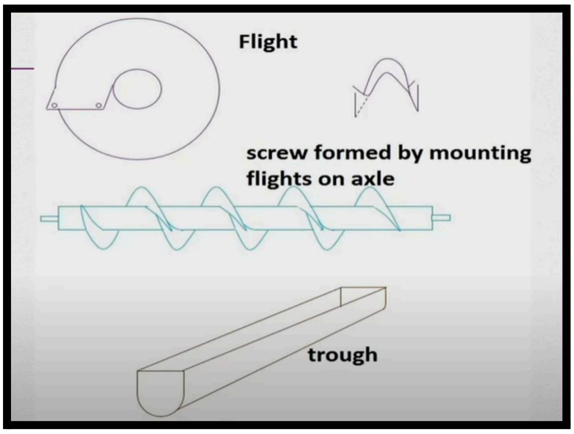


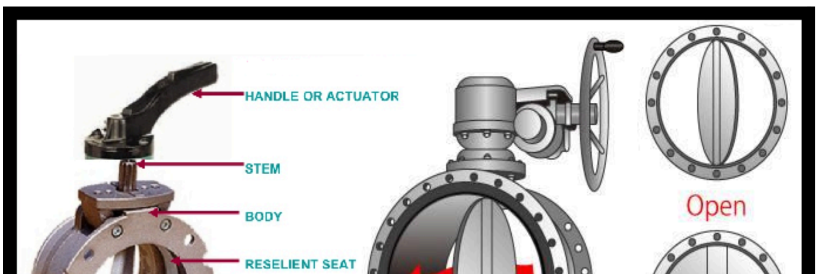
Fig 21: Components of Screw Conveyer

6.9. Valves

A typical processing plant contains thousands of valves of many different sizes and shapes. Despite the variety in their design, however, all valve has a common primary purpose: to slow down or stop the flow of a liquid. Some valves work best in on-or-off service; fully open or fully closed. Others are designed to throttle, to reduce the pressure and flow rate of a fluid. Still others permit flow in one direction only or only under certain conditions of temperature and pressure. A steam trap, which is a special form of valve, allows water an inert gas to pass through while holding back the steam. Finally, by using sensors and automatic control system to adjust the valve position and thus the flow through the valve, the temperature, pressure, liquid level, or other fluid properties can be controlled at points remote from the valve itself.

Butterfly Valve

Butterfly valves are most simple yet versatile valves.



They are quarter turn operated valves which are commonly used in multiple industries for varied applications. Quarter turn operation ensures quick operating of the valve. In the open condition there is minimum obstruction to the fluid flow through the valve as the flow passes around the disc aerodynamically. This results in very less pressure drop through the valve. Refer Fig 22.

Fig 22: Butterfly Valve

Due to its unique mode of operation, the valve can be actuated easily without requiring high torques and wear and tear. Due to lack of friction, use of bulky actuators can be avoided. Another advantage offered by butterfly valve is their compact size. The valve is quite compact, resembling a metal disc. This makes their installation very easy. They can be used to handle slurries and fluids with suspended solids.

Gate valves

In a gate valve the diameter of the opening through which the fluid passes are nearly the same as that of the pipe, and the direction of the flow does not change. As a result, a wide-open gate valve introduces only a small pressure drop. The disk is tapered and fits into a tapered seat; when the valve is opened, the disk rises into the bonnet, completely out of the path of the fluid. Gate valves are not recommended for controlling flow and are usually left fully open or fully closed. Refer Fig 23.

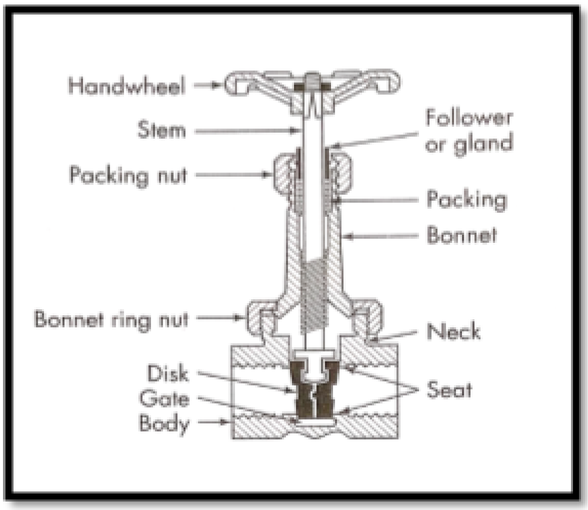
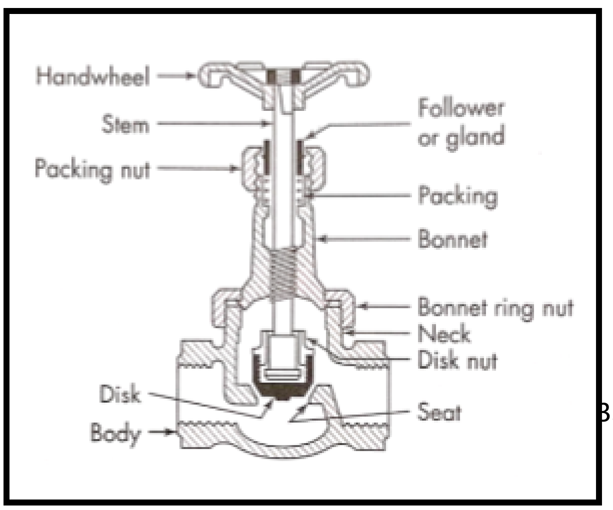


Fig 23: Gate valve

Globe valves

(So called because in the earliest designs the valve body was spherical) are widely used for controlling flow. The opening increases almost linearly with stem position, and wear is evenly distributed around the disk. The fluid passes through



a restricted opening and changes direction several times, as can be seen by visualizing the flow through the valve illustrated in Figure. As a result, the pressure drops in this kind of valve is large. Refer Fig 24.

Pinch Valve

Pinch valves consist of a plastic tube/sleeve which is made up of reinforced elastomers. The sealing/ closing action is achieved by throttling or pinching this sleeve/tube. Pinch valves are best suited for handling slurries and fluids having suspended solids. Pinch valves offer many benefits over the other types of valves. They can be used for handling corrosive fluids as there is no contact between the fluid carried and the actual valve mechanism. Once suitable sleeve material is selected, this valve can work with a variety of fluids. As fluid being carried does not come in contact with the metal parts, these valves can be used for food grade applications also. Refer Fig 25. Generally, pinch valves are suitable for low pressure applications. When used with abrasive slurries, they should be used as on-off valves; if used for throttling purposes, the sleeve will get worn out.

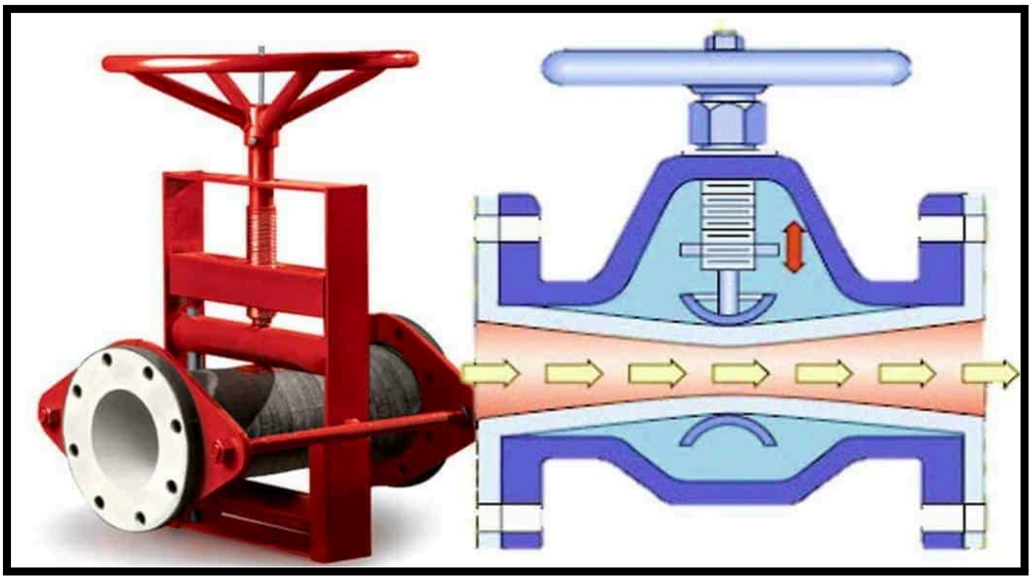
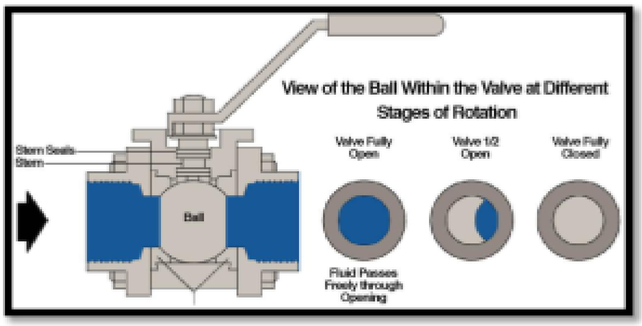


Fig 25: Pinch Valve

Plug cocks and ball valves

For temperature below 250ºC, metallic plug cocks are useful in chemical process lines. As in a laboratory stopcock, a quarter turn of the stem takes the valve from fully open to fully closed; and when it is fully open, the channel through the plug may be as large as the inside of the pump itself, and the pressure drop is minimal. Refer Fig 26. In a ball valve the sealing element is spherical, and the problems of the alignment and “freezing” of the elements are less than with a plug cock. In both plug cocks and ball valves, the area of the contact between the moving elements and seat is large, and both can therefore be used in throttling service. Ball valves find



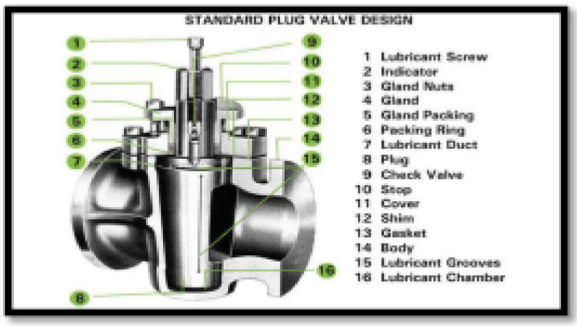


Fig 26: Ball Valve design

Fig 27: Plug Valve design

occasional applications in flow control. Refer Fig 27.

Check Valves.

A check valve permits flow in one direction only. It is opened by the pressure of the fluid in the desired direction; when the flow stops or tends to reverse, the valve automatically closes by gravity or by a spring pressing against the disk. Common types of check valves are shown in Figure. The movable disk is shaded. Refer Fig 28.

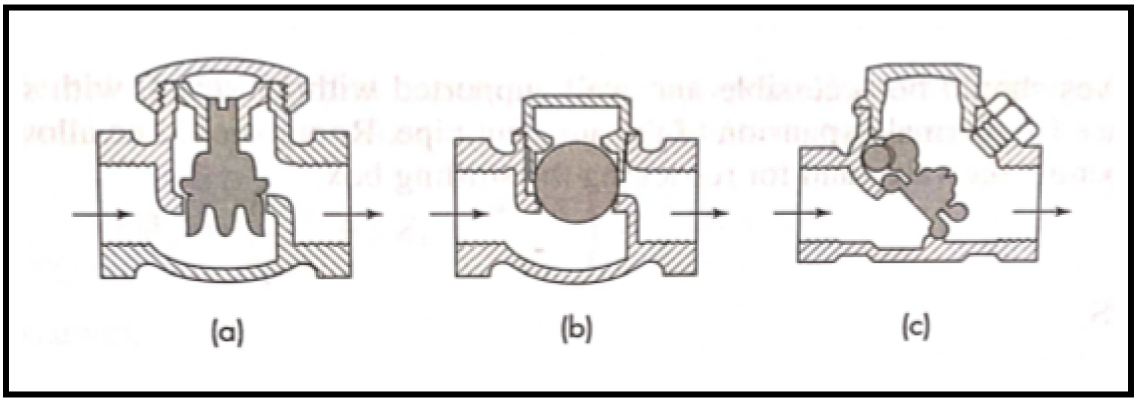


Fig 28: Check valve (a) lift check (b) ball check (c) swing check.

6.10. Dryers

Rotary dryers

Usage in the MCPI. Plant: In the preparation of crude CTA after the crystallization operation is performed Rotary dryer is used to dry the wet CTA powder. Rotary dryers are used in the D.P plant.

A rotary dryer consists of a revolving cylindrical shell, horizontal or slightly inclined toward the outlet. Wet feed enters one end of the cylinder; dry material discharges from the other. As the shell rotates, internal flights lift the solids and shower them down through the interior of the shell. Rotary dryers are heated by direct contact of gas with the solids, by hot gas passing through an external jacket, or by steam condensing in a set of longitudinal tubes mounted on the inner surface of the shell. The last of these types is called a steam-tube rotary dryer. In a direct-indirect rotary dryer, hot gas first passes through the jacket and then through the shell, where it comes into contact with the solids. Refer Fig 29.

A typical adiabatic countercurrent air heated rotary dryer is shown in Figure. A rotating shell A made of sheet steel is supported on two sets of rollers B and driven by a gear and pinion C. At the upper end is a hood D, which connects through fan E to a stack and a spout F, which brings in wet material from the feed hopper. Flights G which lifts the material being dried and shower it down through the current of hot air, are welded inside the shell. At the lower end of the dried product discharges into a screw conveyor H. Just beyond the screw-conveyor is a set of steam heated extended-surface pipes that preheat the air. The air is moved through the dryer by a fan, which may if desired, discharge into the air heater so that the whole system is under a positive pressure. Alternatively, the fan may be placed in the stack as shown, so that it draws air through the dryer and keeps the system under a slight vacuum. This is desirable when the material tends to dust. Rotary dryer of this kind is widely used for salt, sugar, and all kinds of granular and crystalline materials that must be kept clean and may not be directly exposed to very hot flue gases.

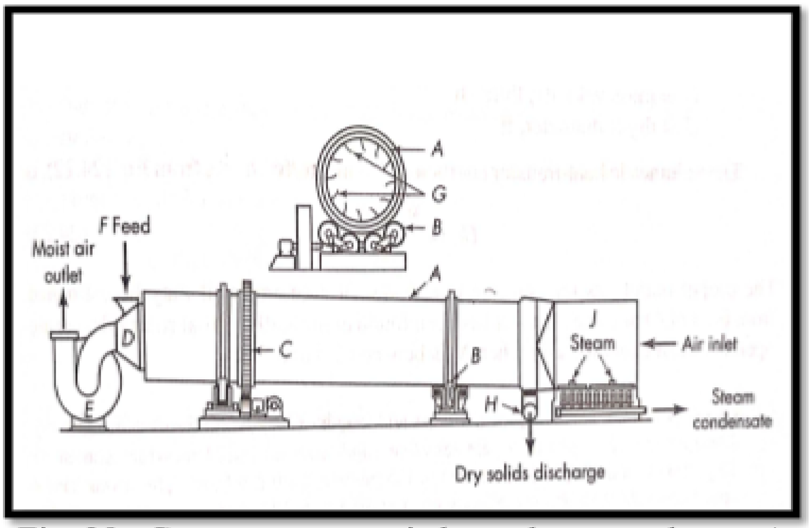


Fig 29: Countercurrent air-heated rotary dryer: A, dryer shell; B, shell-supporting rolls; C, drive gear; D, air discharge hood; E, discharge fan; F, feed chute; G, lifting flights; H, product discharge; J, air heater.

<u>Flash Dryer</u>

Usage in the MCPI Plant: - Flash dryer is used in the CTA section of the H.P Plant. To dry the wet CTA powders. In a flash dryer, a wet pulverized solid is transported for a few seconds in a hot gas stream. Drying takes place during transportation. The rate of heat transfer from the gas to the suspended solid particles is high, and drying is rapid, so that no more than 3 or 4 s is required to evaporate substantially all the moisture from the solid. The temperature of the gas is high—often about 650ºC (1,200ºF) at the inlet—but the time of contact is so short that the temperature of the solid rarely rises more than 50ºC(90ºF) during drying. Flash drying may therefore be applied to sensitive materials that in other dryers would have to be dried indirectly by a much cooler heating medium. Sometimes a pulverize is incorporated in the flash drying system to give simultaneous drying and size reduction. Refer Fig 30.

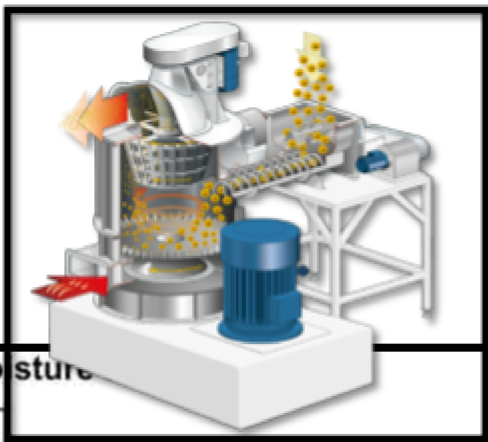


Fig 30: Flash Dryer

Fluidized Bed Dryer

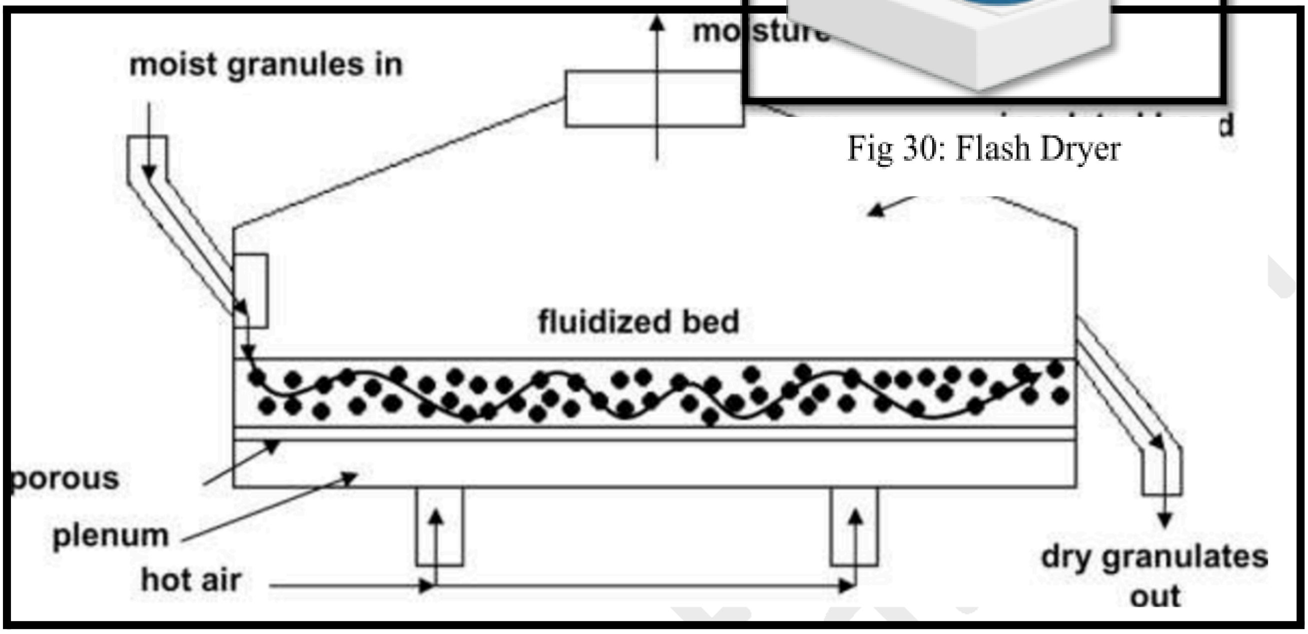


Fig 31: Fluidized Bed Dryer

Usage in the MCPI Plant: - Fluidized Bed Dryer is used in the PTA section of the H.P Plant to dry the wet PTA powder. Refer Fig 31.

Dryers in which the solids are fluidized by the drying gas find applications in a variety of drying problems. The particles are fluidized by air or gas in a boiling- bed unit, as shown in Figure. Mixing and heat transfer are very rapid. Wet feed is admitted to the top of the bed; dry product is taken out from the side near the bottom. In the dryer shown in Figure. there is a random distribution of residence times; the average time a particle stays in the dryer is typically 30 to 120 s when only surface liquid is vaporized and up to 15 to 30 min if there is also internal diffusion. Small particles are heated essentially to the exit dry-bulb temperature of the fluidizing gas; consequently, thermally sensitive materials must be dried in a relatively cool suspending medium. Even so, the inlet gas may be hot, for it mixes so rapidly that the temperature is virtually uniform, at the exit gas temperature, throughout the bed. If fine particles are present, either from the feed or from particle breakage in the fluidized bed, there may be considerable solids carryover with the exit gas, and cyclones and bag filters are needed for fine recovery. Some rectangular fluid bed dryers have separately fluidized compartments through which the solids move in sequence from inlet to outlet. These are known as plug flow dryers; in them the residence time is almost the same for all particles. Drying conditions can be changed from one compartment to another, and often the last compartment is fluidized with cold gas to cool the solids before discharge. Dryer of the kind shown in Figure. may also be operated batchwise. A charge of wet solids in a perforated container attached to bottom of the fluidizing chamber is fluidized, heated until dry, then discharged. Such units have replaced tray dryers in many processes.

6.11. Activated Carbon Filter

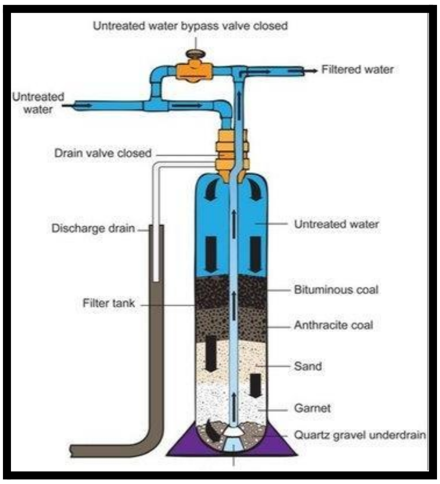


Fig 32: Activated Carbon Filter

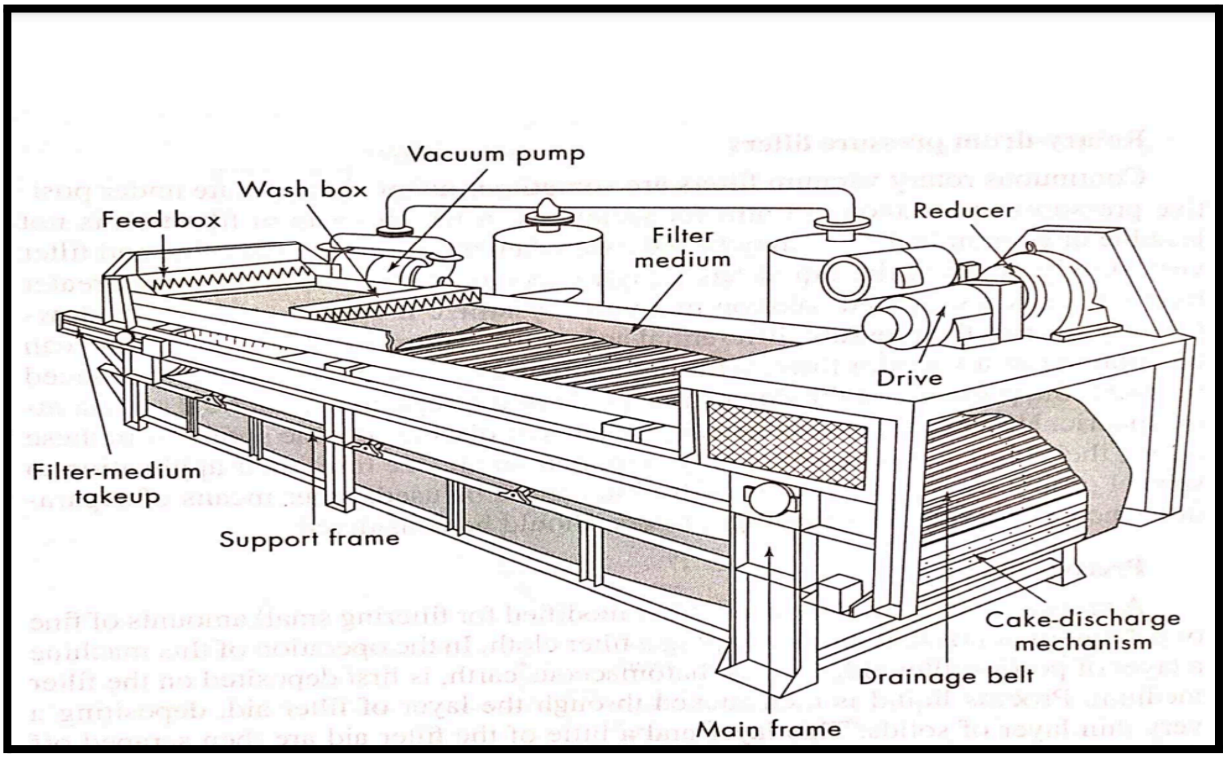
The Activated carbon Filters are designed to remove free chlorine, organic matter, odour and colour present in the raw water and waste water. Due to its high degree of micro porosity, activated carbons provide a huge surface area. Activated carbon filter operates through adsorption. Adsorption is directly related to the surface area of the media. This great surface area furnishes a huge adsorption area for organic as well as chlorine molecules to attach themselves. The Activated Carbon Filters consist of Activated carbon granules supported by very fine quartz filter media. Various grades of carbon are available for specialized treatments.

Filtration is the most frequently used, robust method to remove suspended solids from water. The filter consists of a multiple layer of sand/ Filter Media with a variety in size and specific gravity. The Filters are designed to remove turbidity and suspended particles present in the feed water with minimum pressure drop. Fluid Systems offers a wide range of filters for varying applications with single/multiple media options to meet specific process. Refer Fig 32.

6.12. Horizontal Belt Filter

Usage in the MCPI Plant: D.P Plant contains filter, which filters out the liquid from the solid. When the feed contains coarse, fast settling particles of solid, a rotary drum filter works poorly or not at all. The coarse particles cannot be suspended well in the slurry trough, and the cake that forms often will not adhere to the surface of the filter drum. In this situation a top-fed horizontal filter may be used. The moving belt filter is shown in Figure. is one of several types of horizontal filter; it resembles a belt conveyor, with a transversely ridged support or drainage belt carrying the filter cloth, which is also in the form of an endless belt. Central openings in the drainage belt slide over a longitudinal vacuum box, into which the filtrate is drawn. Feed slurry flows onto the belt from a distributor at one end of the unit; filtered and washed cake is discharged from the other. Belt filters are especially useful in waste treatment. Refer Fig 33.

Fig 33: Horizontal Belt Filter



6.13. Cooling Tower

When warm liquid is brought into contact with unsaturated gas, part of the liquid evaporates and the liquid temperature drops. The most important application of this principle is in the use of cooling towers to lower the temperature of recirculated water used for condensers and heat exchangers in chemical plants, power plants, and air conditioning units. Cooling towers are large-diameter columns with special type of packing designed to give good gas-liquid contact with low pressure drop. Warm water is distributed over the packing by spray nozzles or a grid of notched troughs or pipes. Air is passed through the packing by forced-draft or induced-draft fans, or in some designs it is drawn through by natural convection. Refer Fig 34.

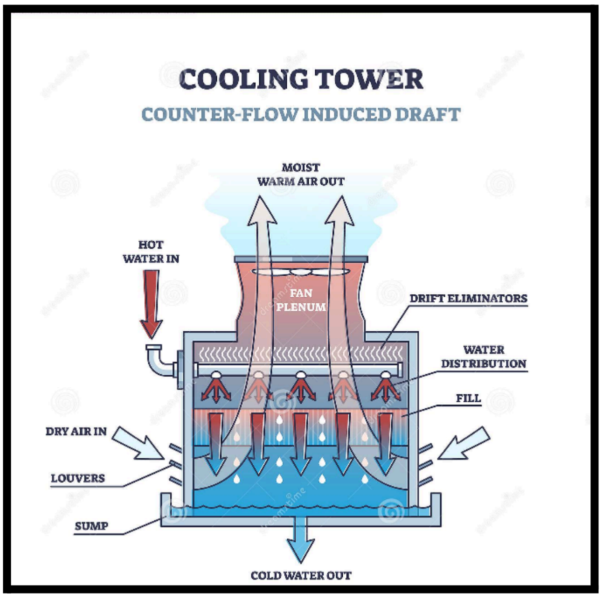


Fig 34: Cooling Tower

Two of the major types of forced-draft cooling towers are shown in Figure.

The preferred material for the outer shell is corrugated glass-reinforced polyester.

The most type of packing for new installations is cellular fill or film-type packing, which consists of corrugated sheets of plastic similar to those used in plate-type heat exchangers. Water flows over the surface of the packing, giving more transfer area per unit volume than splash-type packings. The plastic sheets are spaced ¾ to 1.0 in. (18 to 25 mm) apart to permit high flow rates of air and water with only moderate pressure drop. The depth of fill may be only a few sheets, a small fraction of the total height of the unit. With cellular fill, it is especially important to get good distribution of water at the top, since redistribution does not occur naturally, as it does with random dumped packings.

6.14. Cyclone Separator

Most centrifugal separators for removing particles from a gas streams contain no moving parts. They are typified by the cyclone separator shown in Figure. It consists of a vertical cylinder with a conical bottom, a tangential inlet near the top, and an outlet for dust at the bottom of the cone. The inlet is usually rectangular. The outlet pipe is extended into the cylinder to prevent short-circuiting of air from inlet to outlet.

The incoming dust-laden air travels in a spiral path around and down the cylindrical body of the cyclone. The centrifugal force developed in the vortex tends to move the particles radially towards the wall, and the particles that reach the wall slide down into the cone and are collected. The cyclone is basically a settling device in which a strong centrifugal force, acting radially, is used in place of a relatively weak gravitational force acting vertically. Refer Fig 35.

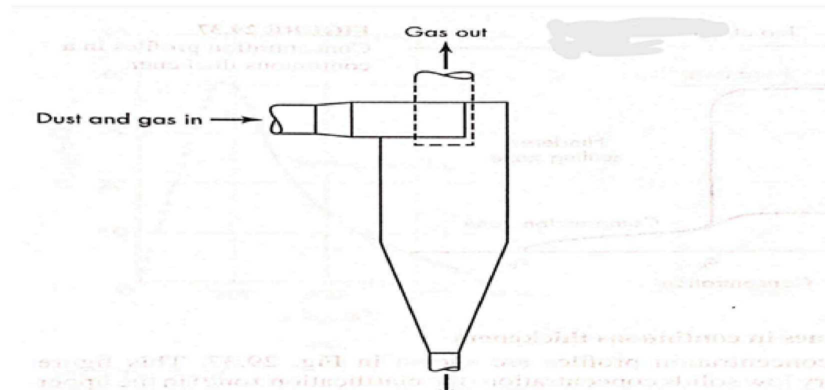


Fig 35: Cyclone Separator

The centrifugal force F_c at radius r is equal to mu^2_{tan}/r, where m is the mass of the particle and u_{tan} is its tangential velocity. The ratio of the centrifugal force to the force of gravity is then

$$\frac{F_c}{F_g} = \frac{\frac{mu^2_{tan}}{r}}{mg} = \frac{u^2_{tan}}{rg}$$

F_c/F_g is called the *separation factor*

The dust particles entering a cyclone are accelerated radially, but the force on a particle is not constant because of the change in *r* and because if the tangential velocity in the vortex varies with *r* and with distance below the inlet.

The three cyclones are of similar proportions with diameters of about 14,32, and 72 in. (0.36, 0.81, and 1.83 m), and the lower efficiency of the larger cyclones is mainly a result of the decrease in centrifugal force. For a given airflow rate and inlet velocity, however, moderate increase in cyclone diameter and length improves the collection efficiency, because the increase in surface area offsets the decreased centrifugal force.

The collection efficiency of a cyclone increases with the particle density and decreases as the gas temperature is increased because of the increase in gas viscosity.

6.15. Storage and Conveying of Solids

Bulk Storage

Coarse solids such as gravel and coal are stored outside in large piles, unprotected from the weather. When hundreds or thousands of tons of material are involved, this is the most economical method. The solids are removed from the pile by dragline or tractor shovel and delivered to a conveyor or to the process. Outdoor storage can lead to environmental problems such as dusting or leaching of soluble material from the pile. Dusting may necessitate a protective cover of some kind for the stored solid; leaching can be controlled by converting the pile or by locating it in a shallow basin with an impervious floor from which the runoff may be safely withdrawn.

Silos, Bins & Hoppers Storage

A silo is tall and relatively small in diameter. A bin in not so tall and usually fairly wide. A hopper is a small vessel with a sloping bottom, for temporary storage before feeding solids to process. These are cylindrical or rectangular vessels of concrete or metal. All these containers are loaded from the top by some kind of elevator; discharging is ordinarily done from the bottom.

Pressure in bins and silos: When granular solids are placed in a bin or silo, the lateral pressure exerted on the walls at any point is less than predicted from the head of materials above that point Furthermore there usually is friction between the wall and the solid grains, and because of the interlocking of the particles, the effect of this friction is felt throughout the mass. The friction force art the wall tends to offset the weight of the solid and reduces the pressure exerted by the mass on the floor of the container. Refer Fig 36.

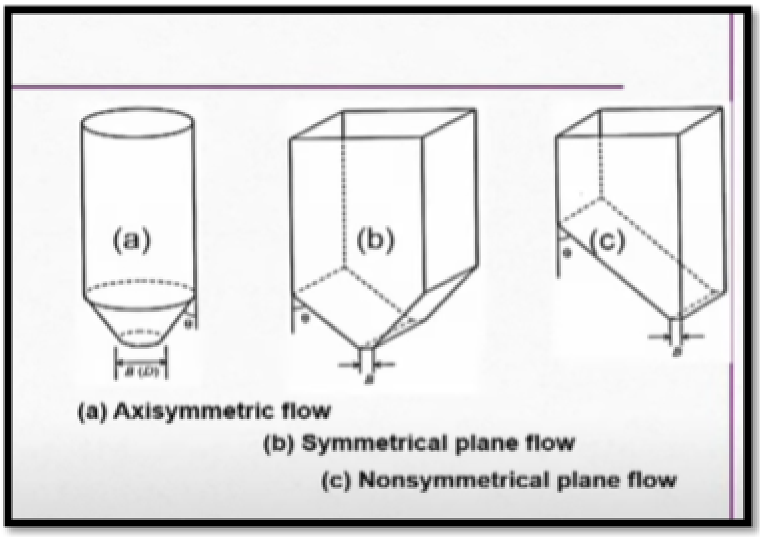


Fig 36: Common Hopper Geometries

The vertical pressure on the vessel floor or the packing support is much smaller than that exerted by a column of liquid of the same density and height. The actual pressure from the solids depends on the value of K' for the solids, the coefficient of friction between the solids and the vessel wall, and the way the solids are placed in the vessel. In general, when the height of the solid's column is greater than about 3 times the diameter of the container, additional solids have no effect on the pressure at the base. The total mass, of course, increases if more solids are added, but the additional mass is carried by the walls and foundation, not by the floor of the vessel.

In granular solids a high pressure does not always increase the tendency of the material to flow, as it does in a liquid; instead, pressure packs the grains more tightly together and makes flow more difficult. In extreme cases the combination of gravitational and frictional forces at some point in the container causes the solids to arch or bridge, so that they do not fall even when the material below them is removed. Nearly all large bins contain an *arch-breaker*, an upward pointing shallow metal cone set near the bottom to keep the solids at the discharge opening from becoming tightly packed. Granular solids, especially with angular particles, must be loos in order to flow.

7. Main Project

7.1. Assignment 1: Theoretical Air Requirement Calculation of an Industrial Boiler

&

Caustic Requirement Check for a Desulphurization Tower

<u>Theoretical Air Calculation</u>

Stoichiometric air or theoretical air is the exact amount of air required to provide the right amount of oxygen for complete combustion. The amount of air required for stoichiometric combustion is fairly constant on the air/gas weight ratio, with an approximate value of 16.

Theoretical Air Quality is calculated based on the chemical reaction between the elements and oxygen.

Carbon combines with oxygen to form carbon-dioxide and heat:

$$C + O_2 \square CO_2$$

$$1\ C + 32/12\ O \square 44/12\ CO_2$$

1 kg Carbon + 2.67 kg Oxygen □ 3.67 kg Carbon Dioxide

Hydrogen combines with oxygen to form water and heat:

$$2\ H_2 + O_2 \square 2H_2O$$

$$1\ H + 32/4\ O \square 36/4\ H_2O$$

1 kg Hydrogen + 8 kg Oxygen □ 9 kg Water

Sulphur combines with oxygen to form Sulphur dioxide:

$$S + O_2 \square SO_2$$

$$1\ S + 32\ /32\ O \square 64\ /32\ SO_2$$

1 kg Sulphur + 1 kg Oxygen □ 2 kg Sulphur Dioxide.

The expression for theoretical oxygen required for complete combustion is then:

$$A = 2.67 \times C\% + 8 \times H\% + 1 \times S\% - O\%$$

Air contains 23.2% by weight of oxygen.

The theoretical air required for complete combustion = A / 23.2%

This is the theoretical air required for complete combustion.

Industrial Boiler

A Boiler is a closed vessel in which water or other suitable liquid is heated to generate steam or vapour. The steam/vapour is then exited and is used for various purposes like heating applications (water heating, central heating), boiler based power generation or even for cooking and other purposes which could be domestic or industrial.

It basically follows the concept of a pressure cooker but in a bigger way. The boiler concept is used across places from domestic purposes to industrial activities. The fluid is generally incorporated into a system and it works to provide steam through connecting combustion products and the water.

There are many types of boilers based on their uses. While domestic boilers are small and are used for daily household chores, the industrial boilers today play a magnanimous role in the production process.

Industrial boilers can also be environment friendly if the fuel used is natural gas or other types of non-harming fuels. They not only deliver the desired performance but also help industries to keep a check on the toxic emissions that are harming the environment in the worst possible way.

For centuries we have been using boilers in various forms to heat water or to produce steam. Household boilers and Industrial boilers though have different purposes, but the operational aspect is similar. Good Industrial Boilers are known for their energy efficiency and massive heat production that has the capability of running your production processes. From steam-powered locomotives to external combustion engines to power plants, for various purposes, industrial boilers are used.

Heat is vital for life. Without it, we cannot sustain. From cooking to styling your hair, we need heat for almost everything. Our pressure cookers can explain the basic concept of steam boilers where steam is pressurized and used for cooking. Heat energy also reduces the reliance on fossil fuels like petrol, diesel and more.

Ever thought of enhancing your production efficiency without wasting money on electric energy? Did you know Industrial Boilers are powering many industries? Did you know Industrial Boilers are of various types and have different utilities? If not, here's everything that you must understand about Industrial Boilers.

The importance of Industrial Boilers is not unknown to manufacturing companies. They use industrial boilers for their many advantages; one of them is saving the cost of using electric energy for the entire process. Electric power becomes extremely expensive if used on a large scale, but Industrial Boilers help in keeping the extra expense in check. Boilers offer maximum efficiency and minimum menace like fewer hassles of handling and depending on electric energy.

Parts of Industrial Boiler:

1. Burner: The burner is the starter of the combustion reaction inside the boiler. There is a mechanism that sends the message to start the process of producing heat. A nozzle in the burner that turns the fuel pumped from the fuel source ignites it to create the combustion.

2. Combustion Chamber: The combustion chambers are made of cast iron and can have a temperature of several hundred degrees in minutes. It burns the fuel and generates heat which is transferred to the heat exchanger.

3. Heat Exchanger: Also called the economiser, it is responsible for increasing the efficiency of the boiler. The heat exchanger is placed before the air heater in the fuel gas path.

4. Steam Drum and Mud Drum: The steam drum collects the steam while the mud drum is placed beneath the steam drum and collects the solid which is removed periodically.

Fuel Sources used in boilers: From coal, kerosene to natural gases, the fuel can be of various types.

How does Industrial Boiler work?

Industrial Boilers are water-containing vessels that generate heat with the help of a fuel source. It is then transferred to various tubes connecting to the various industrial equipment. The steam energy is used for running the machinery, giving industries a cost-effective way of powering their production.

Problem: Consider for an industrial boiler where complete combustion is taking place:

Fuel Consumption(wt.%)

C	86.47
O_2	0.27
N_2	0.24
S	3.7
H_2	9.32

Fuel flow in the Boiler 4500 L/h

Density of the fuel 920 Kg/m^3

1.a. Calculate the theoretical air requirement for complete combustion?

b. Calculate the amount of SO_2 produced and the amount of 10 % caustic require to neutralize the SO_2.

2. Calculate the amount of CO_2 produced per litre of FO.

3. Explain Green House Effect? Describe how can you contribute to reduce the Green House Effect?

Solution:

1. a) Theoretical Air Requirement

Volumetric flow rate of fuel = 4500 L/h = 4500 *10^{-3} m^3/h = 4.5 m^3/h

So, Mass flow rate of fuel = 4.5 m^3/h * 920 Kg/m3 = 4140 Kg/h

The combustion reactions which are taking place are:

$C + O_2 \rightarrow CO_2$................................(i)

$S + O_2 \rightarrow SO_2$................................(ii)

$2H_2 + O_2 \rightarrow 2H_2O$ ....(iii)

Oxygen requirement for all three combustion reactions calculation:

For reaction (i):

Amount of Carbon present in the fuel per hour = 4140 * 0.8647 = 3579.858 kg

12 kg Carbon reacts with 32 kg Oxygen

1 kg Carbon reacts with 32/12 kg Oxygen

3579.858 kg Carbon reacts with (3579.858*32/12) = 9546.288 kg Oxygen

So, the amount of Oxygen required for combustion of Carbon present in the fuel = 9546.288 kg.

For reaction (ii):

Amount of Sulphur present in the fuel per hour = 4140 * 0.037 = 153.18 kg

32 kg Sulphur reacts with 32 kg Oxygen

1 kg Sulphur reacts with 32/32 kg Oxygen

153.18 kg Sulphur reacts with (153.18*32/32) = 153.18 kg Oxygen

So, the amount of Oxygen required for combustion of Sulphur present in the fuel = 153.18 kg.

For reaction (iii):

Amount of Hydrogen present in the fuel per hour = 4140 * 0.0932 = 385.848 kg

4 kg Hydrogen reacts with 32 kg Oxygen

1 kg Hydrogen reacts with 32/4 kg Oxygen

385.848 kg Hydrogen reacts with (385.848*32/4) = 3086.784 kg Oxygen

So, the amount of Oxygen required for combustion of Hydrogen present in the fuel = 3086.784 kg.

Oxygen present in the fuel:

Amount of Oxygen present in the fuel = (4140 * 0.0027) = 11.178 kg Oxygen

So, total theoretical Oxygen requirement for complete combustion of the fuel = 9546.288 + 153.18 + 3086.784 – 11.78 = 12775.074 kg O_2

Mole % of O_2 in air = 21 %

Mass % of O_2 in air = 0.21 * 32 *100/ ((0.79 * 0.28) + (0.21 * 0.32)) = 23%

23 kg O_2 is contained in 100 kg air

1 kg O_2 is contained in 100/23 kg air

12775.074 kg O_2 is contained in 100*12775.074/23 = 55543.8 kg air

b) <u>Amount of SO_2 produced and amount of 10% Caustic required to neutralise the SO_2</u>

From the reaction $S + O_2 \rightarrow SO_2$

Amount of Sulphur present in the fuel = 4140*0.037 =153.18 kg Sulphur per hour

We can write that:

32 kg Sulphur reacts to produce 64 kg SO_2

1 kg Sulphur reacts to produce 64/32 kg SO_2

153.18 kg Sulphur reacts to produce 153.18*64/32=306.36 kg SO_2

The neutralization reaction of SO_2 is as follows:

$SO_2 + 2NaOH \rightarrow Na_2SO_3 + 2H_2O$

So, we can write that:

64 kg SO2 will be neutralized by 80 kg 100% NaOH

1 kg SO2 will be neutralized by 80/64 kg 100% NaOH

306.36 kg SO2 will be neutralized by 306.36*80/64 = 382.95 kg NaOH

So, the amount of 10% NaOH = 382.95*100/10 = 3829.5 kg NaOH

2. <u>CO_2 produced per litre of FO</u>

From the reaction: $C + O_2 \rightarrow CO_2$

Total amount of Carbon present in the fuel = 4140*0.8647 =3579.858 kg per hour

We can write that:

12 kg Carbon produces 44 kg CO_2 in complete combustion

1 kg Carbon produces 44/12 kg CO_2 in complete combustion

3579.858 kg Carbon produces 3579.858*44/12 = 13126.146 kg CO_2 in complete combustion

The volume of Fuel Oil per hour = 4500 l/h

So, CO_2 production rate per unit volume of Fuel Oil = 13126.146/4500 = 2.91692 kg CO_2 per litre of Fuel Oil

7.2. Assignment 2: Measures to reduce Greenhouse Effect

3. Greenhouse effect and measures to reduce it

The greenhouse effect is a process that occurs when energy from a planet's host star goes through its atmosphere and warms the planet's surface, but the atmosphere prevents the heat from returning directly to space, resulting in a warmer planet. Light arriving from our Sun passes through Earth's atmosphere and warms its surface. The warmed surface then radiates heat, which is absorbed by greenhouse gases such as carbon dioxide. Without the natural greenhouse effect, Earth's average temperature would be well below freezing. Current human-caused increases in greenhouse gases trap greater amounts of heat, causing the Earth to grow warmer over time.

Just like a glass greenhouse, Earth's greenhouse is also full of plants! Plants can help to balance the greenhouse effect on Earth. All plants — from giant trees to tiny phytoplankton in the ocean — take in carbon dioxide and give off oxygen.

The ocean also absorbs a lot of excess carbon dioxide in the air. Unfortunately, the increased carbon dioxide in the ocean changes the water, making it more acidic. This is called ocean acidification.

More acidic water can be harmful to many ocean creatures, such as certain shellfish and coral. Warming oceans from too many greenhouse gases in the atmosphere can also be harmful to these organisms. Warmer waters are a main cause of coral bleaching.

BIBLIOGRAPHY

1. Unit Operations of Chemical Engineering (Warren McCabe, Julian C Smith, Peter Harriot) 7th Edition

2. Mass Transfer Operations; Robert E. Treybal (Third Edition)

3. Process Heat Transfer DQ Kern.

4. Google Images

https://en.wikipedia.org/

http://www.mcpi.co.in

ABBREVIATIONS

C.T. A	Crude Terephthalic Acid
P.T. A	Purified Terephthalic Acid
H. P	Haldia Project
D.P	Delhi Project
T	Temperature
MW	Mega Watt
L/D	Length/Diameter
DCS	Discrete Control System
CSTR	Continuous Stirred Tank Reactor
F.U. G	Fenske, Underwood, Gilliland
Pd	Palladium
C	Carbon
Zn	Zinc
Cu	Copper
NBA	n-butyl alcohol
ppm	parts per million
rpm	rotation per minute
ft	feet
MpaG	Mega Pascal Gauge
g-force	gravity force
atm	atmospheric pressure
N_t	number of theoretical/ideal plates
R_{min}	minimum reflux ratio
in	inch
m	meter
Gcal	Giga calorie
kCal	kilo calorie