PHARMACEUTICAL ENGINEERING

UNIT 2 NOTES

HEAT TRANSFER
- OBJECTIVES
- HEAT TRANSFER MECHANISM
- CONDUCTION
- CONVECTION
- RADIATION

EVAPORATION
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DISTILLATION
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IMPERFECT PHARMACY

HEAT TRANSFER

- Heat Transfer is defined as transfer of thermal energy from one body or system to another due to temperature difference.
- In Heat Transfer thermal energy moves from region of higher temperature to region of lower temperature.
- Heat Transfer continues until thermal equilibrium is achieved.

OBJECTIVES OF HEAT TRANSFER

- Minimization of Heat Loss
- Maximizing Heat Recovery
- Designing Efficient Heat Exchangers.
- To maintain a desired temperature or temperature range.
- Material selection & development.

APPLICATION OF HEAT TRANSFER

- Sterilization
- Drying
- Evaporation
- Crystallization
- Distillation

Mechanism Of Heat Transfer

Heat Transfer occurs through following three mechanisms.

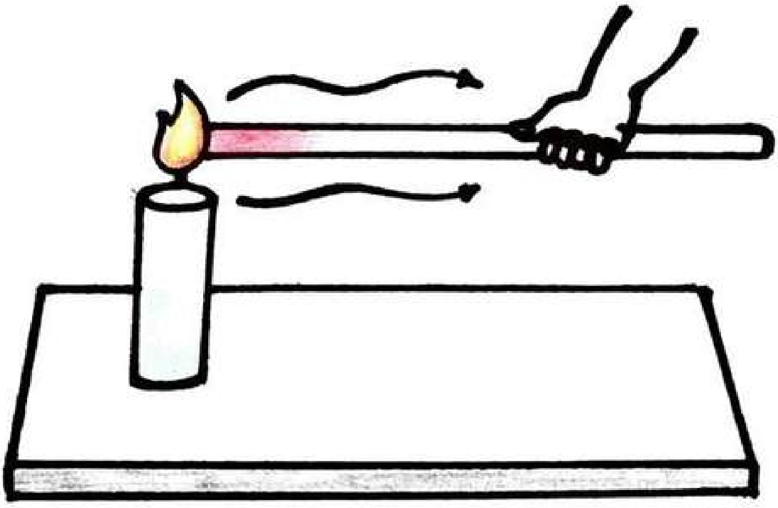
- Conduction
- Convection
- Radiation

CONDUCTION

- Heat Transfer through Conduction is the process by which thermal energy is transferred through a material by direct contact between its particles.
- In Conduction, no actual movement of matters occurs, instead, the heat is transferred through vibrations of particles with in the material.

Mechanism : At the molecular level, when one part of the material is heated, the particles in that region vibrate faster due to added energy.

- These faster moving particles collide with adjacent particles, transferring some of their energy.
- This process continues, with energy moving from higher energy particles to those with lower energy, spreading heat throughout the material.



CONDUCTION

THERMAL CONDUCTIVITY

- The ability of material to conduct heat is defined by its Thermal Conductivity (k)
- Materials with high thermal conductivity, such as Metals, conduct heat efficiently.

RATE OF HEAT TRANSFER THROUGH CONDUCTION

The rate of heat transfer through conduction is given by Fourier's Law :

$$Q = \frac{-kA\Delta T}{d}$$

- Q= Rate of Heat Transfer
- k = Thermal conductivity of the material
- A = Cross sectional area perpendicular to heat flow
- ΔT = Temperature difference b/w Hotter & Colder region.
- d= Thickness

CONVECTION

- Heat Transfer through Convection occurs when heat is transported by the movement of a fluid (liquid or gas)
- Unlike conduction, which relies on molecular vibration and energy transfer in solids, convection involves the bulk motion of fluid particles, making it highly efficient in fluids.

Mechanism Of Heat Transfer In Convection

- When a fluid near a heat source is heated, its temperature increases, causing its density to decrease.
- This creates a buoyant force that causes the warmer, less dense fluid to rise while cooler, denser fluid sinks.
- The process forms a convective current.
- Heat Energy is carried by movement of fluid particles from one location to another
- In natural convection, this motion is driven by density differences, while in forced convection, external forces like pumps or wind drive the motion.

TYPES OF CONVECTION

Convection can be divided into two types:

1. Natural Convection
2. Forced Convection

① Natural Convection

- Natural Convection occurs due to density differences caused by temperature variations.
- Example : Heating water in a pot.

② Forced Convection

- In forced convection, External forces like fans, pumps or mechanical stirring.
- Example : Air conditioning, where fans circulate cool air etc.

RATE OF HEAT TRANSFER THROUGH CONVECTION

The rate of heat transfer through convection is described by Newton's Law of cooling.

$$Q = hA(T_s - T_\infty)$$

Where,
- Q = Rate of Heat Transfer
- h = Convective heat transfer coefficient
- A = Surface area in contact with fluid
- T_s = Surface temperature
- T_∞ = Temperature of fluid far from surface.

RADIATION

- Heat Transfer through Radiation is the process of heat transfer through electromagnetic waves, primarily in the form of infra red radiation.
- Unlike conduction and convection, radiation does not require a medium, In this heat can be transferred through a vacum or a transparent media.

Mechanism Of Radiation

- All objects with a temperature above absolute zero emit electromagnetic radiation.
- The intensity and wavelength of this radiation depend on the object's temperature and surface properties.
- The net radiative heat transfer occurs when there is a temperature difference between objects.
- Heat flows from the hotter object to the cooler object.

Rate Of Heat Transfer Through Radiation

The rate of heat transfer through radiation is defined by Stefan - Boltzmann law of radiation.

$$Q = \sigma e A (T_2 - T_1)$$

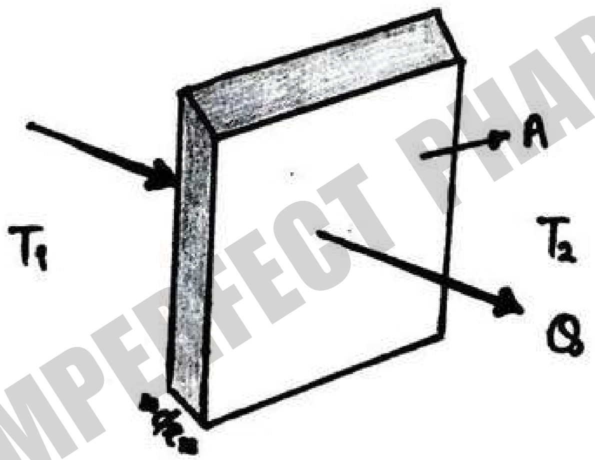
Here
- Q = Rate of Heat Transfer
- σ = Stefan- Boltzmann Constant
- e = emmissivity of the body
- A = surface area of the object
- $T_2 - T_1$ = Absolute temperature difference between two surfaces.

FOURIER'S LAW OF HEAT TRANSFER

Fourier's law of heat transfer states that rate of heat transfer (Q) through a material is proportional to the negative gradient of the temperature ($-dT/dx$) across the material & the cross-sectional area of the material (A)

$$Q \propto A$$

$$Q \propto -\frac{dT}{dx}$$



$$dT = T_1 - T_2$$

$$\boxed{Q = -kA \frac{dT}{dx}}$$

Here Q = Rate of heat transfer
k = Thermal conductivity of material
A = Cross - sectional area of the material
$\frac{dT}{dx}$ = temperature gradient

-ve sign indicates drop in temperature.

Application Of Heat Transfer

- Designing Heat Exchangers.
- Designing insulation system to reduce heat transfer.
- Heat Transfer analysis.

HEAT INTERCHANGER & EXCHANGER

Heat Interchanger & Heat Exchanger are often used interchangeably but there's a difference as follows :

HEAT INTERCHANGER

- Heat Interchanger is is a less commonly used term that ~~transform~~ transfers heat between two ~~or~~ more fluids within the same system and also allows for the possibility of fluid mixing or interaction.
- Heat Exchangers are general devices while Heat Interchangers are specific type of Heat Exchangers.

HEAT EXCHANGER

- A Heat Exchanger is a device designed to transfer heat between two or more fluids (liquid, gas or both) without mixing them.
- It is a broad term that applies a wide variety of devices used in industries,
- Some most commonly used Heat Exchangers are as follows:

(1) Shell & Tube Heat Exchanger
(2) Double Pipe Heat Exchanger
(3) Plate Heat Exchanger

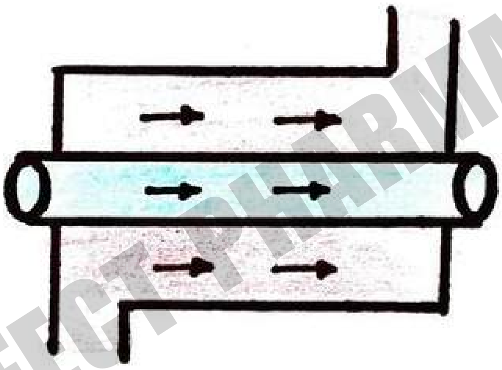
Types Of Heat Exchangers : Based On Flow Management

There are three types of heat exchangers :

1. Parallel Flow
2. Counter Flow
3. Cross Flow

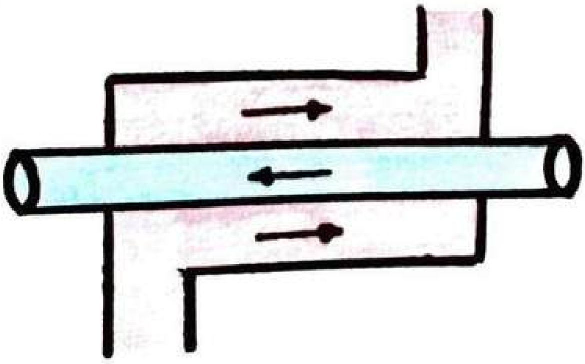
1. Parallel Flow

Parallel flow is a type of flow setup where both hot and cold fluids travel in the same direction.



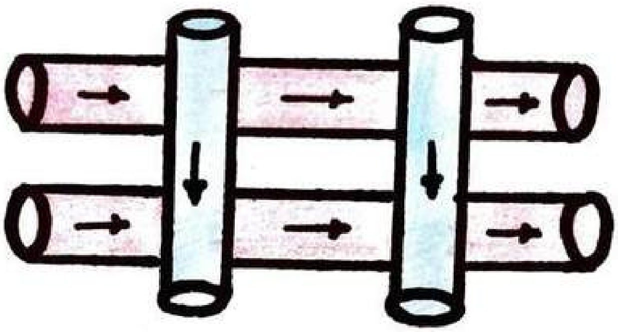
2. Counter Flow

In counter flow heat exchanger, the hot fluid & cold fluid travels in opposite directions.



③ Cross Flow

Cross Flow is another type of flow management, where one fluid flows perpendiculars to another fluid.

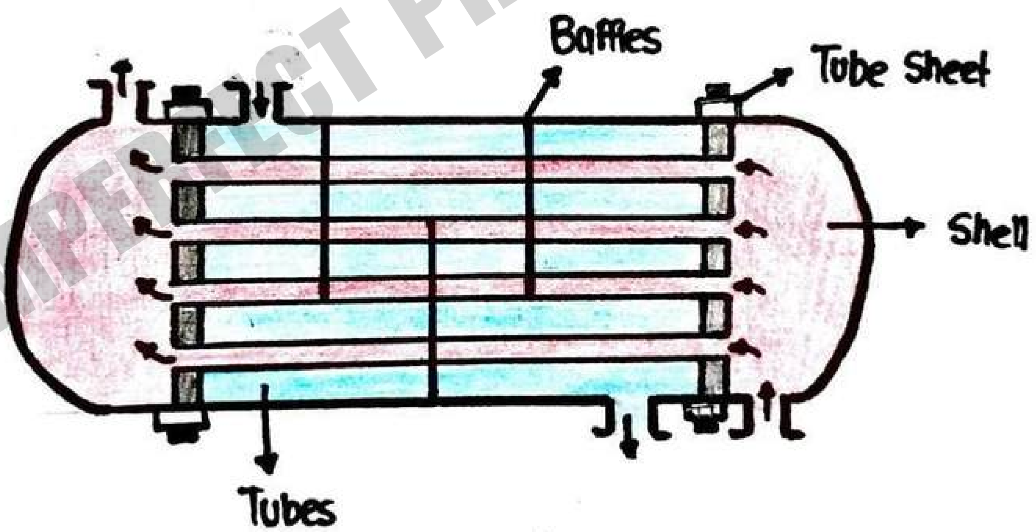


SHELL & TUBE HEAT EXCHANGER

A Shell & Tube Heat Exchanger is a common device used in many industries to transfer heat between two liquids.

PRINCIPLE

- The shell & tube heat exchanger operates on the principle of heat transfer through convection and conduction.
- It allows heat exchange between two fluids (hot & cold) without mixing them.
- One fluid flow through the tubes & other over the tube (within the shell).



SHELL & TUBE HEAT EXCHANGER

CONSTRUCTION

- Shell : A cylindrical vessel that contains the tube bundle.
- Tubes : A set of small diameter tubes placed inside the shell.
- Tube Sheets : Plates that hold the tubes at both ends, sealing them.
- Baffles : Plates placed within the shell to direct fluid flow, increasing turbulence and improving heat transfer.
- Nozzles : Provide inlet & outlet for both shell - side & tube side fluids.

WORKING

- One fluid flows inside the tube while other fluid flow outside the tube i.e. inside the shell.
- The hot fluid transfers its heat to the cold fluid through the walls of the tubes.
- Heat exchange occurs due to temperature difference between two fluids.

APPLICATION

- In power plants
- Chemical Processing
- HVAC Systems

ADVANTAGES

- High Efficiency
- High Durability
- Low Maintainance

DISADVANTAGES

- High Initial Cost
- Space Requirment
- Complexity .

EVAPORATION

Evaporation is the process by which a liquid substance transforms into gaseous state at a temperature below its boiling point. It occurs primarily at the surface of the liquid.

MECHANISM OF EVAPORATION

- At any given temperature, molecules in a liquid are in a constant motion. Some molecules have more kinetic energy than others.
- The molecules at the surface of the liquid, which experience less intermolecular force from surrounding molecules, are more likely to gain enough energy to overcome the liquid's surface tension and escape into the air as gas.

FACTORS AFFECTING EVAPORATION

Several factors influence the rate of evaporation.

- Temperature
- Surface Area
- Humidity
- Wind Speed
- Pressure
- Boiling Point

① Temperature

- High temperature increases the kinetic energy of molecules in the liquid, making it easier for them to overcome the intermolecular forces and escape into the gas phase.
- This is why clothes dry faster on a hot sunny day.

② Surface Area

- Evaporation occurs at surface of the liquid.
- A larger surface area exposes more molecules to the surrounding air, increasing the rate of evaporation.
- This why spreading out wet clothes helps them dry faster.

③ Humidity

- Humidity refers to the amount of water vapour already present in the air
- When the air is saturated with water vapour, the rate of evaporation decreases.
- This is because air cannot hold any more water vapour, so the escaping molecules tend to return to the liquid phase.

④ Wind Speed

- Wind carries away water vapour molecules from the surface of the liquid, reducing the concentration of water vapour in the air around the liquid.
- This creates a lower humidity environment, promoting evaporation

⑤ Pressure

- Lower atmospheric pressure makes it easier for molecules to escape from the liquid, thus increasing evaporation.

⑥ Boiling Point

- Evaporation is inversely proportional to boiling point
- Liquids with a higher boiling point such as water evaporate more slowly than liquids with lower boiling points such as alcohol.

OBJECTIVES OF EVAPORATION

- To increase the concentration of a solution by removing excess solvent
- To separate and purify a substance from a mixture by removing impurities.
- To reduce the volume of liquids for easier handling, storage.
- To remove moisture from a substance to produce a dry product.

APPLICATION OF EVAPORATION

- Food Industry : Evaporation is used to concentrate fruit juices, milk and other food products.
- Pharmaceutical Industry : Evaporation is used to purify & concentrate pharmaceutical products.
- Water Treatment : Evaporation is used to remove impurities from water to produce clean drinking water.
- Textile Industry : Evaporation is used to dry textiles, such as fabrics or fibers.
- Chemical Industry : Evaporation is used for concentration of chemical solutions such as caustic soda.

EQUIPMENTS USED IN EVAPORATION

- Steam Jacketed kettle
- Horizontal Tube Evaporator
- Climbing Film Evaporator
- Forced Circulation Evaporator
- Multiple Effect Evaporator

DIFFERENCE BETWEEN EVAPORATION & OTHER HEAT PROCESS

① Evaporation vs Boiling

- Evaporation occurs at surface of the liquid at a temperature below its boiling point.
- Boiling occurs throughout the liquid when it is heated to its boiling point.

② Evaporation vs Distillation

- Evaporation is used to concentrate a solution or remove excess solvent.
- Distillation is used to separate mixtures based on differences in boiling points.

③ Evaporation vs Drying

- Evaporation involves removal of moisture from a solution or liquid mostly.
- Drying involves removal of moisture from solid.

④ Evaporation vs Sublimation

- Evaporation involves a phase transition from to gas.
- Sublimation Involves phase transition from solid to gas

① STEAM JACKETED KETTLE

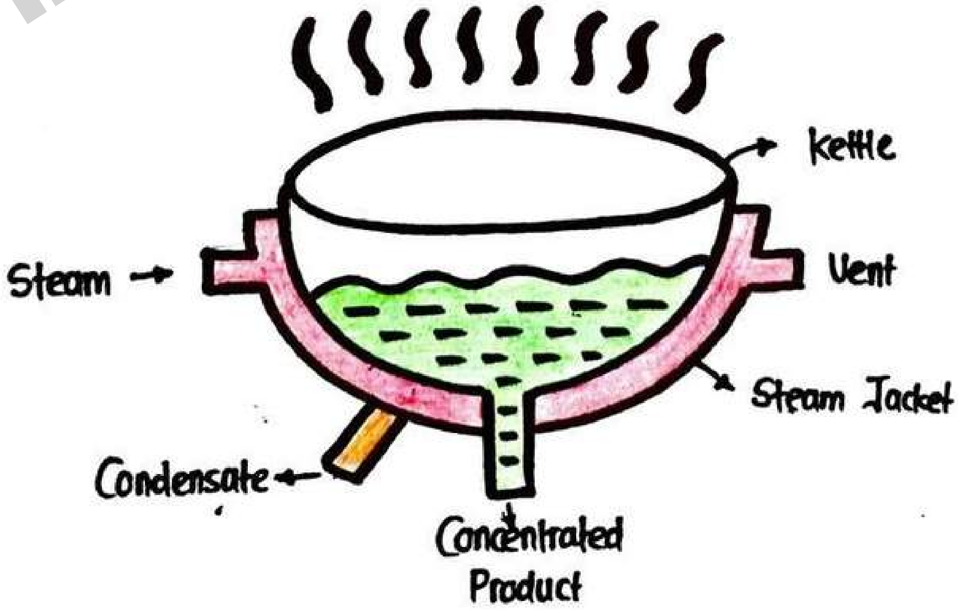
Principle

Steam Jacketed kettle work on the principle of heat transfer, where steam is used to heat a liquid or semi-solid mixture in a kettle.

Construction

A steam jacketed kettle typically consist of:

- Kettle: A cylindrical or hemispherical vessel made of a heat-conductive material. (eg. stainless steel, copper etc)
- Steam Jacket: A surrounding Jacket that allows steam to circulate and heat the kettle
- Steam Inlet: Connection that allows steam to enter the jacket
- Steam Outlet: Connection that allows condensate to exit the jacket.



Working

- Steam from an external source (like a boiler) enters the jacket surrounding the kettle.
- The steam transfers heat to the kettle, heating the contents. The temperature inside the kettle is controlled by adjusting the steam flow.
- After the steam has released its heat, it condenses into water and exits through the steam outlet.

Advantages

- Efficient Heat Transfer
- Uniform Heating
- Easy Cleaning

Disadvantages

- Dependency on steam supply
- Corrosion Risk.

Application

- Food Processing
- Pharmaceuticals
- Cosmetics

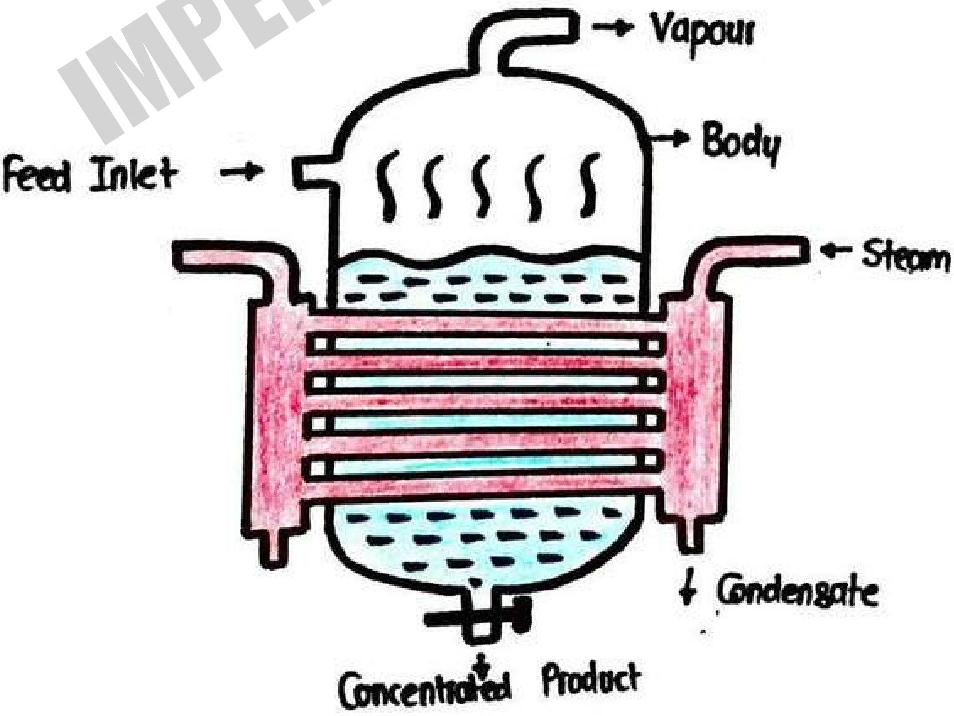
② HORIZONTAL TUBE EVAPORATOR

Principle

- A Horizontal Tube Evaporator works on the principle of Heat Transfer.
- When the steam is passed through horizontal tubes it transfer its heat to the feed outside the tubes, leads to evaporation of the feed.

Construction

- Body: A cylindrical vessel that houses the entire assembly.
- Tube Bundle: A group of horizontal tubes typically made of stainless steel.
- Vents: An Inlet & outlet for the steam.
- Feed Inlet: Through which feed enters
- Feed Outlet: Through which concentrated product comes out.



Working

- Steam is introduced into the horizontal tubes.
- The heat from the steam is transferred to the liquid surrounding the tubes.
- The liquid absorbs heat and begins to evaporate.
- The vapour rises to the top of the shell and is collected in the vapour space.
- The concentrated liquid collects at the bottom of the shell.

Advantages

- High Heat Transfer Efficiency
- Easy Cleaning
- Low Maintainance.

Disadvantages

- Limited Capacity
- Not suitable for viscous Liquids.

Application

- Food Processing
- Chemical Industry
- Pharmaceutical Industry

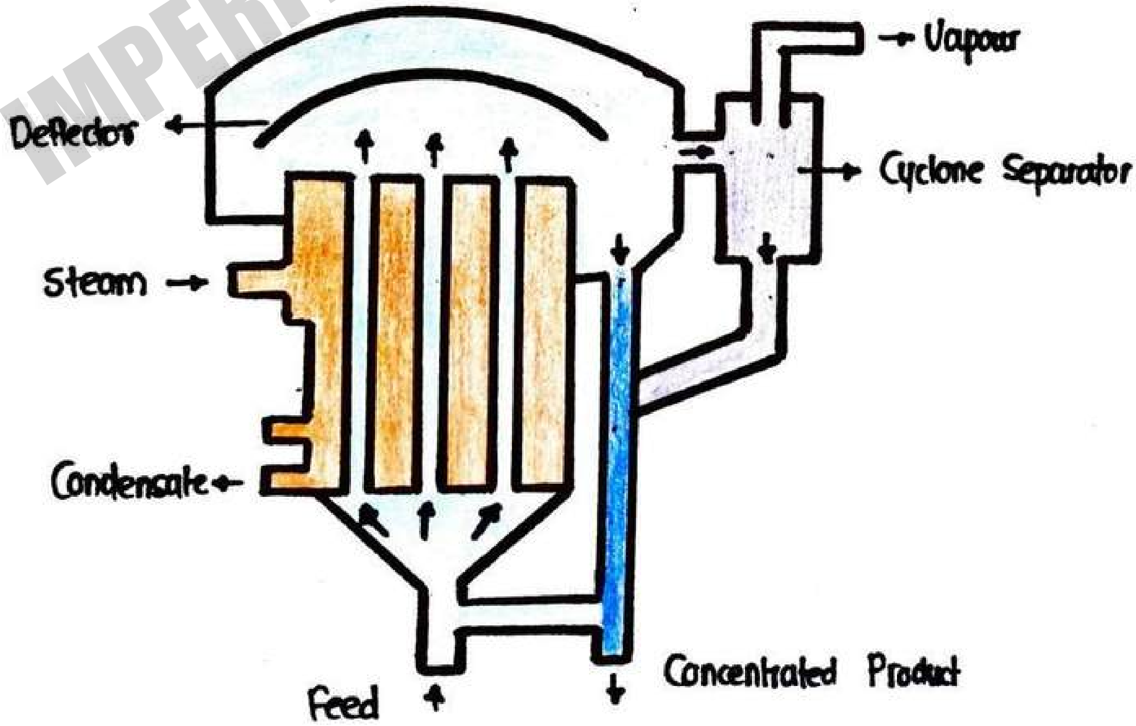
③ CLIMBING FILM EVAPORATOR

Principle

- A Climbing film evaporator works on the principle of Thin Film Evaporation
- The steam is introduced inside the tubes while the liquid to be concentrated is fed into the bottom of the tubes & forms a thin film which rises due to evaporation process.

Construction

- Shell : A cylindrical vessel that houses the entire assembly.
- Tubes : A Group of vertical tubes, typically made of steel.
- Steam Inlet : Through which steam enters
- Vapour Outlet : At the top of the evaporator, through which vapour escapes.
- Concentrate : A connection through which product is collected.
- Feed Inlet : A connection through which feed is introduced.



WORKING

- The heating source (e.g. steam) is introduced into the tubes Liquid is introduced at the bottom of the tubes.
- As the liquid absorbs the heat, it forms a thin film that climbs upward due to natural flow of liquid
- The thin film (basically a vapour-liquid mixture) reaches at the top of the tube where it strikes with deflectors and separated into liquid & vapour.
- The concentrated liquid is collected at the top of the shell & removed through concentrate outlet while vapour removed separately.

Advantages

- Efficient Heat Transfer
- Suitable For Heat-sensitive liquids
- Compact Design

Disadvantages

- High Maintainance
- High Initial Cost

Application

- Pharmaceutical Industry
- Chemical Industry

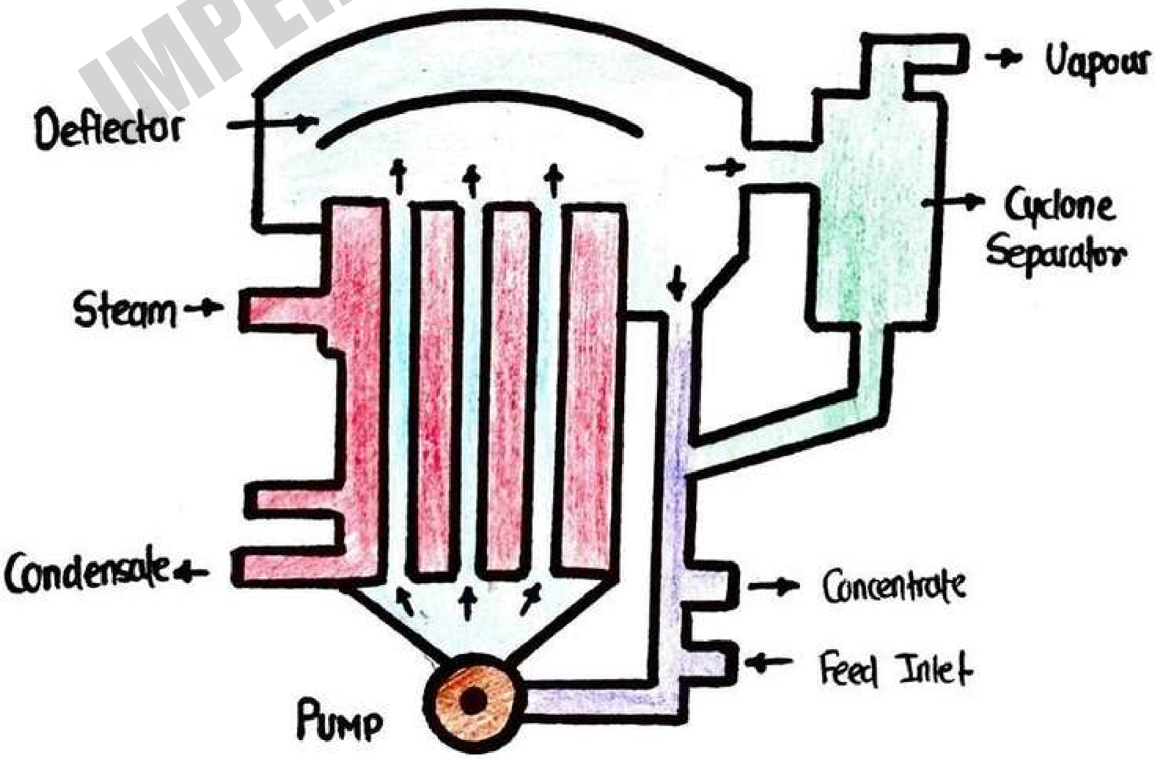
④ FORCED CIRCULATION EVAPORATOR

Principle

The forced circulation evaporator based on the principle of external pumping to circulate the liquid throughout the chamber.

Construction

- Shell : Cylindrical vessel that houses the entire assembly.
- Tubes : A bundle of tubes through which steam flows.
- Feed Inlet : A connection through which feed is introduced.
- Circulation Pump : A pump that circulates the heat
- Vapour Outlet : A connection that allows exit of vapour.
- Concentrate : A connection through which concentrated liquid collected.
- Steam Inlet : A connection through which steam enters.



WORKING

- Steam is introduced into the tubes through steam inlet.
- The liquid to be evaporated is fed into vessel.
- The pump circulates the liquid through evaporating chamber.
- The vapour-liquid moves upwards & strikes the deflector which separates liquid & vapour
- The liquid is collected through concentrate while vapour removes through vapour outlet.

Advantages

- Suitable for viscous liquids.
- Efficient heat transfer.
- Suitable for Heat sensitive materials.

Disadvantages

- High Initial Cost
- High Maintainance
- Energy Consumption

Application

- Pharmaceutical Industry
- Chemical Industry
- Food Industry

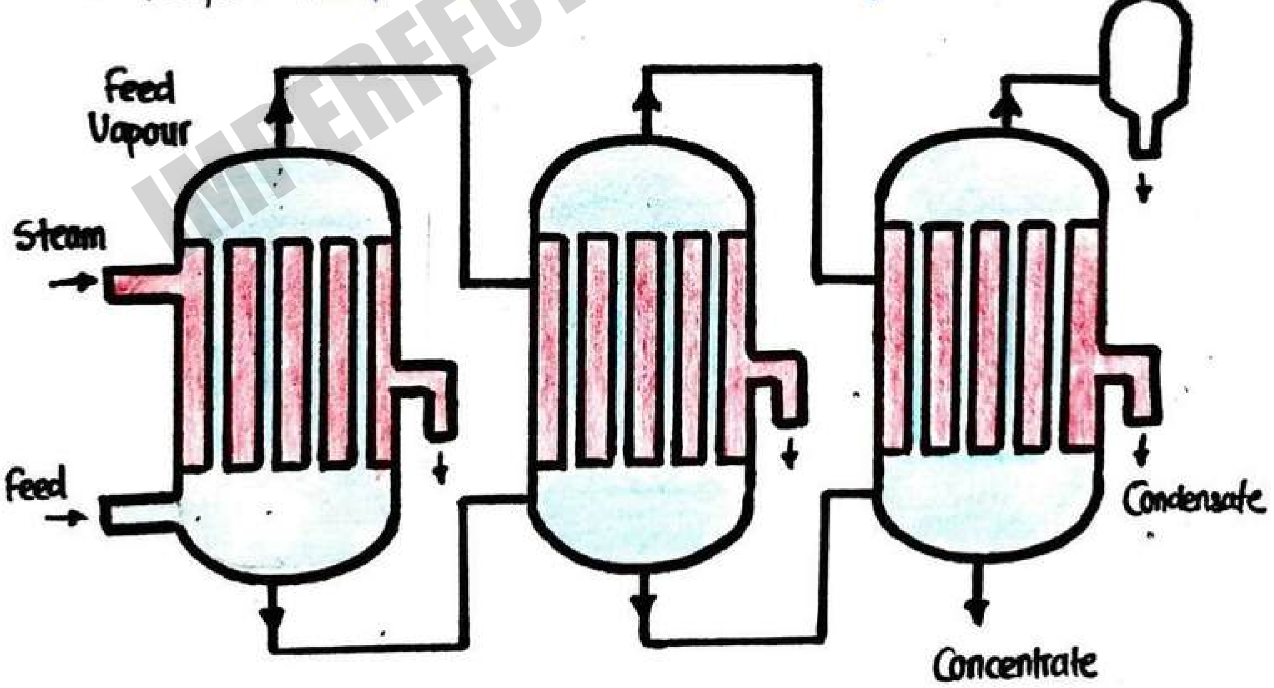
⑤ MULTIPLE EFFECT EVAPORATOR

Principle

- The multiple effect evaporator works on principle of heat transfer.
- The solution to be evaporated is fed into the first effect where it is heated by steam.
- The vapour generated in the first effect is then used to heat the solution in the subsequent effects & so on.

CONSTRUCTION

- Effects : A series of vessel typically 3-7, where liquid is evaporated.
- Steam Inlet : It is used to supply the steam to the first effect
- Condensers : Exit for condensed H steam.
- Pumps : Pumps circulate the solution through the effects.



Working

- Steam is supplied to the first effect, where it heats the solution and generates vapour.
- The vapour from first effect is transferred to the second effect, where it acts as heating medium.
- The process is repeated in each subsequent effect, with each operating at a lower pressure and temperature.
- At the last utilized vapour is condensed in condenser.
- The solution becomes progressively more concentrated as it passes through the effect.

Advantages

- Energy Efficiency
- Cost Effective
- Customizable

Disadvantages

- High Initial Cost
- High Maintainance

APPLICATION

- Food Processing
- Chemical Industries
- Pharmaceutical Industries

DISTILLATION

- Distillation is a physical separation process used to separate components of a mixture based on differences in their boiling points.
- It is commonly used in industries, laboratories and everyday application to purify liquids, recover solvents or separate components of a mixture.

PRINCIPLE OF DISTILLATION

- Each component of a mixture has a specific boiling point. When the mixture is heated, the components with the lower boiling point vaporizes first.
- The vapour is then cooled in a condenser to convert it back into a liquid form.
- By carefully controlling the heating and condensation process, the components can be separated.

APPLICATION OF DISTILLATION

- Purification of chemicals.
- Alcohol Production
- Isolating active ingredients
- Extraction of aromatic compounds.
- Separation of crude oils.

TYPES OF DISTILLATION

- Simple Distillation
- Flach Distillation
- Fractional Distillation
- Distillation Under Reduced Pressure
- Steam Distillation
- Molecular Distillation

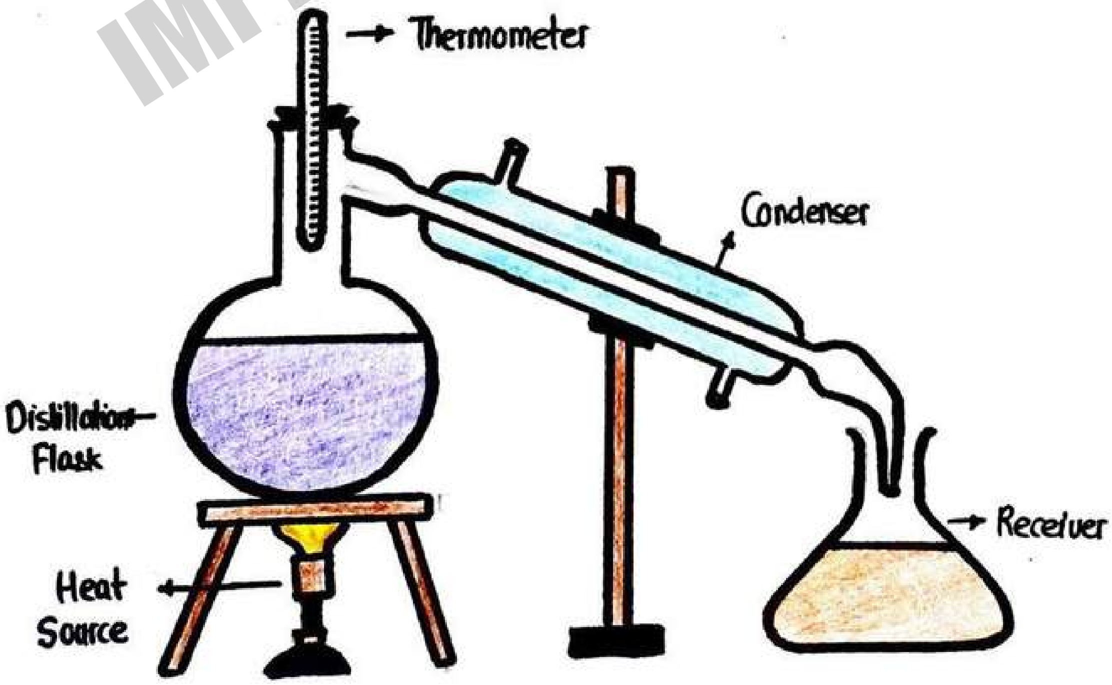
① Simple Distillation

Principle

- The process is based on the differences in boiling points of components in a mixture.
- The liquid with lower boiling point vapourizes first when the mixture is heated, leaving behind other components.
- The vapour is then condensed back into liquid & collected separately.
- The effectiveness of simple distillation is optimal when boiling points of components differs by at least 25°C.

Construction

- Distillation Flask: Holds the liquid mixture to be separated.
- Heat Source: Heat the mixture to induce boiling.
- Condenser: Cools the vapour back into liquid.
- Receiving Flask: Collects the condensed liquid.
- Thermometer: Monitors the temperature to ensure proper separation.



Working

- The liquid mixture in distillation flask is heated.
- The component with lower boiling point vaporizes first.
- The vapour passes through the condenser, where it cools and condenses into liquid.
- The condensed liquid is collected in the receiving flask
- The process continues allowing for separation of components.

Advantages

- Simple setup
- Cost effective
- Minimum Energy Utilisation

Disadvantages

- Inefficient for mixtures with close boiling point.
- Not suitable for heat-sensitive substances.

Application

- Water purification
- Purification of organic solvents
- Alcohol Distillation.

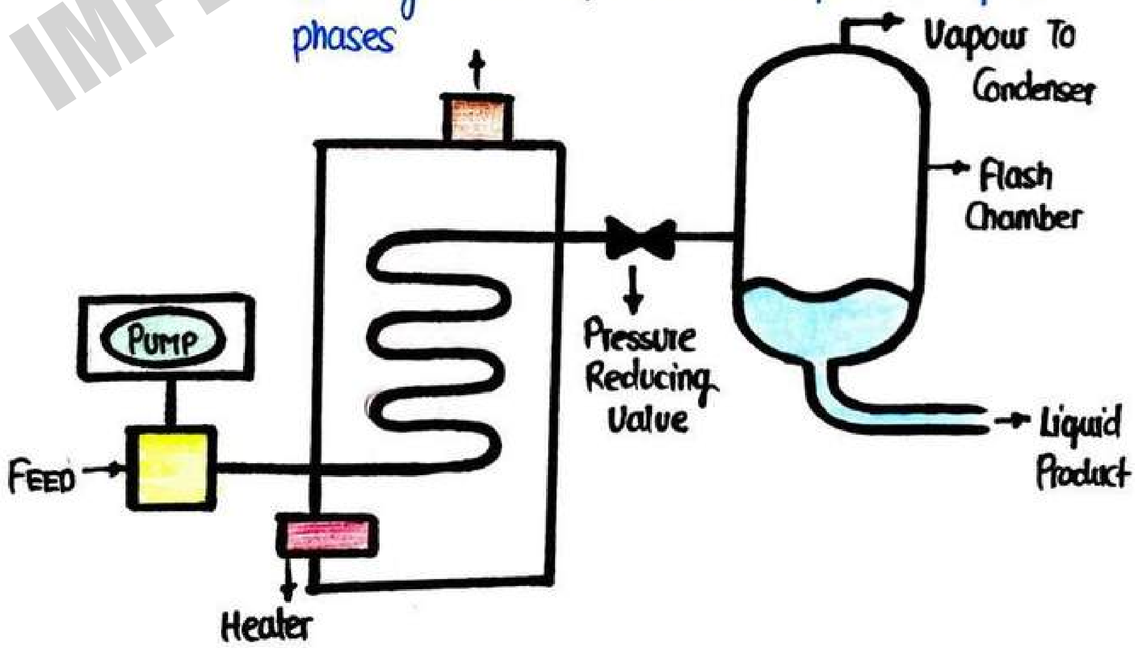
② FLASH DISTILLATION

PRINCIPLE

- The process operates on the principle that when a heated liquid mixture undergoes a sudden reduction in pressure, it partially vaporizes.
- This rapid vaporization occurs because the reduced pressure lowers the boiling point of mixture's components.

CONSTRUCTION

- Feed : Contains the liquid mixture to be separated.
- Pump : Transfers the liquid mixture from feed to the heater.
- Heater : Elevates the temperature of the liquid mixture
- Pressure Reducing Value : Lowers the pressure of the heated liquid mixture as it enters the flash chambers.
- Flash Chamber : A vessel where mixture undergoes flash vaporization resulting in the separation of vapour & liquid phases



WORKING

- The liquid mixture is pumped from the feed reservoir into the heater, where it is heated to a specific temperature.
- The heated mixture passes the pressure reducing value, causing a sudden drop in pressure.
- A portion of liquid instantly vaporizes due to reduced pressure.
- The vapour and liquid phases separates within the flash chamber.
- The vapour phase is collected from the top of the drum, while the liquid phase is collected from the bottom.

Advantages

- Simple Design
- Low Operating Cost
- Fast Separation

Disadvantages

- Limited Separation
- Not suitable for Heat-Sensitive Materials.

Application

- Petroleum Refining
- Chemical Processing
- Food Processing

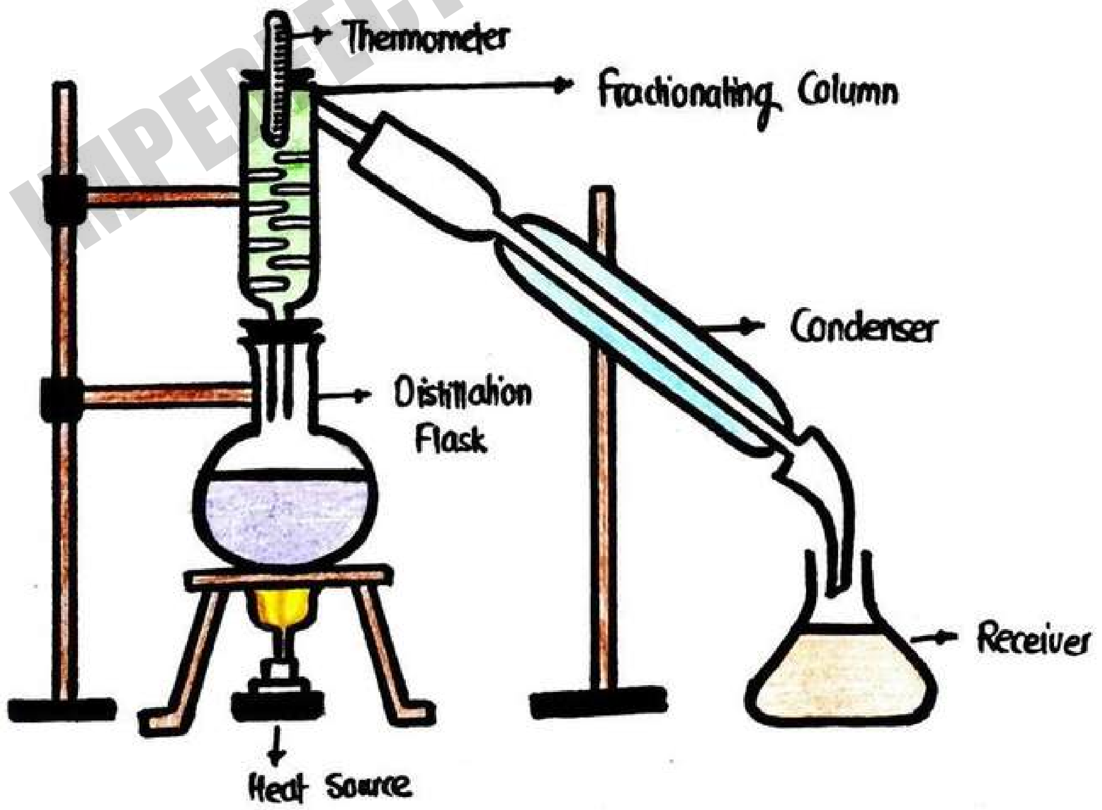
③ FRACTIONAL DISTILLATION

Principle

- When the mixture is allowed to heat, the partial condensation of the vapour is allowed to occur in a fractionating column.
- The ascending vapours ~~allowed~~ escapes from the column while condensing vapour return back to the flask.

CONSTRUCTION

- Distillation flask: A round bottom flask that hold the liquid mixture
- Fractionating Column: A vertical column that separates the vapour phase from liquid phase.
- Condenser: A coil or tube that condenses the vapour back into a liquid
- Collection Vessel: A vessel that collects the distilled fractions



WORKING

- The mixture is heated in the distillation flask.
- The component with low boiling vaporizes first and escaped from fractionating column & collected in the receiver.
- The component with high boiling point condensed back into distillation flask through fractionating column.

Advantages

- Efficient separation
- High Purity
- Suitable for both laboratory & industrial process.

Disadvantages

- Complex Setup
- Time Consuming

Applications

- Petroleum Industry
- Pharmaceutical Industry
- Food Industry

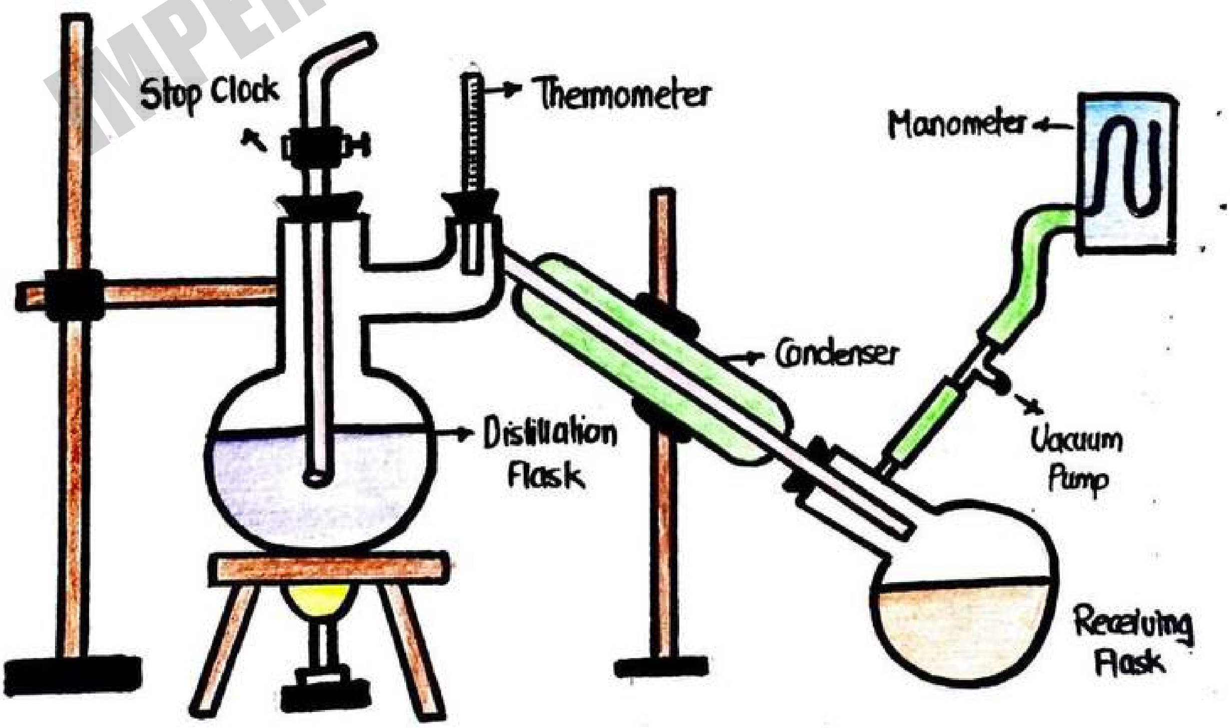
④ Distillation Under Reduced Pressure

Principle

- Distillation under reduced pressure, also known as vacuum distillation is based on the principle that the boiling point of a liquid decreases as surrounding pressure decreases.
- By reducing the pressure, the liquid can be vaporized at a lower temperature, which helps to prevent thermal degradation and preserve the quality of the product.

Construction

- Distillation Flask: A vessel where feed mixture is heated & vaporized.
- Condenser: Condensed ~~liquid~~ ~~back into~~ vapour back into liquid
- Vacuum Pump: A device that creates and maintains the reduced pressure environment.
- Collection Vessel: A container where distilled product is collected.



WORKING

- The feed mixture is introduced into the distillation flask.
- The feed mixture is heated, causing the liquid to vaporize.
- The vacuum pump creates a reduced pressure environment, which facilitates vaporization at low temperature
- The vapour rises into condenser, where it condensed back into liquid.
- The distilled product is collected into the collection vessel.

Advantages

- Lower Temperature
- Increased Efficiency
- Reduced Energy Consumption

Disadvantages

- Higher Equipment cost
- Increased complexity

Application

- Chemical Processing
- Food Processing
- Pharmaceutical Manufacturing

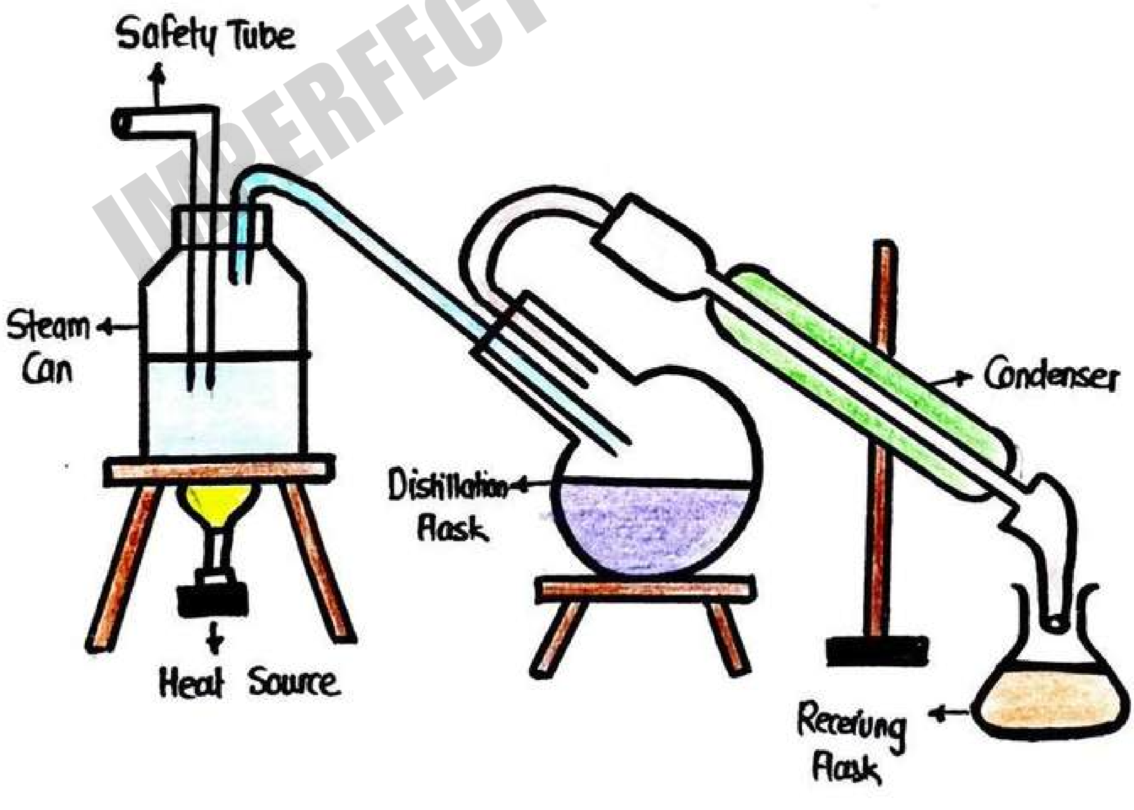
⑤ STEAM DISTILLATION

PRINCIPLE

- Steam distillation is a technique used to purify or isolate heat-sensitive compounds.
- It utilizes steam to separate a mixture of two or more liquids based on their differences in boiling points.

CONSTRUCTION

- Distillation Flask : A Vessel where feed mixture is heated & vaporized.
- Steam Generator : A device that produces steam.
- Condenser : Device that condensed vapour back into liquid.
- Collection Vessel : Container where distilled product is received.



WORKING

- The feed mixture is introduced into the distillation flask.
- Steam is injected into the distillation flask, causing the more volatile component to vaporize.
- The vapour rises into condenser, where it is condensed back into liquid.
- The condensed liquid is separated into two or more layers based on their densities.

Advantages

- Low temperature requirment
- Increased Efficiency
- Reduced Energy consumption

Disadvantages

- Higher equipment cost
- Complexity.

Application

- Food Processing
- Chemical Processing
- Pharmaceutical Processing.

THANK YOU

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