

Heat transfer is considered as a unit operation in which heat energy is transferred from a region of higher temperature to a region of lower temperature.

- It is transferred through medium (solid, liquid) and also transfer through surrounding (air).

Application :-

- Evaporation:- It is a process in which liquid transform into gas, through heat.
- Distillation:- It is the process of separating components of a mixture based on different boiling points and we boil mixture through heat.
- Drying:- Removal of water or another solvent from a solid, semi-solid with the help of heat transfer.
- Sterilization:- A process which used to remove or kill bacteria, microorganisms by using heat.

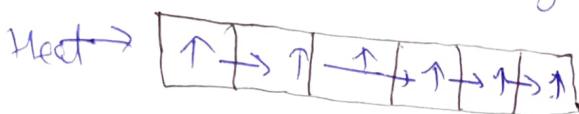
Heat transfer Mechanism

- It involves three process, How heat transferred.
- Conduction
 - Convection
 - Radiation

① Conduction :-

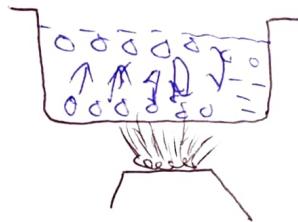
Conduction is a process in which heat flow in a body is achieved by the transfer of the momentum of individual atom or molecules without mixing."

- ⇒ In this particles must be stationary.
- ⇒ Heat transfer from high temp. to low.



② Convection :-

Convection is a process in which heat flow is achieved by actual mixing of warmer portions with cooler portions of the same material."



③ Radiation :-

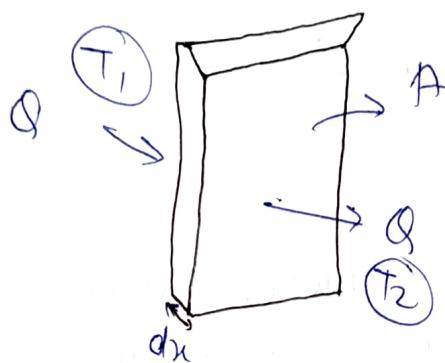
Radiation is a energy transfer process in which heat flow through space by means of electromagnetic waves."

- ⇒ In which heat direct transfer without medium (use surrounding air).

e.g. Sun's heat to water for vapourisation

Fourier's Law

It states that "the rate of heat transfer is directly proportional to the area of normal to the direction of heat flow and temperature gradient and inversely proportional to the width of wall from which heat transfer"



Temperature gradient:- It is the difference of temperature from one place to another (ΔT)

According to law,

$$Q \propto A$$

$$Q \propto \Delta T$$

$$Q \propto \frac{1}{dx}$$

So,

$$Q \propto \frac{A \cdot \Delta T}{dx} \Rightarrow$$

$$Q = -\frac{KA \cdot \Delta T}{dx}$$

Where,

Q = Rate of change of heat transfer.

A = Area of wall

ΔT = change in temp.

dx = thickness of wall

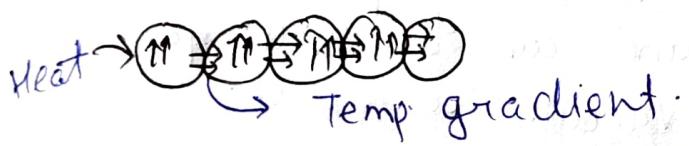
$-K$ = Constant

- Negative sign indicates the drop in temp. from high temp. to low. (47)

Heat transfer by Conduction

Transfer of heat through a solid material depends upon temperature gradient because heat transfer ~~high~~ from high temp. to low temp. (or hot surface to cool surface).

- When we provide heat at one end of substance, then particles of that end vibrate vigorously and then they collide with neighbouring particles and transfer their energy. And this process should be continuous until the last end particles should absorb heat.



- The basic law of heat transfer by conduction can be written in the form of a rate equation as follows:

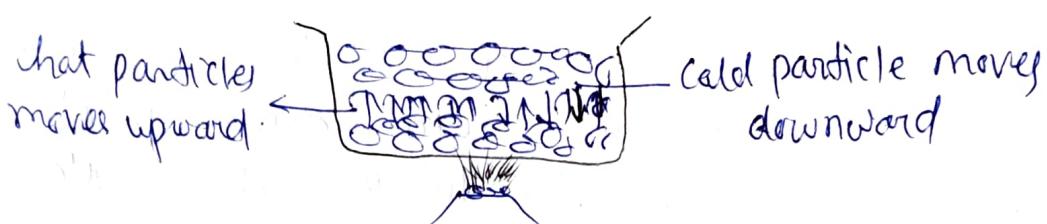
$$\text{Rate} = \frac{\text{driving force}}{\text{resistance}}$$

Heat transfer by conduction Convection

It is the mode of heat transfer which occurs mostly in liquid and gases.

- In this method, heat transfer is achieved by actual mixing of warmer portion with cooler portions of the same material.

- Convection process in which mixing of fluid may be obtained by the use of a stirrer or agitator or pumping the fluid for recirculation, is called forced convection.
- This is example of convection in which hot water at bottom become lighter and moves upwards, and denser water at the top to come down and thus heated up.



Heat transfer by Radiation

It is another form of heat transfer. It does not require any medium and can be used for transfer of heat in a vacuum as well.

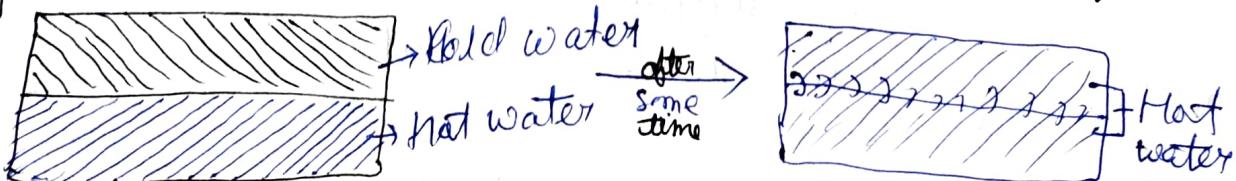
→ This method uses electromagnetic waves which transfer heat from one place to other.

Eg. In winter when we sit near a fire, we feel warm without touching fire, this is possible by radiation and called Thermal Radiation.

Heat interchangers:-

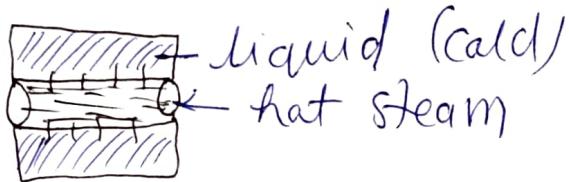
Heat interchangers are the device used for transferring heat from one liquid to another or from one gas to another gas through a metal wall.

e.g.



Heat Exchangers:-

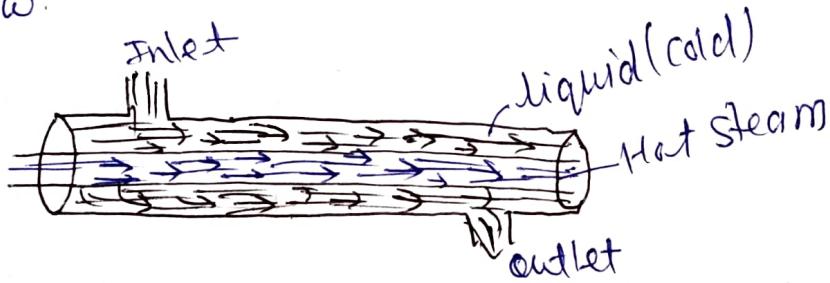
These are those device used for transferring heat from one fluid (hot gas or steam) to another fluid (liquid) through any medium (metal wall).



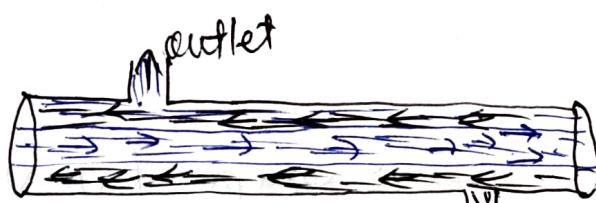
Type of Heat Exchanger or (Heaters)

- ↳ Parallel flow
- ↳ Counter flow
- ↳ Cross flow.

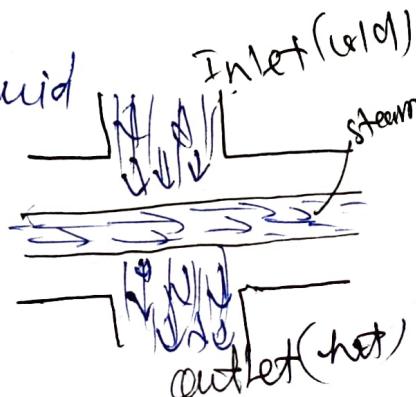
i) Parallel flow :- In which, hot steam and ~~hot~~ ^{cold} liquid direction is same is called parallel flow.



ii) Counter flow :- If, direction of flow of hot steam and ~~cold~~ ^{cold} liquid is opposite, then it is called counter flow.



iii) In which, direction of flow of fluid are perpendicularly cross to flow of hot steam is called cross flow.

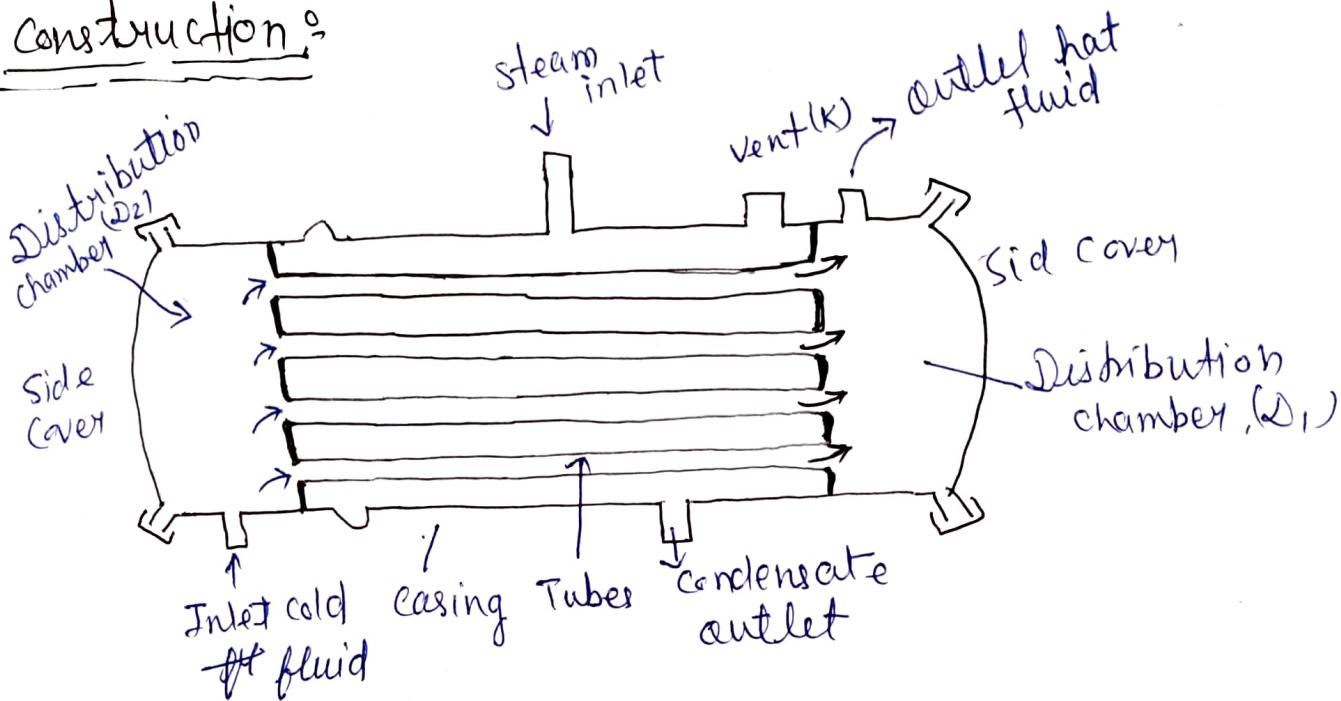


Heat Exchangers examples :-

① Tubular Heater (Shell-and-tube heater)

Principle :- It is a single pass tubular heater and work as a heat exchanger.

Construction :-



- It consists of bundle of parallel tubes → with thin wall.
- The tubes are enclosed in cylindrical casing
- Two distribution chambers D_1 and D_2 each end of casing.
- Fluid inlet in D_2 and heated fluid outlet at D_1 .
- Steam or other vapour is introduced from steam inlet
- non-condensed vapour escape from vent and condensed vapour drain at outlet

Working :- Steam is introduced into tube and tubes get heated.

⇒ The fluid to be heated pumped into distribution chamber D_2 .

fluid flow through heated tubes.
steam and fluid are physically separated but are
in thermal contact.

↓
fluid get heated by single pass of fluid

↓
heated fluid reached distributing chamber (D_1)
and leaves through hot fluid outlet

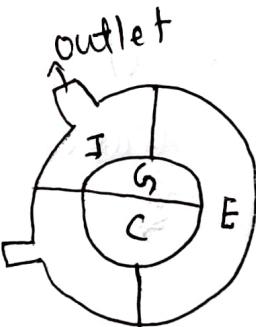
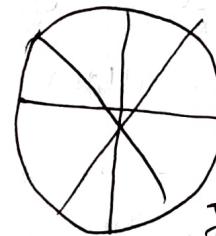
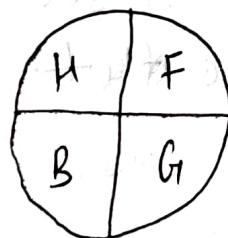
Advantages: Large heating surface area into small
space.

Disadvantages: Velocity of fluid is low, so heat transfer
coefficient is also low.

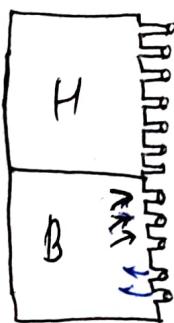
② Multipass Heater

Principle: In this heater \rightarrow velocity of fluid ↑
 \downarrow
so heat transfer coefficient also increases

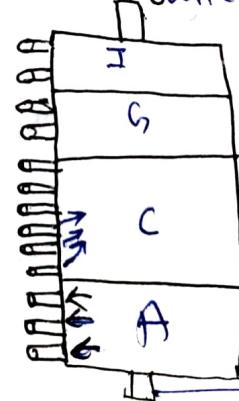
Construction:



Top View



Front View



outlet hot fluid

Inlet cold fluid

→ It consists of bundle of parallel tubes wrapped in cylindrical casing.
↓
Two distribution chambers are provided at each end of casing
↓
So same liquid flows through several tubes back and forth.

Working :- Steam introduced into space surrounding the tubes
↓
Tubes get heated
↓
Fluid to be heated pumped at high velocities into right distribution chamber A.
(high velocity facilitates effective heat transfer)
→ Liquid enters compartment A and flows to compartment B and from compartment B to C.
→ So fluid passes back and forth in several tubes and leaves the equipment from outlet.

Advantages :- Multipass - decreases the cross section of fluid path, so increase the fluid velocity.

Disadvantages:-

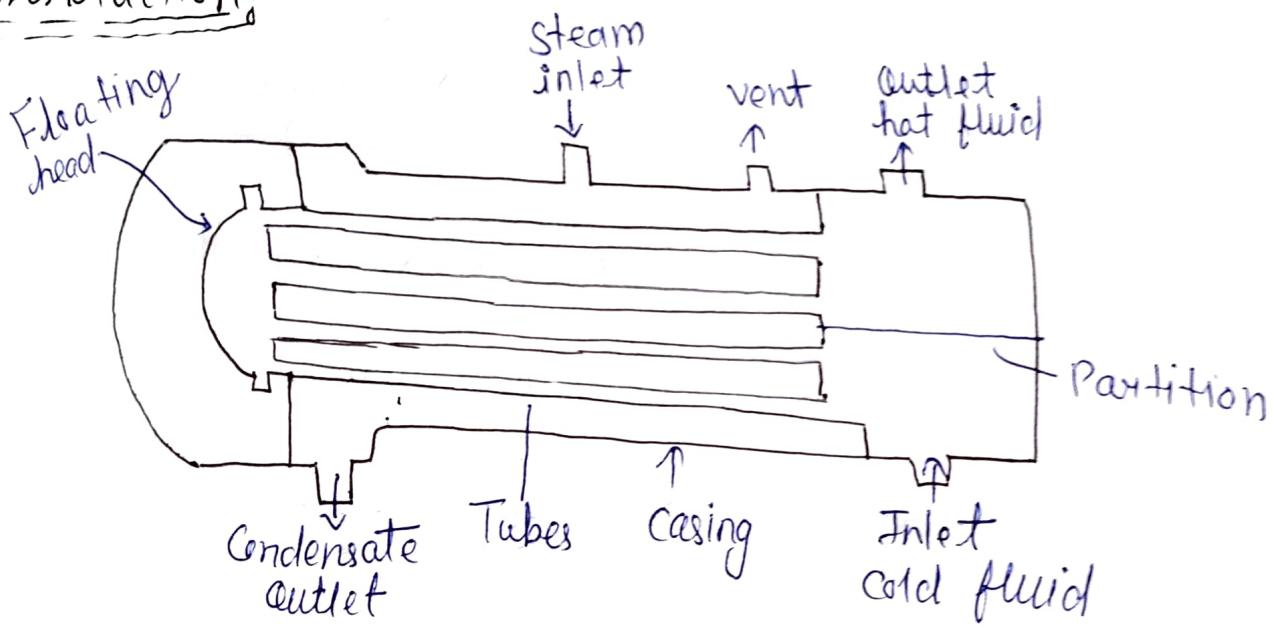
- Fabrication is complicated.
- Pressure drop through pipes increases due to enhanced velocity.

③ Floating-Head two-pass heater.

(153)

Principle: In this heater ends of tubes are structurally independent of the shell or floating type.

Construction:



- Consist of bundle of parallel tubes inclosed in a casing.
- Right side of distribution chamber partitioned fluid inlet and outlet
- Left side of distribution chamber → not connected to casing (known as floating head).
- Steam or vapour is introduced through inlet
provisions are made for
 - escape of non-condensed vapour
 - exit of condensate.

Working :- Steam is introduced through inlet
 ↓
 flow down the tubes and tubes get heated
 ↓
 fluid to be heated introduced into distribution chamber
 ↓
 fluid flow through the pipes reaches floating head and change direction.
 ↓
 then reach next part of distribution chamber
 ↓
 during this pass fluid get heated
 due to heat transfer by conduction
 by metal wall then by convection in the fluid
 ↓
 then heated fluid leaves from outlet

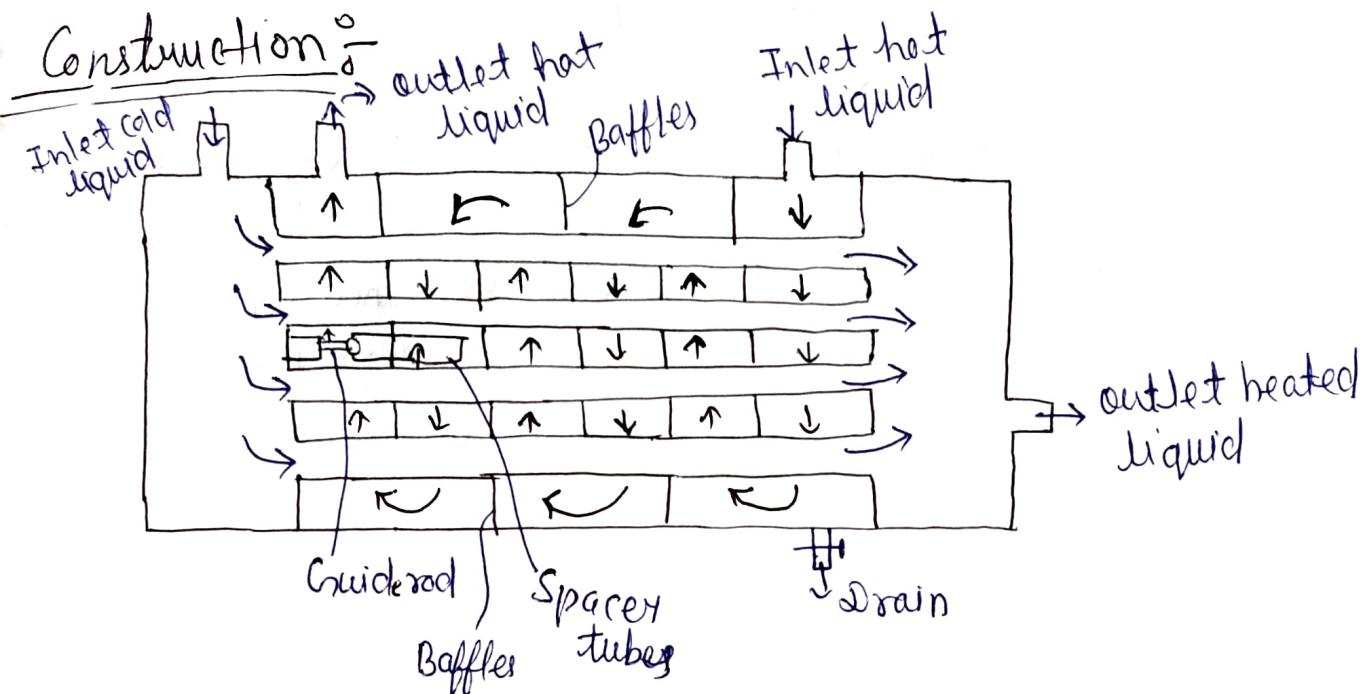
Examples of Heat Interchanger :-

① Baffles :- Baffles consist of circular discs
 ↓
 these are perforated to receive tubes

Working :- Baffles are placed outside the tubes
 ↓
 these increase velocity of liquid outside
 the tubes ↓
 which creates more turbulence
 ↑
 so increase heat transfer coefficient

② Liquid-to-liquid Interchanger

(15)



- ⇒ Tubes sheets, spacer rods and baffles are assembled first and tubes are installed.
- ⇒ Baffles are arranged with appropriate spacing.
- ⇒ The shell has provision for introducing heating medium outlet for fluid at right side tube
- ⇒ Each side of tube → 2 distribution chamber is provided
 - ↓
 - left side chamber contains an inlet for fluid to be heated
 - ↓
 - & right side chamber contain outlet for heated liquid at center.

Working :

Hot fluid is pumped through inlet fluid moves downside
then it change the direction and rises again.

baffles increase the velocity of liquid
create more turbulence

liquid to be heated is pumped through inlet

pass through the tubes and get heated
single pass

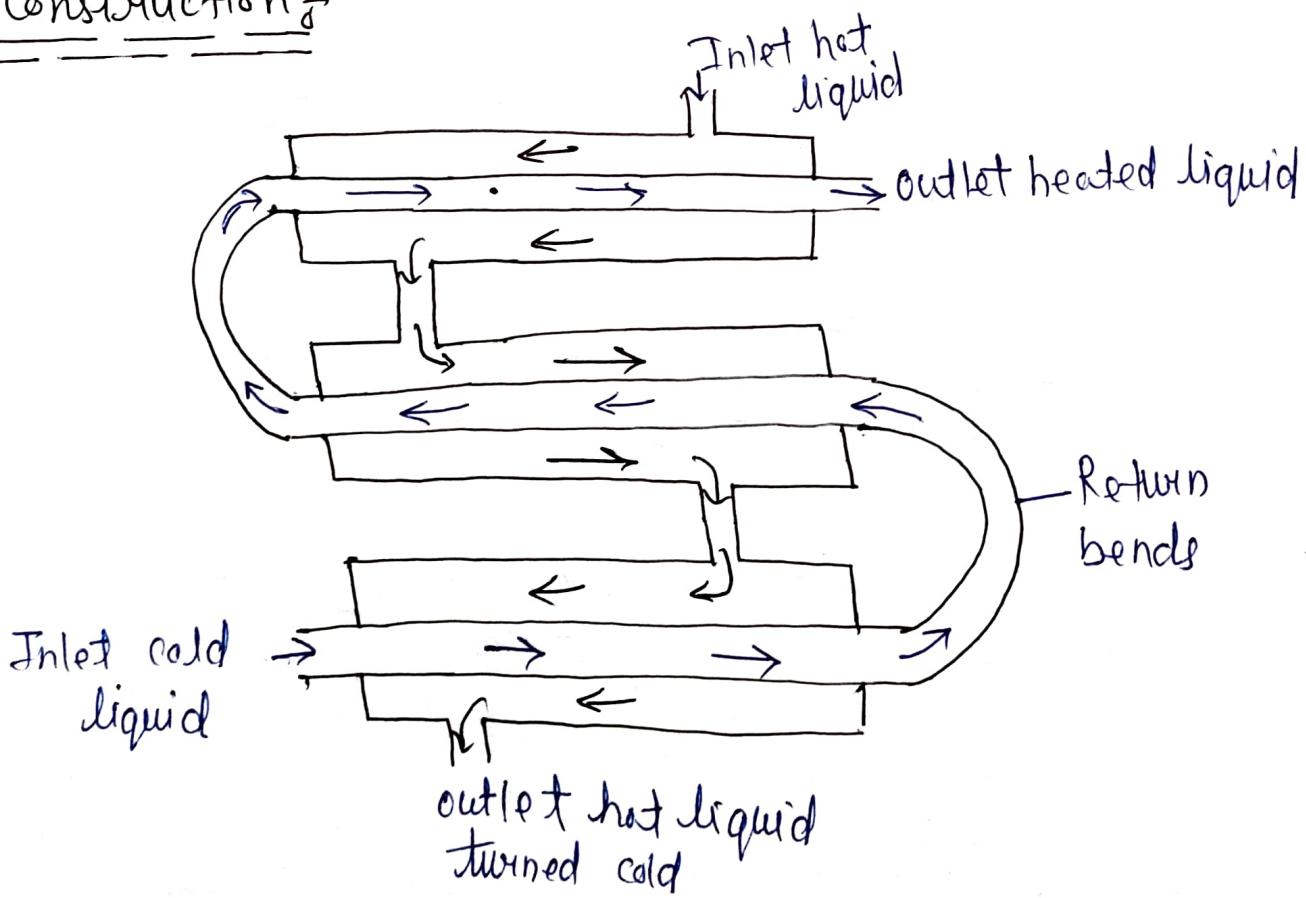
heated liquid collected from outlet

Advantage: Heat transfer is rapid.

③ Double Pipe Heat Exchanger

- Heat transfer in this equipment is more efficient than liquid-liquid heat exchanger.

Construction



- ⇒ Two pipes are used one inserted into other. (157)
- ⇒ Inside tube is for cold liquid to be heated and outside pipe act as jacket for circulating hot liquid.
- ⇒ Glass tube, standard iron pipe, graphite tubes are available.

Working : Hot liquid is pumped into jacked section

↓
pipes get heated
↓

↓
liquid to be heated is pumped through inlet.
liquid travels through tubes and get heated.

↓
Leave the interchanger through outlet .

Evaporation

• Evaporation is a process of evapourising large quantities of volatile liquid to get a concentrated product.

→ It is a process in which liquid is converting into gas (vapour) by absorbing heat.

Boiling point: the temp. at which a liquid converts starts to boil, and liquid converts into vapours.

→ Boiling point is different for different liquids.

Vapour pressure: It is a measure of the tendency of a material to change into the gaseous or vapour state, and it increase with temp.

e.g. Boiling point of water = 100°C

Boiling point of alcohol = 78.37°C

Evaporation is a surface phenomenon, in which firstly liquid on surface evaporate.

Objective and Applications

- To get concentrated product.
- To remove water from aqueous solution.
- Removal of water from solid particles to get dry product.
- For weight reduce
- Manufacture of drug.

→ Drying of clothes
⇒ Drying of drugs that are further use for manufacture in medicine.

Factor Influencing Evaporation

The rate of evaporation depends on several factors.

- ① Temperature
 - ② Surface Area
 - ③ Vapour pressure
 - ④ Humidity (moisture content of the feed)
 - ⑤ Wind speed
- ① Temperature $\propto T \propto$ Rate of evaporation
- As the temperature increases, the rate of evaporation also increase. As evaporation increases with increase in temperature.
- ② Surface Area $\propto S.A. \propto$ Rate of Evaporation.
- As the surface area increases, the rate of evaporation increases.
- ③ Vapour pressure: $V.P. \propto$ Rate of Evaporation.
- As the vapour pressure of liquid increases, the rate of evaporation also increases. and
- ④ Humidity: Humidity \propto Rate of evaporation

As the humidity in atmosphere increases ^③, the rate of evaporation decreases.

⑤ Wind speed \rightarrow Wind speed \propto Rate of evaporation.
Rate of evaporation increases with the increase of speed of wind.

Differences between Evaporation and other heat process.

other heat process - Drying, Distillation, Crystallization, boiling, sublimation.

Evaporation

Other heat process

→ The residue is a concentrated liquid.

Transforming liquid

into a gas (no need of separation)

to separation

purpose to get concentrated liquid.

Liquid in to gas

→ Drying; Residue is solid.
Distillation is the process of separation.
Separation is compulsory.

Cry stallization: purpose of concentration to get crystal.

Sublimation: transition of solid to gas

→ It happened also on
boiling \Rightarrow process of evaporation
of a liquid at the boiling point of the liquid.

1. Steam Jacketed Kettle "or" Evaporating Pan

Principle: The conduction and convection mechanism is involved in the evaporation process, in which (hot) steam passes and by absorbing heat liquid get evaporate.

Construction:

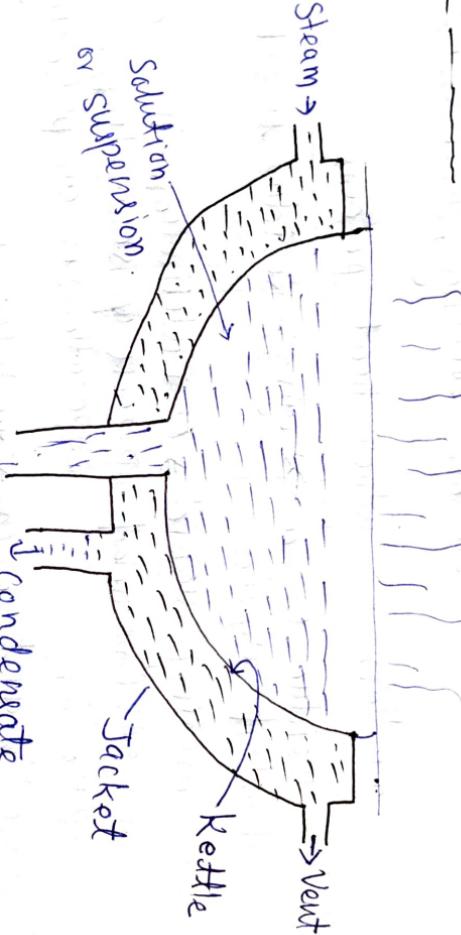


Fig.: Steam jacketed kettle

- ⇒ It is a hemispherical structure consisting of a inner pan called kettle.
- ⇒ It is enveloped with an outer pan called jacket that are made of copper because it is good conductor of heat.
- ⇒ Steam is passed from a jacket so jacket contain one inlet and for steam and vent outlet for non-condensed gases.

* And one outlet at downside in kettle ⑤
for discharge of products.

Working:

Firstly solution (aqueous extract) is placed in kettle then hot steam is supplied in jacket. Now, if we do this in small scale then we stirred it manually and if we do it on large scale, then we machines for stirring solution absorb heat from jacket and start converting into vapour. That steam which condensed it out from condensate outlet and remaining steam is out in the form of vent. And where there is kettle, after evaporation final product is converted from the product outlet.

Use: It is used for concentrating aqueous extracts and thermosable liquors.

Advantages:

→ It is used on both, small and large scale.
→ Simple construction, easy in use, cleaning and also its maintenance and not very expensive.

Disadvantages:

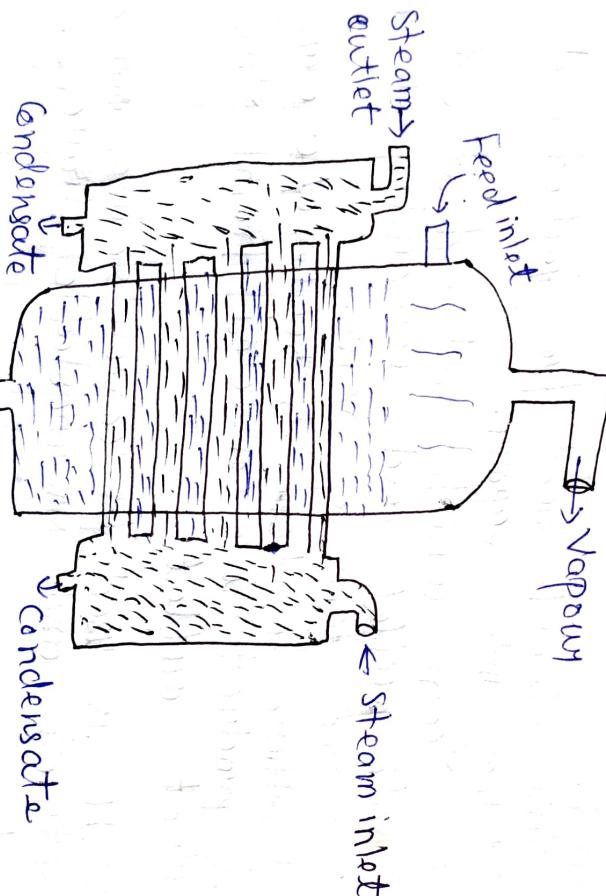
→ Not suitable for heat sensitive material.
→ Heat economy is less.

2. Horizontal Tube Evaporator

⑥

Principle— In this evaporation, steam passes through horizontal tubes and liquid outside the tube get heated by absorbing heat and convert into vapour and pass out from top.

Construction:



- It consist of a large cylinder body in which some tubes are fitted horizontally.
- It is made up with cast iron or plated steel.
- It is about 1.8 - 2.4 m diameter and from 2.4 to 3.6 m. long.

- ⇒ One inlet for feed and outlet at downside for concentrate product.
- ⇒ One inlet for feed is placed on the side of cylindrical body.
- ⇒ It also consist a steam inlet and steam outlet.
- ⇒ One outlet at top for discharge vapours.
- ⇒ And their are steam compartment in which 6-8 tubes placed horizontally and steam passed through it.

Working :-

- ⇒ Firstly feed enter through inlet and steam enter from steam inlet.
- ⇒ Now, steam release heat through tubes and absorb that heat and become hot air and started to convert into vapours.
- ⇒ Vapours is escape from outlet at top.
- ⇒ Process continue until we get the concentrated product, which we want.
- ⇒ And then product is collected through outlet at bottom.

Use :- Use for non-viscous solution.

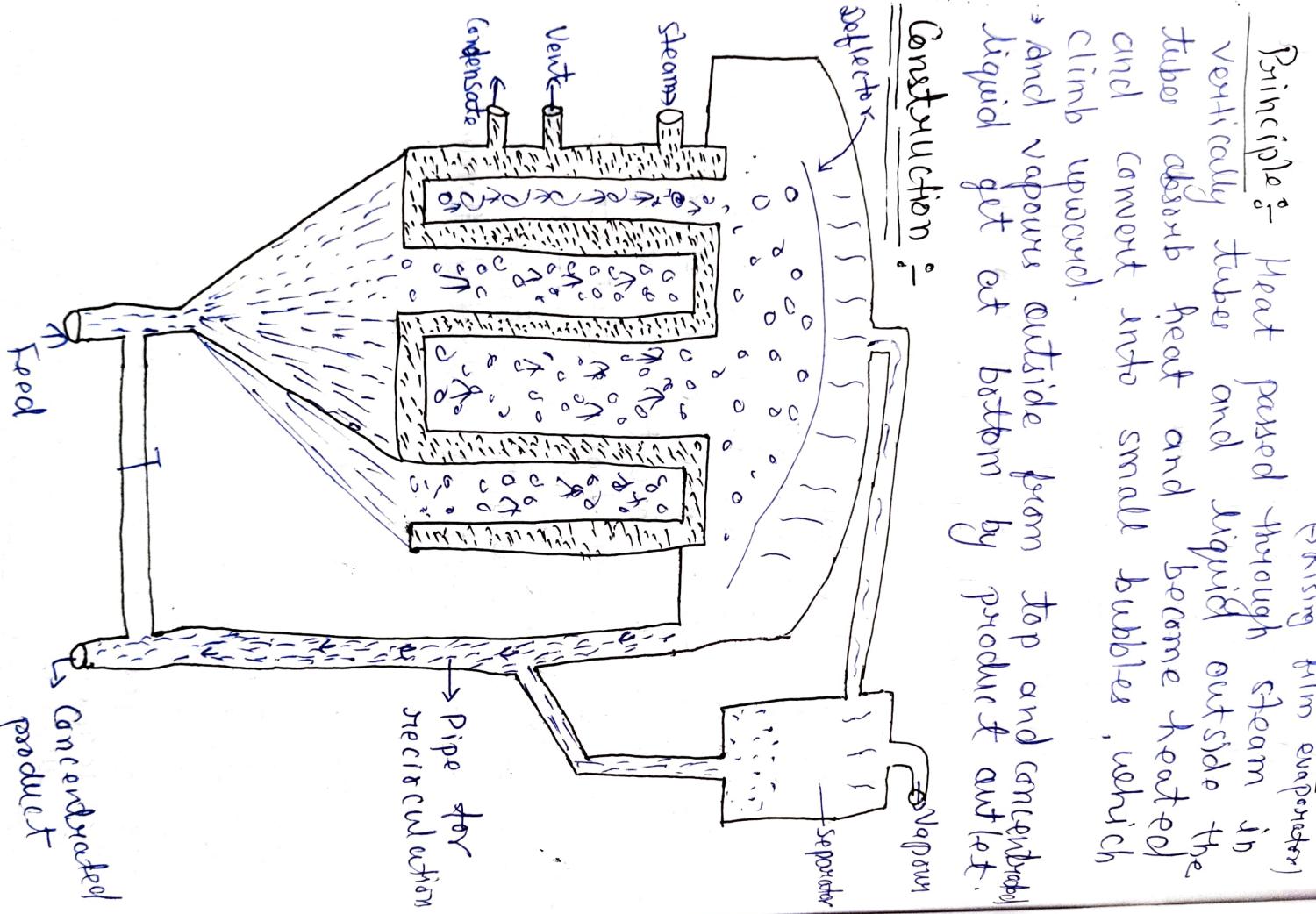
Advantages:-

- ⇒ Easy to install and operate
- ⇒ Not expensive.
- ⇒ Suitable for non-viscous liquid.
- ⇒ Disadvantages:-
 - Not suitable for viscous liquid.
 - Not suitable for heat sensitive material.

3. Climbing film evaporator

③

(Rising film evaporation)



⑤

It consist of steam jacketed tube.
An entrainment separator (Deflector) is placed at the top to the vapour head, also condensate outlet for steam and vent outlet.

→ feed inlet from bottom.

→ And one pipe for recirculation which circulates feed again.
→ And at bottom one product outlet, from which we get product (concentrated).

Working :-

Preheated liquid feed is introduced from bottom and steam introduce into tubes.
Liquid absorb heat which started to climb upward.

Then that bubbles separated through deflector which is present on vapour head
And our liquid portion is passed in pipe for recirculation and vapour goes into separator.

In which vapour discharge from top and liquid recirculate.

And when liquid is concentrated (which we want) product get from product outlet.

Use:- Used for clear liquids forming liquids and corrosive solution.
Also used for insulin and vitamins.

Advantages:-

- ⇒ Provide large area of heat transfer.
- ⇒ Suitable for heat sensitive material.
- ⇒ Suitable for foaming liquid because foam can be broken by an entrainment separator (Deflector).

Disadvantages:-

- ⇒ Expensive and construction is complicated.
- ⇒ It is difficult to clean and maintain.
- ⇒ Large head space is required.

4. Forced Circulation Evaporator

Principle :- In this evaporator, liquid is circulated through the tubes at high pressure by using pump. Hence, boiling does not take place because boiling point is elevated. When the liquid leaves the tubes and enters the vapour head, pressure falls suddenly.

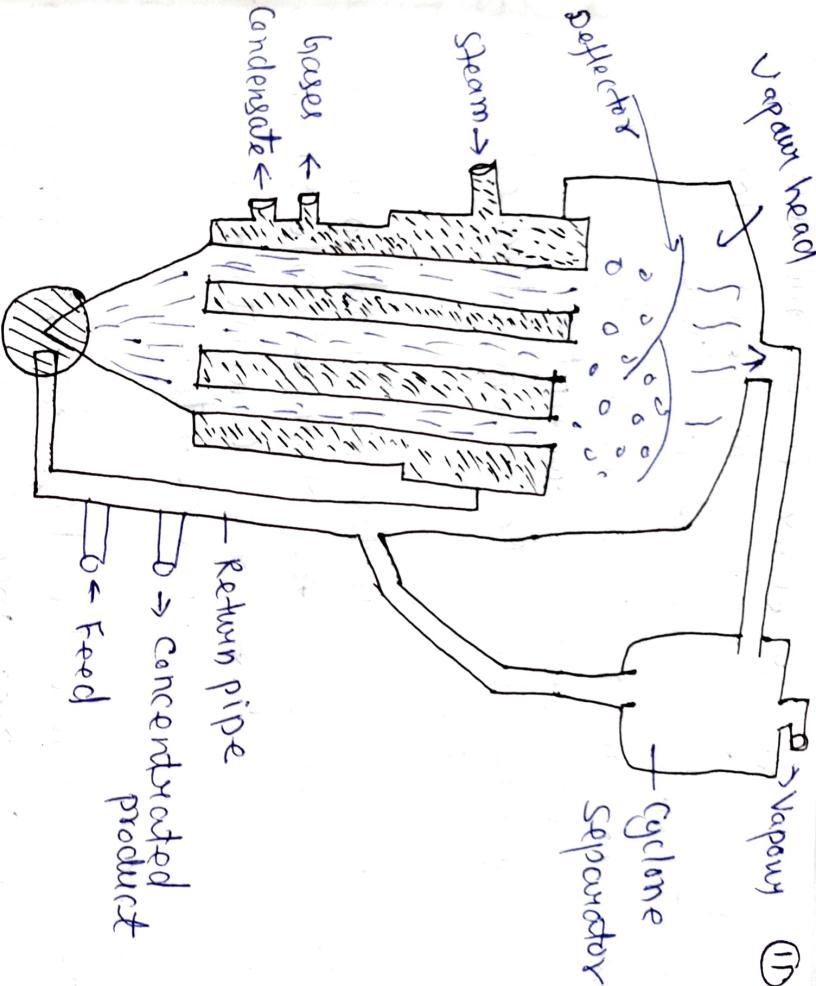
⇒ This lead to the flashing of super heated liquor, thus evaporation occurs.

Construction :-

- ⇒ One centrifugal pump.
- ⇒ Steam jacketed tubes are held between two tube sheets.

Vapour head

⑩



- ⇒ Tube measure $\rightarrow 0.1$ meter diameter & 5 meter long.
- ⇒ A vapour head with deflector and one cyclone separator which separate vapour and discharge from top from liquid.
- ⇒ An outlet for product discharge at the bottom.

Working

- ⇒ Firstly steam is supplied in tubes then liquid introduce to the tubes with high pressure by pump.
- ⇒ Then liquid get heated and move upward.
- ⇒ Then it (liquid or vapour) strikes the deflector and by deflector liquid or vapour separated.

→ Further vapour enter in cyclone separator
from top and
in which vapour discharge from top and
concentrated liquid fallen down.

- ⇒ And it recirculate again, if we want
more concentrated product.
- ⇒ The finally we collect concentrated prod.
from outlet.

- Use : It is used under reduced pressure,
it is suitable for thermolabile substance.

⇒ It is used for the concentration of
insulin and liver extract.

Advantages:

⇒ It is suitable for high viscous preparation
because pumping mechanism is used.

⇒ The heat transfer coefficient is
high due to rapid liquid movement

Disadvantage:

⇒ The equipment is expensive, because pump
(pump) is required for circulatting
liquid.

5. Multiple Effect Evaporator

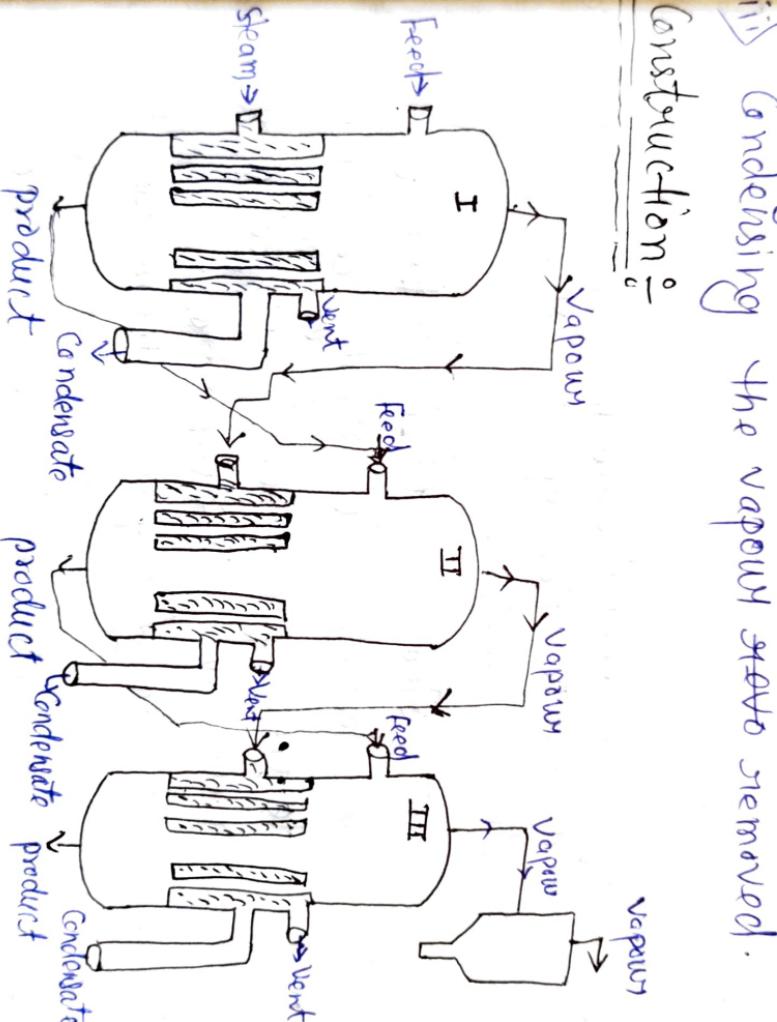
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Principle :- In this, vertical tube evaporator are connected in series, it is used for large scale evaporation and also for higher concentrated product.

It occurs in three steps:

- i) Pre-heating of solution.
- ii) Removal of water as vapour by steam heating.
- iii) Condensing the vapour into removed.

Construction :-



→ It consists of three evaporators in series, in which each evaporator consists of large cylindrical body made of white cast iron).

First evaporator has one steam inlet and one for feed. Then first's evaporator's

vapour outlet is attached with 2nd evaporator inlet and same 2nd is attached with steam 3rd.

- ⇒ In 3rd evaporator there are one outlet in which we get highly concentrated product.
- ⇒ In which approx (10) tubes are fitted.
- ⇒ Each evaporate has condensate for steam.
- ⇒ And last evaporate vapour is discharge in atmosphere through separator.

Working

- ⇒ Firstly pre-heated solution (feed) is introduce in each evaporator up to the level of upper tube sheet.
- ⇒ The hot steam (heat) is introduce in 1st evaporator and it supply continued until desired pressure is created in steam space of 1st evaporator.
- ⇒ And heat transfer from steam to liquid, during this also some steam is convert into condensate, which is remove from condensate outlet.
- ⇒ By absorbing heat, liquid temperature increase and its convert to converted into vapours.

⇒ And the space steam.

⇒ Then heat and the condensate.

⇒ The steam.

⇒ And heat.

⇒ And connect So, for

⇒ The evapo-

⇒ And from

⇒ And separator connect

Use: Cont

⇒ High si

And these formed vapour move to steam space of 2nd evaporator and work as a steam.

The vapour of 1st evaporator transmit its heat to the liquid of 2nd evaporator and then condensate removed through condensate outlet.

The same happened in 3rd evaporator.
And steam is continuous supplied until heat is same in all three evaporators.
And evaporator's product outlet is also connect in next evaporator feed inlet.
So, feed is constant (same) in all evaporator.
The process is continued until liquid in evaporators reaches the desired viscosity.
And final concentrated product collected from third evaporator outlet.
And remaining vapour is discharge or separated through separator which is connect with 3rd evaporator.

Use: It is used for large scale and continuous operation.
Highly economical when compared with single effect.

Economy of multiple effect

$$\text{Economy} = \frac{\text{Quantity of vapour produced}}{\text{Steam admitted}}$$

→ In this we use pre-heated liquid, so does not require any extra heat for boiling.

→ No loss of heat, completely transferred into liquid.

So, Economy of an multiple effect evaporator is N times the economy of the single effect evaporator.

N = No. of evaporator used in multiple effect evaporator.

→ This is because we use one steam inlet and get vapours in one evaporator in single effect.

→ But in multiple effect we get vapour more & more in many evaporators by applying steam in only one evaporator.

Distillation

(P)

Distillation is defined as the separation of the components of a liquid mixture by a process involving vaporization and subsequent condensation at another place.

- The distillation process involves two steps:
- ① Converting a liquid into vapour phase
 - ② transferring the vapour to another place and re-covering liquid by condensation.
- The feed liquid is known as distilland.
 - The condensed liquid is known as distillate or condensate.

Simple Distillation

It is used for separating the components of liquid mixtures.

Principle :- It is used for separating liquid having different boiling point approx. 25°C . The liquid having the lower boiling point, evaporate first and then collected it in another beaker through condensation and other liquid is left behind round bottom flask.

e.g. Distillation of (Acetone + water)
Distillation of (Alcohol + water) etc.
 $\text{B.P. of water} = 100^{\circ}\text{C}$, $\text{B.P. of Acetone} = 56^{\circ}\text{C}$.

—Thermometer

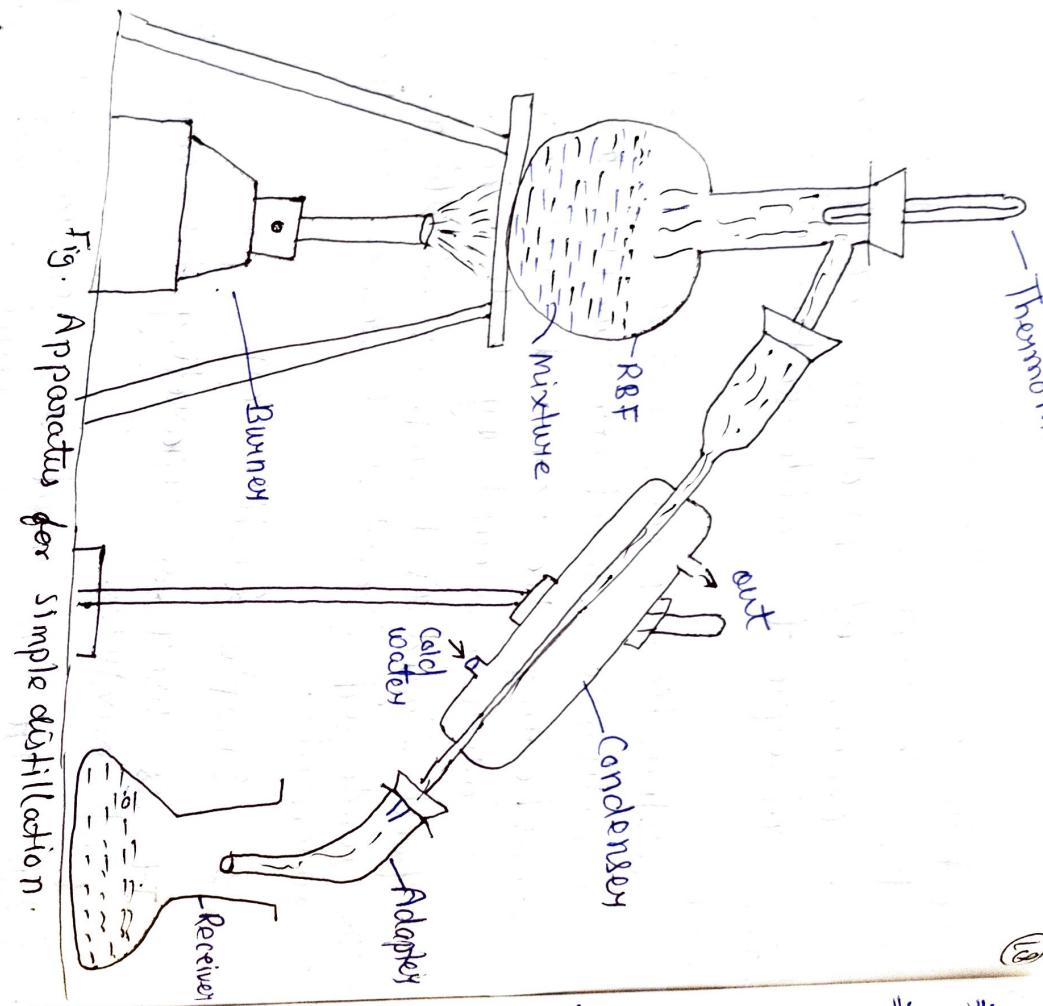


Fig. Apparatus for simple distillation.

Methodology

- ⇒ First put the mixture in distillation flask or Round bottom flask which we want to separate.
- ⇒ Then fit the thermometer at top for check the temperature in the RBF.
- ⇒ Then vapour's outlet tube is connected with condenser which open in receiver.

And then start to provide heat to round bottom flask.

On reached on boiling point, liquid which boiling point is now start to converting into vapours.

Then it collect in receiver through condenser, because when vapour passed through it again convert into vapour into liquid.

Their are cold liquid in condenser which condens vapours.

And other liquid (high boiling point) left in round bottom flask and collected it.

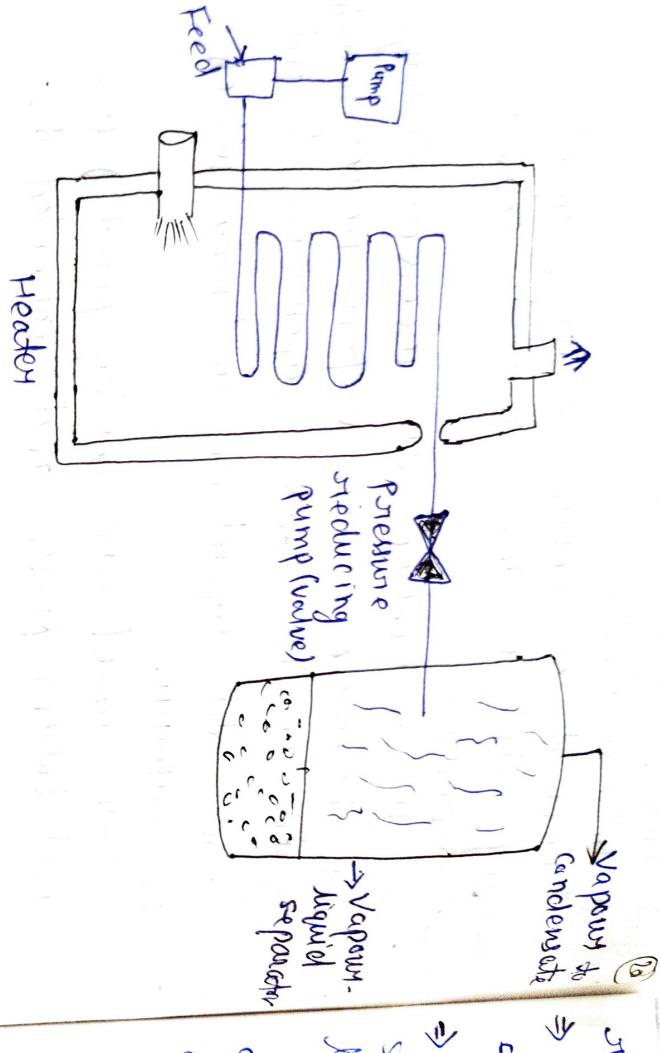
2. Flash Distillation

Principle :- In flash distillation, we pass the entire liquid mixture from heater and increase the temperature upto their boiling point, so mixture is suddenly vaporized and when we pass it through pressure zone to a low pressure zone through reducing pump. So vapour become cool and convert into liquid.

It happened due to difference in boiling point. Low boiling point vapour condense first, which we separate from second liquid.

Methodology

- ⇒ Firstly feed is pumped through a heater at a certain pressure (when mixture vaporized).
- ⇒ Then liquid get heated and converting into vapour which further enters the vapour - liquid separator, through a pressure reducing valve.
- ⇒ Pressure reducing valve reduce the pressure and vapour start to be condensed.
- ⇒ Now, firstly vapour's of high boiling fraction get condensed which we get in vapour-liquid separator and low boiling fraction



→ remains as vapour ..

⇒ Then after some time second liquid also condense and we collect it.

⇒ In vapour - liquid separator, there are sufficient time to separate out the liquid portion.
So, liquid is collected from bottom and vapour of second liquid separated out from top.

3. Fractional Distillation

(2)