# Unit II
# Evaporation


# Objective

- Students will learn Objectives, applications and factors influencing evaporation, differences between evaporation and other heat process.
- Student will be able to define Fourier's law.
- Students can derive equation for Heat transfer by conduction, convection &radiation.
- Students can explain construction, working, advantages, disadvantages and applications of Heat interchangers &heat exchangers
- ,. principles, construction, working, uses, merits and demerits of Steam jacketed kettle, horizontal tube evaporator, climbing film evaporator, forced circulation evaporator, multiple effect evaporator& Economy of multiple effect evaporator.

# Classification of evaporators

I. **Evaporators with heating medium in jacket** (steam jacketed kettle/evaporating pan)

**II. Vapour heated evaporators with tubular heating surfaces**

**(A) Evaporators with tubes placed horizontally** (horizontal tube evaporator)

**(B) Evaporators with tubes placed vertically**

**(i) Evaporators with short tubes**

**(a) single effect evaporators** ( short tube vertical evaporator, short tube vertical evaporator with propeller, basket type evaporator)

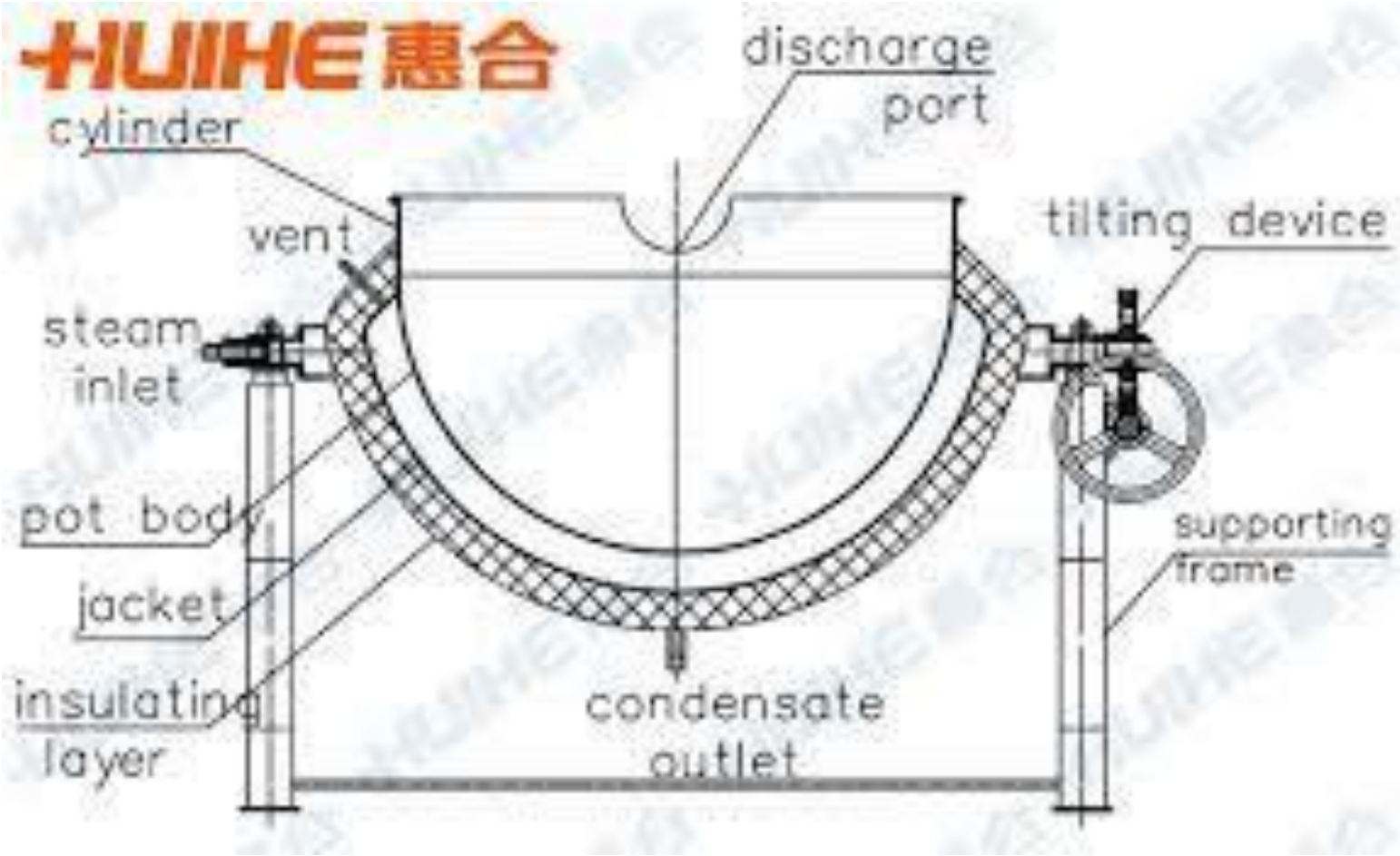
**(b) Multiple effect evaporator** (triple effect evaporator)

- **(ii) Evaporators with long tubes**

**(a) Evaporators with natural circulation** (climbing/ rising film evaporator, falling film evaporator)

**(b) Evaporators with forced circulation** (forced circulation evaporator)

# Steam jacketed kettle/evaporating pan



- **Principal:-**
- **-Steam is supplied to jacketed kettle (having aqueous extract)**
- **-steam → kettle → Aqueous extract**
- **(conduction &convection)**
- **temperature increases**
- **molecules evaporate**

- **Construction:-**

- It is hemispherical structure
- Inner pan – kettle
- Outer envelop—jacket
- The two pans joins to enclose a space through which steam is passed.
- For small quantities –single sheet of metal is used for kettle
- For large quantities- several metal sheets are used as construction metal.
- Copper (good conductivity) is excellent material for kettle.
- For acidic substances –tinned copper is used
- Iron (minimum conductivity)—construction of jacket
- To prevent rusting it is tinned or enamelled on inner side.
- There is inlet for steam and outlet for non condensed gases (at top)
- Condensate leave from a vent at bottom.
- kettle has one outlet for concentrated material at the bottom as well as condensate.

- **Working :-**
- **-aqueous extract to be evaporated is placed in kettle**
- **-Steam is supplied through inlet.**
- **-steam transfers heat to contents and condensate leaves through outlet.**
- **-contents must be stirred.**
- **-Rate of evaporation is fast in initial stages and decreases in the later stage as the liquid gets concentrated.**
- **-The room where evaporation is done should be well ventilated to remove the vapour.**
- **-The kettle can be fixed or made to tilt. Above 90 litres capacity, it becomes difficult to tilt.**
- **-so bottom outlet is provided.**
- **Use:- Concentrating aqueous and thermo stable liquors (eg. Liquorice extract)**

- **Advantages:-**

1. **For small scae and large scale operations**
2. **Simple, easy to use, clean and maintain.**
3. **Cost of installation and maintenance is low.**
4. **Vide variety of material can be used for construction. (copper, aluminium, stainless steel etc)**
5. **Stirring an removal of contents is easy.**

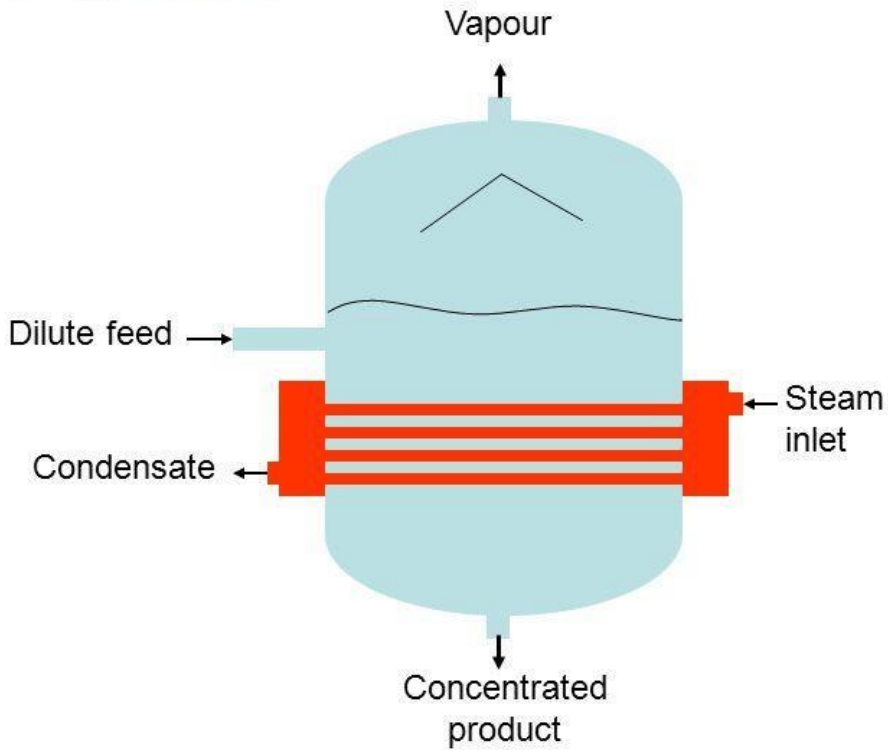
- **Disadvantages: -**

1. **Less heat economy, hence cost per unit material production is low.**
2. **Not suitable for heat sensitive material**
3. **Heating area decreases as product gets concentrated**
4. **As it is open vapour passes to atm which can lead to saturation, slowing of evaporation and causing discomfort**
5. **Cannot apply pressure to reduce the B.P. since it is open**

# HORIZONTAL TUBE EVAPORATOR

## Types of evaporators

### Horizontal-tube evaporator:



- **Principal:**
- **Steam is passed through horizontal tubes which are immersed in a pool of liquid to be evaporated.**
- **Steam transfer take place through the tubes and outside liquid gets heated.**
- **solvent evaporates and escapes through the top.**
- **Concentrated liquid is collected from the bottom.**

- **Construction:**

- **Large cylindrical body with conical/ dome shaped top and bottom.**
- **Made up of caste iron/ plate steel.**
- **Average size- 2.4 to 3.6 meters height.**
- **Lower part has steam compartment with steam inlet at one side and vent for non condensed gases on other.**
- **Condensate outlet is provided at the bottom of steam compartment.**
- **steam compartment consist of 6-8 stainless horizontal tubes.**

- The tubes are cut as they project about 25 mm beyond the tube sheet on both ends.
- Width of steam compartment is usually half the diameter of the body.
- At a point inlet for feed is provided.
- Outlet for vapour is placed at the top.
- One outlet for condensate is placed at the centre of conical bottom of the body.

- **Working:**

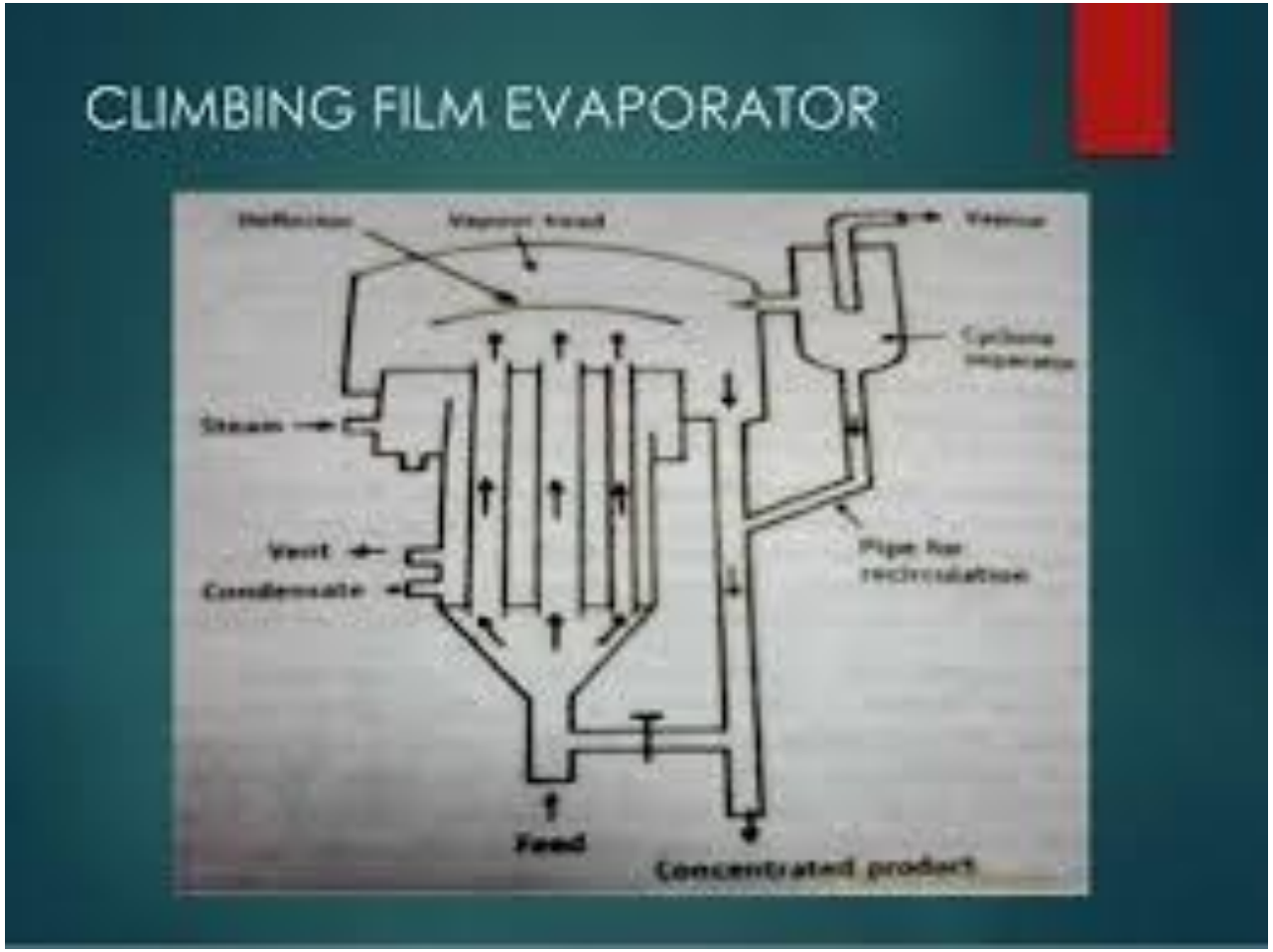
- Feed is introduced till the steam compartment is immersed.
- Steam is introduced in the steam compartment.
- Horizontal tubes receive heat from steam and conduct it to liquid.
- Steam condensate passes through the outlet provided.
- Feed absorbs heat and solvent gets evaporated.

- Vapour escapes through outlet t the top.
- It continues till a thick liquid is formed. Which is then collected from the bottom.

- **Use:** for non viscous solutions that do not deposite scales crystals on evaporation. (eg. Cascara extract)

- **Advantages:** cost per sq.m. of heating surface is less.

# Climbing film evaporator



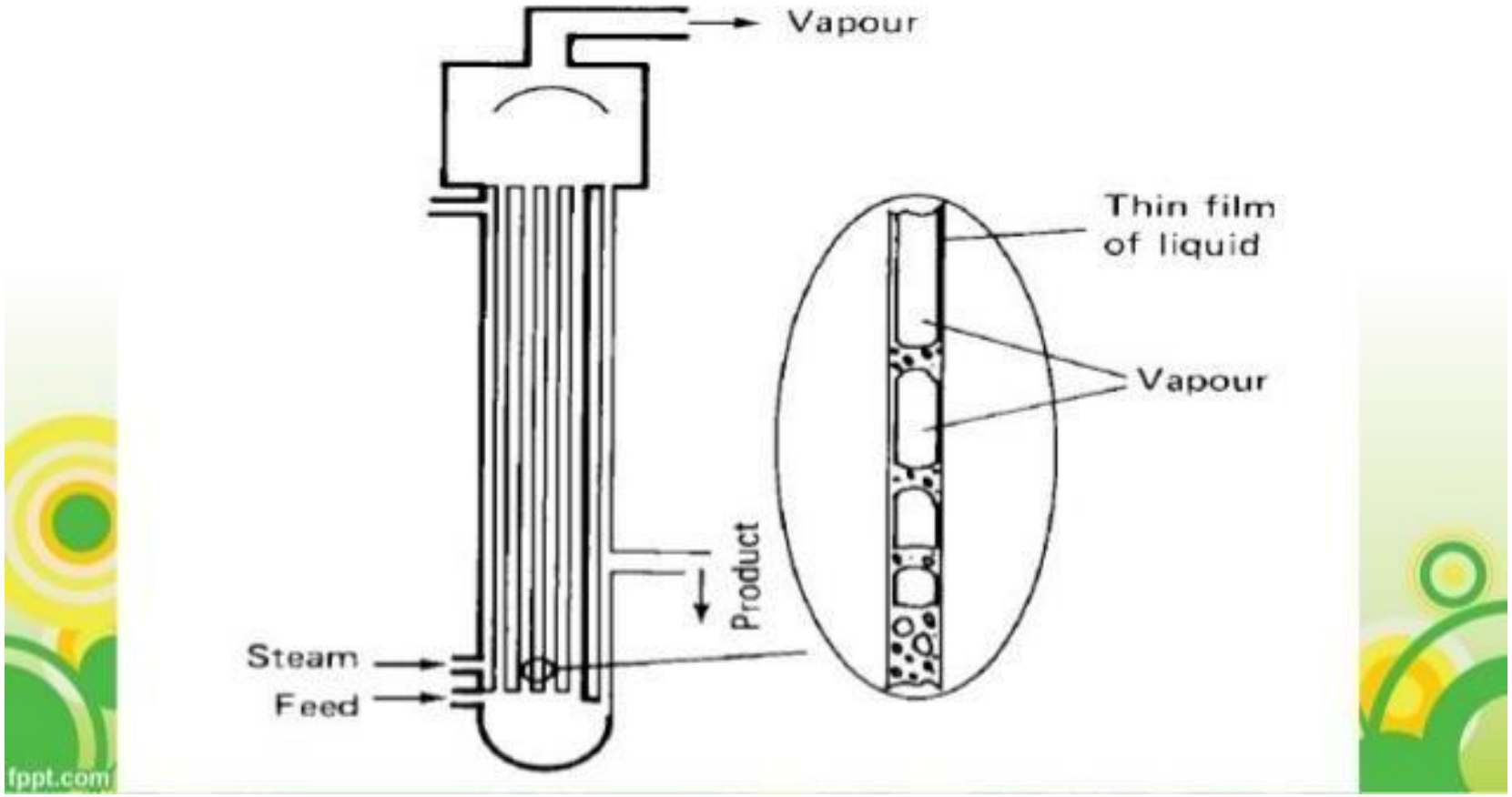
- **Principal:**
- **-tubes are heated externally by steam.**
- **-Preheated feed enters from bottom and flows up through hated tubes.**
- **-liquid gets heated rapidly due to enhanced overall coefficient of preheated feed.**
- **-the liquid near the wall becomes vapour and forms small bubbles.**
- **-These fuse to large bubbles and travel up from bottom along with entrained slug then strike the entrainment separator (deflector) kept above. This throws liquid concentrate into lower part from where it is withdrawn.**
- **Construction:**
- **-heating unit consist of steam jacketed tubes. Long tubes are held between two plates.**
- **-entrainment separator is placed at the top. Evaporator has steam inlet, vent outlet and condensate outlet.**
- **- Feed inlet is from the bottom.**

- **Working:**

- **Preheated liquid id introduced from the bottom of the unit. The height of the liquid column is maintained low, i.e. 0.6-1.2 meters above the bottom tube sheet.**
- **steam enters into space outside the tubes through inlet. Heat is transferred through walls.**
- **Liquid → vapour → forms small bubbles → fuse to form large bubbles**
- **These bubbles trap part of liquid (slug) on its way up. As more vapour is formed, slug moves up and forms a thin layer of liqid over the wall.**
- **This thin film vaporize faster**
- **Finally mixture of condensate and vapour eject at high velocity from the top of the tubes.**
- **Entrainment separator prevents entrainment and also act as foam breaker.**
- **Vapour leaves from top and concentrate is collected from the bottom.**

# Climbing-film evaporator

- Thin film of liquor is forced up the evaporator tubes
- For low-viscosity foods (for example milk)



- **Use: forthermolabile substances such as insulin, liver extract and vitamins.**
- **Clear liquids, foaming liquids and corrosive solutions can beoperated.**
- **Deposite of scales can beremoved by increasing feed rate/ reducing steam rate.**
- **Advantages:**

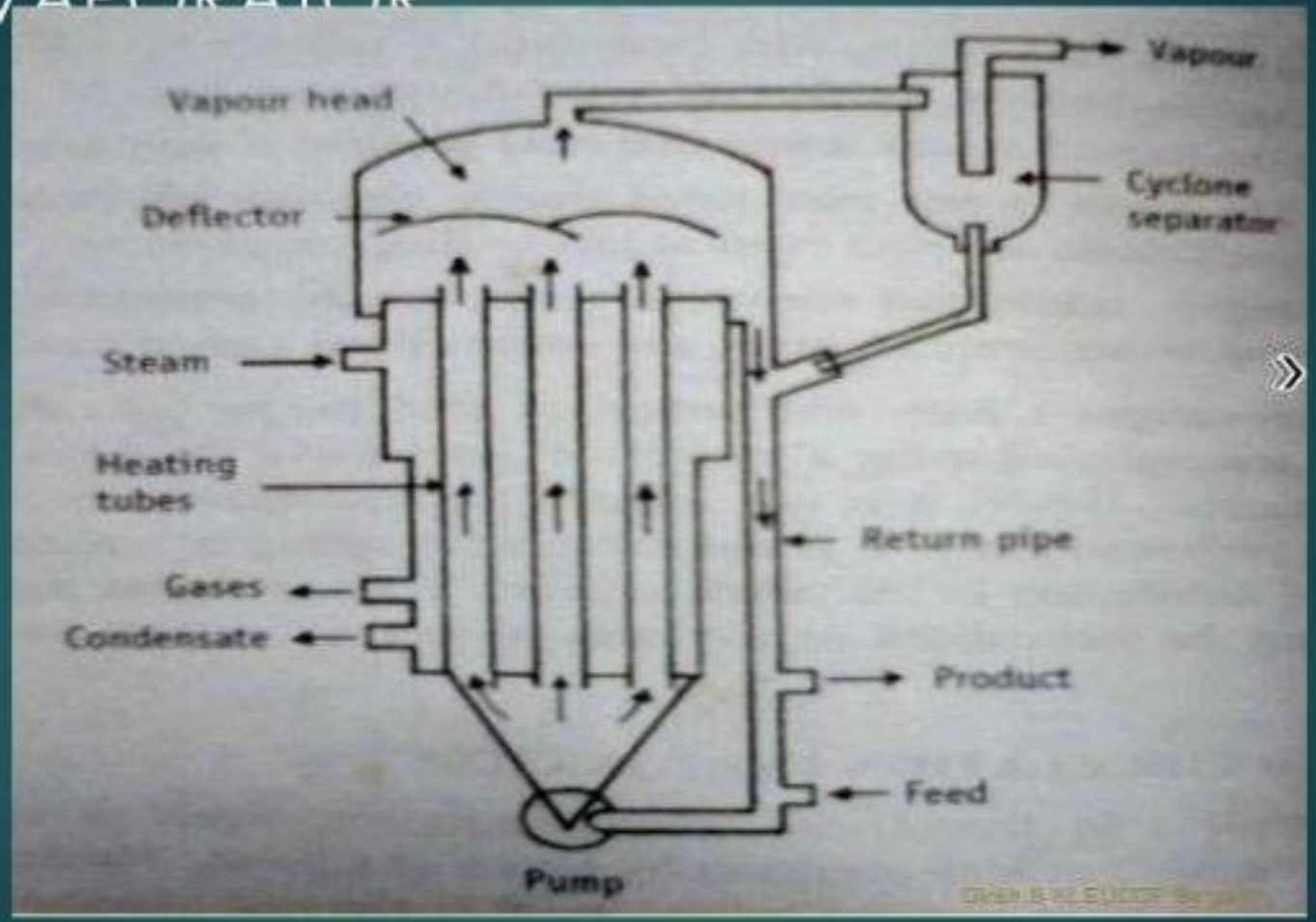
- **Large area is provided**
- **Liquid flows at high velocity hence there is reduced resistance to heat transfer. Enhanced heat transfer.**
- **Suitable for heat sensitive mterial as residence time is low**
- **As tubes are not immersed there is no elevation of boiling point.**
- **Suitable for foaming liquids**
- **Require low hold up and small floor space.**

- **Disadvantages:**
- **-expensive, construction is complicated**
- **-difficult to clean and maintain.**
- **-large head space is required**
- **-not for very viscous liquids, salting liquids and scaling liquids**
- **-if feed rate is very high → insufficient concentration.**
- **Low fed rate → film cannot be maintained.(formation of dry patches.**

# FORCED CIRCULATION EVAPORATOR

- **Principal:**
- **-Here the liquid is forced through the tubes by means of a pump.**
- **-Thus liquid passes with high pressure.**
- **-Due to this it also get agitate.**
- **-As the liquid leaves the tubes, it enters the vapour head and pressure falls suddenly.**
- **-This leads to flashing of the super heated liquid and thus evaporation is effected.**

# FORCED CIRCULATION EVAPORATOR



- **Construction:**
- -steam jacketed tubes are held between two tube sheets. Tube measures 0.1 m inside diameter and 2.5 m long.
- The part of tube projects into the vapour head (flash chamber).
- It consist of deflector.
- The vapour head is connected to a return pipe which runs down and enters into the inlet of a pump.
- **Working:**
- Steam is introduced into calandria.
- Pump sends the liquid with positive velocity.
- Liquid moves up and get heated and begins to boil.
- Thus vapour and mixture rushes out of tube at high velocity. This mixture strikes the deflector which throws the mixture down.
- This results in effective separation of the liquid and the vapours.
- Vapour enters cyclone separator and leaves the equipment.
- Concentrated liquid returns to the pump. Finally it is collected.

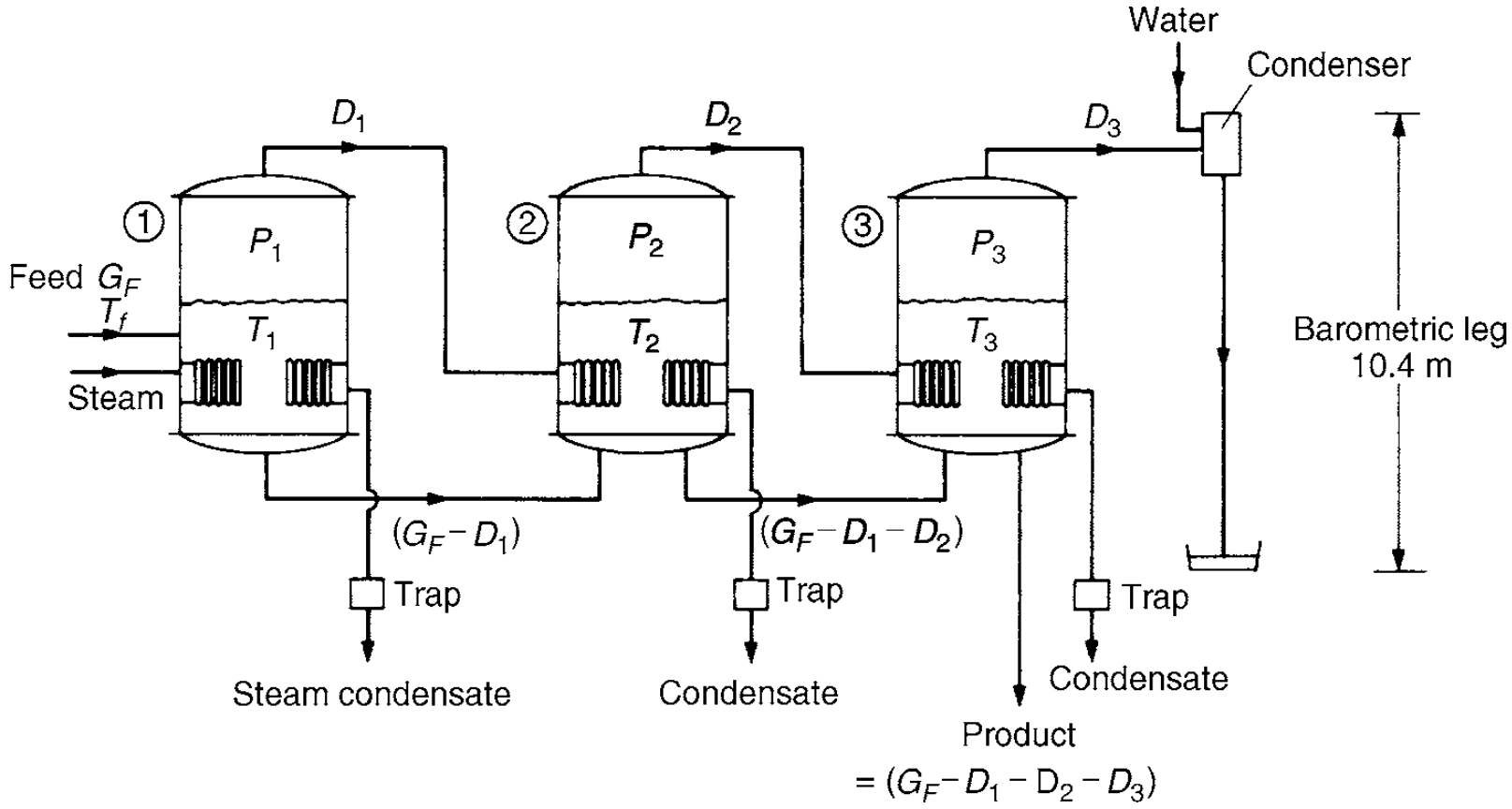
- **Use:**
- **suitable for thermolabile products.**
- **Concentration of insuline and liver extract**
- **Well suited for crystalliziling operations.**
- **Advantages:**

1. **High heat transfer coefficient**
2. **Salting, scaling and fouling is notpossible due to forced circulation**
3. **Suitable for thermolabile substances because of rapid evaporation.**
4. **Suitable for high viscous preparations because pumping mechanism is used.**

- **Disadvantages:**
- **-Expensive equipment due to power (pump) required.**
- **-Hold up of liquid is high**

# MULTIPLE EFFECT EVAPORATOR

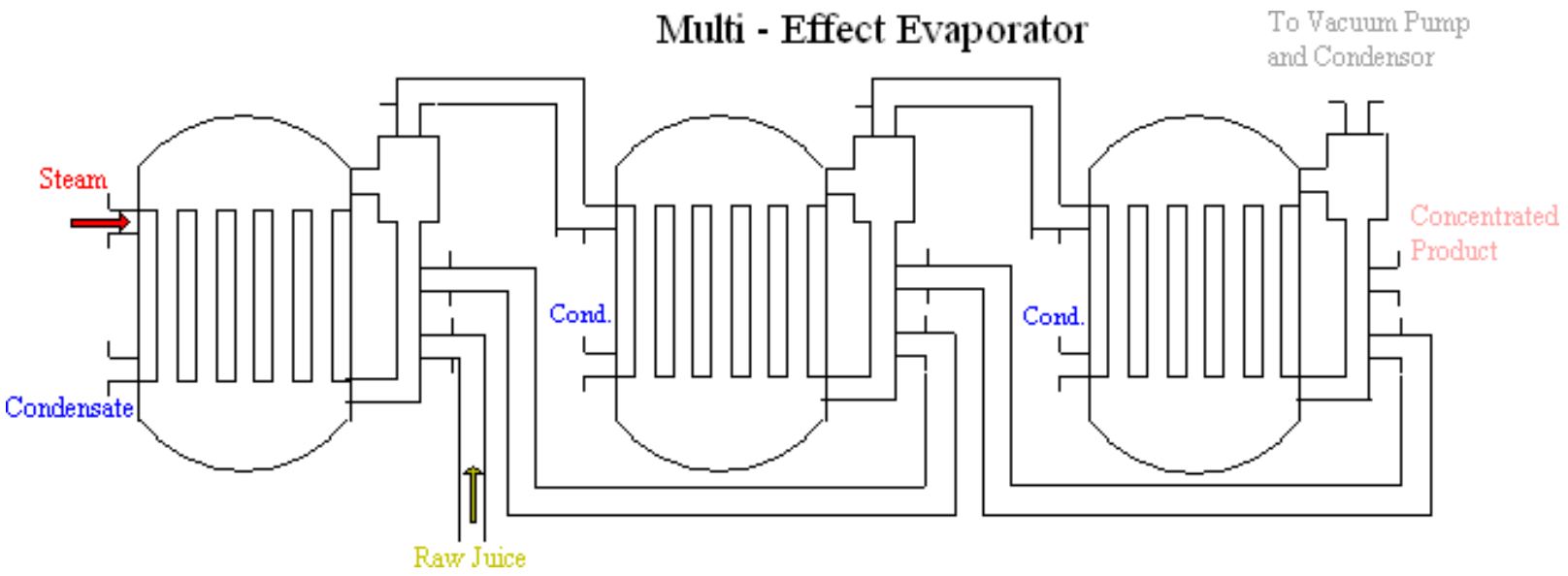
- **-Single effect evaporator is connected in several ways to achieve large scale evaporation as well as greater economy.**



# • Construction:

- **The above shown evaporator consist of three evaporators i.e. triple effect evaporator.**
- **Single evaporator consist of a large cylindrical body made up of cast iron with dome shaped top and bottom.**
- **At the bottom calandria is fitted. (calendria consist of number of vertical tubes whose diameter ranges from 0.05 to 0.075m and 1-2 m long. About 100 such tubes are fitted).**
- **Inlet are provided for steam and feed. Outlet is provided for vapour, concentrated product and non condensed gases and concentrate.**
- **Here the vapour from first evaporator serves as heating medium for 2nd evaporator. Similarly, vapour from 2nd evaporator serves as heating medium for third. Last evaporator is connected to a vaccum pump.**

- Working:


Multi - Effect Evaporator
To Vacuum Pump
and Condensor
Steam
Condensate
Cond.
Cond.
Concentrated
Product
Raw Juice

- **Parallel feed arrangement is shown here.**
- **Here, hot saturated feed is directly fed into each of three effects (evaporation) in parallel without transferring material from one effect to other.**
- **In the beginning the equipment is at room temperature and atmospheric pressure.**
- **The liquid feed is introduced to all the three evaporators up to the level of upper tube sheets.**
- **1. The vent valves are kept on and all other valves are closed.**
- **2. High vaccum is created in the liquid chambers of evaporators.**
- **3. Steam valve and condensate valve are opened. Steam is supplied. Steam replaces cold air in the steam space of 1st evaporator. When all the steam is removed the valve is closed.**
- **4. Supply of steam is continued until desired pressure is created in steam space of 1st evaporator.**
- **5. Steam transfer heat to feed in 1st evaporator and gets condensed.**
- **Condensate is removed through condensate valve.**

- **6. Due to heat transfer, the liquid gets heated and reaches boiling point. Due to this vapour is generated from liquid feed.**
- **7. This vapour formed displaces air in the space. Then this vapour displaces air in the steam space of 2nd evaporator.**
- **8. After complete displacement of air by vapour in the steam compartment of 2nd evaporator, valve is closed.**
- **9. Vapour of 1st evaporator transmit its heat to the liquid of 2nd evaporator and gets condensed. Condensate is removed and these steps continue in the 3rd evaporator also.**

- **Here as the liquid in the 1st evaporator gains temperature, difference in temperature between liquid and steam decreases hence rate of condensation decreases. So pressure increases.**
- **Hence the liquid begins to boil.**
- **Similar change take place in the 2nd evaporator and liquid reaches boiling point.**
- **Same thing take place in 3rd evaporator.**

- As boiling proceeds the levels of feed come down. So feed is introduced through feed valve. This is continued until the liquid in all evaporators reaches desired viscosity.
- Then product valve is opened to collect the thick liquid.
- Thus, here is continuous supply of feed, continuous supply of steam and continuous removal of liquid from all the three evaporators.
- Hence it works continuously.
- evaporator can be fed by forward feed method, backward feed method and mixed feed method.

# Economy of MULTIPLE EFFECT EVAPORATOR

- **Economy of an evaporator is quantity of vapour produced per unit steam admitted.**
- **It is calculated as:**

1. **Feed is introduced at boiling point.**
2. **So does not require more heat to raise the temperature.**
3. **So supplied steam gets condensed to give its heat of condensation.**
4. **This heat is transferred to liquid completely.**
5. **This serves as latent heat of vaporisation i.e. liquid undergoes vaporisation by receiving heat.**
6. **Loss of heat is negligible.**

- **Economy is expressed as:**
- **Economy of evaporator= total mass of vapour produced/**
- **total mass of steam supplied**
- **In single evaporator, steam produces vapour only once. Hence,**
- **Economy of single effect evaporator= N Units of vapour produced/ = 1**
- **N Units of steam supplied.**
- **In multiple effect evaporator, one unit of steam produces vapour many times depending on evaporators connected. Hence,**
- **Economy of multiple effect evaporator= N Units of vapour produced/=N**
- **1 Units of steam supplied.**
- **Therefore, economy of multiple effect evaporator is N times the economy of single effect evaporator.**
- **It is approximately true as it depends on factors as temperature of feed, temperature range of evaporator, ratio of feed to product and pressure difference.**