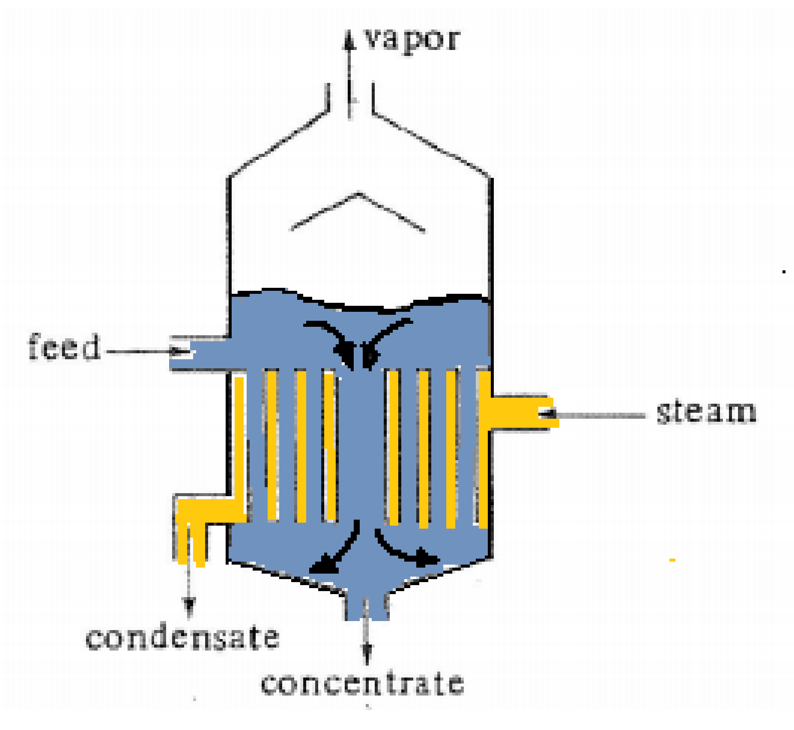
# Evaporation

# Introduction

- Evaporation is a type of vaporization of a liquid that ***occurs from the surface of a liquid into a gaseous phase that is not saturated with the evaporating substance***
- The term 'evaporation' essentially involves the vaporization of a liquid or a solvent from a solution to yield a more concentrated solution
- The ***main objective*** of evaporation is **to *concentrate a solution consisting of a non-volatile solute and a volatile solvent***
- In this process, the solvent (most commonly water) is boiled out to recover an end product with an optimum solids content
- Evaporation is different from drying where the entire solvent is vaporized yielding a solid residue as the product – *drying refers to removal of small amounts of water from the solid* while *evaporation involves the removal of relatively large amounts of water from the solution*
- It is a unit operation that is used extensively in *processing foods, chemicals, pharmaceuticals, fruit juices, dairy products, paper and pulp, and both malt and grain beverages* – common examples are concentration of aqueous solutions of sugar, sodium hydroxide, sodium chloride, glycerol, milk, orange juice etc
- Evaporation is an unit operation, which apart from distillation, is the *most energy intensive*

- Most of the evaporators used in the process industry have tubular heating surfaces
- The solution to be concentrated is circulated through the tubes
- Heat required for evaporation is supplied by steam (usually low pressure steam)
- The steam condenses on the outer surface and releases the latent heat of condensation
- Steam has a high latent heat of condensation (2257 kJ/kg) and is hence a popular heating agent
- The vaporized solvent rises up, impinges on a deflector which removes most of the entrained liquid droplets from the vapour, and leaves through the top
- The concentrated solution is collected from the bottom



- Evaporators are of various types – open kettle, short tube vertical type, basket type, long tube vertical type, forced circulation type etc
- The physical and chemical properties of the solution being concentrated and the vapour removed determines which type of evaporator is used and the temperature and pressure of the process

- Some of these ***properties which affect the evaporation process*** are

***Concentration of the liquid:***

- Usually the liquid feed to the evaporator is relatively dilute, so its viscosity is low, similar to water and leads to relatively high heat transfer coefficients
- As evaporation proceeds, the solution becomes very concentrated, the viscosity and density increases and causing the heat-transfer coefficient to decrease substantially
- As the solution becomes more concentrated, there is a rise in the boiling point
- The basic heat transfer equation in an evaporator is $Q = UA\Delta T$ where $\Delta T$ is the difference between the saturation temperature of steam and the boiling point of the liquid
- An increase in the boiling point of the liquid in the evaporator, reduces the driving force $\Delta T$ and decreases the heat transfer rate

***Solubility:***

- As the concentration of a solution increases, the solubility limit of the solute in solution may be exceeded and crystals may form
- Usually the solubility of the salt increases with temperature – when a hot concentrated solution from an evaporator is cooled to room temperature, crystallization may occur
- If this occurs, the crystals need to be removed immediately in order to prevent choking

***Foaming/Frothing:***

- In some cases, materials composed of caustic solutions, food solutions such as skim milk, and some fatty acid solutions form a foam or froth during boiling
- This foam accompanies the vapour coming out of the evaporator and entrainment losses occur

***Temperature sensitivity of materials***

- Many food products (milk, orange juice, and vegetable extracts), pharmaceutical products and other biological materials, may be very temperature-sensitive and degrade at higher temperatures or after prolonged heating
- The amount of degradation is a function of the temperature and the time of heating
- Techniques must be used to reduce both – the temperature of the solution can be lowered by operating the evaporator under vacuum (decrease in pressure decreases boiling point)

***Scale deposition:***

- Some solutions deposit solid materials known as scales on the walls of the heating surfaces
- Scales being bad conductors of heat decreases the overall heat transfer coefficient
- In such cases, the evaporator needs to be cleaned intermittently

***Operation of Evaporators***

- The rate of heat transfer in an evaporator depends on the driving force,

$$Q = UA(T_s - T_b)$$

- The driving force can be increased by either increasing $T_s$ or decreasing $T_b$
- $T_s$ can *be increased by increasing the pressure of steam*
- However, the most common steam used industrially is the low pressure exhaust steam. Thus, $T_s$ cannot be increased to a large extent
- $T_b$ can be *decreased by decreasing the pressure*
  - for eg. at 1 atm (30” Hg) water boils at 100$^{o}$C, steam which is used for evaporation is at 107$^{o}$C, this gives a driving force of (107-100) = 7$^{o}$C
  - if the pressure is now reduced to 4” Hg (0.134 atm) or 26” vacuum, water boils at ~ 52$^{o}$C, giving a driving force of (107- 52) = 55$^{o}$C

- Another issue to be kept in mind is that, when the tubes are filled with liquid, the pressure at the bottom of the tube is = 4” + hydrostatic pressure of the liquid

- The bottom of the liquid is at a higher pressure and the water will now not boil at 52$^o$C but at a higher temperature – this reduces the driving force

- Therefore, the tube lengths in an evaporator are usually within 4-6 ft (never above 6 ft), as increase in liquid height reduces the driving force due to higher pressure at the bottom

***Performance of Evaporators***

- The performance of steam-heated evaporators is measured in terms of ***evaporator capacity*** and ***evaporator economy***

- The ***capacity*** of an evaporator gives the vaporization capacity, i.e., the number of kgs of water (solvent) it can vaporize in one hour

- Any factor that enhances the rate of heat transfer increases the capacity

$$\boldsymbol{Evaporator\ capacity = \frac{kg\ of\ solvent\ evaporated}{time}}$$

- The ***economy*** of an evaporator is the kgs of water (solvent) it can vaporized per kg of steam fed
- A higher economy is always desirable

$$\boldsymbol{Evaporator\ economy = \frac{kg\ of\ solvent\ evaporated}{kg\ of\ steam\ used}}$$

Now we see that,

$$\boldsymbol{\frac{Evaporator\ Capacity}{Evaporator\ Economy} = Steam\ consumption\ (\frac{kg}{h})}$$

- In a single evaporator unit, steam economy is around 0.8
- About 1.1 to 1.3 kg steam is required to vaporize 1 kg of water
- The latent heat of vaporization of water decreases with increasing temperature (at 100$^{o}$C, 1 bar, heat of vaporization = 2257.56 kJ/kg, and at 110$^{o}$C, 1.43 bar, heat of vaporization = 2238.2 kJ/kg)
- Steam condensing outside the tubes is at a higher temperature than the solution inside the tubes, and the latent heat released by 1 kg steam is less than that required for vaporizing 1 kg water from the boiling solution
- This causes the single evaporator to have steam economy < 1

***Feed temperature of the solution***

- The feed temperature of the solution can have three possibilities:

  A) Feed is at its boiling point

  B) Feed is at a temperature lower than boiling point

  C) Feed is at a temperature higher than the boiling point

- If the feed to the evaporator is *at its boiling point*, the latent heat available is used to vaporize the feed

- If the feed is cold (*feed temperature is less than the saturation temperature*) part of the latent heat is used to raise the temperature of the feed to the saturation temperature, and the steam economy goes down

- If the *feed is above the saturation temperature*, a part of the feed vaporizes immediately by means of flash vaporization and steam economy is > 1

  However, getting the feed to the superheated state requires energy, and this extra cost balances out the advantage obtained from having steam economy > 1