Evaporation

Evaporation is a unit operation that consists of the elimination of water of a fluid food by means of vaporization or boiling.

Several foods are obtained as aqueous solutions and, in order to facilitate their preservation and transport, they are concentrated during a water elimination stage.

This elimination can be performed in different ways, although evaporation is one of the most used methods.

Evaporation is a type of vaporization that occurs on the surface of a liquid as it changes into the gas phase.

Evaporation is the process of a substance in a liquid state changing to a gaseous state due to an increase in temperature and/or pressure.

Evaporator

- An evaporator consists mainly of two chambers, one for condensation and another for evaporation.
- Steam condenses in the condensation chamber, giving off the latent heat of condensation, which is contained in the evaporation chamber.
- The evaporated water leaves the evaporation chamber at boiling temperature, obtaining at the same time a stream of concentrated solution.
- Many food solutions are heat sensitive and can be adversely affected if exposed to high temperatures.
- For this reason, it is convenient to operate under vacuum conditions in the evaporation chamber, which causes the boiling temperature of the aqueous solution to decrease, and the fluid to be affected by heat to a lesser extent.

Purpose of Evaporation

To *concentrate solution* by removing the vapor from a boiling liquid solution

Example: concentration of aqueous solutions of sugar, sodium chloride, sodium hydroxide, glycerol, glue, milk, and orange juice.

In these cases, the *concentrated solution is the desired product,* and the evaporated water is normally discarded.

Evaporation processes to evaporate seawater to provide drinking water have also been developed and used.

Processing factors

Concentration in the liquid

- low viscosity: high mass transfer coefficient
- high viscosity: low mass transfer coefficient
- adequate circulation and/or turbulence must be present to keep the coefficient from becoming too low

Solubility

- solubility increases with temperature
- crystallization may occur when a hot concentrated solution is cooled to room temperature

Temperature sensitivity of materials

- food and biological materials may be temperature sensitive and degrade at higher temperature

Processing factors

Foaming or frothing

- food solution such as skim milk and some fatty-acid solution form a foam or froth during boiling.

Pressure and temperature

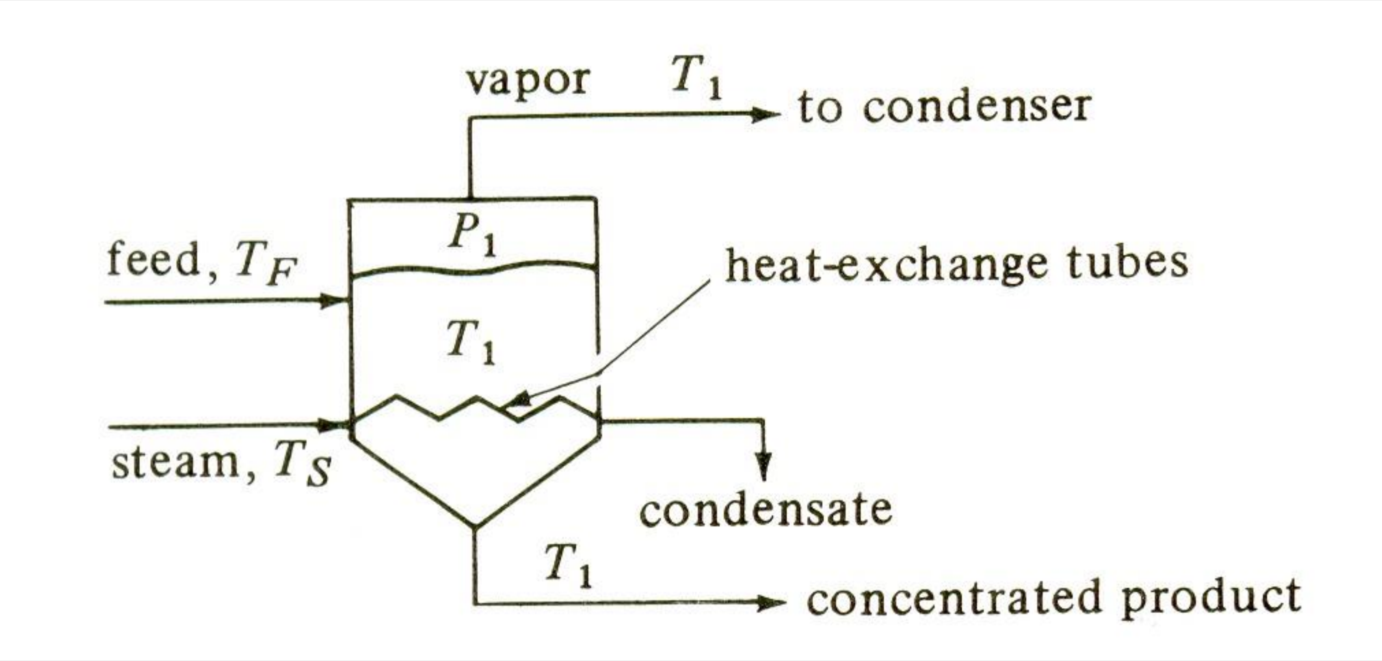
- high operating pressure: high boiling point

Scale deposition and materials of construction

- Some solutions deposit solid materials called *scale* on the heating surfaces.
- results in the overall heat-transfer coefficient decreases and evaporator must be cleaned.

Types of evaporation equipment

Single-effect evaporator



- The feed enters at T_F
- Saturated steam at T_S enters the heat-exchange section.
- Condensed steam leaves as condensate or drips.
- The solution in the evaporator is assumed to be completely mixed
- Hence, the concentrated product and the solution in the evaporator have the same composition.
- Temperature T_1 is the boiling point of the solution.
- The temperature of the vapor is also T_1, since it is in equilibrium with the boiling solution.
- The pressure is P_1, which is the vapor pressure of the solution at T_1.

Single-effect evaporator

If the solution to be evaporated is assumed to be dilute and like water, then 1 kg of steam condensing will evaporate approximately 1 kg of vapor (if the feed entering has T_F near the boiling point)

The concept of an overall heat-transfer coefficient is used in the calculation of the rate of heat transfer in an evaporator

The general equation can be written

$$q = UA\,\Delta T = UA(T_S - T_1)$$

Where:
q is the rate of heat transfer in W (btu/h),
U is the overall heat-transfer coefficient in W/m^2. K (btu/h ft. °F),
A is the heat-transfer area in m^2 (ft^2),
T_S is the temperature of the condensing steam in K (°F),
T_1 is the boiling point of the liquid in K (°F).

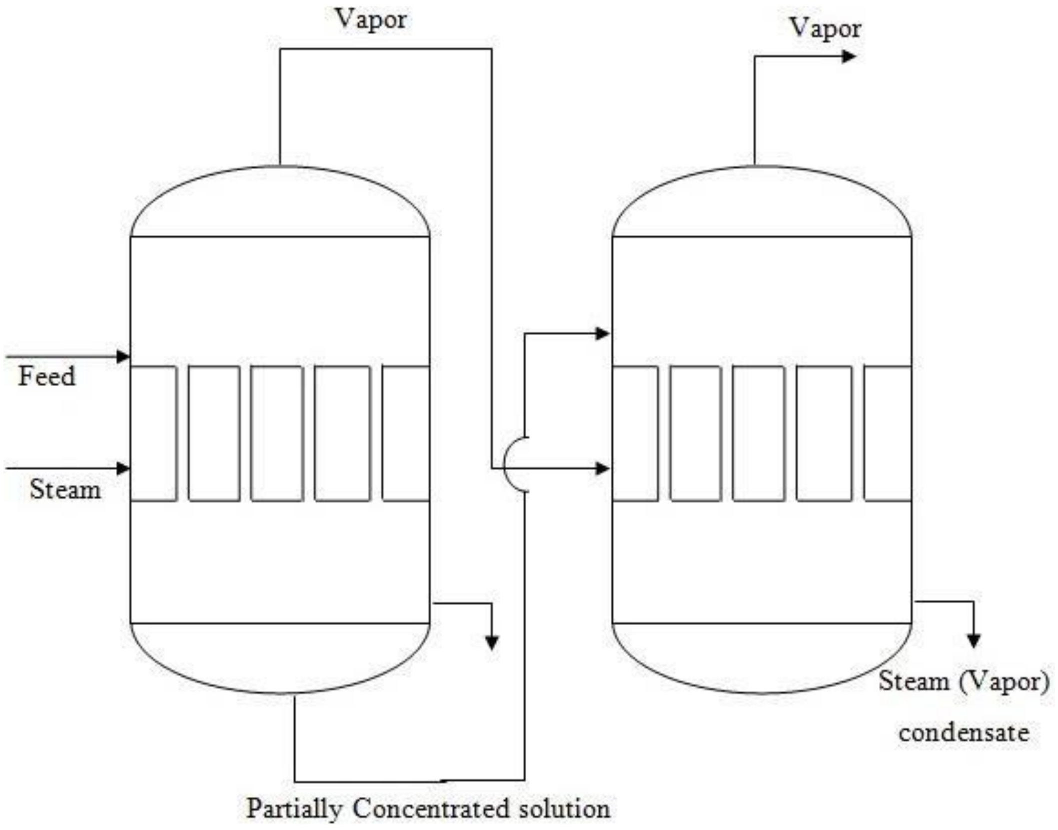
Single-effect evaporators

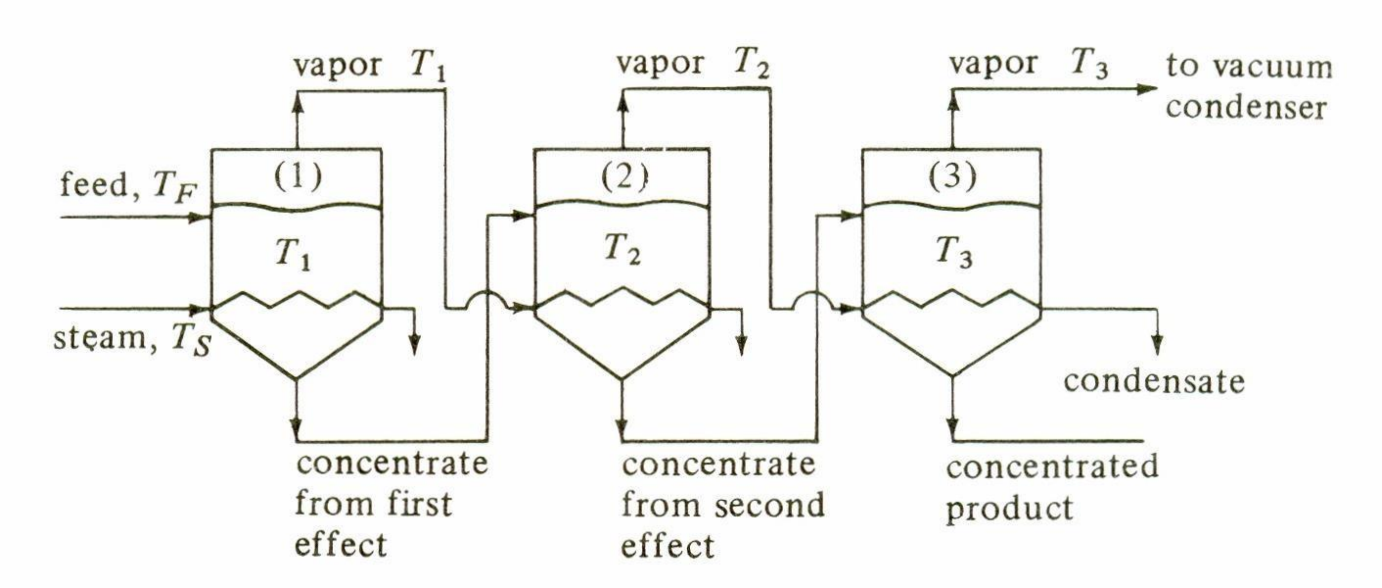
Single-effect evaporators are often used when the required capacity of operation is relatively small and/or the cost of steam is relatively cheap compared to the evaporator cost.

However, for large-capacity operation, using more than one effect will markedly reduce steam costs.

Multiple - effect evaporator

- A single-effect evaporator – energy lost as vapor
- The latent heat of the vapor leaving is not used but is discarded.
- Much of this latent heat, however, can be recovered and reused by employing a multiple - effect evaporator.
- A simplified diagram of a forward-feed double-effect evaporation system is shown.





Simplified diagram of forward -feed triple-effect evaporator.

Forward -feed triple-effect evaporator

If the feed to the first effect is near the boiling point at the pressure in the first effect, 1kg of steam will evaporate almost 1 kg of water.

The first effect operates at a temperature that is high enough that the evaporated water serves as the heating medium to the second effect.

Here, again, almost another kg of water is evaporated, which can then be used as the heating medium to the third effect.

As a very rough approximation, almost 3 kg of water will be evaporated for 1 kg of steam in a triple-effect evaporator.

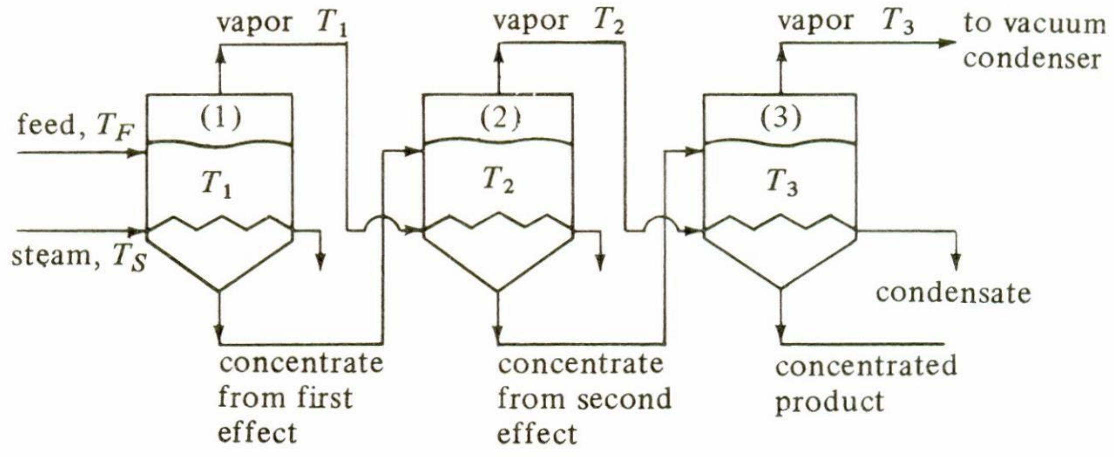
Hence, the steam economy, which is kg vapor evaporated/kg steam used, is increased.

This also holds approximately for more than three effects.

However, the increased steam economy of a multiple-effect evaporator is gained at the expense of the original first cost of these evaporators.

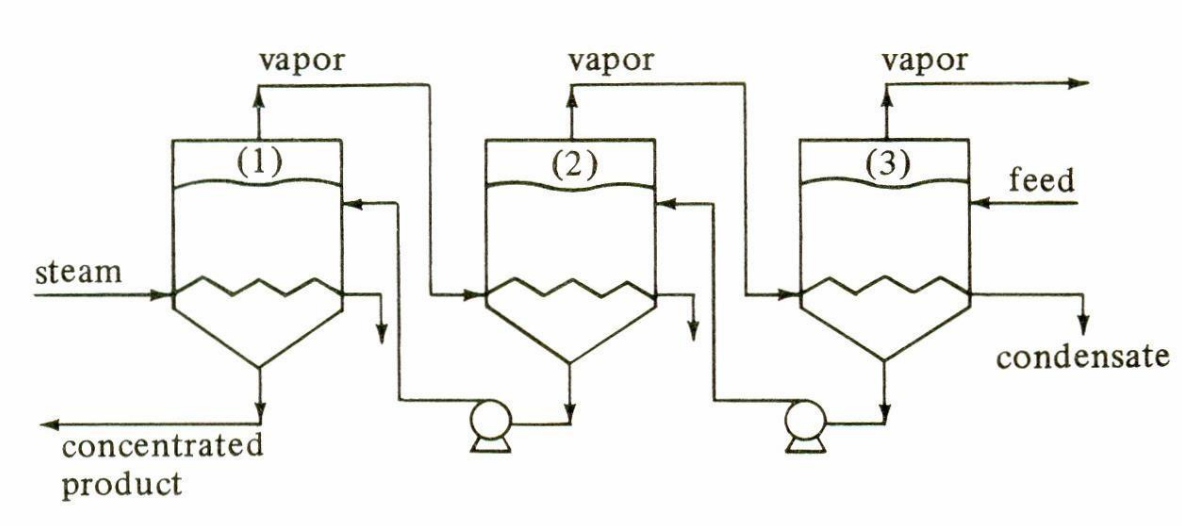
Forward feed evaporator

- In forward-feed operation, the fresh feed is added to the first effect and flows to the next in the same direction as the vapor flow.
- This method of operation is used when the feed is hot or when the final concentrated product might be damaged at high temperatures.
- The boiling temperatures decrease from effect to effect. This means that if the first effect is at P_1 = 1 atm abs pressure, the last effect will be under vacuum at a pressure P_3.



Backward-feed multiple-effect evaporator

- In the backward-feed operation, for a triple-effect evaporator, the fresh feed enters the last and coldest effect and continues until the concentrated product leaves the first effect.



Simplified diagram of backward-feed triple-effect evaporator.

Backward-feed multiple-effect evaporator

This method of reverse feed is advantageous when the fresh feed is cold, since a smaller amount of liquid must be heated to the higher temperatures in the second and first effects.

However, liquid pumps must be used in each effect, since the flow is from low to high pressure.

This reverse-feed method is also used when the concentrated product is highly viscous.

The high temperatures in the early effects reduce the viscosity and give reasonable heat-transfer coefficients.

Open pan evaporator

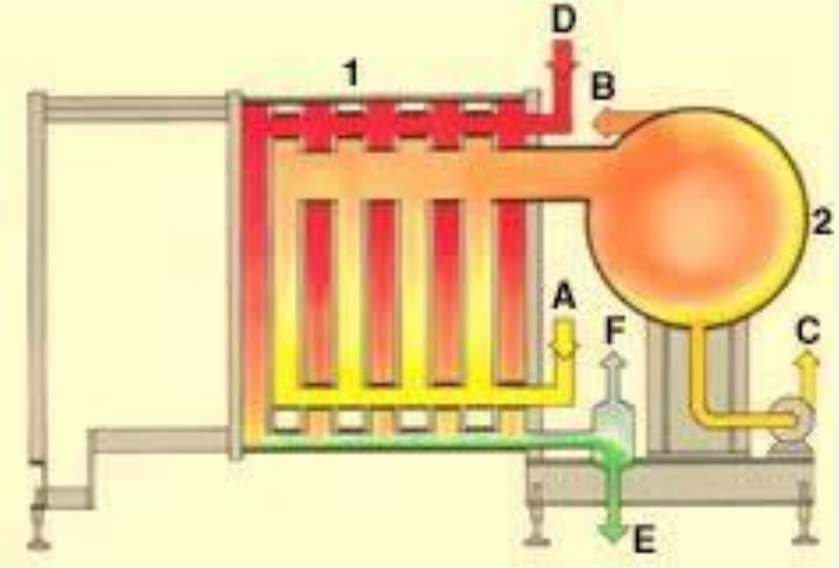
- The simplest, consisting a container open to the atmosphere in which fluid is heated directly, or by a heating coil or external jacket.
- Have a low evaporation rate, a poor thermal economy.
- The advantage is that they are useful when low-capacity units are required.
- Heating is not effective in large capacity units, since the ratio of heat transfer surface to volume of liquid is low.
- Used to concentrate tomato pulp, prepare soups and sauces, and boil marmalades and confectionery products.

Plate type evaporator

1) Plate Evaporator
2) Separator

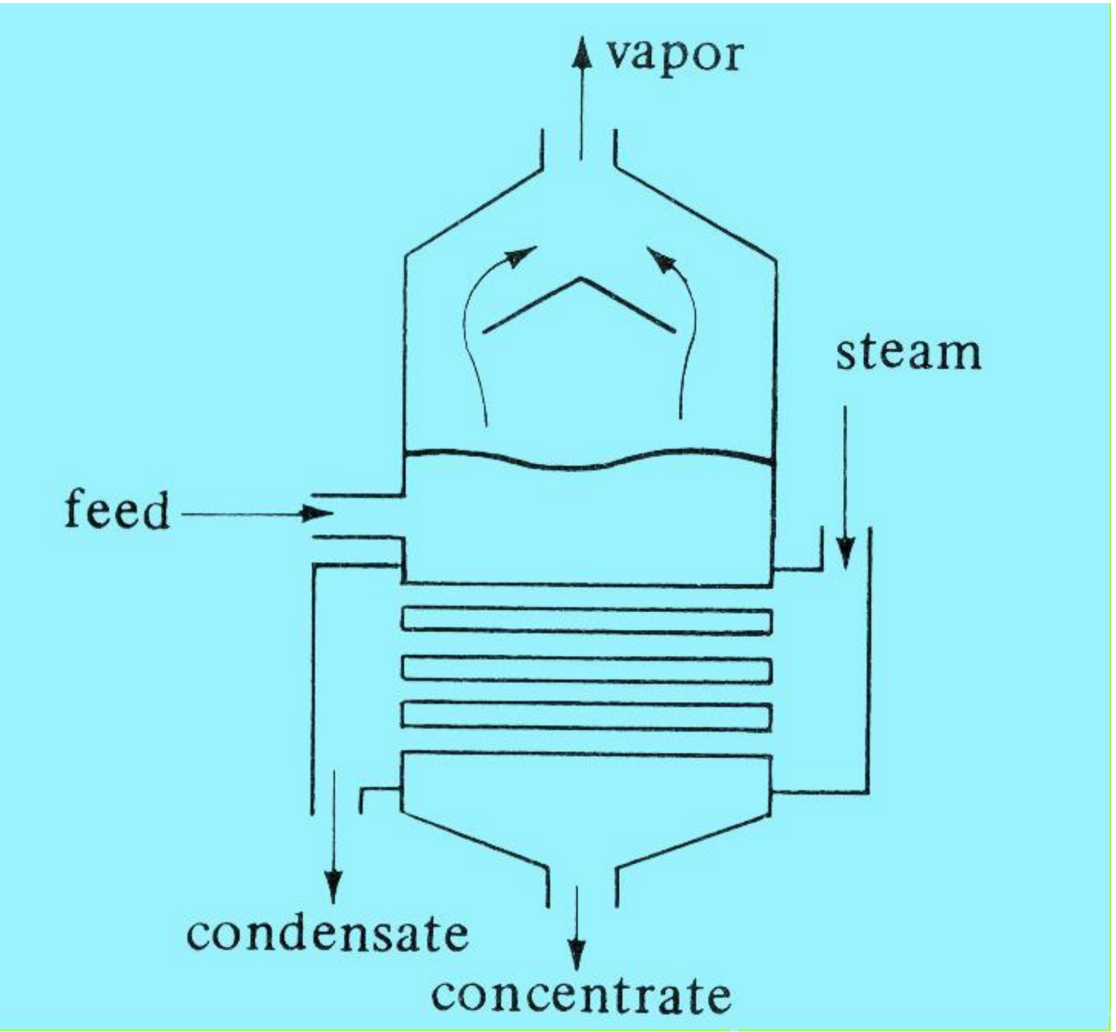
A) Feed
B) Vapor
C) Concentrate
D) Steam
E) Condensate
F) Excess Vapor

- Consist of a set of plates distributed in units in which vapor condenses in the channels formed between plates.
- The heated liquid boils on the surface of the plates, ascending and descending as a film.
- The liquid and vapor mixture formed goes to a centrifugal evaporator.
- Useful to concentrate heat sensitive products, since high treatment velocities are achieved, allowing good heat transfer and short residence times of the product in the evaporator.
- Occupy little space on the floor and are easily manipulated for cleaning, since setup and dismount are easy and quick.
- Usually employed to concentrate coffee, soup broth, light marmalades, and citric juices.



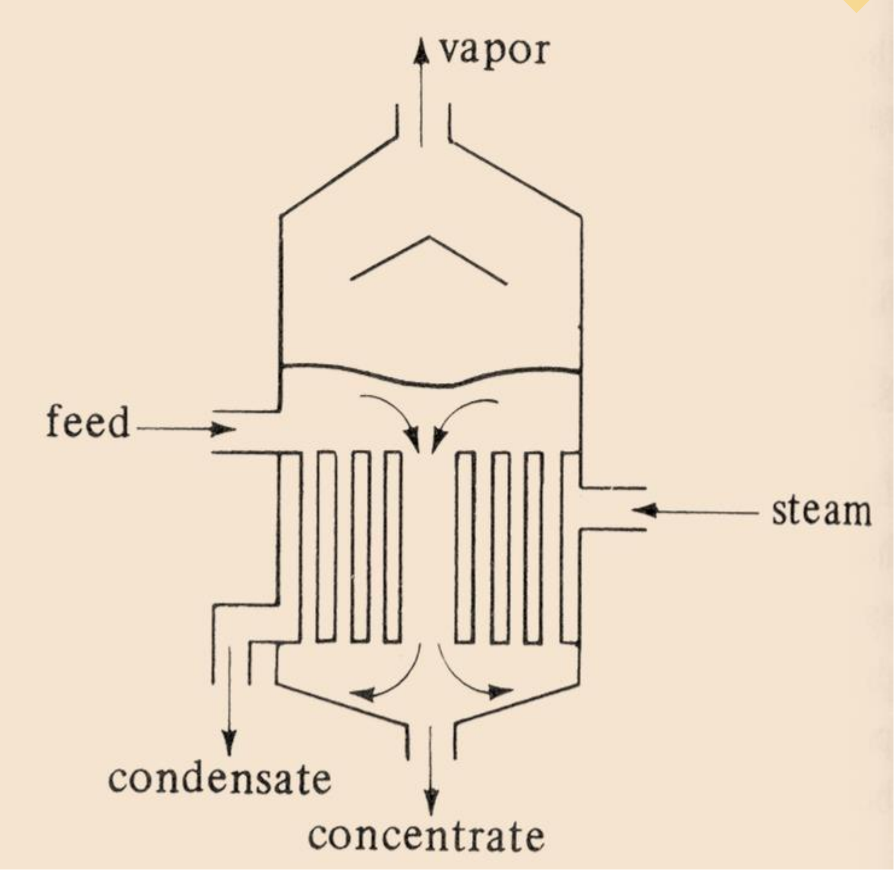
Short Tube Horizontal Evaporator

- These evaporators are formed by a chamber, the bottom of which is crossed by a bundle of interior horizontal tubes that circulate steam acting as heating fluid.
- Above the tubes is a space that allows the separation by gravity of drops carried away by the vapor released in the base.
- Impact slabs are arranged in order to facilitate the separation and carrying away of drops.
- Since the tube bundle makes the circulation of liquid difficult, poor heat transfer coefficients.
- Usually employed for the concentration of low viscosity liquids.



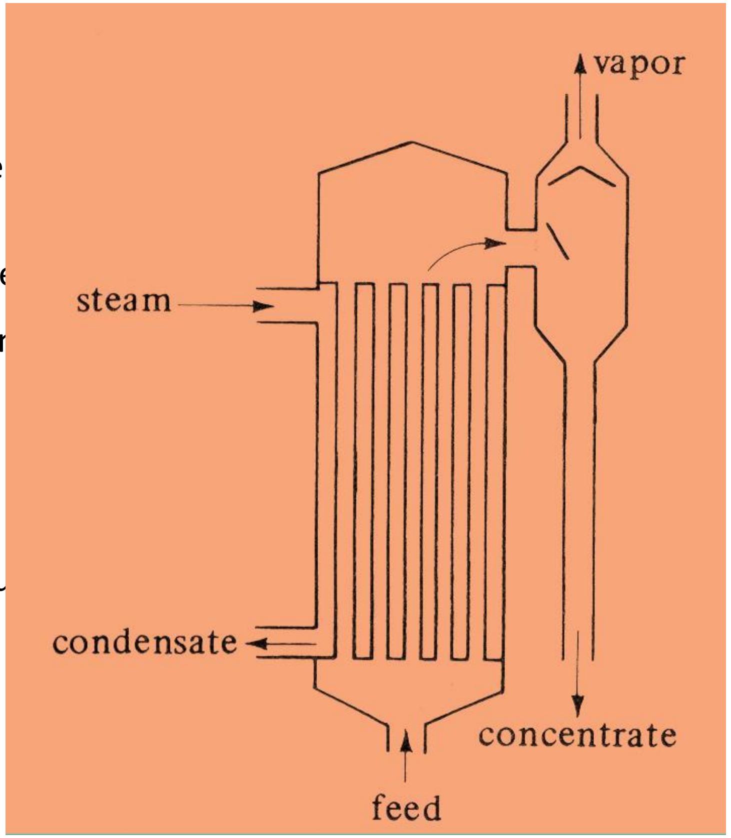
Short Tube Vertical Evaporator

- The heating steam condenses outside tubes vertically arranged inside the evaporation chamber.
- The tube sheet, called the calandria, has a large central return tube through which a liquid colder than the liquid that circulates in the heating ascending tubes, thus forming natural circulation streams.
- The length of the tubes usually ranges between 0.5 and 2 m, with a diameter of 2.5 to 7.5 cm, while the central tube presents a transversal section between 25 and 40% of the total section occupied by the tubes.
- Adequate evaporation velocities for noncorrosive liquids with moderate viscosity.
- Usually employed for the concentration of sugar cane and beet juices, fruit juices, malt extracts, glucose, and salt.



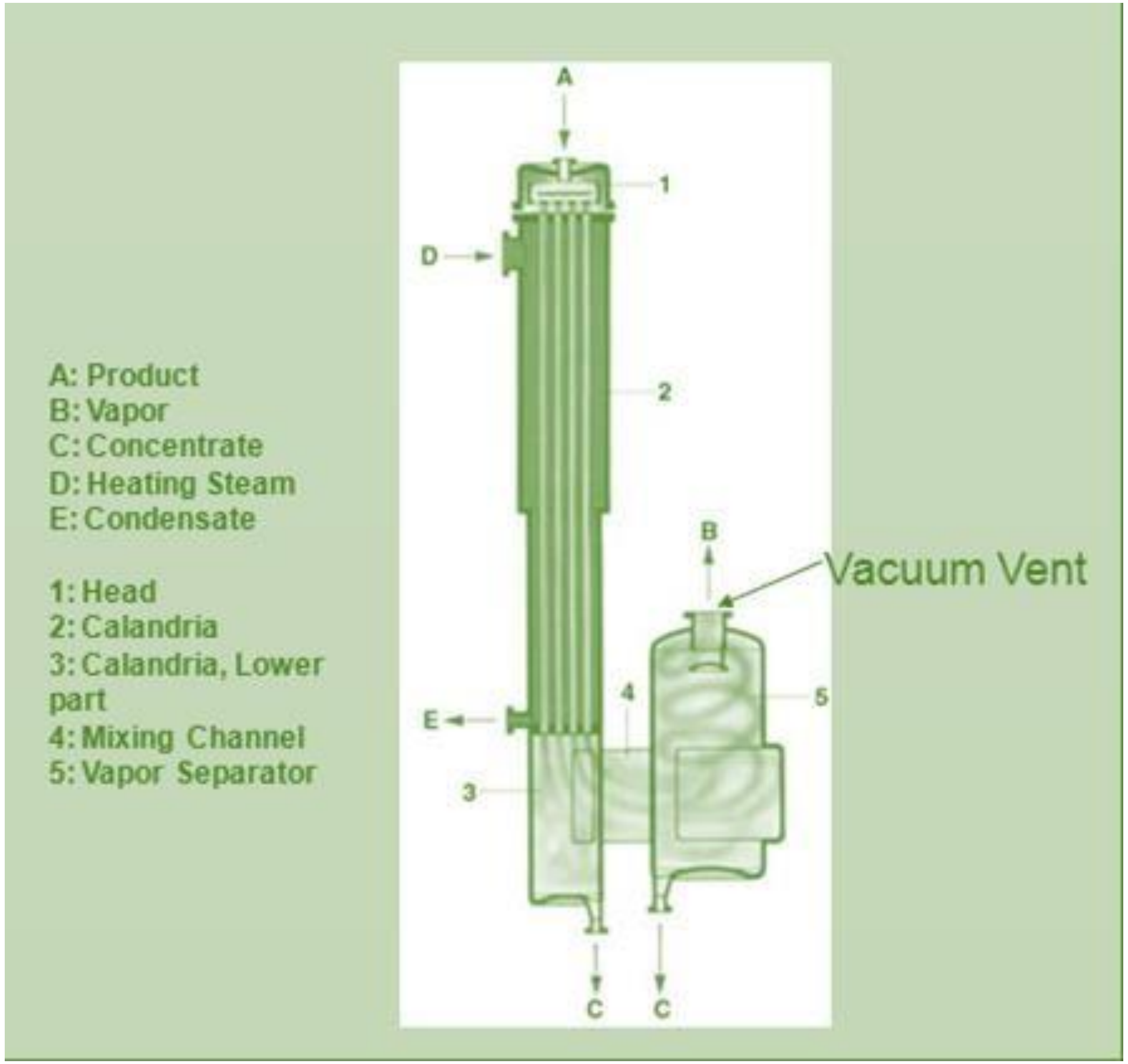
Long Tube Evaporators

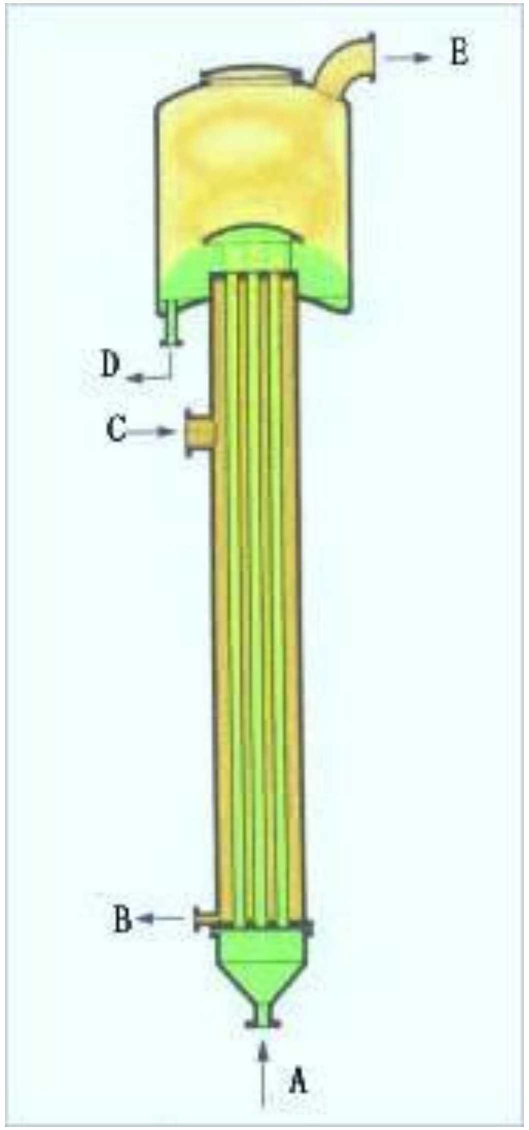
- The diluted liquid is preheated to almost boiling temperature before entering the tubes.
- Once inside the tubes, the liquid begins to boil, and the expansion due to vaporization yields the high velocity and carry away the liquid, which continues concentrating as it moves forward.
- The liquid–vapor mixture then enters the separation chamber, where baffle plates facilitate vapor se
- The concentrated liquid obtained can be directly extracted or mixed with nonconcentrated liquid ar evaporator where concentration can be increased.
- Long tube evaporators can be of ascending film, falling film.
- Generally, overall heat transfer coefficients are high.
- In film evaporators, the residence time of the liquid treated in the heating zone is short since it circu
- The product is thus not greatly affected by heat; therefore, these evaporators are useful for evaporation of heat-sensitive liquids.
- Descendent film evaporators are widely used to concentrate milk products.



Falling film evaporator

In falling film evaporators, the feed is performed at the top of the tubes, so the vapor formed descends through the center of the tubes as a jet at great velocity.

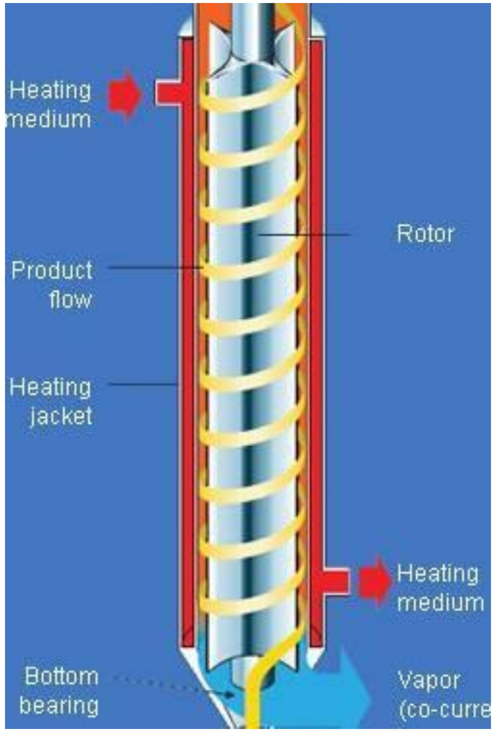




Climbing up / ascending film evaporator

In ascending film evaporators, the liquid enters the bottom of the tubes; vapor bubbles that ascend through the center of the tube begin to form, creating a thin film on the tube wall that ascends at great velocity.

Agitated Thin Film Evaporators



7. Agitated-film evaporator. In an evaporator the main resistance to heat transfer is on the liquid side. One way to increase turbulence in this film, and hence the heat-transfer coefficient, is by actual mechanical agitation of this liquid film. This is done in a modified falling-film evaporator with only a single large jacketed tube containing an internal agitator. Liquid enters at the top of the tube and as it flows downward, it is spread out into a turbulent film by the vertical agitator blades. The concentrated solution leaves at the bottom and vapor leaves through a separator and out the top. This type of evaporator is very useful with highly viscous materials, since the heat-transfer coefficient is greater than in forced-circulation evaporators. It is used with heat-sensitive viscous materials such as rubber latex, gelatin, antibiotics, and fruit juices. However, it has a high cost and small capacity. For interested readers, Perry and Green (P2) give more detailed discussions and descriptions of evaporation equipment.


Thank you