BASIC PRINCIPLES OF EVAPORATORS

Introduction

Evaporation and vapouration are two processes in which simultaneous heat and mass transfer processoccurs resulting into separation of vapour from a solution. Evaporation and vapourization occur where molecules obtain enough energy to escape as vapour from a solution. The rate of escape of the surface molecules depends primarily upon the temperature of the liquid, the temperature of the surroundings, the pressure above the liquid, surface area and rate of heat propagation to product.

Vapourization and Evaporation

Evaporation and vaporization are quite different from each other. The differences are shown in Table 1

Table 1 Differences between evaporation and vaporization

	Vaporization		Evaporation
1	Vapourization occurs when entire mass of liquid is raised to the boiling point.	1	It is only a surface phenomenon with only surface molecules escaping at a rate depending upon area of open surface.
2	It is a much faster process for the production of vapours.	2	It is a relatively slow process and depends mainly on temperature difference and on difference of vapour pressure between air and liquid.
3	Boiling point is related to the pressure above the liquid surface and the amount of solute.	3	Evaporation occurs at normal room temperature and application of heat is not necessary under normal evaporation process.
4	Vapourization of liquid is visual in the form of vapour bubbles rising and escaping at the surface.	4	Evaporation is not usually visual and hence not detected easily

5	Vapourization can be controlled by variation in pressure.	5	Liquid will evaporate until the pressure of its vapour is equal to the equilibrium value. It is the vapour pressure of the liquid for the given temperature of the liquid, for the closed system. In case of open system, evaporation will continue till there is no more liquid in the vessel.

Evaporation and vapourization occur where molecules obtain enough energy to escape as vapour from a solution. The rate of escape of the surface molecules depends primarily upon the temperature of the liquid, the temperature of the surroundings, the pressure above the liquid, surface area and rate of heat propagation to product. In a closed container with air space above the liquid, evaporation will continue until the air is saturated with water molecules. Removal of water from a liquid product by evaporation is enhanced by adding heat and by removing the saturated air from above the liquid. This is done by removal of vapour from the space above the liquid surface and there by creating vacuum. The boiling point of solution due to dissolved solutes is higher than that of pure water and depends on the molecular weight of the solute. Vacuum is utilized to remove water from liquid/solids at lower temperatures to reduce damage to heat sensitive products which might decompose at higher temperatures.

In the dairy industry evaporation means the concentration of liquid milk products containing dissolved, emulsified or suspended constituents. During this process water is removed by boiling. This process is used in the dairy industry for manufacture of evaporated milk, condensed milk and traditional Indian Dairy products i.e. Kheer, Basundi, Khoa etc.

In milk condensing plant, milk is condensed by evaporating a part of its water content by using saturated steam. The milk is boiled under vacuum. As the milk boils, water vapour is formed. This vapour is utilized for heating the milk further in the next stage which is at a higher vacuum.

Modern dairy plants use evaporators to remove part of water from milk by boiling it under low pressure. The process of evaporation takes place at a maximum temperature of about 70 ^{0}C corresponding to an absolute pressure of 230 mm (9.0 inch) of mercury (Hg). Evaporation of milk under low pressure or vacuum is carried out in a specially designed plant. The plant design depends much on the characteristics of liquid milk during boiling at low pressure than any other factor. Some of the important properties of evaporating milk are as under.

i Concentration of solids (initial and final)

ii Foaming under vacuum

iii Heat sensitivity

iv Viscosity change

The engineering design of plant requires certain other factors which provide a suitable milk contact surface, cleaning without frequent dismantling, faster heat transfer and economy of steam/power used for operating the plant.

Following factors are important for evaporation process.

(i) Concentration: The initial and final concentration of solute in the solution should be considered. As the concentration increases, the boiling point rises.

(ii) Foaming: Few products have tendency to foam, which reduce heat transfer and there is difficulty in controlling level of liquid which ultimately increases product (entrainment) losses.

(iii) Heat sensitivity: Milk, like many other food products, is sensitive to high temperatures. If time of exposure is more, there will be severe damage to milk proteins.

(iv) Scale formation / Fouling: It is a common phenomenon of deposition of solids on the heat exchanger surface. However, the scale forming tendency can be very much reduced by maintaining reasonably low temperature difference and relatively clean and smooth heat transfer surface. The flow velocity of product has also significant effect. If scale formation starts, rate of heat transfer decreases and cleaning becoming more difficult.

(v) Materials of construction: Stainless steel is the most common metal for evaporators in the dairy and food industry. Other metals may be used in chemical evaporators. The factors like strength, toughness, weld-ability, non-toxicity, surface finish, cost etc. are important in the selection of material of construction.

(vi) Specific heat: It changes with concentration of solution. More heat is required to be supplied at high specific heat values.

(vii) Gas liberation: Few products liberate gases when heated under boiling pressures.

(viii) Toxicity: The gases liberated in few cases may be toxic and should be handle carefully.

(ix) Viscosity: There is increase in viscosity of solution during evaporation which increases time of contact and hence chances of burning or damage the product.

(x) Capacity: It is expressed as the amount of water evaporated per hour. It depends on the surface area of heat transfer, temperature difference and the overall heat transfer co-efficient.

(xi) Economy: It is based on the amount of water evaporated per kg of steam used. It increases with number of effects.

TYPES OF EVAPORATORS

Introduction

The major types of evaporators used in dairy industry are

a) Vertical tube circulation evaporator
b) Batch vacuum pan evaporator
c) Long tube vertical (rising and falling film type).
d) Plate evaporators
    - Film evaporators with mechanically moved parts (SSHE)
    - Expanding flow evaporator

Different Types of Evaporators

Evaporators are of many different shapes, sizes and types of heating units. The major objective is to transfer heat from heat source to the product to evaporate water or other volatile liquids from the product. The general classification for evaporator bodies may be made based on

a) Source of heat,
b) Position of tubes for heating
c) Method of circulation of product
d) Length of tube
e) Direction of flow of film of product
f) Number of passes
g) Shape of tube assembly for heat exchanger
h) Location of steam
i) Location of tubes

The most important and widely used evaporator is the long tube vertical (calandria) type evaporator with climbing or falling film principle. The type is of the forced circulation type with steam condensing in the jacket surrounding a most of small diameter tubes. This type of evaporator has higher rate of heat transfer, less contact time with hot surface, flexibility of operation, economy of evaporation and easy in-place cleaning. It can be operated in stages reusing vapours by Thermo-Vapour Recompression (TVR) and Mechanical Vapour Recompression (MVR), for steam economy.

Long tube vertical (rising and falling film type) evaporator

In natural convection evaporators, the velocity of the fluid is usually less than one to 1.25 m/s. It is difficult to heat viscous materials with a natural circulation unit. Therefore the use of forced circulation to obtain a velocity of liquid up to 5 m/s, at the entrance of the tubes is desired for more rapid heat transfer. The liquid head above the heat exchanger is usually great enough to prevent boiling in the tubes. A centrifugal pump is normally used for circulation of milk products, but a positive pump is used for highly viscous fluids.

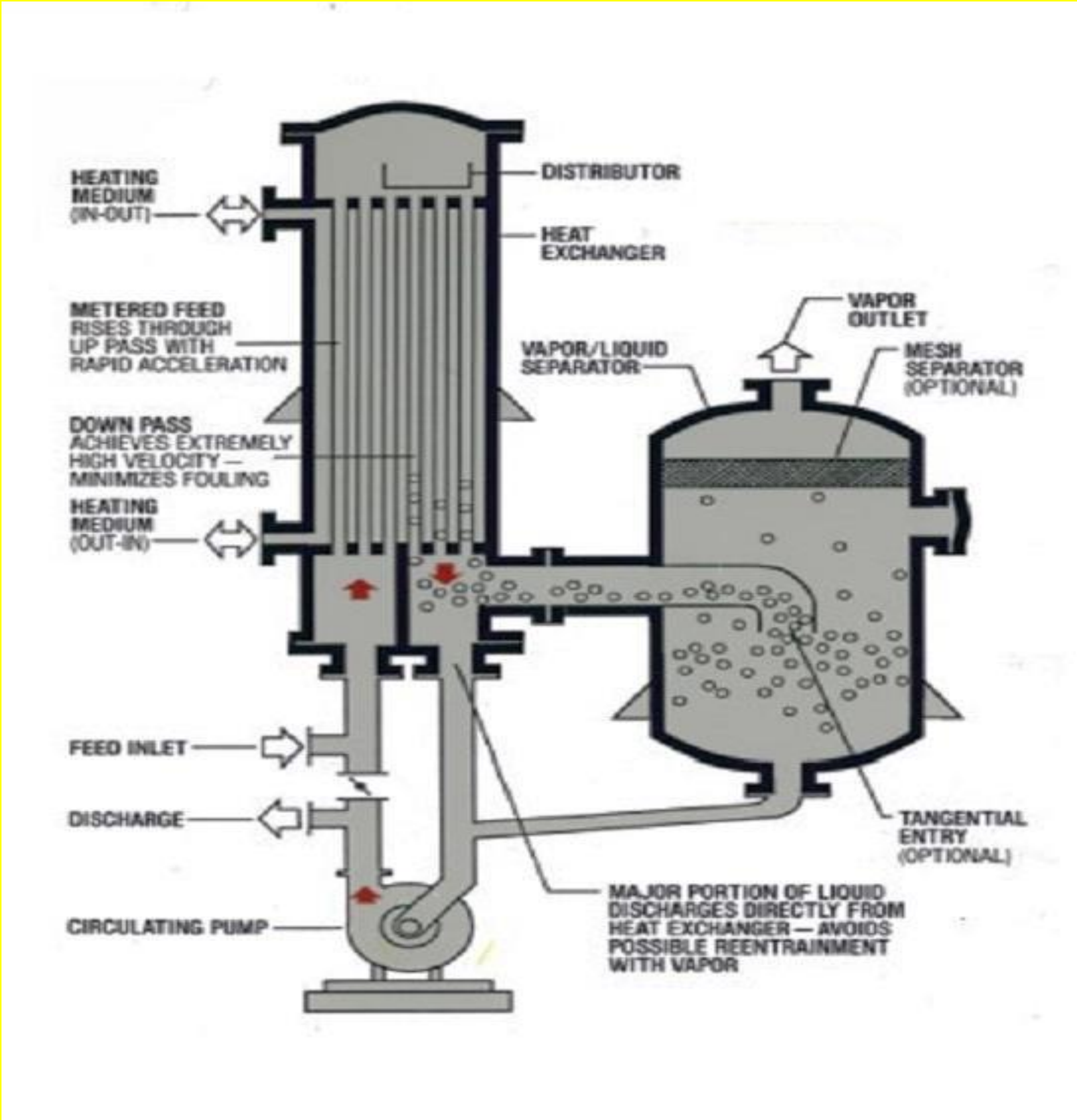

Fig 1 Rising Film Type Evaporator

Tubes of 3 to 5 cm diameter and 300 to 500 cm long are used to move the liquid on the inside. These are placed in a steam chest. So that steam heats from the outside of the tube. The Long Tube Vertical (LTV) evaporator is used normally with the heating element separate from the liquid-vapour separator. The product enters at the bottom of the evaporator body and as it is heated by steam condensing on the opposite side of the tube, the product moves rapidly to the top of the tube and then into a separation chamber. The evaporator is thus a continuous one in operation. Within the tubes there are three distinct regions. At the bottom under the static head of liquid, no boiling takes place, only simple heating occurs. In the center region the temperature rises sufficiently for boiling and vapour is produced, heat transfer rates are still low. In the upper region the volume of vapour increase and the remaining liquid is being wiped into a film on the tube surfaces resulting in good heat transfer conditions.

The falling film evaporator is used to reduce the amount of heat treatment and exposure of heat to the product. The tubes are from 4 to 5 cm diameter and up to 600 cm long in the falling film evaporator. The product is sprayed or otherwise distributed over the inside of the tubes which are heated with steam. Unless the tubes are fairly heavily loaded there is a risk that some of the tubes may not get their fair share of feed and will overheat or over concentrate the liquid flowing down. The distributor is provided for uniform distribution of feed to each and every tubes of calandria to form thin film over the inner surface of tubes.

Moisture removed moves downward along with the concentrated product and finally separated in the vapour separator. The product may be recirculated for further concentration or removed from the system. The Reynolds number of the falling film should exceed 2000 for good heat transfer.

The great advantage of the falling film is the short time the product remains inside the tube. This gives better quality product with minimum changes or damage to the product.

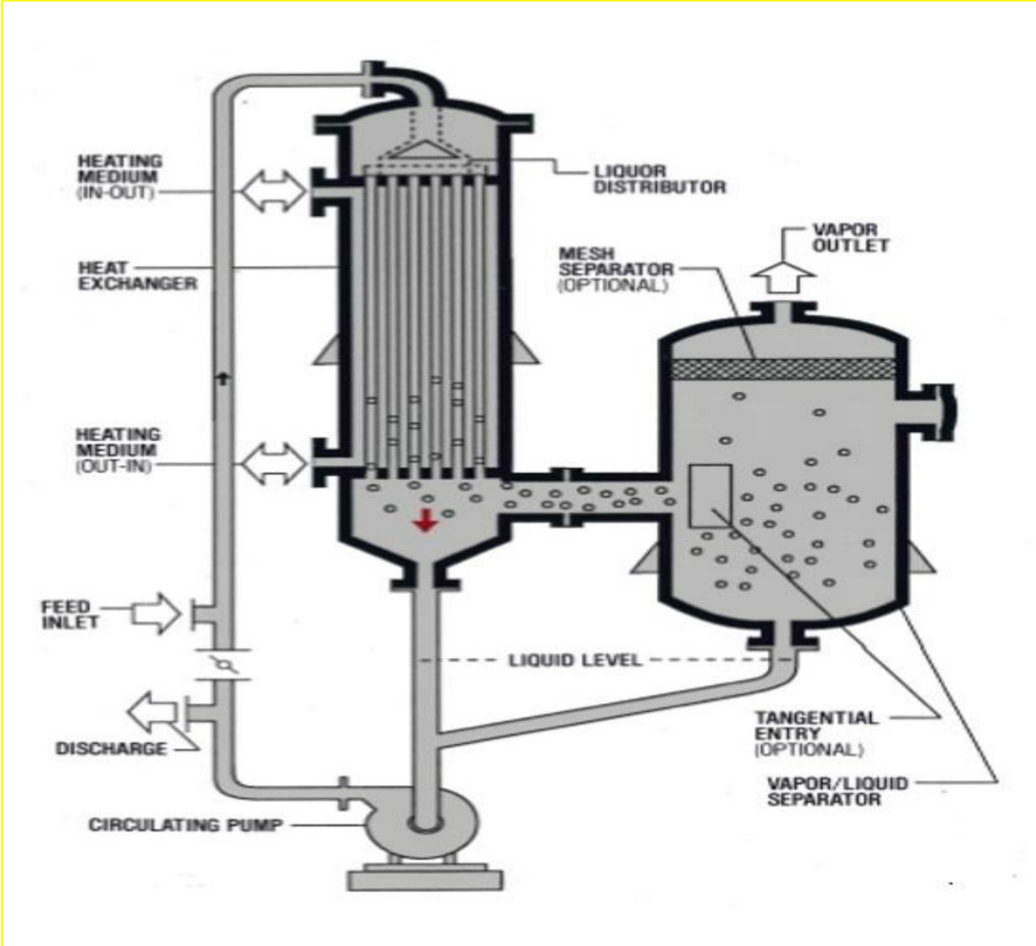

Fig 2 Falling Film Type Evaporator

Rising film evaporator	Falling film evaporator
more residence time	Less residence time
More temperature difference is required between heating medium and feed	Less temperature difference is required between healing medium and feed
Less overall heat transfer coefficient	More overall heat transfer coefficient
There is a static head and hence change in the boiling point due to hydrostatic head in the tube	There is no static head and no change in the boiling point due to hydrostatic head in the tube
Higher vacuum is not possible	Higher vacuum is possible

It is not used for heat sensitive products	Used for heat sensitive product as gentle heating
More fouling problem	Less fouling problem

Plate evaporator

The plate evaporator is characterized by a large heat exchanger surface occupying a relatively small space which need not be very high. Like the plate heat exchanger, it is constructed from profile plates, with the condensing steam used as heating medium and the evaporating product passing between alternate pairs. High heat transfer coefficients are obtained and viscous materials are handled at relatively high temperature but for shorter contact times. The plate arrangement may be such that it offers a combination of rising and falling film principle or falling film principle alone. By varying the plate gap, width of the plates and the relative dimensions of the various channels, the vapour velocity is controlled for efficient heat transfer. As the diagram shows, larger cross-sectional areas are provided for the inlet of the steam used for heating than for the discharge of condensate. Similarly, the cross-sectional areas for discharge of vapour and of concentrate are also enlarged.

The advantages of plate evaporator are its, flexibility, low head space, sanitary construction and shorter residence time which makesevaporation of heat sensitive products possible. It also offers possibility of multiple effects. However, rubber gaskets for sealing are costly; Liquid having suspended matter cannot be easily processed. For even distribution and to ensure good wetting of the surface, orifice pieces are to be inserted at header ports. Sometimes recirculation is necessary to ensure proper wetting.

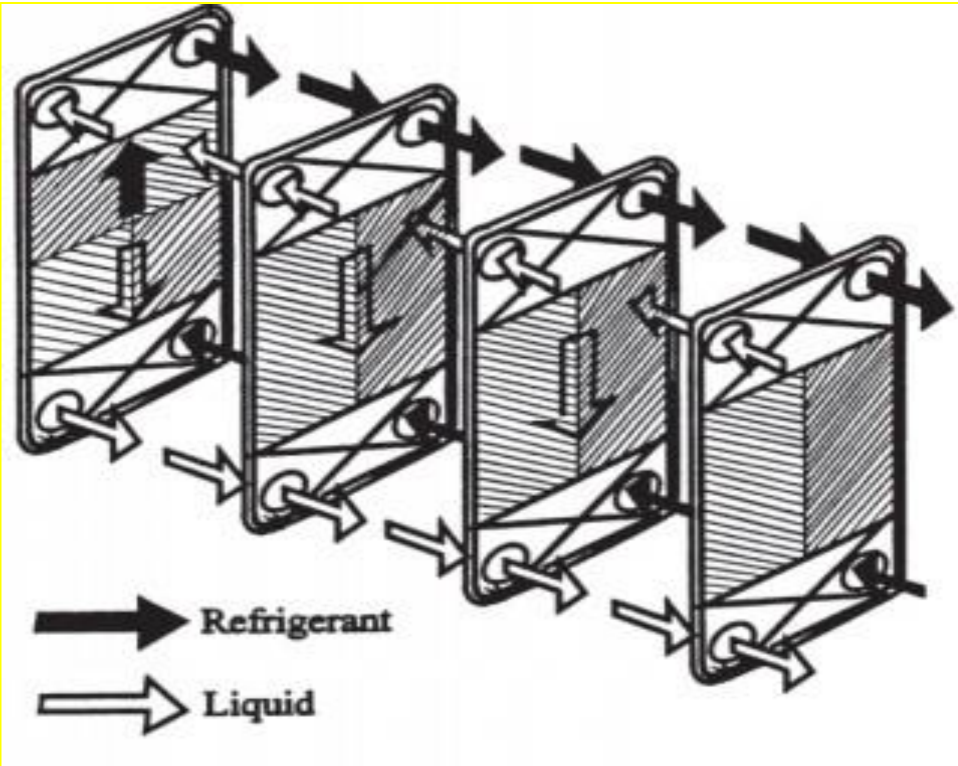

Fig 3 plate Evaporator

Film evaporators with mechanically moved parts (SSHE)

When highly viscous products (viscosity more than 1 Pa s) or fluids containing suspended matter are to be evaporated, it may happen that the forces which normally move the liquid along with gravity and propelling power of the vapour, are not sufficient to move the product satisfactorily. This intensifies the problem of maintaining high rates of heat transfer and proper distribution.

An evaporator with a rotating inner section is suitable here. A shaft fitted with wiper blades, scrapers, vanes or other device rotates within a vertical tube of relatively large diameter. This tube is surrounded by a heating jacket. The rotor may have a fixed clearance of 0.2 – 2.0 mm or fixed blades with adjustable clearance, or blades which actually wipe the heat exchanger surface.

The purpose of the blades etc. is to produce thorough mixing of the film, to distribute it evenly and to transport the product through the evaporator. The film thickness differs from one liquid to another depending on its physical properties.

The advantages of this evaporator are:

1. It can handle highly viscous, pulpy and foaming materials.
2. Evaporation rates are high.

3. Fouling problem non-existent.

The disadvantages are:

1. Requires precise alignment because of small blade clearance.
2. Difficult to clean.
3. High capital and operating cost.
4. High headspace required for demounting rotor for inspection and cleaning.

Expanding flow evaporator

It is compact and its heating element and expansion vessel are a single unit. In put milk acts as coolant in condenser. Steam condensate is used in milk pre heater. CIP is possible. Flexible in its capacity. One can get concentration in one pass. It has shorter residence time of < 1 min. Hence it is giving the advantage of gentle heating. Also because of low holding the plant has the characteristic of quick start up. It is made up of number of inverted, S.S. cones. Gaskets maintain narrow passages between cones.